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Electrodeposition of Functional Epitaxial Films for Electronics

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 J. Electrochem. 2022, 28(7), 2213006 (1 of 24)

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 Electrodeposition of Functional Epitaxial Films for Electronics 电 化 学

J. Electrochem. 2022, 28(7), 2213006 (1 of 24)

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 f Functional Epitaxial Films for Electronics

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 IERENATION BEVALUATE:
 IERENATION OF Functional Epitaxial Films for Electronics

Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu^{1,2} (*k.)*

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(*Runctional Epitaxial Films for Electronics*

(*Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,2*}

(<i>Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,2*}

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5. Su-Qin Liu^{1, 2}, Zhen He^{1, 2*}
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 emical Power Sources, Central South Un (1. College of Chemistry and Chemical Engineering, Central Power Sources, Central South University, Changsha 410083,

(1. College of Chemistry and Chemical Engineering, Central South University, Changsha 410083,

(1. Coll $\frac{1}{2}$ $\frac{1}{2}$ **Example 12022, 28(7), 2213006 (1 of 24)**

DOI: 10.13208/j.electrochem.2213006 Http://electrochem.xmu.edu.cn
 Functional Epitaxial Films for Electronics

Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,22}

semical Engin

Extract: Electrodeposition is a solution-based synthesis technique that can be used to fibricate various functional materials on
unductive or semiconductive substrates under umbient conditions. Electrodeposition is usual a solution-based considerate substrates under ambent conditions. Electrodeposition is usually triggered by an artificial electric

simulation (i.e., anglied potential/current) to the substrate to cooking or reduce ions, mo Extra content is a method of the substrate in ordinal method in the substrate incomplexes in the deposition solution

time distribution (i.e., applied potential/current) to the substrate. During electrodeposition, matery e ition layer near the substrue surface, which drives this solution hayer to depart from its thermodynamic equilibrium and consequently
cousse the suses the stability of targeted deposits on the substrue. During electrodepos cuses the useenbly of langeted deposits on the substrate. During electrodeposition, many experimental parameters could affect the
properties of the deposits in different ways. To date, may dements (both metals and nonmolat properties of the deposits in different ways. To date, many elements (both metals and aonmetals), compounds (e.g., metal oxides,
hydroxides, and chaloegraides), and composites have been electrodeposited, mosaly as either p by throwides, and chalcogenides), and composites have been electrodeposited, mostly as either polycrystalline, textured, or epitaxial
films. Among them, the epitaxial films are a kind of single-grossal-like films gown with hydrothermal/solvothermal synthesis, chemical/physical vapor of
the synthetic synthetic synthesis, and μ and $\$ ical vapore the stan be used to fabricate various functional materials on
Electrodeposition is usually triggered by an artificial electric
or reduce ions, molecules, or complexes in the deposition solu-
o depart from its t the mate an be used to tabreate various functional materials enterchedeposition is usually triggered by an artificial electric Deretdre coins, molecules, or complexes in the deposition solu-
o depart from its thermodynamic Electrodeposition is usually ingered by an articlear electrode
or or reduce ions, molecules, or complexes in the deposition solu-
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ctrodeposition, many experiment r leads to objet the steaded proses in the exponsion society of equation, and consequently ctrodeposition, many experimental parameters could affect the (both metals and nonmetals), compounds (e.g., metal oxides, eposited, **LEctrodeposition of Functional Epitaxial Films for Electrodem.** $202,28(7),2213006$ Http://electrodem.xma.edu.cn
 Electrodeposition of Functional Epitaxial Films for Electronics

(*i. College of Chemistry and Chemical E* **Example of the Conductive Substrates under ambient conditions.** The properties of the deposition is usually triggered by an artificial electrodeposition of **Functional Epitaxial Films for Electronics**
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(*i. College of Chermistry and Chermical Bepita* $\begin{array}{ll} \Phi & \Leftrightarrow \\ \text{[Review]} & \text{1:} \text{Eeterochem, 2022, 28(7), 2213006 (1 of 24)} \\ \text{[Review]} & \text{1:} \text{1:} \text{1:} \text{2083} \text{,} \text{decrrochen, 213006} & \text{[Hmp//decrroben, 2083]} \\ \text{**Electrodeposition of Fundamental Epitaxial Films for Electronics} \\ & \text{Kui Huang}^1, \text{Rong-Jiao Huang}^1, \text{Su-Oin Liu}^{1,2}, \text{Zhen He}^{1,2*} \\ \text{[**$ *Electrodeposition of Functional Epitaxial Films for Electronics.*

Flevicosy (Review) DOI: 10.13208/j.electrochem.2213006 Http://electrochem.xma.cdu.cn
 Electrodeposition of Functional Epitaxial Films for Electronics
 Proview Properties of the deposition of Functional Epitaxial Films for Electronics
 Electrodeposition of Functional Epitaxial Films for Electronics

Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu¹², Zhen He¹²

(*I.* **FReview]** DOI: 10.132085 descreades 2213006 Http://descreades.x.and.ch.cn
 Electrodeposition of Functional Epitaxial Films for Electronics

(*I. College of Chemistry and Chemical Engineering, Central South University,* **Electrodeposition of Functional Epitaxial Films for Electronics**

Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu¹², Zhen He¹²

(*I. College of Chemistry and Chemical fragineering, Central South University, Ghapaba 4100* **Electrodeposition of Functional Epitaxial Films for Electronics**

Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,27}

(*I. College of Clemistry and Clemical Engineering, Central South University, Changsha 4* **Electrodeposition of Functional Epitaxial Films for Electronics**

Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,27}

(*I. College of Chemistry and Chemical Engineering, Central South University, Changsha 4* **Example 10** Kui Huang¹, Rong-Jiao Huang¹, Su-Qin Liu¹²; Zhen He¹²²

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Hunan, China; 2. Hunan Provincial Key Laboratory* **Kui Huang**¹, Rong-Jiao Huang¹, Su-Qin Liu^{1,2}, Zhen He^{1,27}
(1. College of Chemistry and Chemical Engineering, Central South University, Changsha 410083,
Hunan, China; 2. Hunan Provincial Key Laboratory of Chemical discussed. *C.* C. Congre or Chemical Emplementary and Contentral Emplementary Chemical Dover Sources, Central South University, Uluman, China, 2. Human Provincial leve γ Laboratory of Chemical Power Sources, Central South Univer

roduction

bydrothermal/solvothermal synthechion, also known as electroplating, is

ical vapor deposition, and react

cate various finctional materials of desired very effective deprocess

cate corrostantic formation and

1 Introduction hydrothermal/solvothermal synthesis, chemical/phys-Films. Among them, the epitaxial films are a kind of single-crystal-like films grown with certain out-of-plane and in-plane crientions.
Due to the highly odverd acous are measurent in epitaxial films, they usually exhibit ions. Due to he highly ordered atomic arrungement in episodial Elmis, they usually exibitationize electric und magnetic properties.
In this review, the common synthetic routes for the electrodeposition as well as the key e In this review, the connor symplectic counts for the electrodeposition as well as the key experimental parameteriz that after the episode parameterize the electrodeposite function and parameterize of the depositions, elec The encore of the encore of the consequent of the processes in the set of the processes of the produced by the discussed.
 I Infroduction
 I Infroducti unitantly, are electrodeposite intertinal spinals in
mix win special electromic, escalimigation, and particularly physical
 Every words: electrodepositi, electrophaing, thin film; highly oriented
 Every words: electro **IECONDITY:** However, the entrophaing thin film; highly oriented
 also by vords: electrodeposition, also known as clectroplating, is
 $\frac{1}{2}$ also transformed by the synthetic method for control and the synthetic meth trodeposition, many experimental parameters could affect the
(both metals and nonmetals), compounds (e.g., metal oxides,
eposited, mostly as either polycrystalline, textured, or epitaxial
ke films grown with certain out-of (both metals and nonmetals), compounds (e.g., metal oxides,
eposited, mostly as either polycrystalline, textured, or epitaxial
ke films grown with certain out-of-plane and in-plane orienta-
s, they usually exhibit unique sposited, mostly as either polycrystalline, textured, or epitaxial
ke films grown with certain out-of-plane and in-plane orienta-
s, they usually exhibit unique electric and magnetic properties.
as well as the key experime is the films grown with certain out-of-plane and in-plane orienta-
s, they usually exhibit unique electric and magnetic properties.
as well as the key experimental parameters that affect the epi-
sused to characterize epit is, they usually exhibit unique electric and magnetic properties.

as well as the key experimental parameters that affect the episosed to characterize epitaxial films are briefly introduced. Fur-

al electronic, electromag as well as the key experimental parameters that affect the episor-
the viscosition characterize epitaxial films are briefly introduced. Fur-
al electronic, electromagnetic, and photovoltaic properties are
the endowed the m issed to characterize epitaxial tims are bnetty introduced. Fur-
al electronic, electromagnetic, and photovoltaic properties are
the afore are afore the afore afore the standard values of the sweet of the synthetic approac are rectionic, electromagnetic, and photovolate properties are

hydrothermal/solvothermal synthesis, chemical/phys-

ical vapor deposition, and reactive magnetron sput-

terring, electrodeposition offers several advantages ented

hydrothermal/solvothermal synthesis, chemical/phys-

ical vapor deposition, and reactive magnetron sput-

tering, electrodeposition offers several advantages

over other synthetic approaches. First, electrodeposi-
 Electrodeposition, also known as electroplating, is

and valore deposition, and reactive magnetron sput-

and solution-hased synthesis method at the colub be used

to fibricate various functional materials of desired over **Exercution** hydrothermal/solvothermal synthesis, chemical/phys-

Electrodeposition, also known as electrodeposition of the used term

is a solution-based synthesis method that could be used terming. electrodeposition offe

thended the method of line of the materials and leads to superior device of the materials and leads to superior detectode of the integrated circuit (IC) manufacture^[3]. a well-defined growth orientation to the substrate $# \&L \# (J. \nEletrochem.) 2022, 28(7), 2213006 (2 of 24)$ straints, such as the back-end-of-line (BEOL) process-

polycrystalline or textured films, epitaxial films (with

ing for the integrated circuit (IC) manufacture ^[3]. a wel $\exists \ell \neq \emptyset, \ell \neq \ell \neq 0$. Straints, such as the back-end-of-line (BEOL) process-
polycrystalline or textured films, epitaxial films (with
ing for the integrated circuit (IC) manufacture^[3]. a well-defined growth orient **fg** $f(z^{\omega})$, *Electrochem.*) 2022, 28(7), 2213006 (2 of 24)

straints, such as the back-end-of-line (BEOL) process-

polycrystalline or textured films, epitaxial films (with

ing for the integrated circuit (IC) manufactu $\frac{d}{dt}\frac{d}{dt}\left(\frac{d}{dt}\right)$ Electrochem.) 2022, 28(7), 2213006 (2 of 24)

straints, such as the back-end-of-line (BEOL) process-

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ing for the integrated circuit (IC) **EAPPLA Electrochem.**) 2022, 28(7), 2213006 (2 of 24)

straints, such as the back-end-of-lin (BEOL) process-

polycrystalline or extured films, epitaxial films (with

ing for the integrated circuit (IC) manufacture¹⁹¹. **EVALUATION THE TENDE CONDET THE CONDETERT CONDENTIFY (***E Reetnochem.***) 2022, 28(7), 2213006 (2 of 24)
straints, such as the back-end-of-line (BEOL) process-
polyerystalline or textured films, epitaxial films (with
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straints, such as the back-end-of-line (BEOL) process-
polyerystalline or textured films, epitaxial films (with
ing for the integrated circuit (IC) manufacture^[2] $\pm \frac{1}{2}$ the substrate surface are two exclusive ones that are two medicines are polycystalline or textured films, epitaxial films (with thing for the integrated circuit (IC) manufacture ^[3]. a well-defined growth or $\pm 4E\%$ *(L Electrochemi*) 2022, 28(7), 2213006 (2 of 24)
straints, such as the back-end-of-line (BFOL) process-
polyerystalline or textured films, epitaxial films (with
ing for the integrated circuit (IC) manufacture¹ **intervalse and the deposition** of the substrates, which generates and the substrainties, and energy controlline of the integrated circuit (IC) manufacture¹⁹⁾. a well-defined growth orientation to the substrate) Second, $\mathbb{E}(k\mathcal{F}_n/L$ *Eternochem.*) 2022, 28(7), 2213006 (2 of 24)

straints, such as the back-end-of-line (BEOL) process-

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ing for the integrated circuit (IC) manufac **Electrical contact the deposite of the deposite and the sub-deposited contact of the sub-deposited contact contact contact contact contact and the method of the method of the substrate of Second, electrodeposition provid** $\mu_2(E\neq C_L E_{leurocheen.}) 2022, 28(7), 2213066 (2 or 24)$
straints, such as the back-end-of-line (BEOL) process-
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ing for the integrated circuit (IC) manufacture ⁰¹. a well-d **EQUE ACT ENERTO (EXECT CONDERT)** 2022, 28(7), 2213006 (2 of 24)

straints, such as the back-end-of-line (BEOL) process-

polycrystalline or textured films, epitaxial films (with

ing for the integrated circuit (IC) manuf straints, such as the back-end-of-life (BEOL) process-

signs for the integrated circuit (IC) manufacture¹⁹. a well-defined growth orientation to the substrate)

Second, electrodeposition provides many degrees of usuall strains, such as the back-end-of-line (BEOL) process-
polycrystalline or textured films, epitaxial films (with
me of the integrated circuit (IC) manufacture¹⁹¹. a well-defined growth circuition to the substrate)
Second, ing for the integrated circuit (IC) manufacture^[ja]. a well-defined growth orientation to the substrate)
Second, electrodeposition provides many degrees of usually possess fewer grain boundaries and electrodeposition
of Second, electrodeposition provides many degrees of

susully possess fewer grain boundarics and defects,

frequend reg, composition, pH, temperature, and al-

which allows better exploitation of the intrinic prop-

ditives freedom (e.g., composition, pH, temperature, and ad-
which allows better exploitation of the intrinsic prop-
ditives of the deposition bulk, applied potential/eur-
error, and the substrates) in terms of tuning the prop-
p ditives of the deposition bath, applied potential/cur-
ertics of the materials and leads to superior device
rertic, and the substrates) in terms of tuning the prop-
performance⁸⁰^m. Therefore, the fabrication of equisarent, and the substrates) in terms of tuning the prop-
performance^{rs, an}. Therefore, the fabrication of epitaxi-
erties of the targeted deposits^{of}. Among these experi-
mental variables, the applied potential and curren erties of the targted deposits¹⁶. Among these experi-
mental variated more atten-
mental variables, the applied potential and current on tion. Although cpitaxial films can be fabricated by
the substrate strince are two e mental variables, the applied potential and current on

tion. Although epitaxial films can be fabricated by

the substrate surface are two occlusive ones that are

urarious methods such as molecular beam

not applicable in the substrate surface are two exclusive ones that are

on trapicals in other symbolic mechanisms. Thind, dur-

one principalize in other symbolic mechanisms in the chemical physical vapore deposition, and reactive

one pr not applicable in other synthetic methods. Third, dur-

one chemical/physical vapor deposition, and reactive

imgelectrodeposition, the deposit grow from the bot-

magnetron sputtering, the fabrication of epiaxial

form up ing electrodeposition, the deposits grow from the bot-
magnetron sputtering, the fabrication of epitaxial
tom up on the substrates, which guarantees a good films by electrodeposition is more attractive due to its
strate^m from up on the substrates, which guarantees a good films by electrodeposition is more attractive due to its electrical contact between the deposit and the sub-

high accessibility and low cost.

strate¹². This feature i electrical contact between the deposit and the sub-

strate¹³. This facture is critical for device applications

in electronics, and energy conversion and storage,

in electronics, and energy conversion and storage,

tr strate²¹. This feature is critical for device applications

and chectronics, and chergy conversion and storage, rodeposition, they mainly focused on polycystalline

in electromagne, and the formation of p-n

reat collect in electronies, and energy conversion and storage,

such as the booking redictions and polyerystalline

such as the loading of active materials on the cur-

flink (rank-ther than epitavial films) used in electrodes¹⁰,
 such as the loading of active materials onto the cur-

rent collectors in batterics and the formation of p-n photoelectordes³¹¹, and batterics memories and the formation of p-n photoelectordes³¹¹, and batterics memorie rent collectors in batteries and the formation of $p-n$ photoelectrodes^[1], and batteriuncions in photovoltaic devices. By virtue of these trodeposited epitaxial ultrated davantages, electrodeposition has been utilized o erions in photovoltaic devices. By virtue of these

trodeposited epitaxial ultrathin magnetic layers have

aratheyis are the metallized or the electrodegressium and been united or

was potential in fabricating many importa advantages, electrodeposition has been utilized or

shown potental in functions (in the inclusion magnetic inves-

shown potential in functions (inter metals, alloys, compounds, or com-

tion, characterizations, and applic shown potential in fabricating many important com-

tigations. This review will focus on the electrodeposi-

posites) with required electric, angenetic, and photo-

Interimeterations, and applications of epitaxial

posites poncals (either metals, alloys, compounds, or com-

tion, characterizations, and applications of epitaxial

posites) with required electric, magnetic, and photo-

function productions We will stat with the

voltaic propert posites) with required electric, magnetic, and photo-

functional films for electronics. Ne will start with the

voltaic properties in electronics role in the crystallographic modes

electrophating is currently the prevail voltaie properties in electronics. For instance, copper
electrocharion on the design of electrodeposition routes
the control of the regination technology in the manufacture of integrated cir-
films. Then, the characterizat

28(7), 2213006 (2 of 24)
polycrystalline or textured films, epitaxial films (with
a well-defined growth orientation to the substrate)
usually possess fewer grain boundaries and defects,
which allows better exploitation of 28(7), 2213006 (2 of 24)
polycrystalline or textured films, epitaxial films (with
a well-defined growth orientation to the substrate)
usually possess fewer grain boundaries and defects,
which allows better exploitation of $(28(7), 2213006 (2 \text{ of } 24))$
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polycrystalline or textured films, epitaxial films (with
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well-defined growth orientation to the substrate)

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sich allows better exploitation of the in $28(7)$, 2213006 (2 of 24)
polycrystalline or textured films, epitaxial films (with
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usually possess fewer grain boundaries and defects,
which allows better exploitatio $f(z(t), 2213000 (2.0124)$
polycrystalline or textured films, epitaxial films (with
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usually possess fewer grain boundaries and defects,
which allows better exploitation of t polyerystalline or textured films, epitaxial films (with
a well-defined growth orientation to the substrate)
usually possess fewer grain boundaries and defects,
which allows better exploitation of the intrinsic prop-
ertie a well-defined growth orientation to the substrate)
usually possess fewer grain boundaries and defects,
which allows better exploitation of the intrinsic prop-
erties of the materials and leads to superior device
performa usually possess fewer grain boundaries and defects,
which allows better exploitation of the intrinsic prop-
erties of the materials and leads to superior device
performance^[9, 10]. Therefore, the fabrication of epitaxi-
 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (2 of 24)

line (BEOL) process-

polycrystalline or textured films, epitaxial films (with

(IC) manufacture^[3]. a well-defined growth orientation to the substrate)

des many

which allows better exploitation of the intrinsic properties of the materials and leads to superior device
performance^{[0, [0]}. Therefore, the fabrication of epitaxi-
al films has currently attracted more and more attenerties of the materials and leads to superior device
performance^[9, 10]. Therefore, the fabrication of epitaxi-
al films has currently attracted more and more atten-
tion. Although epitaxial films can be fabricated by
va performance^[9, i0]. Therefore, the fabrication of epitaxi-
al films has currently attracted more and more atten-
tion. Although epitaxial films can be fabricated by
various methods such as molecular beam epitaxy,
chemica al films has currently attracted more and more atten-
tion. Although epitaxial films can be fabricated by
various methods such as molecular beam epitaxy,
chemical/physical vapor deposition, and reactive
magnetron sputterin tion. Although epitaxial films can be fabricated by
various methods such as molecular beam epitaxy,
chemical/physical vapor deposition, and reactive
magnetron sputtering, the fabrication of epitaxial
films by electrodepos various methods such as molecular beam epitaxy,
chemical/physical vapor deposition, and reactive
magnetron sputtering, the fabrication of epitaxial
films by electrodeposition is more attractive due to its
high accessibilit chemical/physical vapor deposition, and reactive
magnetron sputtering, the fabrication of epitaxial
films by electrodeposition is more attractive due to its
high accessibility and low cost.
Although there have been some re magnetron sputtering, the fabrication of epitaxial films by electrodeposition is more attractive due to its high accessibility and low cost.

Although there have been some reviews on electrodeposition, they mainly focused films by electrodeposition is more attractive due to its
high accessibility and low cost.
Although there have been some reviews on elec-
trodeposition, they mainly focused on polycrystalline
films (rather than epitaxial f high accessibility and low cost.

Although there have been some reviews on electrode

position, they mainly focused on polycrystalline

films (rather than epitaxial films) used in electrodes^[11],

photoelectrodes^[1], a discussed. trodeposition, they mainly focused on polycrystalline
films (rather than epitaxial films) used in electrodes^[11],
photoelectrodes^[1], and batteries^[12]. In addition, elec-
trodeposited epitaxial ultrathin magnetic l otoelectrodes¹⁰¹, and batteries¹⁶⁴. In addition, elec-
deposited epitaxial ultrathin magnetic layers have
n reviewed^[13] with the emphasis on magnetic inves-
ations. This review will focus on the electrodeposi-
n, ch trodeposited epitaxial ultrathin magnetic layers have
been reviewed^[13] with the emphasis on magnetic inves-
tigations. This review will focus on the electrodeposi-
tion, characterizations, and applications of epitaxial been reviewed^{toj} with the emphasis on magnetic investigations. This review will focus on the electrodeposition, characterizations, and applications of epitaxial functional films for electronics. We will start with the di tigations. This review will focus on the electrodeposi-
tion, characterizations, and applications of epitaxial
functional films for electronics. We will start with the
discussion on the design of electrodeposition routes
a tion, characterizations, and applications of epitaxial
functional films for electronics. We will start with the
discussion on the design of electrodeposition routes
and control of growth orientations for the epitaxial
fil

Electrodeposition

electroplating is currently the prevailed interconnecastion of growth orientations for the cpitaxial
cion technology in the manufacture of integrated cir-
^{elime}ntition, the characterization methods for the epi-
critics a tion technology in the manufacture of integrated cir-

tima. Then, the characterization methods for the cpi-

cuits and printed circuit boards¹⁹. Resides, many fer-

reiversionness, the controlled controlled controlled entis and printed eircuit boards¹⁹. Besides, many fer-

civilial films will be briefly introduced. Furthermore,

civilians (also the media of media of media of the same decordopesired functional epitaxia films

ides^{19,} ri/Erromagnetic thin films of metals¹⁶ and metal ox-

various electrodeposited functional epitaxial films

ideals the cold be used or potentially used in electrome,

then fabricated by electrodeposition and could be decl functional films for electronics. We will start with the
discussion on the design of electrodeposition routes
and control of growth orientations for the epitaxial
films. Then, the characterization methods for the epi-
taxi discussion on the design of electrodeposition routes
and control of growth orientations for the epitaxial
films. Then, the characterization methods for the epi-
taxial films will be briefly introduced. Furthermore,
various and control of growth orientations for the epitaxial
films. Then, the characterization methods for the epi-
taxial films will be briefly introduced. Furthermore,
various electrodeposited functional epitaxial films
that cou films. Then, the characterization methods for the epi-
taxial films will be briefly introduced. Furthermore,
various electrodeposited functional epitaxial films
that could be used or potentially used in electronic,
electro taxial films will be briefly introduced. Furthermore,
various electrodeposited functional epitaxial films
that could be used or potentially used in electronic,
electromagnetic, and photovoltaic devices will be
discussed.
 various electrodeposited functional epitaxial films
that could be used or potentially used in electronic,
electromagnetic, and photovoltaic devices will be
discussed.
2 Designs and Controls of Epitaxial
Electrodeposition

 $\frac{d}{dx}$ the electrodeposition of different kinds of func-
for the electrodeposition of different kinds of func-
redox couple. This electronemical process involves
distant and materials that could be used in electronics. $\#E\#(J. Electrochem.)$
 $\#E\#(J. Electrochem.)$ 2022, 28(7), 2213006 (3 of 24)

for the electrodeposition of different kinds of functional materials that could be used in electronics.

Then, the key parameters that affect the epitaxial

f

trodeposition is triggered by an artificial elec-

timulation (i.e., the applied potential/current on

electrochemical-chemical (EC)

strate) that could precisely control the solution

EC mechanism is commonly seen

tear

 E (Mⁿ⁺/M), could trigger the deposition of the correposites commonly involves bonh electrochemical and

the deposition of Fe.O, through the following elemi-

deposition are summarized as follows based on their combine cannot could also be electrochemi-

deposition are summ chemical reactions²¹. Some common routes of electro-

cal reaction (Eq. 3). In addit

deposition are summarized as follows based on their

molecules in the solution coul

different ways to trigger the deposition.

2.1.1 . ssition are summarized as follows based on their

renotations in the solution could also be electrochemi-

rent was to trigger the deposition

1 Direct Electrochemical Reduction of lons to following the EC mechanism. Fo different ways to trigger the deposition.

2.1.1 Direct Electrochemical Reduction of lons to following the EC mechanism. For instance, Pb₁^{Em}

2.1.1 Direct Electrochemical Reduction of lons to and Bil₃^{Em} were elect 1.1 Direct Flectrochemical Reduction of Ions to

Their Atoms

The intractions (M^{ex}, either in a coor-

1) yrelation golecule and bill-³⁰ were cletrodeposited by electrodemical-

The direct reduction of ions (M^e, eit Their Atoms

The direct reduction of ions (M*, either in a coor-

The direct deposited form) into their atoms (M)

presence of the corresponding metal ions in the dep-

by driving the electrode potential on the substrate
 The direct reduction of ions (M", either in a coor-

diractor or incordinated form) into their atoms (M) presence of the corresponding mediations of the chereoformation

by driving the electrode potential on the substrate dinated or uncoordinated form) into their atoms (M) presence of the corresponding metal ions in the depotential
by driving the electrode potential on the substrate sition solutions due to the small solubility-product
surf by driving the electrode potential on the substrate sition solutions due to the small solubility-product
surface to a value that is more negative than the equi-
constant (K^0_{γ}) of these two metallic iodides (Eqs. 4
E (

 M^{n+} + ne⁻ \rightarrow M

 $\# \ell \# (J. Electron) 2022, 28(7), 2213006 (3 of 24)$
for the electrodeposition of different kinds of func-redox couple. This electrochemical process involves
tional materials that could be used in electronics.
Then, the key parameter the $\#E^*(J. Electronen.)$ 2022, 28(7), 2213006 (3 of 24)
for the electrodeposition of different kinds of func-
tional materials that could be used in electronics. electron transfer between the substrate surface and
Then, the key p the $\#E^*(J. Electron, 2022, 28(7), 2213006 (3 of 24)$
for the electrodeposition of different kinds of func-
redox couple. This electrochemical process involves
tional materials that could be used in electronics.
Then, the key parame $\pm \frac{\mu}{2}$ (*L Electrochem.*) 2022, 28(7), 2213006 (3 of 24)

for the electrodeposition of different kinds of func-

trional materials that could be used in electronics.

Then, the key parameters that affect the epitix **deposition** tions to form the targeted deposit on the substrate, $\# \&L^{\infty}(I \&Electrochem.) 2022, 28(7), 2213006 (3 of 24)$
the electrodeposition of different kinds of func-
redox couple. This electrochemical process involves
and materials that could be used in electronics.
electron transfer bet **EXALUAT EXAMORE 19:20**
 EXALUAT EXAMORE 19:2022.28(7), 2213006 (3 of 24)

for the electrodeposition of different kinds of func-

redox couple. This electrochemical process involves

trical materials that could be used **Example 12**
 Example 12 the $\mathcal{R}_c(F, Klerismel, and Klerismel) = 0.022$

the substract of the substrate surface in the substrate surface and

for the electrodeposition of different kinds of functions. electron transfer between the substrate surface and

Then, **EVALURE (EXALURE 1999)**
 EVALURE 1999 (3 of 24)

for the electrodeposition of different kinds of functions and comple. This electrochemical process involves

tional materials that could be used in electronics. electron **stimulation** $\frac{1}{2}$ $\frac{1}{2$ $\frac{d_1}{dx}\sqrt{x}$ *C. Electrochemi*, 2022, 28(7), 2213006 (3 of 24)
for the electrodeposition of different kinds of functions. electron transfer between the substrate surface and
triend, the key parameters that affect the ep **EVALUAT ENTERT (FOCT)** 2022, 28(7), 2213006 (3 of 24)

for the electrodeposition of different kinds of func-

tedox couple. This electrochemical process involves

tional materials that could be used in electronics. elect for the electrode
position of different kinds of functions. edectron transfer between the substrate surface and
Then, the key parameters that affect the epitaxial the corresponding electrochemically active species in
Then for the electrodeposition of different kinds of functions comple. This electrochemical process involves

tions materials that could be used in clettronics, celectron transfer between the substrate suffice and

Then, the k tional materials that could be used in electronics.

electron transfer between the substrate surface and

Then, the key parameters that affect the epitaxial the corresponding electrodeposition

growth of the depositis du Then, the key parameters that affect the epitaxial the corresponding electrochemically active species in

growth of the depositt aring the electrodeposition and the deposition solution. If the generated position

will be growth of the deposits during the electrodeposition the deposition solution. If the generated species is not

will be dissussed.

2.1 Common Synthetic Routes of Electro-

als) and participates in the following chemical re will be discussed.
 Common Synthetic Routes of Electro-
 Solison dependentigates in the following chemical read-
 deposition
 Electrodeposition
 Electrodeposition
 Electrodeposition
 Electrodeposition
 Elec 2.1 **Common Synthetic Routes of Electro**
 deposition
 deposition
 deposition
 decretice deposition is triggered by an artificial elections to form the targeted deposition of the substrate in the substrate in the **Exercution**

Electrochemical simulation is triggered by an artificial clec-

Electrochemical chimical clectrochemical simulation (i.e., the applied potential/current on selectrochemical chimical CEC) mechanism. Such an
 cal stimulation (i.e., the applied potential/current on

electrochemical-chemical (EC) mechanism. Such is

esubstrate) that could precisely control the solution

EC mechanism is commonly seen in the electrode

per meant t tential/current on

electrochemical-ehemical (EC) mechanism. Such an

to the solution

EC mechanism is commonly seen in the electrodep-

deviate from its offic only on the propounds^{18, 20}. For example, the electrode-

e the substrate) that could precisely control the solution

lever near the substrate surface to deviate form is situen of compounds¹⁶⁷¹³ Here cannelle, the cletrode-

thermodynamic equilibrium. Although the electrical
 layer near the substrate surface to deviate from its sition of compounds^{paral}. For example, the electrode-
thermodynamic equilibrim. Although the electrical position of Fe-O_ch has been achieved by electrodentin-
trimu thermodynamic equilibrium. Although the clearical

strinulation ord Fe,O₁ has been achieved by electrochemi-

strinulation ord the similar in electrodeposition, the cally reducing Fe¹-trinulation

triggers for the acc stimulation could be similar in electrodeposition, the

religions for the accumulation of different deposits on

the substrate surfaces could be completely different. (Eq. 2) Due to the meth lower formation constant

In g for the accumulation of different deposits on TEA from an alkaline Fe(TEA)" complex solution^{[33,21}]
stats surfaces could be completely different. (Fe₁ 2). Due to the much lower formation constant
ral, the electrodepos the substrate surfaces could be completely different. (Eq. 2). Due to the much lower formation constant

In general, the clectrodeposition of metalsialleys usu-
 (K°) of the Fe(FIFA)² complex, the generated of Fe² In general, the electrodeposition of metals/alloys usu-

ally involves only an electrodeposition of compounds/com-

in the strong stakinies solution, which the most

subset whereas the electrodeposition of compounds/com-
 ally involves only an electrochemical reaction, (TEA)³ complex, the generated of Fe³ is not stable
whereas the electrodeposition of compounds/com-
in the strong allahies solution, which then triggers
posites commonly whereas the electrodeposition of compounds/com-

in the strong alkaline solution, which then triggers

commonly involves both electrochemical and the deposition of Feo, through the following cheme

chemical electrochemica $28(7)$, $2213006(3 \text{ of } 24)$
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the g $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species is
the deposition solution. If the ge $28(7)$, 2213006 (3 of 24)

redox couple. This electrochemical process involves

electron transfer between the substrate surface and

the corresponding electrochemically active species in

the deposition solution. If th $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the ge $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the genera 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the genera 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the final product (unlike the electrod 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the final product (unlike the electrod 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the genera 28(7), 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the genera $28(7)$, 2213006 (3 of 24)
redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the $(K⁰_f)$ of the Fe(TEA)²⁺ complex than that of the Fe of the subsection of the substrate since
the ferrom transfer between the substrate surface and
corresponding electrochemically active species in
deposition solution. If the generated species is not
final product (unlike t redox couple. This electrochemical process involves
electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the generated species is not
the fi electron transfer between the substrate surface and
the corresponding electrochemically active species in
the deposition solution. If the generated species is not
the final product (unlike the electrodeposition of met-
al the corresponding electrochemically active species in
the deposition solution. If the generated species is not
the final product (unlike the electrodeposition of met-
als) and participates in the following chemical reac-
 the deposition solution. If the generated species is not
the final product (unlike the electrodeposition of met-
als) and participates in the following chemical reac-
tions to form the targeted deposit on the substrate,
t the final product (unlike the electrodeposition of metals) and participates in the following chemical reac-
tions to form the targeted deposit on the substrate,
this whole process of electrodeposition follows an
electroch als) and participates in the following chemical reac-
tions to form the targeted deposit on the substrate,
this whole process of electrodeposition follows an
electrochemical-chemical (EC) mechanism. Such an
EC mechanism i tions to form the targeted deposit on the substrate,
this whole process of electrodeposition follows an
electrochemical-chemical (EC) mechanism. Such an
EC mechanism is commonly seen in the electrodepo-
sition of compound [22] this whole process of electrodeposition follows an
electrochemical-chemical (EC) mechanism. Such an
EC mechanism is commonly seen in the electrodepo-
sition of compounds^[18.30]. For example, the electrode-
position of F ble process of electrodeposition follows an
hemical-chemical (EC) mechanism. Such an
hanism is commonly seen in the electrodepo-
compounds^{[18-20}]. For example, the electrode-
of Fe₃O₄ has been achieved by electroche electrochemical-chemical (EC) mechanism. Such an
EC mechanism is commonly seen in the electrodepo-
sition of compounds^[18,20]. For example, the electrode-
position of Fe₅O₄ has been achieved by electrochemi-
cally r EC mechanism is commonly seen in the electrodeposition of compounds^[18-20]. For example, the electrode-
position of Fe₅O₄ has been achieved by electrochemi-
cally reducing Fe³¹-triethanolamine (TEA) to Fe^{2*i*} sition of compounds^[18-20]. For example, the electrode-
position of Fe,O₄ has been achieved by electrochemi-
cally reducing Fe³¹-tricthanolamine (TEA) to Fe^{2*²*} and
TEA from an alkaline Fe(TEA)^{3*²*} complex position of Fe,O₄ has been achieved by electrochemically reducing Fe³⁺-triethanolamine (TEA) to Fe²⁺ and
TEA from an alkaline Fe(TEA)³⁺ complex solution^{[18,21}]
(Eq. 2). Due to the much lower formation constant
e₅O₄ has been achieved by electrochemi-
ig Fe³⁺-triethanolamine (TEA) to Fe²⁺ and
alkaline Fe(TEA)³⁺ complex solution^[18,21]
to the much lower formation constant
Fe(TEA)²⁺ complex than that of the Fe
plpex, cally reducing Fe³⁺-triethanolamine (TEA) to Fe²⁺ and
TEA from an alkaline Fe(TEA)³⁺ complex solution^{[18,21}]
(Eq. 2). Due to the much lower formation constant
 (K^{Θ}) of the Fe(TEA)²⁺ complex than that of the Fe TEA from an alkaline Fe(TEA)³⁺ complex solution^{[18,21}]
(Eq. 2). Due to the much lower formation constant
(K^{Θ}) of the Fe(TEA)²⁺ complex than that of the Fe
(TEA)³⁺ complex, the generated of Fe²⁺ is not stabl (Eq. 2). Due to the much lower formation constant
 (K^{Θ}) of the Fe(TEA)²⁺ complex than that of the Fe

(TEA)³⁺ complex, the generated of Fe²⁺ is not stable

in the strong alkaline solution, which then triggers

th (TEA)³⁺ complex, the generated of Fe²⁺ is not stable
in the strong alkaline solution, which then triggers
the deposition of Fe₃O₄ through the following chemi-
cal reaction (Eq. 3). In addition to metallic cations, the deposition of Fe₃O₄ through the following chemi-
cal reaction (Eq. 3). In addition to metallic cations,
molecules in the solution could also be electrochemi-
cally reduced to anions to trigger the deposition
follo reaction (Eq. 3). In addition to metallic cations,
blecules in the solution could also be electrochemi-
ly reduced to anions to trigger the deposition
lowing the EC mechanism. For instance, $PbI_2^{[22]}$
HBiI₃^[23] were molecules in the solution could also be electrochemically reduced to anions to trigger the deposition
following the EC mechanism. For instance, $PbI_2^{[22]}$
and BiI₃^[23] were electrodeposited by electrochemical-
ly re cally reduced to anions to trigger the deposition
following the EC mechanism. For instance, $PbI_2^{[22]}$
and BiI₃⁽²³⁾ were electrodeposited by electrochemical-
ly reducing molecular iodine to iodide ions with the
pres 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (3 of 24)

fferent kinds of func-redox couple. This electrochemical process involves

used in electronics. electron transfer between the substrate surface and

t affect the epi

$$
Fe(TEA)^{3+} + e \rightarrow Fe^{2+} + TEA \tag{2}
$$

$$
Fe^{2+} + 2Fe(TEA)^{3+} + 8OH \rightarrow Fe_3O_4 + 2TEA + 4H_2O
$$

$$
I_2 + 2e^- \to 2I \tag{4}
$$

(3)

$$
M^{n+} + nI \to MI_n \tag{5}
$$

following the EC mechanism. For instance, $PbI_2^{[22]}$
and BiI₃^[23] were electrodeposited by electrochemical-
ly reducing molecular iodine to iodide ions with the
presence of the corresponding metal ions in the depo-
 and BiI₃⁽²³⁾ were electrodeposited by electrochemical-
ly reducing molecular iodine to iodide ions with the
presence of the corresponding metal ions in the depo-
sition solutions due to the small solubility-product
co ly reducing molecular iodine to iodide ions with the
presence of the corresponding metal ions in the depo-
sition solutions due to the small solubility-product
constant (K^{ω}_{π}) of these two metallic iodides (Eqs. 4
and presence of the corresponding metal ions in the deposition solutions due to the small solubility-product
constant (K°_{sp}) of these two metallic iodides (Eqs. 4
and 5).
Fe(TEA)³⁺ + e⁻ → Fe²⁺ + TEA (2)
 $[Fe^{2+} + 2Fe(TE$ sition solutions due to the small solubility-product
constant (K°_{π}) of these two metallic iodides (Eqs. 4
and 5).
Fe(TEA)³⁺ + e⁻ → Fe²⁺ + TEA (2)
 Fe^{2+} + 2Fe(TEA)³⁺ + 8OH⁻ → Fe₃O₄ + 2TEA + 4H₂O

 $# \&L \# (J. Electron) 2022, 28(7), 2213006 (4 of 24)$ ways, including the electrochemical reactions conclusion of the taming H⁺/OH^T ions or electrochemical oxidation/re-
suming H⁺/OH^T ions or electrochemical oxidation/re-
dir suming H⁺/OH ions or electrochemical oxidation/re-**Example 19**
 Example 19 H(EF)(*L Electrochem.*) 2022, 28(7), 2213006 (4 of 24)
ways, including the electrochemical reactions concerned oxidation of the tartrate ligand of the Cu(II)
suming H'/OH ions or electrochemical oxidation/re-
darriate c $\pm \frac{\mu}{2}$ (*J. Electrochem.*) 2022, 28(7), 2213006 (4 of 24)
ways, including the electrochemical cractions con-
startiate complex is a startiate complex and some other ains to generate
duction of water and some other an **EVACU Electrochem.**) 2022, 28(7), 2213006 (4 of 24)

ways, including the electrochemical reactions concerned oxidation of the tartrate ligand of the Cu(II)

suming H7OH ions or electrochemical oxidation/re-

dartate comp **EVALUAT THE 1998**
 EVALUAT THE 1998
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 $\mathbb{E}(E)$ $\mathbb{E}(E)$ **from a saturated** Ca (*Hetrochemical* carticons con-
 from a saturated CA (*HCO3)*²²¹³⁰⁰⁶ (4 of 24)
 saming H'/OH ions or electrochemical oxidation/re-

dentrical oxidation of the tartrate ligand of the Cu(II)

sum **EVALUATIVE 12**
 EVALUATIVE 12000 (4 of 24)
 EVALUATIVE 12000 (**ACT and some of the minumic to ge EVALUATION THE SUBSTRATE (EXECTS)** 1992, 28(7), 2213006 (4 of 24)
 **Surface surface in the surface surface surface in the surface surface surface surface surface in the surface of the Cu(II)

suming H'/OH ions or electro** $\text{#E}\#(J. Electron) = 2022, 28(7), 2213006 (4 of 24)$ ways, including the electrochemical reactions con-

suming H'/OH ions or electrochemical oxidation/re-

starting complex in an alk

duction of water and some other anions to gene **EVALUATION**
 EVALUATION THE interactions concerned oxidation of the fartrate ligand of the Cu(II)

Hi ions or electrochemical reactions concerned oxidation of the fartrate ligand of the Cu(II)

Hi ions or electrochemic \pm (E \neq C.E. Electrochemical cracinos concernent contribute that in the tractic ligand of the Cu(II)
suming HVOH⁷ ions or electrochemical voidation/re-
duratate complex in an alkaline solution of water and some obse the $^{46}E^{46}$, *Ehermahem.*) 2022, 28(7), 2213006 (4 of 24)

ways, including the electrochemical reactions con-

chemical oxidation of the tratrate ligand of the Cu(II)

suming H¹/OH ions or electrochemical oxidation/ ways, including the electrochemical cactions con-

ways, including the electrochemical cactions con-

suming H'/OH ions or electrochemical cacidation/^{to}-

-tartrate complex in an alkaline solution^[29]. When

duetion o ways, including the electrochemical reactions con-

electriche condition of the tartrate ligand of the Cu(II)

suming HYOPF ions or electrochemical oxidation/ie-

duction of water and some other anions to generate

duction surming HYOH^T ions or electrochemical oxidation/re-

durbution of water and some other animos to generate

dured in the surface consisting the protecting ligands, the formation consisting

durid in the stand of the form duction of water and some other anions to generate

acids/hascs, which have been covered in detail in the stant of the formed medialitic complex, the attact

diterature¹²⁴¹. Understandbly, electrochemical base

literatu . generation has been widely used to electrodeposit and the equilibrium potential of the reations metal oxides¹⁵⁹ and hydroxides^{18, 27} (Eqs. 6 the ligand need to be comprehensively and 7). Besides, it could also be the various metal oxides^[35] and hydroxides^{[36} ³⁷⁶] (Eqs. 6 the ligand need to be comprehent and 7). Besides, it could also be the trigger for the **2.2 Key Parameters for Electrodeposition** of other compounds such as Ca

$$
M^{n+} + nOH^- \to M(OH)_n
$$

$$
M^{n+} + nOH^- \to MO_{2/n} + H_2O \tag{7}
$$

$$
2H_2O + 2e^- \rightarrow H_2 + 2OH^-(8)
$$

$$
\text{OH}^{\cdot} + \text{Ca}^{\cdot} + \text{HCO}_3 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}
$$
\n
$$
\text{CHO}^{\lambda} + \text{H}_2\text{O} = \text{CHO} + \text{H}_2^{\cdot} + \text{H}_2\text{O}
$$
\n
$$
\text{(10)}
$$

$$
C_6H_7O_6^{2+} + H_2O \rightarrow C_6H_8O_7 + H^+ + 2e^-
$$
 (10)

$$
Zn(OH)_3 + H^+ \rightarrow ZnO + 2H_2O \tag{11}
$$

$$
Zn(OH)42 + 2H+ \to ZnO + 3H2O
$$
 (12)

 $Zn(OH)$, $+ H^{-} \rightarrow ZnO + 2H+O$ (11) to promote the growth of the deposits at desired po-
 $Zn(OH)_1 + 2H^+ \rightarrow ZnO + 2H_2O$ (12) stimes (e.g., for the clearotedposition of metal inter-
 $2.1.4$ Descriation of Protecting Ligands of M $Zn(OH)_x + 2H \rightarrow ZnO + 3H_xO$ (12) stitions (e.g., for the electrodeposition of metal inter-

2.1,4 Destruction of Protecting Ligands of Metal Ions

In many cases, metallic compounds colud be pro-

Moreover, many other 2.1.4 Destruction of Protecting Ligands of Metal Ions connects in the manufacture of integrated circuits)

In many cases, metallic compounds could be pro- Moreover, many other experimental parameters, such
duced by direct

 $\# \# \# (J. Electron) \geq 222, 28(7), 2213006 \ (4 \text{ of } 24)$
ways, includin g the electrochemical reactions con-
suming H⁺/OH² ions or electrochemical oxidation/re-
duction of water and some other anions to generate complex in an $\#E\#(J. Electronen.)$ 2022, 28(7), 2213006 (4 of 24)

g the electrochemical reactions concrete the complex in an alkaline solution^[30]. When

r and some other anions to generate the complex in an alkaline solution^[30]. When
 duction of water and some other anions to generate $(28(7), 2213006 (4 of 24))$
chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic comple $28(7)$, 2213006 (4 of 24)
chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic c $(28(7), 2213006)$ (4 of 24)
chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic co stant, $28(7)$, 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic c 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic c $(28(7), 2213006 (4 of 24)$

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic co $(2.28(7), 2213006 (4 of 24)$

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic (7), 2213006 (4 of 24)

There are more and a solution con-

Dosing the protecting ligands, the formation con-

and of the formed metallic complex, the affinit 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

start of the formed metallic c 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic c 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (4 of 24)

unical reactions concremical oxidation of the tartrate ligand of the Cu(II)

hemical oxidation/re-

actritate complex in an alkaline solution^[30]. When

the protec

deposition

to ent properties of the deposits sin (6) sides, many additives in the deposition solution could ature¹²¹. Understandably, electrochemical base

raten has here metallic eations and the targeted anions,

ratio mass here widely used to electrodeposition and the equilibrium potential of the redox couple of

20. Hesid (8) certain crystallographic orientations (resulting in difes¹⁸¹) and hydroxides¹⁸^{6. 70} (Eqs. 6 the ligand need to be comprehensively considered.

could also be the trigger for the **2.2 Key Parameters for Epitaxial Electro-**

folder compunds such as CaCO₃ be deposited and Besides, it could also be the trigger for the **2.2 Key Parameters for Epitaxial Elec**
deposition of other compounds such as CaCO, **deposition**
saturated Ca(HCO₃) solution, in which the There are many adjustable experime be the trigger for the **2.2 Key Parameters for Epitaxial Electro-**

bounds such as CaCo,
 deposition

colution, in which the

There are many adjustable experimental parameters

cal reduction of H₅O ters for electrodep (10) the electric field distribution on the substrate surface position of other compounds such as CaCO₃

deposition

automated CaHCO₃, solution, in which the There are many adjustable experimental parame-

dOH² by electrochemical reduction of H₂O

dOH² by electrochemical aturated Ca(HCO_{b)} solution, in which the

10HF veloctrochemical reduction of H₂O is tre for electrodeposition, which could affect differ-

bistrate urince (Fq. 8) reacts with HCO_j to

2- ample, the deposition potent generated OH by electrochemical reduction of H_3O ters for electrodeposition, which could affect differ-
on the substruction of Protocolic measure of the deposits imultaneously. For co-
produce CO₂⁺ and riggers the the substrate surface (Eq. 8) reates with HCO; to

controporties of the deposition simultaneously. For ex-

order Co₂³ and triggers the CaCO₁ deposition (Fq. amplie, the deposition potential could affect the com-

 produce CO_i² and triggers the CaCO₁ deposition (Eq. ample, the deposition potential could affect the com-

b)⁽²¹⁾. The electrochemical generation of acids could position, morphology, grain size, and crystallograph 9)²⁹¹. The electrochemical generation of acids could
position, morphology, grain size, and erystallographic
be used to deposit amphological cations correlated coids from al-
orientation of the depositions. An example of be used to deposit amphoteric metal oxides from alcording to deposity π , alcording contents and example of it is the electrodeposition correct is deposited and the deposite station of Endows An example of this the elec kaline solutions. An example of it is the electrodepo-

surface radiates on different on the deposits to the

stroch card be surface rather on the surface rather on the surface rather

surface rather on the surface rather sition of ZnO by decreasing the local pH at the elec-

gy, growth rate, and adhesion of the deposits to the

succordent claim of CF(as. 10-12)²⁰.

As electrochemically oxidizing the substrate, and denosition tennerance trode surface via electrochemically oxidizing the substrate, and deposition temperature could change
ascorbate daintoms (Eqs. 10-12)²⁸⁾.
M⁻ + n OH⁻ - M(OH),
M⁺ + n OH- - M(OH),
M⁺ n OH- - M(OH),
M⁺ n OH- ascorbate dianions (Eqs. 10-12)²⁹⁾.

the growth rate and crystallinity of the deposits. Be-

M^T + nOH¹ → M(OH₁), (6) sides, many additives in the deposition solution could

2H₃O + 2C → H₃ + 2OH² (8) certain $M^+ + nOH \rightarrow M(OH)$,
 $2H + nOH \rightarrow M(O_{8+} + H_5O)$ (6) sides, many additives in the deposition solution could
 $M^+ + nOH \rightarrow M_0$, $2H_5O + H_5O$ (8) be used to adjust the growth of the deposits along
 $2H_5O + H_5O \rightarrow CaCO + H_5O$ (8) creatin crys $M^* + nOH \rightarrow MO_{2n} + H_2O$ (7) be used to adjust the growth of the deposits along
 $2H_2O + 2c \rightarrow H_1 + 2Ot$ (8) certain crystallographic orientanion (resulting in dif-
 $CH_2O_s^* + H_2O \rightarrow C_6H_3O_s + H^2 + 2c$ (10) the electric field dist 21¹₂O + 2e → 1¹₂ + 2e → 11³ + 201¹ (8) certain erystallographic orientations (resulting in diferent to CH and CH + Ca² + HCO₃ + F C_O₃ + C_O₃ + C_O₃ + C_O₂ + C_O₂ + C_O₂ + C_O₂ + C_O OH \pm Ca² + HCO₃ \rightarrow CaCO₃ + H₂O (9) ferent morphologies of the deposits)^{[28,34}] or regulate $C_{\text{eff}}(D_{\text{eff}}^2 + H_2(O + H_2^+ + L_2^0) \rightarrow H^+ + 2e$ (10) the electrofic field distribution on the substrate surface $Zn(O$ Cal:O_n² + H₁O \rightarrow Cal1_C) + H² + 2 e (10) the clectric field distribution on the substrate surface
 $Zn(OH)_1$ ² + H² \rightarrow ZnO + 2H₂O (11) to promote the growth of the deposits at desired po-
 $Zn(OH)_1$ ² + 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic c 28(7), 2213006 (4 of 24)

chemical oxidation of the tartrate ligand of the Cu(II)

-tartrate complex in an alkaline solution^[30]. When

choosing the protecting ligands, the formation con-

stant of the formed metallic c $28(7)$, 2213006 (4 of 24)
chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[39]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic c chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic complex, the affinity be-
twee chemical oxidation of the tartrate ligand of the Cu(II)
-tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic complex, the affinity be-
twee -tartrate complex in an alkaline solution^[30]. When
choosing the protecting ligands, the formation con-
stant of the formed metallic complex, the affinity be-
tween the metallic cations and the targeted anions,
and the choosing the protecting ligands, the formation con-
stant of the formed metallic complex, the affinity be-
tween the metallic cations and the targeted anions,
and the equilibrium potential of the redox couple of
the ligan stant of the formed metallic complex, the affinity be-
tween the metallic cations and the targeted anions,
and the equilibrium potential of the redox couple of
the ligand need to be comprehensively considered.
2.2 Key Pa tween the metallic cations and the targeted anions,
and the equilibrium potential of the redox couple of
the ligand need to be comprehensively considered.
2.2 Key Parameters for Epitaxial Electro-
deposition
There are and the equilibrium potential of the redox couple of
the ligand need to be comprehensively considered.
2.2 Key Parameters for Epitaxial Electro-
deposition
There are many adjustable experimental parame-
ters for elect the ligand need to be comprehensively considered.
 2.2 Key Parameters for Epitaxial Electro-

deposition

There are many adjustable experimental parameters for electrodeposition, which could affect differ-

ent properti 2.2 Key Parameters for Epitaxial Electro-
deposition
There are many adjustable experimental parame-
ters for electrodeposition, which could affect differ-
ent properties of the deposits simultaneously. For ex-
ample, the **deposition**
There are many adjustable experimental parame-
ters for electrodeposition, which could affect differ-
ent properties of the deposits simultaneously. For ex-
ample, the deposition potential could affect the co There are many adjustable experimental parame-
ters for electrodeposition, which could affect differ-
ent properties of the deposits simultaneously. For ex-
ample, the deposition potential could affect the com-
position, m ters for electrodeposition, which could affect different properties of the deposits simultaneously. For example, the deposition potential could affect the composition, morphology, grain size, and crystallographic orientati ent properties of the deposits simultaneously. For example, the deposition potential could affect the com-
position, morphology, grain size, and crystallographic
orientation of the deposits^[31-33], deposition current
den ample, the deposition potential could affect the com-
position, morphology, grain size, and crystallographic
orientation of the deposits^[31,33], deposition current
density could vary the nucleation density, morpholo-
gy position, morphology, grain size, and crystallographic
orientation of the deposits^{[31,33}], deposition current
density could vary the nucleation density, morpholo-
gy, growth rate, and adhesion of the deposits to the
subs orientation of the deposits^{[31,33}], deposition current
density could vary the nucleation density, morpholo-
gy, growth rate, and adhesion of the deposits to the
substrate, and deposition temperature could change
the grow density could vary the nucleation density, morphology, growth rate, and adhesion of the deposits to the substrate, and deposition temperature could change the growth rate and crystallinity of the deposits. Besides, many ad gy, growth rate, and adhesion of the deposits to the
substrate, and deposition temperature could change
the growth rate and crystallinity of the deposits. Be-
sides, many additives in the deposition solution could
be used substrate, and deposition temperature could change
the growth rate and crystallinity of the deposits. Be-
sides, many additives in the deposition solution could
be used to adjust the growth of the deposits laong
certain c the growth rate and crystallinity of the deposits. Be-
sides, many additives in the deposition solution could
be used to adjust the growth of the deposits along
certain crystallographic orientations (resulting in dif-
fere sides, many additives in the deposition solution could
be used to adjust the growth of the deposits along
certain crystallographic orientations (resulting in dif-
ferent morphologies of the deposits)^{$[28, 34]$} or regulat be used to adjust the growth of the deposits along
certain crystallographic orientations (resulting in dif-
ferent morphologies of the deposits)^{$[28, 34]$} or regulate
the electric field distribution on the substrate sur certain crystallographic orientations (resulting in dif-
ferent morphologies of the deposits)^{$[28, 34]$} or regulate
the electric field distribution on the substrate surface
to promote the growth of the deposits at desir ferent morphologies of the deposits)^{$[28, 34]$} or regulate
the electric field distribution on the substrate surface
to promote the growth of the deposits at desired po-
sitions (e.g., for the electrodeposition of metal the electric field distribution on the substrate surface
to promote the growth of the deposits at desired po-
sitions (e.g., for the electrodeposition of metal inter-
connects in the manufacture of integrated circuits).
Mo promote the growth of the deposits at desired po-
ions (e.g., for the electrodeposition of metal inter-
nnects in the manufacture of integrated circuits).
Devover, many other experimental parameters, such
pH of the deposit sitions (e.g., for the electrode
position of metal inter-
connects in the manufacture of integrated circuits).
Moreover, many other experimental parameters, such
as pH of the deposition solution, conductivity of the
subst connects in the manufacture of integrated circuits).
Moreover, many other experimental parameters, such
as pH of the deposition solution, conductivity of the
substrate, and mass transfer of the active species in
the deposi

 $\pm \frac{k \cdot \gamma}{L}$ *Lectrochem.*) 2022, 28(7), 2213006 (5 of 24)

sin gle-crys talline substrates, including conductive ferred substrates for epitaxial electrodeposition due

metal single crystals (e.g., Au, Ni, and Cu) and s **EORTA SET ALL EXAMORE THE EXAMORE SET ALL SET ALL SET ALL SIDE CONDUCT SIDE CALL SIDE CALL SIDE CALL SIDE CALL SIDE CALL SIDE CONDUCT SINGLET SIDE CALL SIDE CALL SIDE CONDUCT SIDE CALL SIDE CONDUCT SIDE CAS NOT precious** t<u>E</u>{*l*^{2\2}}*(L Electrochem.)* 2022, 28(7), 2213006 (5 of 24)

sin gle-crys talline substrates, including conductive

ferred substrates for epitaxial electrodeposition due

metal single crystals (e.g., Si, InP, and G $\mathbb{E}(\mathcal{H}_{\text{eff}}^{\text{eff}}(L \text{Electrochem.}) 2022, 28(7), 2213006 (5 of 24)$

sin gle-crys talline substrates, including conductive ferred substrates for epitaxial electrodeposition due

metal single crystals (e.g., Au, Ni, and Cu) and **EVALUATE 1998**
 EVALUATE 1999
 such as Fe3O4 such as $Fe_3O_4^{[7, 38]}$, $Co_3O_4^{[19]}$, $Co_3Fe_{3x}O_4^{[8]}$, $ZnO^{[29, 39]}$, substrate might not be suitable for epitaxial elec- $Cu₂O^[40]$ and $CuO^[41]$ on Au single crystals, $Cu₂O^[42]$ and the R_2 on \mathbb{R}^2 on \mathbb{R}^2 on the films on the films on the single crystals for expiration of the energy of formation of the films one and \mathbb{R}^2 on the single crystals (e.g., Si, InP, and Cu) and semi-
con (a) $\frac{1}{2}$ (b) $\frac{1}{2}$ (d) $\frac{1}{2$ the $\ell \gg 0$ and $\ell \gg 0$ **EVALUATION CONTINUATION**
 EVALUATION CONTECT (EXECUTE ARE CONTECT ARE CONTINUATION CONTINUATION CONTINUATION CONTINUATION CONTINUATION CONTINUATION CONTECT (EXECUTE ARE CONTECT ARE CONTECT ARE CONTECT ARE CONTECT ARE C **fromation**
fromation $\mathcal{H}/k\mathcal{F}(L\text{ Rleenowhem.})$ 2022, 28(7), 2213006 (5 of 24)

sin gle-crys talline substrates, including conductive ferred substrates for epitaxial electrodeposition due

eneral single crystals (e.g., **EVALUATION**
 EVALUATION $4k^2\mathcal{R}(L\text{ *Heermebem*}) 2022, 28(7), 2213006 (5 of 24)$

sin gle-crys talline substrates, including conductive ferred substrates for epitaxial electrodeposition due

metal single crystals (e.g., Au, Ni, and Cu) and semi-
 equation, conductor single crystals (e.g., Si, InP, and GaN). To
ertness. Non-precious metal substrates s
date, various functional materials have been epitaxi-
Cu single crystals might not be stable
ally electrodeposited onto diffe

gle-crystal surfaces⁵⁸⁰. Normally, the clectrodeposited

eincarchical film stend to grow with erystal paraphic ori-

enviations film stend to grow with erystal grouphic ori-

enviations film stend to grow with erystal c epitaxial films tend to grow with erystallographic ori-
entations interfaces results in more challenges in
entations that minimize the lattice mismatch between epintaxial electrodeposition on semiconductors. Take
the depo entations that minimize the lattice mismatch between epitaxial electrodeposition on semiconductors. Take
the deposited film and the single crystal surface, the most used single-crystalline semi-conductor sub-
which could the deposited film and the single crystal surface,

when could be calculated by using the following strate, single-crystalls, as an example, it is challenge-

equation, ing to epitaxially electrodeposit metal on H-termina which could be calculated by using the following strate, single-crystal Si, as an example, it is challeng-
equation,
Lattice mismatch = $(d_{\text{flux}} - d_{\text{down}})/d_{\text{down}}$ (13) et als pleasured from H-crimina-
Lattice mismatch = $(d$ equation,

lattice mismatch = $(d_{\text{fin}} - d_{\text{dom}})d_{\text{obsms}}$ = (13)

Lattice mismatch = $(d_{\text{fin}} - d_{\text{dom}})d_{\text{obsms}}$ = (13) eds i) eds i) eds incomes a sur-

where *d* is the lattice spacing of the crystal planes fine or okea b Lattice mismatch = $(d_{\text{fla}} - d_{\text{abs}})/d_{\text{abs}}$ (13) ed Si because of the propensity of Si to form a sur-
where d is the lattice spacing of the crystal planes face oxide layer in aqueous electrolytes (examples
parallel to t where *d* is the lattice spacing of the crystal planes face oxide layer in aqueous electrolytes (examples
parallel to the substrate surface. Grenerally, it is ideal will be given in Section 2.2.2). Therefore, a suffi-
par parallel to the substrate surface. Generally, it is ideal
will be given in Section 2.2.2). Therefore, a suffi-
for the cpinxial growth of the cleared position mate-
minis when the lattice mismatch is less than 5%. Epised for the epitaxial growth of the electrodeposited mate-
intring the si sually applied he rains a stally applied he achieved by the formation could still be a chieved by the formation could still and the condensity of the s rials when the lattice mismatch is less than 5%. Epi-

straing the Si substrate into the electrolyte to a

taxial electrodeposition could still be achieved by

the formation of amorphous SiO, layers. This pre

formation a

 $#E\#(J. Electron.) 2022, 28(7), 2213006 (5 of 24)$

line substrates, including conductive

ferred substrates for epitaxial electrod

ystals (e.g., Au, Ni, and Cu) and semi-

to their great conductivity and excellen

le crystals (e. \pm / $k \neq (J. Electrochem.)$ 2022, 28(7), 2213006 (5 of 24)
ates, including conductive ferred substrates for epitaxial electrodeposition
Au, Ni, and Cu) and semi-
to their great conductivity and excellent chemica
e.g., Si, InP, and *Electrochem.*) 2022, 28(7), 2213006 (5 of 24)

g conductive ferred substrates for epitaxial electrodeposition due

to their great conductivity and excellent chemical in-

ind GaN). To ertness. Non-precious metal substrat $\pm \frac{1}{2}$ (*LE LE LE and Cu₂ A a*, *A*, *b*₁, *and Cu₂</sub> <i>A and Gs*, *A and Association and association and stress and also strates in the single crystals* (*c.g.*, *Au*, *Ni*, *and Cu₂ <i>and G* trodeposition in acidic deposition solutions due to its $\pm \frac{1}{2}$ *H*₂ *Electrochem.*) 2022, 28(7), 2213006 (5 of 24)

ne substrates, including conductive ferred substrates for epitaxial electrodeposition due

atals (e.g., Au, Ni, and Cu) and semi-

to their great conducti the $2\pi (L)$ Electrochemon.) 2022, 28(7), 2213006 (5 of 24)

sin gle-crys talline substrates, including conductive formed substrates for cpitaxial electrodeposition due

metal single crystals (e.g., St, InP, and GaN). To sin gle-crys talline substrates, including conductive ferred substrates for epitaxial electrodeposition due
metal single crystals (e.g., Si, InP, and Cu) and semi-
conductor single crystals (e.g., Si, InP, and Gu) and sem sin gle-crys talline substrates, including conductive
metal single crystaal electrodeposition due
nend single crystaal e.g., AN, and CaN) and can-
including the calculation-conductor single crystaals (e.g., Si, InP, and C date, various functional materials have been epitaxi-

Cu single crystals might not be stable in some depo-

stach as Fe,Q,^{*0.8*}, Co,Q_c(α ₎, Co,_F_C,Q_iⁿ, Z₀(B^c), Z₀(B^c), 3 substrate might not be suit ally electrodeposited onto different single crystals,
surfon systems. For instance, the single-crystalline Ni
such as Fe-Q₁^{(2,m}, Co₁^{(2),m}, Co₁(2)⁽²⁾, Zo(2)⁽²⁾, Zo(2)⁽²⁾, Zo(2)⁽²⁾, Zo(2)⁽²⁾, Zo(2)⁽²⁾, such as Fe₃Q_L^{i, 20}₍₁₀_L^{1, 20}₍₁₀^{1, 2}), 20^{(28, 29⁽²), 20^{(28, 29)²² substrate might not be suitable for epinaxial elec-
Cu_C^{0/28} and Cu_CO⁴¹ on Au amigle crystals, Cu_C₀^C⁶⁶ and tradedepositi}} CucO¹⁸¹ and CuO¹⁸¹ on Au single crystals, CuO¹⁸¹ and

codeposition in acidic deposition solutions due to its

cdTe¹⁸¹ on InP single crystals, and Au²⁶¹⁸. (Q_{L}^{th} on the cattice mismatch to electrode
 CdTe⁽ⁿ⁾ on lnP single crystals, and Au^{[04,16}], Cu^{[66,10}], dissolution in acids. In contrast to the electrodeposi-
Ag^{[04}, and Cu₀O³⁰ on Si single crystals. In most cas-
on on conductive media substrates, the el Ag^{tin}, and Cu₅O¹⁸⁹ on Si single crystals. In most eas-

tion on conductive metal substrates, the electrodepo-

est, these equiaxial films grow with thermodynamical-

by controlled orientations that are determined by es, these epitaxial films grow with thermodynamical-
stion on semiconductors is more complicated. First, y controlled orientations that are determined by the the recitying property of semiconductors needs to be
free energ ly controlled orientations that are determined by the the rectifying property of semiconductors needs to be
the control of the films on the sin-
considered if used as the substrates for clearing electrosters are the
set a free energy of formation of the films on the sin-

considered if used as the substrates for electrodeposi-

gele-crystal surfaces¹⁹⁶. Normally, the electrodeposited ion. Second, the complexity of the semiconduc-

epitax $28(7)$, $2213006(5 \text{ of } 24)$
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, $2213006(5 \text{ of } 24)$
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not 28(7), 2213006 (5 of 24)

ferred substrates for epitaxial electrodeposition due

to their great conductivity and excellent chemical in-

ertness. Non-precious metal substrates such as Ni and

Cu single crystals might not b $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might no $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might no $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $\frac{28(7)}{2213006}$ (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might no $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might no $28(7)$, 2213006 (5 of 24)
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might no Eactivity and exactivity and exactivity and exactle
ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu sing ferred substrates for epitaxial electrodeposition due
to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not be stable in some depo-
sition to their great conductivity and excellent chemical in-
ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not be stable in some depo-
sition systems. For instance, the single-crystalline Ni
subs ertness. Non-precious metal substrates such as Ni and
Cu single crystals might not be stable in some depo-
sition systems. For instance, the single-crystalline Ni
substrate might not be suitable for epitaxial elec-
trodepo Cu single crystals might not be stable in some deposition systems. For instance, the single-crystalline Ni
substrate might not be suitable for epitaxial electrodeposition in acidic deposition solutions due to its
dissoluti sition systems. For instance, the single-crystalline Ni
substrate might not be suitable for epitaxial elec-
trodeposition in acidic deposition solutions due to its
dissolution in acidic deposition solutions due to its
diss substrate might not be suitable for epitaxial electrodeposition in acidic deposition solutions due to its dissolution in acidis. In contrast to the electrodeposition on conductive metal substrates, the electrodeposition on trodeposition in acidic deposition solutions due to its
dissolution in acids. In contrast to the electrodeposi-
tion on conductive metal substrates, the electrodeposi-
sition on semiconductors is more complicated. First,
t dissolution in acids. In contrast to the electrodeposi-
tion on conductive metal substrates, the electrodeposi-
sition on semiconductors is more complicated. First,
the rectifying property of semiconductors needs to be
co o the electrodeposi-
es, the electrodeposi-
complicated. First,
ductors needs to be
ss for electrodeposi-
f the semiconduc-
more challenges in
miconductors. Take
emi-conductor sub-
mple, it is challeng-
netal on H-terminat tion on conductive metal substrates, the electrodeposition on semiconductors is more complicated. First, the rectifying property of semiconductors needs to be considered if used as the substrates for electrodeposition. Se sition on semiconductors is more complicated. First,
the rectifying property of semiconductors needs to be
considered if used as the substrates for electrodeposi-
tion. Second, the complexity of the semiconduc-
tor-solutio rectifying property of semiconductors needs to be
nsidered if used as the substrates for electrodeposi-
n. Second, the complexity of the semiconduc--
solution interfaces results in more challenges in
itaxial electrodeposit considered if used as the substrates for electrodeposi-
tion. Second, the complexity of the semiconduc-
tor-solution interfaces results in more challenges in
epitaxial electrodeposition on semiconductors. Take
the most use tion. Second, the complexity of the semiconductor-solution interfaces results in more challenges in epitaxial electrodeposition on semiconductors. Take the most used single-crystalline semi-conductor sub-strate, single-cry tor-solution interfaces results in more challenges in
epitaxial electrodeposition on semiconductors. Take
the most used single-crystalline semi-conductor sub-
strate, single-crystal Si, as an example, it is challeng-
ing t epitaxial electrodeposition on semiconductors. Take
the most used single-crystalline semi-conductor sub-
strate, single-crystal Si, as an example, it is challeng-
ing to epitaxially electrodeposit metal on H-terminat-
ed S the most used single-crystalline semi-conductor sub-
strate, single-crystal Si, as an example, it is challeng-
ing to epitaxially electrodeposit metal on H-terminat-
ed Si because of the propensity of Si to form a sur-
fac 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (5 of 24)

including conductive ferred substrates for epitaxial electrodeposition due

Ni, and Cu) and semi-

to their great conductivity and excellent chemical in-

Si, InP, a

e electrodeposited mate-

eiectrodeposited mate-

eiectrodeposited mate-

thi is less than 5%. Epi-

serting the Si substrate into the electrolyte to avoid

d sill be achieved by the formation of amorphosis SiO, layers. T ial electrodeposition could still be achieved by

the formation of amorphous SiO, layers. This process

match ranges from 5% to 25%. When the lattice $\frac{1}{2}$ shown as prepolarization^{59,1}

smatch ranges from 5% to 25%. forming a semi-coherent interface when the lattice

instancta hypotography.

mismatch ranges from 5% to 25%. When the lattice
 $2.2.2$ Mode and Magnitude of Flectrical Stimulation

mismatch ranges from 5% to 25%. When the mismatch ranges from 5% to 25%. When the lattice 2.2.2 Mode and Magnitude of Electrical Simulation
mismatch is even larger, epitaxy could possibly be Like any common electrodeposition, the electrode-
schieved by in-plane mismatch is even larger, epitaxy could possibly be

Like any common electrodeposition, the electrodeposition

film and/or formation of coincidence lattices, which ing an electrical stimulation, i.e., applying an electrica strate, single-crystal Si, as an example, it is challeng-
ing to epitaxially electrodeposit metal on H-terminat-
ed Si because of the propensity of Si to form a sur-
face oxide layer in aqueous electrolytes (examples
will ing to epitaxially electrodeposit metal on H-terminat-
ed Si because of the propensity of Si to form a sur-
face oxide layer in aqueous electrolytes (examples
will be given in Section 2.2.2). Therefore, a suffi-
eiently ne ed Si because of the propensity of Si to form a sur-
face oxide layer in aqueous electrolytes (examples
will be given in Section 2.2.2). Therefore, a suffi-
ciently negative potential is usually applied before in-
serting face oxide layer in aqueous electrolytes (examples
will be given in Section 2.2.2). Therefore, a suffi-
ciently negative potential is usually applied before in-
serting the Si substrate into the electrolyte to avoid
the f will be given in Section 2.2.2). Therefore, a suffi-
ciently negative potential is usually applied before in-
serting the Si substrate into the electrolyte to avoid
the formation of amorphous SiO_x layers. This process
is ciently negative potential is usually applied before in-
serting the Si substrate into the electrolyte to avoid
the formation of amorphous SiO_s layers. This process
is known as prepolarization^[53].
2.2.2 Mode and Magni serting the Si substrate into the electrolyte to avoid
the formation of amorphous SiO, layers. This process
is known as prepolarization^[53].
2.2.2 Mode and Magnitude of Electrical Stimulation
Like any common electrodepos the formation of amorphous SiO_s layers. This process
is known as prepolarization^[53].
2.2.2 Mode and Magnitude of Electrical Stimulation
Like any common electrodeposition, the electrode-
position of epitaxial films is is known as prepolarization^[53].
2.2.2 Mode and Magnitude of Electrical Stimulation
Like any common electrodeposition, the electrode-
position of epitaxial films is also initiated by impos-
ing an electrical stimulation, 2.2.2 Mode and Magnitude of Electrical Stimulation
Like any common electrodeposition, the electrode-
position of epitaxial films is also initiated by impos-
ing an electrical stimulation, i.e., applying an electri-
cal pot Like any common electrodeposition, the electrode-
position of epitaxial films is also initiated by impos-
ing an electrical stimulation, i.e., applying an electri-
cal potential/current to the substrate. Thus, the elec-
tr 4.2.2).

EVALUATION THE CONDUM
 EVALUATION TEAT THE CONDUMOTE (SIGN) \mathbf{R}^2 (The applied current deposition of the applied poetncial and signal superlattices will be presented in Section (e.g., -1.5 V vs. Ag/AgC)) is powde thence (more detailed introduced in a the content of the contential results in a the contential superlattices (more detailed introduction on epique of the Cu film electrodeposited at a high overpotential reached in Sectio $\text{Q.E.}(L\text{}Electrow, kem.) 2022, 28(7), 2213006 (6 of 24)$
taxial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential
taxial superlattices will be presented in Section (e.g.,-1.5 V v **EVAPALAL ENTERTIFY** (*Electrochem*, 2022, 28(7), 2213006 (6 of 24)

taxial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential

taxial superlattices will be presented in travial superlattices (more detailed introduction on pit α in the Cu³ find nectrodeposited at a high overpotential
taxial superlattices will be presented in Section (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adh taxial superlattices (more detailed introduction on epi

the Cu film electrodeposited at a high overpotential

a superlattices will be presented in Section (e.g.,-1.5 V vs. $\Delta(y/\Delta y|C)$) is powdery with poor adhe-

4.2.2) taxial superlattices will be presented in Section
(e.g., -1.5 V vs. $Ag/AgCl$) is powdery with poor adhesized.
The magnitude of the applied potential/current for metal electrodeposition it high overpotentials. To
could affec 4.2.2).

sion to the substruct, which is a typical phenomenon

The magnitude of the applied potential/current

for metal electrodeposition at high overplotentials. To

monul affect the epitaxial growth of the deposits. As The magnitude of the applied potential/current for metal electrodeposition at high overpotentials. To
could affect the epitaxial growth of the deposits. As tackle this diffentma, Switzer group developed a two-
mentioned i could affect the epitaxial growth of the deposits. As
mexic take this dilemma, Switzer group developed a two-
mentioned in Section 2.21, in many cases the crys-
state location method to epin-
tallographic orientations of mentioned in Section 2.2.1, in many cases the crys-

tate potentiostatic electrodeposition method to epi-

talographic orientations of the deposited films follow ustailly grow Cu(100) film on n-Si(100). First, the

the or tallographic erientations of the deposited films follow
taxially grow Cu(100) film on n-Si(100). First, the
derivation of the single-crystal substrate (i.e., the
e-prinxial Cl asseds were nucleared during the initial
depo the orientation of the single-erystal substrate (i.e., the cpitaxial Cu seeds were nucleated during the initial 2
thermodynamically controlled orientation). However, so pulse ar -1.5 V vs. Ad/AgCl, at which the Hi-eterm thermodynamically controlled orientation). However, spulse at -1.5 V vs. Ag/AgCl, at which the H-termi-
such an epitaxial relationship betwent the electrode-
nated Si surface was also protoceld from oxidation.
posited epi such an epitaxial relationship between the electrode-
noised Si surface was also protected from axidation.
might be overturned when the single-crystal substrate Then, the cpitaxial Cu seeds further grew and con-
might be o posited epitaxial film and the single-crystal substrate Then, the epitaxial Cu seeds further grew and coa-
might be overtured when the applied deposition po-
losed into an epitaxial Cu film at -0.5 V vs. $\Delta y/\Delta gCl$
electri might be overturned when the applied deposition po-

leneral results in an overpotential Cu film at -0.5 V vs. Ag/AgCl

entril results in an overpotential larger than a thresh-

(Figure 1b)^{teq}.

bed value, at which the tential results in an overpotential larger than a thresh—

original results of the desity can influence the crys-

original results of the correlations of the desity of the deposits by affecting the deposition

orientatio old value, at which the growth orientations of the de-

prosited films are switched to kinetically preferred

tallinity of the deposits by

orientations^[84]. For example, the electrodeposited Cu₂O rate. Usually, lower sited films are switched to kinetically preferred tallimity of the deposits by affecting the deposition

entations⁹⁴⁸. For example, the electrodeposited Cu_CO rate. Usanly, lower current densities result in higher

enf orientations³⁹¹. For example, the electrodeposited Cu₂O rate. Usually, lower current densities result in higher
 α hu(100) substrate at a low overpotential but switches rent densities are neven result in amorphous d film follows a [100] out-of-plane orientation of the erytstallinity of the epitaxial films, while too high curr-
Au(100) asshorted at low overposential bus sinces react donsities a en cor nesult in amorphose deposits.
To Au(100) substrate at a low overpotential but switches

can densities can even result in amorphous deposits.

to a kinctically preferied [110] out-of-plane orienta-

the applied current density should be con-

tion at a th to a kinetically preferred [110] out-of-plane orienta-

Therefore, the applied current density should be con-

tion at a threshold overpotential of -118 mV. This trolled within a certain range for the fabrication of

abru tion at a threshold overpotential of -118 mV. This trolled within a certain range for the filorication of a
bitwisted pare of growth orientation of the deposits is epitaxial films by electrodeposition. Furthermore, the
tr

lands on single-crystal substrates. Such a transforma-

increased current density of

tion from the thermodynamically controlled growth

orientation to the kinetically preferred growth orien-

ty. As shown in Figure 1e,

 $\exists k \neq (L \text{ }Electrochem.)$

taxial superlattices (more detailed introduction on epique 1902, 28(7), 2213006 (6 of 24)

taxial superlattices will be presented in Section

(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-

sio $\# \# \# (J. \text{ \textit{Electrochem.}})$ 2022, 28(7), 2213006 (6 of 24)
taxial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential
taxial superlattices will be presented in Section (e.g., $\# \{\ell \neq (J. \text{Electrochem.}) 2022, 28(7), 2213006 (6 of 24) \}$ ial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential

ial superlattices will be presented in Section (e.g., -1.5 V v $\frac{\text{ft}(E\#(f, Electrochem.) 2022, 28(7), 2213006 (6 of 24)}{\text{taxial}}$
taxial superlattices (more detailed introduction on epitarion to the Cu film electrodeposited at a high overpotential
taxial superlattices will be presented in Sectio $\pm \frac{R}{2}(L\text{~Electrochem.}) 2022, 28(7), 2213006 (6 \text{ of } 24)$

taxial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential

taxial superlattices will be presented in Section (e.g., the deposited films (*LE bectrochem.*) 2022, 28(7), 2213006 (6 of 24)

taxial superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential

taxial superlattices will be present the single-crystal substrate (i.e., the critical support of the single-crystal superlattices (more detailed introduction on epi the Cu film electrodeposited at a high overpotential taxial superlattices will be presented i $\text{ft}(L)$ electrochem.) 2022, 28(7), 2213006 (6 of 24)

taxial superlattices (more detailed introduction on epique for Cu film electrodeposited at a high overpotential

taxial superlattices will be presented in Section

(flue $\mathcal{H}(E)$ (*Electrochem.*) 2022, 28(7), 2213006 (6 of 24)
taxial superlattices (more detailed introduction on epital of the Cu film electrodeposited at a high overpotential
taxial superlattices will be presented in txial superlattices (more detailed introduction on epit the Cu film electrodeposited at a high overpotential
taxial superlattices will be presented in Section (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
taxial s $(28(7), 2213006 (6 \text{ of } 24))$
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hi (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
ion to the substrate, which is a typical phenomenon
for metal electrodeposition at high overpotentials. To
tackle this dilemma, Switzer group developed a two-
ste $\frac{1}{28(7)}$, 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition a $(28(7), 2213006 (6 \text{ of } 24)$
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hi 28(7), 2213006 (6 of 24)

the Cu film electrodeposited at a high overpotential

(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-

sion to the substrate, which is a typical phenomenon

for metal electrodeposition at h step potentiostatic electrodeposited at a high overpotential
telectrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal e $(28(7), 2213006 (6 \text{ of } 24)$
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hi $(28(7), 2213006 (6 \text{ of } 24)$
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hi $28(7)$, 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at . 28(7), 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hig . 28(7), 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hig 28(7), 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at high $(28(7), 2213006 (6 \text{ of } 24)$
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at hi 8(7), 2213006 (6 of 24)

CU film electrodeposited at a high overpotential

g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-

m to the substrate, which is a typical phenomenon

metal electrodeposition at high overpotenti $28(7)$, 2213006 (6 of 24)
the Cu film electrodeposited at a high overpotential
(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhe-
sion to the substrate, which is a typical phenomenon
for metal electrodeposition at h **EXECT), EXECTS COVET THETT**

the Cu film electrodeposited at a high overpotential

(e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhesion to the substrate, which is a typical phenomenon

for metal electrodeposition at the Cu film electrodeposited at a high overpotential (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhesion to the substrate, which is a typical phenomenon for metal electrodeposition at high overpotentials. To tackle t (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhesion to the substrate, which is a typical phenomenon for metal electrodeposition at high overpotentials. To tackle this dilemma, Switzer group developed a two-step poten sion to the substrate, which is a typical phenomenon
for metal electrodeposition at high overpotentials. To
tackle this dilemma, Switzer group developed a two-
step potentiostatic electrodeposition method to epi-
taxially 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (6 of 24)

ad introduction on epi the Cu film electrodeposited at a high overpotential

resented in Section (e.g., -1.5 V vs. Ag/AgCl) is powdery with poor adhesion to the subs

for metal electrodeposition at high overpotentials. To
tackle this dilemma, Switzer group developed a two-
step potentiostatic electrodeposition method to epi-
taxially grow Cu(100) film on n-Si(100). First, the
epitaxial tackle this dilemma, Switzer group developed a two-
step potentiostatic electrodeposition method to epi-
taxially grow Cu(100) film on n-Si(100). First, the
epitaxial Cu seeds were nucleated during the initial 2
s pulse a step potentiostatic electrodeposition method to epi-
taxially grow Cu(100) film on n-Si(100). First, the
epitaxial Cu seeds were nucleated during the initial 2
s pulse at -1.5 V vs. Ag/AgCl, at which the H-termi-
nated Si taxially grow Cu(100) film on n-Si(100). First, the
epitaxial Cu seeds were nucleated during the initial 2
s pulse at -1.5 V vs. Ag/AgCl, at which the H-termi-
nated Si surface was also protected from oxidation.
Then, the epitaxial Cu seeds were nucleated during the initial 2
s pulse at -1.5 V vs. Ag/AgCl, at which the H-termi-
nated Si surface was also protected from oxidation.
Then, the epitaxial Cu seeds further grew and coa-
lesced int s pulse at -1.5 V vs. Ag/AgCl, at which the H-terminated Si surface was also protected from oxidation.
Then, the epitaxial Cu seeds further grew and coalesced into an epitaxial Cu film at -0.5 V vs. Ag/AgCl (Figure 1b)⁽⁴ nated Si surface was also protected from oxidation.
Then, the epitaxial Cu seeds further grew and coalesced into an epitaxial Cu film at -0.5 V vs. Ag/AgCl
(Figure 1b)⁽⁴⁶⁾.
The applied current density can influence the Then, the epitaxial Cu seeds further grew and coalesced into an epitaxial Cu film at -0.5 V vs. Ag/AgCl (Figure 1b)⁽⁴⁶⁾.

The applied current density can influence the crystallinity of the deposits by affecting the depo lesced into an epitaxial Cu film at -0.5 V vs. Ag/AgCl
(Figure 1b)⁽⁴⁶⁾.
The applied current density can influence the crys-
tallinity of the deposits by affecting the deposition
rate. Usually, lower current densities re igure 1b)⁴⁶⁰.
The applied current density can influence the crys-
linity of the deposits by affecting the deposition
ince. Usually, lower current densities result in higher
systallinity of the epitaxial films, while too The applied current density can influence the crysinity of the deposits by affecting the deposition

2. Usually, lower current densities result in higher

stallinity of the epitaxial films, while too high cur-

t densitie tallinity of the deposits by affecting the deposition
rate. Usually, lower current densities result in higher
erystallinity of the epitaxial films, while too high cur-
rent densities can even result in amorphous deposits.
 rate. Usually, lower current densities result in higher
erystallinity of the epitaxial films, while too high cur-
rent densities can even result in amorphous deposits.
Therefore, the applied current density should be concrystallinity of the epitaxial films, while too high current densities can even result in amorphous deposits.
Therefore, the applied current density should be controlled within a certain range for the fabrication of epita rent densities can even result in amorphous deposits.
Therefore, the applied current density should be con-
trolled within a certain range for the fabrication of
epitaxial films by electrodeposition. Furthermore, the
grai Therefore, the applied current density should be controlled within a certain range for the fabrication of epitaxial films by electrodeposition. Furthermore, the grain size of the deposits usually decreases with the increa

abrupt change of growth orientation of the deposits is epitaxial films by electrodeposition. Furthermore, the triggered by the collection distringuits or grain size of the deposits usually decreases with the intended by th triggered by the coalescene of three-dimensional is-

largin size of the deposits usually decreases with the

land on single-crystal substrates. Such a transforma-

increased current densities and the formation from the t e-crystal substrates. Such a transforma-
increased current density due to higher nucleation
thermodynamically controlled growth densities endowed by the high applied current densi-
the kinctically preferred growth orien-
 tion from the thermodynamically controlled growth

orientation to the kinetically predict depay tericord growth orient-

twitch could also be schieved by controlling the mag-

mitude of the aleptical crystal subset (2000) orientation to the kinetically preferred growth orien-
trion coincil as be scheicted by controlling the magnetic mic of the clectrodepositiod epitaxial films of Cu₃O
triude of the applied current, where low current dentation could also be achieved by controlling the mag-
nitio of the clectrodeposited epitaxial films of Cu₁O
intice of the applied current where low current density.⁶⁷⁰
is sitics result in thermodynamically controlled nitude of the applied current, where low current den-
strices result in thermedyaminelyl controlled orienta-
tions and high current densities lead to kinetically
(i) Temperature felictrolyte
preferred orientations,⁸⁷⁴. trolled within a certain range for the fabrication of
epitaxial films by electrodeposition. Furthermore, the
grain size of the deposits usually decreases with the
increased current density due to higher nucleation
densiti epitaxial films by electrodeposition. Furthermore, the
grain size of the deposits usually decreases with the
increased current density due to higher nucleation
densities endowed by the high applied current densi-
ty. As s grain size of the deposits usually decreases with the
increased current density due to higher nucleation
densities endowed by the high applied current densi-
ty. As shown in Figure 1c, the grain size and aspect
ratio of t increased current density due to higher nucleation
densities endowed by the high applied current densi-
ty. As shown in Figure 1c, the grain size and aspect
ratio of the electrodeposited epitaxial films of Cu₂O
decrease densities endowed by the high applied current densi-
ty. As shown in Figure 1c, the grain size and aspect
ratio of the electrodeposited epitaxial films of Cu_2O
decrease with the increased applied current density^{ieg}.
2 ty. As shown in Figure 1c, the grain size and aspect
ratio of the electrodeposited epitaxial films of Cu₂O
decrease with the increased applied current density^{(ta}).
2.2.3 Parameters of Electrolyte
(i) Temperature
Epita ratio of the electrodeposited epitaxial films of Cu₂O
decrease with the increased applied current density^{*te*n}.
2.2.3 Parameters of Electrolyte
(i) Temperature
Epitaxial films are the films with well-defined
growth or decrease with the increased applied current density¹⁴³.

2.2.3 Parameters of Electrolyte

(i) Temperature

Epitaxial films are the films with well-defined

growth orientations, which means that they possess

relatively

bility of the deposition solution generally decreases

the temperature increases¹⁶⁹. Therefore, the electro-

the temperature should be carefully optimized for might affect the epitaxial electro-

temperature should be

 $\#E\#(J. Electrochem.)$ 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases and/or OH (such as the electrodeposition of metal ox-

as the temperature increases^[56]. Therefore, the electro-

l $\# \# \# (J. \text{Electrochem.}) 2022, 28(7), 2213006 (7 of 24)$

astability of the deposition solution generally decreases

as the temperature increases^[66]. Therefore, the electro-

ides/hydroxides), the pH of the deposition solution
 the $\#L \#(L \text{ Electrochem.})$ 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases

and/or OH (such as the electrodeposition of metal ox-

as the temperature should be carefully optimized for
 $\frac{d}{dt}\mathcal{H}^{\#}(J. \text{Electrochem.}) 2022, 28(7), 2213006 (7 of 24)$

stability of the deposition solution generally decreases and/or OH (such as the electrode

as the temperature increases^[58]. Therefore, the electrodides/hydroxide $# \# \# (J. Electron) \ge 222, 28(7), 2213006 (7 of 24)$ bility of the deposition solution generally decreases

and/or OH (such as the electric the temperature increases^[56]. Therefore, the electro-

ides/hydroxides), the pH of

te tem $\frac{d}{dt}\mathcal{L}\neq (J. Ehetrochem.) 2022, 28(7), 2213006 (7 or 24)$

bility of the deposition solution generally decreases and/or OH (such as the electrodeposition of metal ox-

the temperature increases¹⁵⁶. Therefore, the electro-

ide \pm *Rectrochem.*) 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases

and/or OH' (such as the electrodeposition of metal ox-

as the temperature increases^[50]. Therefore, the elec the *Reconchem*.) 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases

and/or OH (such as the electrodeposition of metal ox-

as the temperature increases^[88]. Therefore, the electro $\text{EPE}(L. Electrochem.)$
 $\text{EPE}(L. Electrochem.)$ 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases

and/or OH' (such as the electrodeposition of metal ox-

stability of the deposition solution peneral $\frac{d}{dt}\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right)^2\left(\frac{d}{dt}\right$ transfer, which in turn affects the morphology, grain size, and adhesion of the deposit. Epitaxial electrodeth(k^{2+p}(*L Riemwehan.*) 2022, 28(7), 2213006 (7 of 24)

stability of the deposition solution generally decreases

sub temperature increases⁽⁴⁸⁾. Therefore, the clettro-inspaction of figure increases⁽⁴⁸⁾. The prima $\frac{d_1}{2}$ $\frac{d_2}{2}$ $\frac{d_3}{2}$ $\frac{d_4}{2}$ $\frac{d_5}{2}$ $\frac{d_6}{2}$ $\frac{d_7}{2}$ $\frac{d_8}{2}$ $\frac{d_9}{2}$ $\frac{d$ $\frac{4E}{2\pi}(L\text{Electrcenter}) \cdot 28(7), 2213006 (7 \text{ of } 24)$

stability of the deposition solution generally decreases and/or OH (such as the clectrodeposition of metal of

as the temperature increases¹⁹⁶. Therefore, the electrocon bility of the deposition solution generally decreases and/or OH (such as the electrodeposition of metal oxident be the emperature increases¹⁹⁸. Therefore, the electro. integrity engined for the deposition solution integ $28(7)$, $2213006(7 \text{ of } 24)$
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposi 06 (7 of 24)
(such as the electrodeposition of metal ox-
ides), the pH of the deposition solution
t the epitaxial growth of the desired mate-
uencing the deposition potential. In addi-
H of the deposition solution might af $28(7)$, 2213006 (7 of 24)
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposit 28(7), 2213006 (7 of 24)
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposition 28(7), 2213006 (7 of 24)
and/or OH['] (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the depositi $28(7)$, 2213006 (7 of 24)
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposit 28(7), 2213006 (7 of 24)
and/or OH['] (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the depositi 28(7), 2213006 (7 of 24)
and/or OH' (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposition 28(7), 2213006 (7 of 24)
and/or OH' (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposition $28(7)$, 2213006 (7 of 24)
and/or OH' (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the depo 28(7), 2213006 (7 of 24)
and/or OH⁻ (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the depositi 28(7), 2213006 (7 of 24)
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposition $28(7)$, 2213006 (7 of 24)
and/or OH' (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposi $28(7)$, 2213006 (7 of 24)
and/or OH⁻ (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the de $28(7)$, 2213006 (7 of 24)
and/or OH (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the depos 28(7), 2213006 (7 of 24)
and/or OH' (such as the electrodeposition of metal ox-
ides/hydroxides), the pH of the deposition solution
might affect the epitaxial growth of the desired mate-
rial by influencing the deposition **Exercises** (*v.* 0.21)

and/or OH' (such as the electrodeposition of metal ox-

ides/hydroxides), the pH of the deposition solution

might affect the epitaxial growth of the desired mate-

rail by influencing the deposit and/or OH' (such as the electrodeposition of metal oxides/hydroxides), the pH of the deposition solution might affect the epitaxial growth of the desired mate-
rial by influencing the deposition potential. In addition, th 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (7 of 24)

on generally decreases and/or OH (such as the electrodeposition of metal ox-

Therefore, the electro-

ides/hydroxides), the pH of the deposition solution

refully o

current density. Reproduced with permission of Ref.^[42], copyright 2005 American Chemical Society. (d) XRD patterns of Co₃O₄ ele-

.

Films

are a pH of 12.0 (Figure 1e)⁶⁶¹.
 are summarized and epitexxial solutions of the Epitaxial in the films could be defined into figures. Pole figures are the electrodeposited films can be clarified into figure 1.8, epit 3. Characterizations of the Epitaxial of the films could be detected by
 Films figures. Pole figures are run by ch

The electrodeposited films can be clarified into angle for a plane that is not practively

polycrysta **Films**
 Equality figures. Pole figures are run by choosing a diffraction

The electrodeposited films can be clarified into

or the film. The tilt angle of the sample, χ , is then

by pregrataline, textured, and epita The electrodeposited films can be clarified into

polycrystalline, extured, and epitaxial films. As shown of the film. The tilt angle of the sample, χ , is then

in Figure 1a, entails in the sample including the same in

EVALUATE 1999
 Example 19.1
 EXECUTE:
 ¹

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¹
 Electrochem.) 2022, 28(7), 2213006 (8 of 24)
 Electrochem.) 2022, 28(7), 2213006 (8 of 24)
 Electrochem. 2022, 28(7), 2213006 (8 of 24)
 Electrochem. 1202 of the Epitaxial films. The in-plane orient the $\ell \neq (L$ Electrochem.) 2022, 28(7), 2213006 (8 of 24)

pH of 9.0 to nanocubes with the <100> direction

pH of 12.0 (Figure 1e)^[61].

pH of 12.0 (Figure 1e)^[61].
 Characterizations of the Epitaxial of the films **EVALUATION**
 EXECUTE: The COMEX CONSIDERATION CONSIDERATION of STATE ALL AS SUPPOSED AND ARTION OF PARK THEO CONSIDERATION OF THE ALL AS SHOWN THE SUPPOSE THE SUPPOSE THE SUPPOSE THE SUPPOSE THE SUPPOSE THE SUPPOSE THE $\begin{array}{lllllllllllllll} & & & \text{#} \{E \neq (f, *Electrochem*), 2022, 28(7), 2213006 (8 of 24) \right. \\ & & & \text{at a pH of 9.0 to nanocubes with the <100> direction} & & \text{family of planes is presented in the XRD 20 scans for a path of 12.0 (Figure 1e})^{[81]}. \end{array}$ **EVALUATE 12**
 EVALUATE 12 (Eigenvolves with the <100> direction family of planes is presented in the XRD 20 scans for

at a pH of 9.0 to nanocubes with the <100> direction family of planes is presented in the XRD 20 sc **Example 19** EV²²(*L* Electrochem.) 2022, 28(7), 2213006 (8 of 24)

at a pH of 9.0 to nanocubes with the <100~ direction family of planes is presented in the XRD 20 scans for

at a pH of 12.0 (Figure 1e)⁽⁶¹⁾.
 Charac EVALUATION
 EVALUATION CONTEXT (Example SUPPERTY) 1972, 28(7), 2213006 (8 of 24)
 EXALUATE ASSES (Figure 1)^{(a)]}
 **EXALUATE ASSES (Figure 1)^{(a)]}

EXALUATE ASSES (Figure 1)^{(a)]}**
 EXALUATE ASSES (FIGURE CONTEXT EXALUATE 19 (AT 1 the 2° (L *Electrom-bom*) 2022, 28(7), 2213006 (8 of 24)

at a pH of 12.0 (Figure 1e)^[61]. **Connoclearly the CDC** affection family of planes is presented in the XRD 20 scans for

at a pH of 12.0 (Figure 1e)^[61]. **EVALUATION THE SET UNITED THE SET INTERTATION AND THE SET UNITED SACK AND A THE SET UNITED SACK AND A THE SET UNITED SACK AND A THE SET UNITED AND A THE SET UNITED AND THE SET UNITED SACK AND THE SET UNITED SACK AND THE EXALUATION EXACT (Example 19** (θ) θ (θ) and a pH of 9.0 to nanocubes with the <100> direction family of planes is presented in the XRD 2*θ* seams for
 3 Characterizations of the Epitaxial exturded and priximal **out-of-plane and in-plane in-plane orientation**. Therefore, $\frac{1}{2}$ and the films are summarized.
 Solution the films of the films counter the state of the SID of the films of the films of the films of the films of t at a pH of 9.0 to nanocubes with the <100> direction family of planes is presented in the XRD 29 scans for

at a pH of 12.0 (Figure 1e)^{80]},
 Characterizations of the Epitaxial of the films could be detected by using t at a pH of 9.0 to nanocules with the <100> direction

and pH of 12.0 (Figure 1e)⁶⁰.

at a pH of 12.0 (Figure 1e)⁶⁰.

actured and epitaxial films contact in example orientation

contacterizations of the Epitaxial films $(28(7), 2213006 (8 of 24))$
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run by $(28(7), 2213006 (8 of 24))$
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run by $(28(7), 2213006 (8 of 24))$
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run by 28(7), 2213006 (8 of 24)
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run b 28(7), 2213006 (8 of 24)

family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation

of the films could be detected by using the XRD pole

figures. Pole figures are r $(28(7), 2213006 (8 \text{ of } 24))$
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are ru 28(7), 2213006 (8 of 24)

family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation

of the films could be detected by using the XRD pole

figures. Pole figures are r $(28(7), 2213006 (8 \text{ of } 24)$
family of planes is presented in the XRD 20 scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run b $(28(7), 2213006 (8 \text{ of } 24)$
family of planes is presented in the XRD 20 scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run b . 28(7), 2213006 (8 of 24)
family of planes is presented in the XRD 2 θ scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run 2(7), 2213006 (8 of 24)

family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation

of the films could be detected by using the XRD pole

figures. Pole figures are ru 28(7), 2213006 (8 of 24)

family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation

of the films could be detected by using the XRD pole

figures. Pole figures are r $28(7)$, $2213006 (8 \text{ of } 24)$
family of planes is presented in the XRD 20 scans for
textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run spectively. 2.28(7), 2213006 (8 of 24)

family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation

of the films could be detected by using the XRD pole

figures. Pole figures are When the films is presented in the XRD 20 scans for
tured and epitaxial films. The in-plane orientation
the films could be detected by using the XRD pole
queres. Pole figures are run by choosing a diffraction
gle for a pl family of planes is presented in the XRD 20 scans for textured and epitaxial films. The in-plane orientation of the films could be detected by using the XRD pole figures. Pole figures are run by choosing a diffraction ang textured and epitaxial films. The in-plane orientation
of the films could be detected by using the XRD pole
figures. Pole figures are run by choosing a diffraction
angle for a plane that is not parallel with the surface
o of the films could be detected by using the XRD pole
figures. Pole figures are run by choosing a diffraction
angle for a plane that is not parallel with the surface
of the film. The tilt angle of the sample, χ , is then figures. Pole figures are run by choosing a diffraction
angle for a plane that is not parallel with the surface
of the film. The tilt angle of the sample, χ , is then
incrementally varied from 0 to 90°, with the az-
imu angle for a plane that is not parallel with the surface
of the film. The tilt angle of the sample, χ , is then
incrementally varied from 0 to 90°, with the az-
imuthal angle, ϕ , varied from 0 to 360° at each value
of \exists Electrochem.) 2022, 28(7), 2213006 (8 of 24)

h the <100> direction family of planes is presented in the XRD 2 θ scans for

textured and epitaxial films. The in-plane orientation
 of the Epitaxial of the films co

 $\# \# \forall L. \text{ Electronic}, 2022, 28(7), 2213006 (9 of 24)$
tool to analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with
films⁽⁶²⁾. Compared to other characterization methods, certain electronic, $\frac{\text{f}(E\#(J. Electrochem.) 2022, 28(7), 2213006 (9 of 24)}{\text{fold of } B}$

follow analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with

films^[62]. Compared to other characterization methods, ecreat the ℓ^*_{ℓ} *Electrochem.*) 2022, 28(7), 2213006 (9 of 24)
tool to analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with
films^[62]. Compared to other characterization methods, the the multiplet of the multiplet of the term of the term of the principle and the color of the dualyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with films^(ic). Compared to other $\frac{4}{12}$
 EBSD is the out-of-plane orientation of the epitaxial films of metals and semiconductors with

films^{tex}! Compared to other characterization methods, certain electronic, electromagnetic, and photovoltaic

E $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d\mathcal{L}}{dt}\right)$ $\frac{d}{dt}\left(\frac{d$ $\pm \frac{\text{d} \cdot \text{d} \cdot \text{d}}{\text{d} \cdot \text{d} \cdot \$

can be obtained, and the changes of the structure of

the electrodeposited metally violetic metally discussed metally discussed metally observed, thus allowing one

to understand the interaction between the deposited

con the electrodeposited metal with electrode potential

inver costs. In addition, epitaxial electrodeposition

and time can be directly observed, thus allowing one

conderstand the interaction between the deposited

conderst and time can be directly observed, thus allowing one
of mctals has also attracted increasing attention re-
to understand the interaction between the deposited orelly in the metal anodes of rechargeable med-
notation diffe metal and the substrate as well as the mechanism of

nucleation and growth at the initial alsa end effect to the initial stage of electrod-

properties. Furthermore, epitaxial electrod-

properties of a formometric metal of various metals on single-crystal substrates.
 3.4 Reflection High Energy Diffraction
 4.1.1 Proxies for Single Crystal-like metal

ploys a high-energy dictron beam ($E = 5 \sim 100 \text{ keV}$) emsive alternative substrate

 $28(7)$, $2213006 (9 of 24)$
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Enitaxial $28(7)$, $2213006 (9 of 24)$
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitaxial $28(7)$, 2213006 (9 of 24)

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-

plied for electronics.
 4.1 E $28(7)$, 2213006 (9 of 24)

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-

plied for electronics.
 4.1 Epi $28(7)$, $2213006 (9 \text{ of } 24)$

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-

plied for electronics.
 4.1 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (9 of 24)
ne orientation of the epitaxial films of metals and semiconductors with
racterization methods, certain electronic, electromagnetic, and photovoltaic
mple sample prepa

E the $\#$ (*L* Electrochera.) 2022, 28(7), 2213006 (9 of 24)

Il to analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with

sm^{s(ai}). Compared to other characterization methods, **has been** commonly used to investigate the initial signal-cystal-like metal films of the principal of the spin of the spin and semiconductors with films⁸⁰¹. Compared to other characterization methods, ecrtain electroni **EVALUATION**
 EVALUATION EXECUTE THE UNE THE UNE THE UNE THE UNE THE UNE CONSTRANT CONDUCT THE UNE CONDUCT THE UNE UNE UNIT CONDUCT THE UNE THE UNIT CONDUCT UNE THE UNE THAT IS DURNET TO A THE UNIT OF THE UNIT OF THE U tside the number of the the the simulation of the spin state of the spin stat (a) to the method of the section and photovoltaic EBSD h **Example 10**
 Example 10
 Example 10
 EGAL Change 10
 EGAL Change 10
 **EGAL Compared to out-of-plane orientation of the equivarial films of metals and semiconductors with

films¹⁶¹. Compared to obter characteriz** $\pm \frac{1}{2}E \pm \frac{1}{2} (L \cdot R \cdot \text{etrochehen.}) 2022, 28(7), 2213006 (9 of 24)$
tool to analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with
films^[e]. Compared to other characterization methods **and the maximum differation** $\frac{1}{2}$ ($\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ compared to other characterization methods, errain electronic, electromagnetic, and photovoltaic
FIR tool to analyze the out-of-particular energy statistic first and semiconductors with

films⁹²¹, Compared to other characterization methods,

certain electromagnetic, and photovoltaic

EBSD has the advantages of simple s tool to analyze the out-of-plane orientation of the epitaxial films of metals and semiconductors with

films^{om}. Compared to other characterization methods, ecetain electronic, electromagnetic, and photovoltaic

FISED ha films⁸⁸¹. Compared to other characterization methods, ecrtain electronic, electromagnetic, and photovoltaic

FIESD has the advantages of simple sample prepara-

inproduction and rapid analysis. Single color will be pres FBSD has the advantages of simple sample prepara-

properties, which could be applied or potentially ap-

tion and rapid analysis. Single color will be present in

FBSD inverse pole figure (DF) mg for the film with
 $\frac{1$ tion and rapid analysis. Single color will be present in

EISID inverse pole figure (IPP) map for the film with

endical Editation and reserved in-situs scenario (asset in Figure 2d).
 3.3 In-Situ Scenario, The mechanism EBSD inverse pole figure (IPF) map for the film with

ordered out-of-plane orientation (as seen in Figure 2d).

Epitaxial metal films are single-crystal-like metal

3.3 *In-Situ* Scanning Tunneligy Microscopy (in-sins wit ordered out-of-plane orientation (as seen in Figure 2d). Epitaxial metal films are single-crystal-like metal
 Inaxial metal films are single-crystal-like metal
 Inaxial seaming Tunneling Microscopy (insular films with **3** *In-Situ* **Scanning Tunneling Microscopy** films with specific in-plane and out-of-plane orienta-
 *In-situ sca*nning tunneling microscopy (*fin-itu* STM) tions. Due to the low cost and high controllability,

she been co *In-situs* seaming tunneling microscopy (*in-situ* STM) tions. Due to the low cost and high controllability,
has been commonly used to investigate the initial
deprectron beam (h -situs) and the spectron beam (h -situs) has been commonly used to investigate the initial critical circledeposition has been widely utilized
stage of the underprotential deposition (10Ph) of the top repare various single-crystal-like metal films. The
epitixial stage of the underpotential deposition (UPD) of the to prepare various single-crystal-like metal films. The

epitaxial metal films. With the use of *in-sim* STM, single-crystal-like metal films are a great alternative

cr epitaxial metal films. With the use of *in-situ* STM, single-crystal-like metal films are a great alternative
real-line an digh-resolution images of UPD process
concernent and the distance of an electrodeposited metal wit real-time and high-resolution images of UPD process

to bulk single crystals while used as substrates to

can be obtained, and the changes of the structure of

the destrodeposited metal with electrode potential

the destr (7), 2213006 (9 of 24)

itaxial films of metals and semiconductors with

tain electronic, electromagnetic, and photovoltaic

operties, which could be applied or potentially ap-

ed for electronics.
 Lepitaxial Films of M $28(7)$, 2213006 (9 of 24)
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitax $28(7)$, 2213006 (9 of 24)
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epit $28(7)$, 2213006 (9 of 24)
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitax $28(7)$, 2213006 (9 of 24)

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-
 4.1 Epitaxial Films of Metals $28(7)$, 2213006 (9 of 24)

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-
 4.1 Epitaxial Films of Metals $28(7)$, 2213006 (9 of 24)

epitaxial films of metals and semiconductors with

certain electronic, electromagnetic, and photovoltaic

properties, which could be applied or potentially ap-

plied for electronics.
 4.1 Epi $28(7)$, 2213006 (9 of 24)
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitax $28(7)$, $2213006 (9 of 24)$
epitaxial films of metals and semiconductors with
ecrtain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitaxial $28(7)$, $2213006 (9 of 24)$
epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitaxial Example 12
 CONSECUTE CONSTERT CONSTERT CONSTERN CONSTERN CONSTET SPECIES AND A DEPOSITED FOR SPECIES.
 4.1 Epitaxial Films of Metals
 4.1 Epitaxial Films of Metals
 4.1 Epitaxial metal films are single-crystal-li epitaxial films of metals and semiconductors with
certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitaxial Films of Metals
Epitaxial certain electronic, electromagnetic, and photovoltaic
properties, which could be applied or potentially ap-
plied for electronics.
4.1 Epitaxial Films of Metals
Epitaxial metal films are single-crystal-like metal
films w properties, which could be applied or potentially applied for electronics.
 4.1 Epitaxial Films of Metals

Epitaxial metal films are single-crystal-like metal

films with specific in-plane and out-of-plane orienta-

tion plied for electronics.
 4.1 Epitaxial Films of Metals

Epitaxial metal films are single-crystal-like metal

films with specific in-plane and out-of-plane orienta-

tions. Due to the low cost and high controllability,

ep tronics. Epitaxial metal films are single-crystal-like metal
films with specific in-plane and out-of-plane orienta-
tions. Due to the low cost and high controllability,
epitaxial electrodeposition has been widely utilized
to prepar ms with specific in-plane and out-of-plane orienta-

ns. Due to the low cost and high controllability,

itaxial electrodeposition has been widely utilized

prepare various single-crystal-like metal films. The

gle-crystaltions. Due to the low cost and high controllability,
epitaxial electrodeposition has been widely utilized
to prepare various single-crystal-like metal films. The
single-crystal-like metal films are a great alternative
to b epitaxial electrodeposition has been widely utilized
to prepare various single-crystal-like metal films. The
single-crystal-like metal films are a great alternative
to bulk single crystals while used as substrates to
grow to prepare various single-crystal-like metal films. The
single-crystal-like metal films are a great alternative
to bulk single crystals while used as substrates to
grow epitaxial functional materials due to their much
lowe single-crystal-like metal films are a great alternative
to bulk single crystals while used as substrates to
grow epitaxial functional materials due to their much
lower costs. In addition, epitaxial electrode
position
of me to bulk single crystals while used as substrates to
grow epitaxial functional materials due to their much
lower costs. In addition, epitaxial electrode
position
of metals has also attracted increasing attention re-
cently

nucleation and growth at the initial stage of electrode-
position of a ferromagnetic metal on single-crys-
position. So far, Allongue/⁹⁷⁹ and Mao groups⁸⁶⁹ have
tuilized *in-sina* STM to study the mechanism of UPD
reci position. So far, Allongue¹⁰³ and Mao groups⁸⁶⁻⁶⁹ have

ultime conductive or semiconductive substrates is in-

ultime interdeform of UPD

concernation of the mechanism of UPD

of various metals on single-crystal behav utilized *in-situ* STM to study the mechanism of UPD

trerested in electromagnetic applications such as spin-

of various metals on single-erystal substrates.
 Reflection High Energy Diffraction (RHFED) em
 $R = 5 \sim 100 \$ **3.4 Reflection High Energy Diffraction**

Reflection high energy diffraction

Reflection highenergy diffraction (RHFEFD) em-

Reflectrodeposited Function (RHFEFD) in the sample surface at a small grazing in-

metals for e eflection high energy diffraction (RIEED) em-

enflecterystal-like metal films can serve as

a high-energy electron beam $(E = 5 \times 100 \text{ keV})$

ensive alternative substrates to bulk single-

ence angle to diffract ta a small by a high-energy clectron beam $(E = 5 \sim 100 \text{ keV})$ pensive alternative substrates to bulk single-erystal
dient on the sample surface at a small grazing in-metals for epitaxial electrodeposition of granio bund-
elence angle incident on the sample surface at a small grazing in-

metals for epitaxial electrodeposition of grain bound-

eicknow as the structural beam on the structural materials with improved perfor-

sample surface to obtain an cidence angle to diffract the electron beam on the
sample surface in a actional materials with improved perfor-
sample surface to obtain an cletter of both and colored diffraction
term reflecting the structural informatio sample surface to obtain an electron diffraction pat-

term credicting the structural information of the surface relation pathed information of the surface in the section of the surface some control in the section of the grow epitaxial functional materials due to their much
lower costs. In addition, epitaxial electrodeposition
of metals has also attracted increasing attention re-
cently in the metal anodes of rechargeable met-
al-based bat lower costs. In addition, epitaxial electrodeposition
of metals has also attracted increasing attention re-
cently in the metal anodes of rechargeable met-
al-based batteries. Furthermore, epitaxial electrode-
position of of metals has also attracted increasing attention re-
cently in the metal anodes of rechargeable met-
al-based batteries. Furthermore, epitaxial electrode-
position of a ferromagnetic metal on single-crys-
talline conduct cently in the metal anodes of rechargeable metal-based batteries. Furthermore, epitaxial electrode-
position of a ferromagnetic metal on single-crys-
talline conductive or semiconductive substrates is in-
terested in elec al-based batteries. Furthermore, epitaxial electrode-
position of a ferromagnetic metal on single-crys-
talline conductive or semiconductive substrates is in-
terested in electromagnetic applications such as spin-
tronics position of a ferromagnetic metal on single-crys-
talline conductive or semiconductive substrates is in-
terested in electromagnetic applications such as spin-
tronics.
4.1.1 Proxies for Single Crystals
Single-crystal-lik talline conductive or semiconductive substrates is in-
terested in electromagnetic applications such as spin-
tronics.
4.1.1 Proxies for Single Crystals
Single-crystal-like metal films can serve as inex-
pensive alternati terested in electromagnetic applications such as spin-
tronics.
4.1.1 Proxies for Single Crystals
Single-crystal-like metal films can serve as inex-
pensive alternative substrates to bulk single-crystal
metals for epitaxia tronics.
4.1.1 Proxies for Single Crystals
5ingle-crystal-like metal films can serve as inex-
pensive alternative substrates to bulk single-crystal
metals for epitaxial electrodeposition of grain bound-
ary-free functiona 4.1.1 Proxies for Single Crystals

Single-crystal-like metal films can serve as inex-

pensive alternative substrates to bulk single-crystal

metals for epitaxial electrodeposition of grain bound-

ary-free functional mat Single-crystal-like metal films can serve as inex-
pensive alternative substrates to bulk single-crystal
metals for epitaxial electrodeposition of grain bound-
ary-free functional materials with improved perfor-
mance. Si pensive alternative substrates to bulk single-crystal
metals for epitaxial electrodeposition of grain bound-
ary-free functional materials with improved perfor-
mance. Single-crystal Si is an excellent substrate to
electro etals for epitaxial electrodeposition of grain bound-

y-free functional materials with improved perfor-

nnce. Single-crystal Si is an excellent substrate to

ectrodeposit single-crystal-like metal films because

its rela ary-free functional materials with improved perfor-
mance. Single-crystal Si is an excellent substrate to
electrodeposit single-crystal-like metal films because
of its relatively low cost than other single-crystal sub-
str mance. Single-crystal Si is an excellent substrate to
electrodeposit single-crystal-like metal films because
of its relatively low cost than other single-crystal sub-
strates, high compatibility with many microfabrica-
tio

 $\# \# \# (J. Electrochem.)$ 2022, 28(7), 2213006 (10 of 24)
Au single crystals, the direct electrodeposition of epi-
taxial Au films on Si has been widely investigated, and wearable displays, solar cells, and sensors. As
which was p ¹¹ ¹ ¹ ¹ ¹ ² ² *(J. Electrochem.)* 2022, 28(7), 2213006 (10 of 24)

Au single crystals, the direct electrodeposition of epi-

them potentially used in the fabrication of flexible

taxial Au films on Si has b **Example errystals, the direct electrochemic of 237, 2213006 (10 of 24)**

Au single errystals, the direct electrocheposition of epi-

the potential growth of flexible

taxial Au films on Si has been wielpy investigated a $\pm \frac{\text{d} \frac{1}{4} \left(\frac{1}{4} \frac{1}{4} \left(\frac{1}{4} \frac{1}{4} \frac{1}{4} \left(\frac{1}{4} \frac{1}{4} \$ **ELEVALUAT ELECT ANTIFY (ELECT ANTIFY ALCT ALCT ANTIFY ALCT AND THE RESPONSIBLE THE RESPONSIBLE AND A THE SOLUTION OF A THE SOLUTION OF A THE SOLUTION AND THE SOLUTION AND THE SOLUTION AND THE SOLUTION AND THE SOLUTION A** $4E\frac{\omega}{2}(L\text{ Electrochelem.}) 2022, 28(7), 2213006 (10 of 24)$

Au single crystals, the direct electrodeposition of cpi-

them potentially used in the fabrication of flexible

taxial Au films on Si has been widely investigated, and we was observed, and the density of islands and the film the error of the matrix of the most implicate the deposition of equal for the deposition scheme.

Structure were controlled by allongue and converkers, expected, epitaxial Cu_BO films electrodeposited on

and further stu **EVALUATION**
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Au single crystals, the direct electrodeposition of ± 0.22 , $28(7)$, $2213006(10 \text{ of } 24)$
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Au single crystals, the direct electrodeposition of epi-

them potentially used in the fabrication of flexible

axial Au films on Si has been widely inve immersing into the deposition solution to prevent the \pm (*E#C*. *Electrochem.*) 2022, 28(7), 2213006 (10 of 24)
Au single crystals, the direct electrodeposition of epi-
them potentially used in the fabrication of flexible
taxial Au films on Si has been widely investigated, **HER)**
 Althus in the controllant of the factor of the the statistical Au films on Si late decret dectrode
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than by the statistical Au films on Si late corrected position of pi-

than the factor of flexi Au single crystals, the direct electrodeposition of epi-

them potentially used in the fabrication of flexible

taxial Au films on Si has been widely investigated, and wearable displays, solar cells, and sensors. As

whic cally the solution of Si It was been developed that promoting the endation of the endation of the endation of δ i. It was followed provides to the endation of the endation of the endation of the endation of the endation which was pioneered by Allongue and oworkers, expected, epitaxial Cu₂O films electrodeposited on
and further studied by Switzer et al. Allongue and observables are single-crystal-like Au foils show a lower value of
conv and further studied by Switzer et al. Allongue and the single-crystral-like Au folis show a lower velue of
coworkers investigated the electrochemical growth of diode quality factor (n) than the polycrystalline coun-
cowor means and the electrodeposite of the minimal server as a non-server and the server and the minimal server as a non-server and the electrodeposite of the electrodeposite of the scheme conditions and interest the scheme of Even and Magnetial Given the state of the ablaine KAu(CN), or acide IAAuCL solutions^{30,40}, are prinxially electrodeposited on Si is also attraction the alkialine KAu(C or in summation of Si. It was found that promine is the electrodeposited on Si is also attractional and order the alkaline KAuCN), or acidic HAuCI, solutions^{payin}. Age prinxially electrodeposited on Si is also attractiv Ether the alkaline condition, a 3D island growth the due to its lower cost than Au. Nanometer-thick

was observed, and the density of islands and the film epitaxial Ag films were electrodeposited onto sin-

structure were was observed, and the density of islands and the film epitaxial Ag films were electrodeposited onto sin-
structure were controlled by the deposition potential. gle-crystal Si by applying a very negative pre-polar-
structu Even the action of Sk I wand the MV is a more that the selection pointing the deposition pointing and Sk and Age are point-

In the acidic HAuCl_s solution, atomically smooth epi-

in the acidic HAuCl_s solution, atomic

Example and in-plane orientations (as shown in Figure 3a-b).

The studies of the dural stations from the Au islands to When a chiral surface is

the Au/Si boundary^[79]. The prepared epitaxial Au/Si possible to produce c Lift) condine in the properation in the sectode position. The (643) surface of fice-centered-
epitaxial growth of ultrathin magnetic substrate for the electrode
position. The (643) surface of fice-centered-
epitaxial grow eriaxial growth of ultrathin magnetic metals.

Untio (fice) metals such as Au, Ag. Pt, and Cu is chiral

Switzer group electrodeposited nanometer-thick due to the lack of mirror symmetry. Switzer group

epitaxial layers o Switzer group electrodeposited nanometer-thick due to the lack of mirror symmetry. Switzer group
pejuaxial layers of Au on Si(100), Si(110), and Si demonstrated that chiral Au surfaces could be pro-
f(111) to seve as prox primari layers of Au on Si(100), Si(1101), and Si demonstrated that chiral Au arrifices could be pro-
(111) to serve as proxies for bulk single-erystal Au^{[61}]. dueed by epitaxial electrodeposition of Au onto com-
five t

 SiO_x layer which was then etched by 5% HF to de-

 $\# \# \# (J. Electron) 2022, 28(7), 2213006 (10 of 24)$
Au single crystals, the direct electrodeposition of epi-
them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
which was pioneer $\exists x \in \mathbb{R} \{x \neq (L \text{ } {\textit{Electrochem.}}) 2022, 28(7), 2213006 \text{ (10 of 24)}\}$
Au single crystals, the direct electrode
position of epi-
taxial Au films on Si has been widely investigated, and wearable displays, solar cells, and se $(28(7), 2213006 (10 of 24))$
them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
the single-crystal-like Au foils show $(28(7), 2213006 (10 of 24))$
them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
the single-crystal-like Au foils show $(28(7), 2213006 (10 of 24))$
them potentially used in the fabrication of flexible
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expected, epitaxial Cu₂O films electrodeposited on
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the single-crystal-like Au foils sho $(8(7), 2213006 (10 of 24)$

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d wearable displays, solar cells, and sensors. As

pected, epitaxial Cu₂O films electrodeposited on

single-crystal-like Au foils show a lower $(28(7), 2213006 (10 \text{ of } 24)$
them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
the single-crystal-like Au foils s 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (10 of 24)

ctrodeposition of epi-

uvidely investigated, and wearable displays, solar cells, and sensors. As

ngue and coworkers, expected, epitaxial Cu₂O films electrodepos

 $(28(7), 2213006 (10 \text{ of } 24)$
them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
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and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
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them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
the single-crystal-like Au foils them potentially used in the fabrication of flexible
and wearable displays, solar cells, and sensors. As
expected, epitaxial Cu₂O films electrodeposited on
the single-crystal-like Au foils show a lower value of
diode qua wafers. ² metallator analysis, solar bustes and sumpted as the single-crystal-like Au foils show a lower value of ode quality factor (n) than the polycrystalline coun-
parts deposited on stainless steel (Figure 3d and e). Ag ep entence is used to produce chiral energy and the single-crystal-like Au folls show a lower value of diode quality factor (n) than the polycrystalline counterparts deposited on stainless steel (Figure 3d and e). Ag epitaxi diode quality factor (n) than the polycrystalline coun-
terparts deposited on stainless steel (Figure 3d and e).
Ag epitaxially electrodeposited on Si is also attrac-
tive due to its lower cost than Au. Nanometer-thick
ep terparts deposited on stainless steel (Figure 3d and e).
Ag epitaxially electrodeposited on Si is also attrac-
tive due to its lower cost than Au. Nanometer-thick
epitaxial Ag films were electrodeposited onto sin-
gle-cry Experime a upontion of matrices of the lack of region of the set of the lack of the deptinzial Ag films were electrodeposited on Si is also attractive due to its lower cost than Au. Nanometer-thick epitaxial Ag films were rig epainsing precedured on the network of the surface could be price due to its lower cost than Au. Nanometer-thick epitaxial Ag films were electrodeposited onto single-crystal Si by applying a very negative pre-polariza

and the weather with the properties are the significant and the significant in the scide HAuCl, solution, atomically smooth epi-

in the scide HAuCl, solution, atomically smooth epi-

in the scide Au film was obtained by strail Au film was obtained by applying a very nega-

trail Au film was obtained by applying a very nega-

tivis is dependent on not only the aubstrate but also

tive potential^{[91}. The Si wafer was perpolarized before t abundance of the base of a multimation of the deposition solution. The Ag illuse electrodeposition solution to prevent the deposition solution. The Ag illuse electrodeposition solution of Si. It was four other coincide th Eventual The stream of the particular strengthenes with the strengthenes of significant strengthenes and oxidation of Si. It was found that promoting a strong implane orientations of Si(111), Si(110), and Si(100) and Si(1 must
variation of Si. It was found that promoting a strong in-plane orientations of Si(111), Si(110), and Si(100)
hydrogen evolution reaction (HER) in parallel with wafers, whereas the Ag films electrodeposited from
hydro ordered for the scale of the electrodeposited for the scale of the electrodeposition or a set of the electrodeposition was essential to growing atomi-
the equality of the change of the elementation of the elementation of gives viewthen results in products and the results in the spain of the mail vector of the mail vector of the AuXi The meanural material standard means we can be seen the set of the enhance

and plane Au(111) films on Si(111) due to the enhance

and politic of the Au adatoms from the Au islands to

then a chiral surface is used as the neum) or the transmit produce in the electrodeposite in the electrodeposite in the electrodeposite in the electrodeposite of produce chiral metal surfaces by epitaxial il) could serve as a nonmagnetic substrate for the de epitaxial Ag films were electrodeposited onto sin-
epitaxial Ag films were electrodeposited onto sin-
gle-crystal Si by applying a very negative pre-polar-
ization and growth potential^[48]. The epitaxy of the Ag
films i eparation 1 is mum ^{or} vertualled the control control and for experimentation and growth potential^[48]. The epitaxy of the Ag films is dependent on not only the substrate but also the deposition solution. The Ag films ge v₁, sure and growth potential¹⁴⁸¹. The epitaxy of the Ag films is dependent on not only the substrate but also the deposition solution. The Ag films electrodeposited from the acetate bath follow the out-of-plane an Films is dependent on not only the spharae but also
films is dependent on not only the substrate but also
the deposition solution. The Ag films electrodeposit-
ed from the acetate bath follow the out-of-plane and
in-plane the deposition solution. The valuation that control the deposition solution. The Ag films electrodeposited from the actate bath follow the out-of-plane and in-plane orientations of Si(111), Si(110), and Si(100) wafers, wh and exposition solution. The Fig limit succesceptosition and in-plane orientations of $Si(111)$, $Si(110)$, and $Si(100)$ wafers, whereas the Ag films electrodeposited from the cyanide bath grow epitaxially only on $Si(111)$ et non-
in-plane orientations of Si(111), Si(110), and Si(100)
wafers, whereas the Ag films electrodeposited from
the cyanide bath grow epitaxially only on Si (111)
wafers.
When a chiral surface is used as the substrate, trodeposition. Every, metals are rig mins vectom-pointed some cyanide bath grow epitaxially only on Si(111) fers.
When a chiral surface is used as the substrate, it is ssible to produce chiral metal surfaces by epitaxial etrodeposition. wafers.

when a chiral surface is used as the substrate, it is

possible to produce chiral metal surfaces by epitaxial

electrodeposition. The (643) surface of face-centered-

cubic (fcc) metals such as Au, Ag, Pt, and Cu When a chiral surface is used as the substrate, it is
possible to produce chiral metal surfaces by epitaxial
electrodeposition. The (643) surface of face-centered-
cubic (fcc) metals such as Au, Ag, Pt, and Cu is chiral
d **EVALUAT CONTITY CONTITY CONTIC SURVER THE CONTROLLAT CONDUCT CONDUCT (fcc) metals such as Au, Ag, Pt, and Cu is chiral due to the lack of mirror symmetry. Switzer group demonstrated that chiral Au surfaces could be produ** please to the dialet mean intent mean in the deterodeposition. The (643) surface of face-centered-
cubic (fcc) metals such as Au, Ag, Pt, and Cu is chiral
due to the lack of mirror symmetry. Switzer group
demonstrated tha existively metallical for the subsection and Cu is chiral
cubic (fcc) metals such as Au, Ag, Pt, and Cu is chiral
due to the lack of mirror symmetry. Switzer group
demonstrated that chiral Au surfaces could be pro-
duced

Layer of the state of the political properties of the state of the effect
of to serve as proxies for bulk single-crystal Au^{ien}. dueed by epitaxial electro Even though there is a -24.9% lattice mismatch be-

the constrained sected and film and the Si sub-

the method parameters of equivalent systems and the states of the electrodeposited Au film and the Si sub-

estates coul Even increase the statistic statistic of the control of environmental of the principle and principle and principle and principle and principle and principle and μ of Si walers could then streve as substrates to epitaxi are the electrodeposite and interaction of outer of the deposition of coincident site is a street of the formation of coincident site lattices (CSLs), and Ag to produce more active chiral surfaces. This by the formation o due to the lack of mirror syring 1, at \sim to senally due to the lack of mirror symmetry. Switzer group demonstrated that chiral Au surfaces could be produced by epitaxial electrodeposition of Au onto commercially availa demonstrated that chiral of symmetry. Some can demonstrated that chiral Au surfaces could be produced by epitaxial electrodeposition of Au onto commercially available Si(643) wafers^[53]. These Au-coated Si wafers could electrol that vinto the variance and correlate the variance of the polarization devel by epitaxial electrodeposition of Au onto commercially available Si(643) wafers^[53]. These Au-coated Si wafers could then serve as su mercially available Si(643) vanits¹⁵³¹. These Au-coat-
mercially available Si(643) vancts¹⁵³¹. These Au-coat-
ed Si wafers could then serve as substrates to epitaxi-
ally electrodeposit other metals such as Pt, Ni, Cu mercially available St(643) waters¹²³. These Au-coat-
ed Si wafers could then serve as substrates to epitaxi-
ally electrodeposit other metals such as Pt, Ni, Cu,
that Ag to produce more active chiral surfaces. This
wor **Example 1.1** and Ag to produce more metric strategies and Ag to produce more active chiral surfaces. This work provides a pathway for producing chiral surfaces of a wide range of materials by epitaxial electrodeposition.

 $\# \# \# (L \# \text{I} \#$ by 45° . In addition, the formation of a SiO, interlayer could be directly lift-off without etching, producing $\pm \frac{\beta \mathcal{L}^{\infty}(J. Electrochem.) 2022, 28(7), 2213006 (11 of 24)}{\pi}$
films could be produced by a two-step potential elec-
in which the nucleion and growth of Cu are on the
trodeposition on Si(100) (as shown in Figure 33). The top of **Example epitaxial diversion** (1 of 24)
 Electrochem.) 2022, 28(7), 2213006 (11 of 24)
 Electrochemical diverse of Cu (100) (as shown in Figure 3f). The

top of SAMs via electrochemical reduction of Cu¹

mismatch b \pm (*E Fig. Chetmochem.*) 2022, 28(7), 2213006 (11 of 24)

films could be produced by a two-step potential elec-

in which the nucleation and growth of Cu are on the

trodeposition on Si(100) (as shown in Figure 3). The $\begin{tabular}{ll} \textbf{if} & \textbf{if} \& \textbf{if$ **EVALUATION**
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in which the nucleation and growth of Cu are on the

trodeposition on Si(100) (as shown in Figure 3f). **EVALUATION 1989**
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 $\text{#E}\#(J. \text{Electrochem.}) 2022, 28(7), 2213006 (11 of 24)$
films could be produced by a two-step potential elec-
trodeposition on Si(100) (as shown in Figure 3f). The top of SAMs via electrochemical reduction of Cu²⁺
mismatch bet the \mathcal{H}_c (*L Electrochem.*) 2022, 28(7), 2213006 (11 of 24)

films could be produced by a two-step potential elec-

trodeposition on Si(100) (as shown in Figure 3f). The

mismatch between the lattices of Cu(100) an $\frac{16}{2}$ (*L. Electrochem.*) 2022, 28(7), 2213006 (11 of 24)

films could be produced by a two-step potential elec-

in which the nucleation and growth of Cu are on the

trodeposition on Si(100) (as shown in Figure 3f). reduces from -33.43% to -5.86% by rotating in-plane $28(7)$, $2213006(11 of 24)$
in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu²⁺
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epitaxia $28(7)$, $2213006(11 of 24)$
in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu^{2+}
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epitaxi $28(7)$, 2213006 (11 of 24)
in which the nucleation and growth of Cu are on the
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in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu²⁺
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epitaxi $\frac{28(7)}{2213006}$ (11 of 24)
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top of SAMs via electrochemical reduction of Cu²⁺
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from the presence of the SAM, epi $28(7)$, 2213006 (11 of 24)
in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu^{2+}
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epit $28(7)$, 2213006 (11 of 24)
in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu^{2+}
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epit $28(7)$, 2213006 (11 of 24)
in which the nucleation and growth of Cu are on the
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from the presence of the SAM, epitax 7), 2213006 (11 of 24)
which the nucleation and growth of Cu are on the
p of SAMs via electrochemical reduction of Cu^{2*}
as coordinated to the SAM (Figure 3h). Benefiting
m the presence of the SAM, epitaxial Cu films
ul $\frac{28(7)}{213006}$ (11 of 24)
in which the nucleation and growth of Cu are on the
top of SAMs via electrochemical reduction of Cu^{2+}
ions coordinated to the SAM (Figure 3h). Benefiting
from the presence of the SAM, epit 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (11 of 24)
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in which the nucleation and growth of Cu are on the
cown in Figure 3f). The top of SAMs via electrochemical reduction of Cu²⁺
of Cu(100) an

Batteries

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rechargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial elec-

Li anode formed by epitaxial electrodeposition was trod realized by cycling in the electrolyte containing LiBr $\frac{d}{dt}\mathcal{H}^{\#}(J. Electronchem.) 2022, 28(7), 2213006 (12 of 24)$

rechargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial electric

Li anode formed by epitaxial electrodeposition was

redep $\frac{4k}{2}(L \text{ *Electrochem*}) 2022, 28(7), 2213006 (12 \text{ of } 24)$

rechargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial elec-

Li anode formed by epitaxial electrodeposition can serv $\frac{d}{dt}\mathcal{L}\ddot{\mathcal{L}}(L\text{ *Electrochem*), 2022, 28(7), 2213006 (12 of 24)}\n\text{rechargeable metal-based batteries. The dendrite-free} \quad \text{ure 4d). This work demonstrates that epitaxial elec-
Li anode formed by epitaxial electrolyte containing LiBr method to inhibit the formalism of metal dendrites, and LiNO, under O₃ atmosphere^[36]. This dendrite-free which undoubtedly accelerates the development of morphology of Li originated from the formation of an ultrathin and homogeneous Li₂O-rich solid-electrolyte} \quad \text{4.1.3 Ultrathin Ferromagnetic Films} \quad \text{interface layer$ **interface layer during the discharge of the discharged in the discharge of the discharge for the discharge of the discharge from the electrolyte co EVALUATIVE 12** (*LE Eurochen*, 2022, 28(7), 2213006 (12 of 24)
 Techargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial electric

Li anode formed by epitaxial electrodyce c the freshlap metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial electional election of the dendrite-free ure 4d). This work demonstrates that epitaxial electionalized by eyeling in the $#1 \& E \& Electrochem.$

Helettrochem.) 2022, 28(7), 2213006 (12 of 24)

rechargeable metal-based batteries. The dendrite-free ure 4d). This work democ

Li anode formed by epitaxial electrodeposition was trodeposition can serve
 ed by $NO₃$ (as shown in Figure 4a). The symmetrical (as shown in Figure 4a). The symmetrical migratecesistion of Zn and the symbol expections of Z and Z and **EVALUATION EXAMORE (EXAMORENT CONTENT CONTEN HEFRACE INTERTUAL TRANSFER (FRACE)**
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Frechargeable metal-based batteries. The dendritie-free ure 4d). This work demonstrates that epitaxial electro

Li anode formed by epitaxial electro $\frac{1}{2}$ ($\frac{1}{2}$ $\frac{1}{2}$ the t^2 $\#$ (*k kecrmchem.*) 2022, 28(7), 2213006 (12 of 24)
rechargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial elec-
Li anode formed by epitaxial electrodeposition w rechargeable metal-based batterics. The denotestimal session is a redd). This work demonstrates that epitaxial electrodeposition was troted 40, This work demonstrates that princial electrolytic realized by cycling in the rechargeable metal-based batteries. The dendrite-free ure 4d). This work demonstrates that epitaxial electrocolline is a complexed of the metal-based batteries in the receivation can serve as a simple and efficient creati Li anode formed by epitaxial electrodeposition was

encalized by cycling in the electrolyte containing LiBr method to inhibit the formations of metal dendrites,

enal LiNO, under O, sumosphere^{fno}, This dendriti-free whi realized by eycling in the clectrolyte containing LiBr method to inhibit the formations of metal dendrites,
and LiNO, under O_s atmosphere^{rom}. This dendrite-free which undoubledly accelerates the development of
morphol and LiNO, under O₁ atmosphere¹⁹⁶. This dendrite-free which undoubtedly accelerates the development of
norphology of Li originatd from the formation of an metal-based batteries^{pra}.
Ultrathin and homogeneous Li₀O-ri morphology of Li originated from the formation of an metal-based batteries^[31].

ultrathin and homogeneous Li₂O-rich solic-lectrolyte 4.1.3 Ultrathin Ferromagnetic Films

ultreface layer during the discharge process, ultrathin and homogeneous Li-G-rich solid-electrolyte 4.1.3 Ultrathin Ferromagnetic Films
interface layer during the discharge process, in which
the antive incompact passivation layer was removed
has aroused much attentio

 $(28(7), 2213006 (12 of 24))$
ure 4d). This work demonstrates that epitaxial elec-
trodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the develo $(28(7), 2213006 (12 of 24))$
ure 4d). This work demonstrates that epitaxial elec-
trodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the develo $(28(7), 2213006 (12 \text{ of } 24))$
ure 4d). This work demonstrates that epitaxial elec-
trodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the de 28(7), 2213006 (12 of 24)

ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient

method to inhibit the formations of metal dendrites,

which undoubtedly accelerates the deve $(28(7), 2213006 (12 \text{ of } 24)$

ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient

method to inhibit the formations of metal dendrites,

which undoubtedly accelerates the d . 28(7), 2213006 (12 of 24)
ure 4d). This work demonstrates that epitaxial elec-
trodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the dev 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (12 of 24)
ies. The dendrite-free ure 4d). This work demonstrates that epitaxial elec-
electrodeposition was trodeposition can serve as a simple and efficient
olyte containing

(7), 2213006 (12 of 24)

24d). This work demonstrates that epitaxial elec-

deposition can serve as a simple and efficient

thod to inhibit the formations of metal dendrites,

ich undoubtedly accelerates the development o $(28(7), 2213006 (12 \text{ of } 24)$
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the deve $(28(7), 2213006 (12 \text{ of } 24)$
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the deve 28(7), 2213006 (12 of 24)
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the develop 28(7), 2213006 (12 of 24)

ure 4d). This work demonstrates that epitaxial elec-

trodeposition can serve as a simple and efficient

method to inhibit the formations of metal dendrites,

which undoubtedly accelerates the d 28(7), 2213006 (12 of 24)
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the develop $28(7)$, 2213006 (12 of 24)
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the d sary, 2213006 (12 of 24)
ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient
method to inhibit the formations of metal elendrites,
which undoubtedly accelerates the develop (7), 2213006 (12 of 24)

4d). This work demonstrates that epitaxial elec-

deposition can serve as a simple and efficient

thod to inhibit the formations of metal dendrites,

ich undoubtedly accelerates the development of **Example 18** This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient method to inhibit the formations of metal elendrites, which undoubtedly accelerates the development of metal-based b ure 4d). This work demonstrates that epitaxial electrodeposition can serve as a simple and efficient method to inhibit the formations of metal dendrites, which undoubtedly accelerates the development of metal-based batter trodeposition can serve as a simple and efficient
method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the development of
metal-based batteries^[78].
4.1.3 Ultrathin Ferromagnetic Films
Elec method to inhibit the formations of metal dendrites,
which undoubtedly accelerates the development of
metal-based batteries^[78].
4.1.3 Ultrathin Ferromagnetic Films
Electrodeposition of ultrathin ferromagnetic films
has which undoubtedly accelerates the development of
metal-based batteries^[78].
4.1.3 Ultrathin Ferromagnetic Films
Electrodeposition of ultrathin ferromagnetic films
has aroused much attention due to the observed giant
mag metal-based batteries^[78].
4.1.3 Ultrathin Ferromagnetic Films
Electrodeposition of ultrathin ferromagnetic films
has aroused much attention due to the observed giant
magnetoresistance (GMR) and perpendicular magne-
tiz 4.1.3 Ultrathin Ferromagnetic Films
Electrodeposition of ultrathin ferromagnetic films
has aroused much attention due to the observed giant
magnetoresistance (GMR) and perpendicular magne-
tization anisotropy (PMA), which

the Fe film undergoes a structural transition from the **for the Fe film undergoes a structural transition from the**
fcc-Fe(111) to bcc-Fe(110) when the film is thicker
than 2-3 monolayers (ML)^[83]. For the Co/Au(111) Semiconductors possess diverse optical and elec-
system, the Fe film undergoes a structural transition from the alignment.

the Fe film undergoes a structural transition from the alignment.

fcc-Fe(111) to bcc-Fe(110) when the film is thicker **4.2 Epitaxial Films of Semiconduct** system, when the potential is more negative than -1.2 $\text{#}\{E\}\,(L \text{~Electrochem.})\,2022, 28(7), 2213006 \,(13 \text{ of } 24)$
the Fe film undergoes a structural transition from the alignment.
fcc-Fe(111) to bec-Fe(110) when the film is thicker
than 2-3 monolayers (ML)⁽⁸¹⁾. For the Co/Au $\pm \frac{\beta \mathcal{L}^{\infty}(J, \text{Electro-}hem, 2022, 28(7), 2213006 (13 of 24))}{4.2$ **Epiranism and the Fe film undergoes a structure laration from the alignment.**
fcc-Fe(111) to bec-Fe(110) when the film is thicker
than 2-3 monolayers (ML)⁽ \mathbb{R}^m (*Leterochem.*) 2022, 28(7), 2213006 (13 of 24)
the Fe film undergoes a structural transition from the alignment.
fcc-Fe(111) to bcc-Fe(110) when the film is thicker **4.2 Epitaxial Films of Semiconductors**
than **in the Clerifold Electron Controllary** (*I. Beetrochem.*) 2022, 28(7), 2213006 (13 of 24)

the Fe film undergoes a structural transition from the alignment.

fcc-Fe(111) to bcc-Fe(110) when the film is thicker **4.2 Epita** \oplus \oplus $\frac{1}{2}$ the solution set and the solution from the solution of the solution 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (13 of 24)

ural transition from the alignment.

then the film is thicker **4.2 Epitaxial Films of Semiconductors**

For the Co/Au(111) Semiconductors possess diverse optical and

than 2-3 monolayers $(ML)^{(a)}$. For the Co/Au(111) Semiconductors posses diverse optical and elec-
system, when the potential is more regative tham -1.2 trial properties, and are generally the key comp-
system, when the pot system, when the potential is more negative than -1.2

vireal properties, and are generally the key compo-

V vs. mercurous sulfact electrode (MSE), the electro-

deposition of Co on Au(111) transits from a 3D to 2D

pare V vs. mercurous sulfate electrode (MSF), the electro-
eners of various optical and electrical devices. Com-
deposition of Co on Au(111) transis from a 3D to Δ pared to polycyriatline semiconductor films are more attrac deposition of Co on Au(11) transits from a 3D to 2D

graed to polycrystalline semiconductors, epitaxial

growth node. In addition, the growth is in a 2D mode is misconduce films are more attractive due to their

in the C. growth mode. In addition, the growth is in a 2D mode

in the C1 solution but a 3D mode

in the C1 solution but a 3D and coin in the SCN solution and chercis and betterd properties and better

tion. The PMA of the deposite in the Cl solution but a 3D mode in the SCN solu-

improved optical and electrical properties and better

trio. The PMA of the deposited metal films is also

electrodeposition: S. Therefore, the perpartion of epi-

greaty tion. The PMA of the deposited metal films is also

greatly influenced by the thickness of the films^{toj} and

taxial semiconductor

the pH of the solution^[84],

the infinite produced by electrode
position has

Figh-qua eatly influenced by the thickness of the films⁸⁰ and

taxial semiconductor films by simple and inexpensive

electrodeposition has been estendeposition has been estendeposition

High-quality opitwall metal films could al the pH of the solution¹⁸¹³. electrodeposition has been extensively investigated.

High-quality epitaxial metal films could also be In this section, the electrodeposited epitaxial films of

produced by electrodenmically High-quality epitaxial metal films could also be

In this section, the electrodeposited epitaxial films of

produced by lectrodeposited epitaxial metal oxides films produced by detected by chec-closes. comes

produced by produced by electrochemically reducing the pre-elec-
metal oxides, chalcogenides, and metal haides will
trochosited cpitraxim metal oxide films. For exam-
 \sim be covered.

ple, Switzer and IF have reported that epitaxial trodeposited epitaxial metal oxide films. For exam-

be covered.

be, Switzer and He interveloped that epitaxial Neatl Oxide Films

and Bi^{ngo} thin films could be produced by direct elec-

Metal oxides show diverse funct ple, Switzer and He have reported that epitaxial Fe^{eff} 4.2.1 Fipitaxial Metal Oxide Films
and Bi²⁸⁴ thin films could be produced by dirret cle-
treathentical readers of the divides show divierse functionality am

and R⁵⁸⁶ thin films could be produced by direct elec-

Metal oxides show diverse functionality among

trochemical reduction of pre-selectodeposited epitax-

inferent and oxides

inferent and oxides

inferent and control trochemical reduction of pre-electrodeposited epitax-
inorganic materials⁽³⁹⁾. Nanostructured metal oxides
in Fe₅O₁ and S -B₁O₁ bin films on At single crystals, usually chalibit special opitaxi and electronic p ial Fe,O₄ and δ -Bi-O₁ thin films on Au single crystals,

usually exhibit special optical and electronic proper

espectively. This work demonstrates the feasibility

ties which make them important components for var respectively. This work demonstrates the feasibility
of solid-tate princant components for var-
of solid-state epitation alms
form solid antisoform of metal oxide to ious electronics. In this section, epitakial thin films of solid-state epitaxial transformation of metal oxide

ious clectronics. In this section, epitaxial thin films of

films to the corresponding metal films and could be some representative metal oxis fabricated by elec-

s films to the corresponding metal films and could be
some representative metal oxides fabricated by elec-
applied to produce special epitaxial metal/metal ox-
troleposition will be discussed.

ide beterojunetions as well a applied to produce special epitaxial metal/metal ox-

independition will be discussed.

independitions as well as different kinds of epi-

conductor which is of interest for high-frequency

arisai alloly films from the co ide heterojunctions as well as different kinds of epi-

intxial alory films from the corresponding mixed met-

enoted are presence of thierast for high-frequency

al oxides.

aloxides.

aloxides

aloxides is of interast o taxial alloy films from the corresponding mixed met-
activate. The conductor which is of interest for high-frequency
incident costations conduction to the efficient interest inconsinue, the
interaction of the efficient in al oxides.

piezoelectric resonators, conducting transparent win-

Eignizatial electrodeposition of ferromagnetic metal

Effines onto semiconductor substrates is also attractive

dove for photovolutia cells, and UV light-Epiaxial electrodeposition of ferromagnetic metal

dows for photovoltaic cells, and UV light-emitting

dimension semiconductor substrates is also attractive

due to the efficient injection of spin-polarized elec-

ed onto films onto semiconductor substrates is also attractive

duces the effecient injectuation of spin-polarized elec-

tors into semiconductors for spintronic applications,

to not of issolved oxyen in an aqueous solution of

alignment.

 \mathbb{R}^2 is the film undergoes a structural transition from the alignment.

the Fe film undergoes a structural transition from the alignment.

fec-Fe(111) to bee-Fe(110) when the film is thicker **4.2 Epitaxial Films of Example 19**
 Example 1980 (13.6° Alexande Constant Internation from the alignment.

Fe (II11) no bec-Fe (110) when the film is thicker **4.2** Epitaxial Films of Semiconductors
 R^2 anonolayers (ML)⁽⁶³⁾. For the **EVALUATION THE CONSULTERT (FOCULATION ACCELECT (FOCULATION ACCELECT) (THE CONDUCT (FOCULATION OF A CONDUCTED SURFACT (FOR UNITED SOMETHEAD CONDUCTED SURFACT (FOR UNITED SOMETHEAD AND CONDUCT (FOR A CONDUCTED SURFACT UP) EVALUAT EVALUAT (Example 19.22, 28(7), 2213006 (13 of 24)

the Fe film undergoes a structural transition from the alignment.**

fcc-Fe(111) to bcc-Fe(110) when the film is thicker
 \bullet **4.2 Epitaxial Films of Semiconducto** the $\frac{d_1}{dx}$ is the $\frac{d_1}{dx}$ (L $\frac{d_2}{dx}$ (L $\frac{d_2}{dx}$ (L)) when the film is thicker

foc-Fe(111) to bec-Fe(110) when the film is thicker
 $\frac{d_1}{dx}$ **2.2 Epitaxial Films of Semiconductors**

than 2-3 mono **EXECT THE CONDUCE THE CONDUCED TRANSFER (THE CONDUCED TRANSFER (NL) TO have the Film in Siniconductors foc-Fe(111) to hec-Fe(110) when the film is thicker

4.2 Epitaxial Films of Semiconductors passes inverse opical and** the Fe film undergoes a structural transition from the alignment.

Re-Fer(111) to bec-Fer(110) when the Eim is thicker = 4.2 Epitaxial Films of Semiconductors

than 2.3 monolayers (MI)¹⁸¹1, For the Co/Au(111) Semiconduc fce-Fc(111) to bec-Fc(110) when the film is thicker
 4.2 Epitaxial Films of Semiconductors

than 2-3 monologysts (ML)¹⁰³. For the Co/Au(111) Samiconductors possess diverse opital and elec-

system, when the potential $28(7)$, $2213006(13 \text{ of } 24)$
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrica (13.0006 (13.0624)

September 13.0006 (13.0624)
 Epitaxial Films of Semiconductors

Semiconductors possess diverse optical and elec-

tal properties, and are generally the key compo-

tas of various optical and electrica 28(7), 2213006 (13 of 24)

alignment.
 4.2 Epitaxial Films of Semiconductors

Semiconductors possess diverse optical and electrical properties, and are generally the key compo-

nents of various optical and electrical de $28(7)$, 2213006 (13 of 24)

alignment.
 4.2 Epitaxial Films of Semiconductors

Semiconductors possess diverse optical and elec-

trical properties, and are generally the key compo-

nents of various optical and elect $28(7)$, 2213006 (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical d $28(7)$, 2213006 (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical d $28(7)$, $2213006(13 \text{ of } 24)$
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and electrical properties, and are generally the key components of various optical and electrical de $\frac{128(7)}{213006}$ (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical $28(7)$, 2213006 (13 of 24)

alignment.
 4.2 Epitaxial Films of Semiconductors

Semiconductors possess diverse optical and electrical properties, and are generally the key components of various optical and electrical de $\frac{28(7)}{2213006}$ (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical $\frac{28(7)}{2213006}$ (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical 28(7), 2213006 (13 of 24)

alignment.

4.2 Epitaxial Films of Semiconductors

Semiconductors

Semiconductors possess diverse optical and elec-

trical properties, and are generally the key compo-

nents of various optical 28(7), 2213006 (13 of 24)

alignment.
 4.2 Epitaxial Films of Semiconductors

Semiconductors

Semiconductors possess diverse optical and electrical properties, and are generally the key components of various optical and $28(7)$, 2213006 (13 of 24)
alignment.
4.2 Epitaxial Films of Semiconductors
Semiconductors possess diverse optical and elec-
trical properties, and are generally the key compo-
nents of various optical and electrical ment.
 2 Epitaxial Films of Semiconductors
 Semiconductors
 Semiconductors possess diverse optical and elec-

and properties, and are generally the key compo-

ints of various optical and electrical devices. Com-

re alignment.
 4.2 Epitaxial Films of Semiconductors

Semiconductors possess diverse optical and elec-

trical properties, and are generally the key compo-

nents of various optical and electrical devices. Com-

pared to po **4.2 Epitaxial Films of Semiconductors**
Semiconductors possess diverse optical and electrical properties, and are generally the key components of various optical and electrical devices. Compared to polycrystalline semicon Semiconductors possess diverse optical and electrical properties, and are generally the key components of various optical and electrical devices. Com-
pared to polycrystalline semiconductors, epitaxial semiconductor films trical properties, and are generally the key components of various optical and electrical devices. Com-
pared to polycrystalline semiconductors, epitaxial
semiconductor films are more attractive due to their
improved opti nents of various optical and electrical devices. Com-
pared to polycrystalline semiconductors, epitaxial
semiconductor films are more attractive due to their
improved optical and electrical properties and better
device ef pared to polycrystalline semiconductors, epitaxial
semiconductor films are more attractive due to their
improved optical and electrical properties and better
device efficiencies. Therefore, the preparation of epi-
taxial s miconductor films are more attractive due to their
proved optical and electrical properties and better
vice efficiencies. Therefore, the preparation of epi-
cial semiconductor films by simple and inexpensive
ectrodepositio improved optical and electrical properties and better
device efficiencies. Therefore, the preparation of epi-
taxial semiconductor films by simple and inexpensive
electrodeposition has been extensively investigated.
In th

device efficiencies. Therefore, the preparation of epi-
taxial semiconductor films by simple and inexpensive
electrodeposition has been extensively investigated.
In this section, the electrodeposited epitaxial films of
me

erystals, usually exhibit special optical and electronic proper-
assibility
ties which make them important components for var-
all oxide
ious electronics. In this section, epitaxial thin films of
eould be
some representat taxial semiconductor films by simple and inexpensive
electrodeposition has been extensively investigated.
In this section, the electrodeposited epitaxial films of
metal oxides, chalcogenides, and metal halides will
be cov electrodeposition has been extensively investigated.
In this section, the electrodeposited epitaxial films of
metal oxides, chalcogenides, and metal halides will
be covered.
4.2.1 Epitaxial Metal Oxide Films
Metal oxides In this section, the electrodeposited epitaxial films of
metal oxides, chalcogenides, and metal halides will
be covered.
4.2.1 Epitaxial Metal Oxide Films
Metal oxides show diverse functionality among
inorganic materials metal oxides, chalcogenides, and metal halides will
be covered.
4.2.1 Epitaxial Metal Oxide Films
Metal oxides show diverse functionality among
inorganic materials^[89]. Nanostructured metal oxides
usually exhibit specia $ZnCl₂^[90, 91]$. The electrodeposition could be described entrationally and the electroden could be described from enterials of the described position contentials oxides y exhibit special optical and electronic proper-
hich make them important components for variate transition c 4.2.1 Epitaxial Metal Oxide Films

Metal oxides show diverse functionality among

inorganic materials^[89]. Nanostructured metal oxides

usually exhibit special optical and electronic proper-

ties which make them import Metal oxides show diverse functionality among
inorganic materials^[89]. Nanostructured metal oxides
usually exhibit special optical and electronic proper-
ties which make them important components for var-
ious electroni programic materials¹⁸⁹. Nanostructured metal oxides
ally exhibit special optical and electronic proper-
s which make them important components for var-
s electronics. In this section, epitaxial thin films of
me represen usually exhibit special optical and electronic proper-
ties which make them important components for var-
ious electronics. In this section, epitaxial thin films of
some representative metal oxides fabricated by elec-
tro ties which make them important components for various electronics. In this section, epitaxial thin films of some representative metal oxides fabricated by electrodeposition will be discussed.

ZnO is a large bandgap $(3.3$ ious electronics. In this section, epitaxial thin films of
some representative metal oxides fabricated by elec-
trodeposition will be discussed.
ZnO is a large bandgap $(3.3 \sim 3.6 \text{ eV})$ n-type semi-
conductor which is of some representative metal oxides fabricated by electrodeposition will be discussed.

ZnO is a large bandgap $(3.3 \sim 3.6 \text{ eV})$ n-type semi-

conductor which is of interest for high-frequency

piezoelectric resonators, con

$$
Zn^{2+} + 0.5O_2 + 2e \rightarrow ZnO \tag{13}
$$

trodeposition will be discussed.

ZnO is a large bandgap (3.3 ~ 3.6 eV) n-type semi-

conductor which is of interest for high-frequency

piezoelectric resonators, conducting transparent win-

dows for photovoltaic cells, ZnO is a large bandgap $(3.3 \sim 3.6 \text{ eV})$ n-type semi-
conductor which is of interest for high-frequency
piezoelectric resonators, conducting transparent win-
dows for photovoltaic cells, and UV light-emitting
devices. Ep conductor which is of interest for high-frequency
piezoelectric resonators, conducting transparent win-
dows for photovoltaic cells, and UV light-emitting
devices. Epitaxial ZnO films could be electrodeposit-
ed onto sing piezoelectric resonators, conducting transparent win-
dows for photovoltaic cells, and UV light-emitting
devices. Epitaxial ZnO films could be electrodeposit-
ed onto single-crystal gallium nitride (GaN) by reduc-
tion of dows for photovoltaic cells, and UV light-emitting
devices. Epitaxial ZnO films could be electrodeposit-
ed onto single-crystal gallium nitride (GaN) by reduc-
tion of dissolved oxygen in an aqueous solution of
 $ZnCl_2^{[90$ devices. Epitaxial ZnO films could be electrodeposited onto single-crystal gallium nitride (GaN) by reduction of dissolved oxygen in an aqueous solution of $ZnCl_2^{[90, 91]}$. The electrodeposition could be described by the

 $#E\# (J. Electrochem.)$

alutions by electrochemically lowering the local pH at tion on (100) surfaces of Au^[40], Si^[49], and

the electrode surface^[29]. The electrodeposition invo-

an alkaline Cu²⁺-lactate solution. Mor substrate.

posited on Au(100) from an alkaline solution of Cu²⁺- Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O films oxidation of assorbate dianions as mentioned in Sce-

the substrate (Figure 5e). Different epitaxial relation-

columnar structure and an epitaxial relationship of

columnar structure and an epitaxial relationship of

Enc tion 2.1. The obtained epituxial ZnO films have a ships are observed between the deposited Cu₂O and
columnar structure and an epitaxial relationship of the substrates, i.e., Cu₂O(001)[100]/Ano(011][100],
ZnO(0001)[101 columnar structure and an epitaxial relationship of the substrates, i.e., Cu:O(001)[100]/Au(001)[100].

ZnO(0001)[101]¹]/ α [11]¹]^{[1}]^{[1}]^{[1}][1¹][1¹][1¹] Cu:O(001)[1¹00]/sin(001)[110]]. Take the electrode $ZnO(0001)[1011]/Au(111)[110]$ with the Au(111) $CuO(001)[100]/S5i(001)[110]$, and $CuO(001)[100]$

substrate.

CuO with a narrow bandgap in the range of $1.2 \sim 000$ Kia an example, the c-let-dedeposition of CuO

CuO with a narrow substrate. $\langle\ln P(00)\rangle[110]$. Take the electrodeposition of Cu₂-Cu₂
Cu₂ wan absorb light throughout the visible spec-
Cu₂ Sor ean shoorb light throughout the visible spec-
Cu₂ Sor seals by the Si substrates in t CuO with a narrow bandgap in the range of $1.2-$ on Si as an example, the Cu¹ is reduced to epitaxial

1.5 eV can absorb light throughout the visible spec-

Cu₂O exam absorb light throughout the visible spec-

Epitaxi 1.5 cV can absorb light throughout the visible specific selectives in the initial electro-
trum, which can be used in electroderomic devices¹⁰⁹. less deposition, with the concominant oxidation of Si
Epinxial films of Cu trum, which can be used in electrochromic devices¹⁶². less deposition, with the concomitant oxidation of Si

Epixixial films of CuO could be anodically electrode-

to 50:0, Then, the electrodeposition proceeds on the

F Epitaxial films of CuO could be anodically clectrode-

to SiO₂. Then, the electrodeposition proceeds on the

position of Au(100) from an alkialine solution of Cu³⁺. Cu-O epitaxial secolution coeffers

trartate at room posited on Au(100) from an alkaline solution of Cu²-

Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O films

fractricat at room temperature¹⁹¹¹. Paticularly, the de-usually show enhanced opteclectoriae and phototartrate at room temperature¹⁹¹. Particularly, the do-
usually show enhanced optoelectronic and photo-
position mechanism of CuO involves the oxidation of voltatic properties, which is conductive to obtaining
the tartra position mechanism of CuO involves the oxidation of
the iterate lignade of the direct lignade of the Ca-¹--atriture complex rather higher device efficiencies for Cu_O-based diode and
than the redax reaction of Cu³ ie the tatrtate ligands of the Cu³-tartrate complex rather

the the croix result of Cu³-ions i EL or D-tartrat-

ic acid instead of DL-tartaric acid vas used in the de-

ic acid instead of DL-tartaric acid vas used in th than the redox reaction of Cu²⁺ ions. If L- or D-tartar-
solar cells^{pm},
is acid instead of DL-tartaric aid was used in the de-
position solution, the deposited cpitaxial CuO films mixed oxides composed of iron and ano ic acid instead of DL-tartaric acid was used in the de-
position solution, the choosited epitaxial CuO films
on Au(100) could show chirality⁹⁸). That is, the CuO could be produced by direct electrode
position form of an CuO film ((R)-CuO) shows a strong [111] orientation dex planes of Au was realized initially
when deposited from a solution of Cu²⁺-(R,R)-tartrate tion of (NH₂)-Fe(SO₁₂^{ta},⁸⁸ and later from
Figure 5a). These elect

lutions by electrochemically lowering the local pH at the electrodemically lowering the local pH at

tion on (100) surfaces of Au^{teg}, Si^{teg}, and InP^[98] from

the electrode surface^[29]. The electrodeposition invo-

an alkaline Cu²²-lactate solution. Morphologies o the electrochemical dependent of the substrates, i.e., Cu₂O(001)[100]//Au(001)[100]

the electrodeposition invo-

The electrodeposition invo-

an alkaline Cu²⁻¹actate solution. Morphologies of the

through the elec ¹¹(*J. Electrochemically lowering the of ascorbate dianions by electrochemically lowering the local pH at tion on (100) surfaces of Au⁽⁴⁰, Si⁽⁴⁹⁾, and InP⁽⁹⁸⁾ from the electrode surface^[29]. The electrode
positi* $\frac{\text{ft}(E\#(f, Electrochem.) 2022, 28(7), 2213006 (14.6724))}{\text{lutions by electrochemically lowering the local pH at } \text{tion on } (100) surfaces of Au¹⁶⁰, Si¹⁶⁰, and InP¹⁸⁰ from the electrodepsotic) in view of an alkalic Cu₁O were significantly affected by byside in the factrodepsicide (Eq. Q. 20099) and a few additional relationship of the substrate (Figure 5c). Different epitaxial relationship of the substrate (Figure 5c). Different epitaxial relationship of the substrate, i.e., Cu₂O (001)[100]//Au$ **EVALUATION**
 EVALUATION E $\frac{d}{d\theta}$ **E** $\frac{d}{d\$ **EASA Electrochem.**) 2022, 28(7), 2213006 (14 of 24)

ions by electrochemically lowering the local pH at

ion on (100) surfaces of Au^{ten}, Si²⁶¹, and InP^{nes} from

electrode surface^[29]. The electrodeposition invo-**EVALUATIVE EXAMELE 1.5** (1.5 external through the constraint of Altimative spec-

1.5 external through the constraints of Altimative Cu²³. Si⁹¹¹, and In^{peral} from

the electrode surface¹²¹. The electrodeposition ± 0.92 (Electrocheron, 2022, 28(7), 2213006 (14 of 24)

Lutions by electrochemically lowering the local pH at tion on (100) surfaces of Au^{(on}, Si^{(on}, and InP^{iss}) from

the electrode surface^[29]. The electrodepo $\text{L}(E^{\text{22}}(L \text{R}_{\text{P}}(L \$ $(4E^2 + (L \cdot E/cetrochem) \cdot 2022, 28(7), 2213006 (14 of 24)$

and the electrochemically lowering the local pH at ion on (100) surfaces of Au⁽³⁰, Si¹⁶⁰, and InP^{[36}] from

the electrochemically lowering the local pH at ion on (1 th(k^{ω})(*L khennohem,*) 2022, 28(7), 2213006 (14 of 24)

the electroche surface¹³⁹. The lectrodeposition invo-

the electroche surface¹³⁹. The electrodeposition invo-

these by the surface of the the electrode **EVALUATION**
 EVALUATION Lutions by electrochemically lowering the local pH at

tion on (100) surfaces of Au⁽⁸⁰, Si^{tion}, and InP⁹⁸⁾ from

the electrode surface^[29]. The electrodeposition invo-

an alkaline Cu²⁺-lactate solution. Morphol Intions by electrochemically lowering the local pH at tion on (100) surfaces of Au^{jua}, Si²⁶⁹, and lah^{ples} from
the electrode surface²⁹¹. The lectrodenosition invo-
an alksilne Cu²⁺-latats esolution of Hacendores the electrode surface^[59]. The electrodeposition invo-

lives the production of H through the electrodeposition of Herotenchmical electrodeposition (~ 0.00 was significantly affected by

oxidation of assorbate dianio bes the production of H' through the electrochemical

coid Cu_OO were significantly affected by

coidation of ascorbate diamions as mentioned in Sec-

the substrate (Figure 5c). Different epitaxial classical

coidinnar s (100) surfaces of Au^[40], Si^[49], and InP^[98] from
an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (Figure 5c). Different epitaxial rel 28(7), 2213006 (14 of 24)

tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from

an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substrate 2. 28(7), 2213006 (14 of 24)

tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from

an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substra $(28(7), 2213006 (14 of 24))$
tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from
an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (Figu $(28(7), 2213006 (14 of 24)$
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an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (Figu $28(7)$, $2213006(14 \text{ of } 24)$
tion on (100) surfaces of Au^[40], Si^[49], and InP^[08] from
an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate $(28(7), 2213006 (14 of 24))$

tion on (100) surfaces of Au^[40], Si^[49], and InP^[08] from

an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substrate ($(14 \text{ of } 24)$
 $(28(7), 2213006 (14 \text{ of } 24))$

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an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected $(28(7), 2213006 (14 of 24)$

tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from

an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substrate (. 28(7), 2213006 (14 of 24)
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an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (F . 28(7), 2213006 (14 of 24)
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an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (Fi $28(7)$, 2213006 (14 of 24)
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an alkaline Cu³⁻-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate ($28(7)$, $2213006(14 \text{ of } 24)$
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an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate $28(7)$, $2213006 (14 of 24)$

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an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substrate $28(7)$, $2213006 (14 of 24)$

tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from

an alkaline Cu²⁻-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substra **Exampleration**

tion on (100) surfaces of Au^[40], Si^[49], and InP^[98] from

an alkaline Cu²⁺-lactate solution. Morphologies of the

electrodeposited Cu₂O were significantly affected by

the substrate (Figure 5c tion on (100) surfaces of Au^{is0}, Si^[49], and InP^[98] from
an alkaline Cu²⁺-lactate solution. Morphologies of the
electrodeposited Cu₂O were significantly affected by
the substrate (Figure 5c). Different epitaxia alkaline Cu²^{*z*}-lactate solution. Morphologies of the
ectrodeposited Cu₂O were significantly affected by
substrate (Figure 5c). Different epitaxial relation-
ips are observed between the deposited Cu₂O and
substra electrodeposited Cu₂O were significantly affected by
the substrate (Figure 5c). Different epitaxial relation-
ships are observed between the deposited Cu₂O and
the substrates, i.e., Cu₂O(001)[100]//Au(001)[100],
Cu the substrate (Figure 5c). Different epitaxial relationships are observed between the deposited Cu₂O and the substrates, i.e., Cu₂O(001)[100]//Au(001)[100], Cu₂O(001)[100]//Inp(001)[100]. Cu₂O(001)[100]//Inp(001)[ships are observed between the deposited Cu₂O and
the substrates, i.e., Cu₂O(001)[100]//Au(001)[100],
Cu₂O(001)[100]//Si(001)[110], and Cu₂O(001)[100]
//InP(001)[110]. Take the electrodeposition of Cu₂O
on Si as the substrates, i.e., Cu₂O(001)[100]//Au(001)[100],
Cu₂O(001)[100]//Si(001)[110], and Cu₂O(001)[100]
//InP(001)[110]. Take the electrodeposition of Cu₂O
on Si as an example, the Cu²⁺ is reduced to epitaxial
Cu₂ Cu₂O(001)[100]//Si(001)[110], and Cu₂O(001)[100]

//InP(001)[110]. Take the electrodeposition of Cu₂O

on Si as an example, the Cu²⁺ is reduced to epitaxial

Cu₂O seeds by the Si substrates in the initial electr 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (14 of 24)
vering the local pH at tion on (100) surfaces of Au⁽⁴⁰⁾, Si^{49}, and InP^[98] from
ectrodeposition invo-
h the electrochemical electrodeposited Cu₂O were sign

position solution, the deposited epitaxial CuO films mixed oxides composed of iron and another metal),
on Au(100) could show charitly^{10m}. That is, the CuO could be produced by driect elected
equosical finantic finantic on Au(100) could show chirality^{ng}). That is, the CuO could be produced by direct electrodeposition from
Einf(S)-CuO) deposited from a solution of Cu²-(S,S) aqueous solutions without any post-annealing pro-
farmed is a film ((S)-CuO) deposited from a solution of Cu²-(S.S) agueous solutions without any post-annealing pro-
-tartante has a strong [111] orientation whereas the cess. Fpinzial electrodeposition of Fe,Q, on low-
in-tartante -tartrate has a strong [111] orientation, whereas thecass. Epitaxial electrodeposition of Fo,O, on low-in-
CuO film ((R)-CuO) shows a strong [111] orientation dex planes of Au was realized initially from a solution
of Cu en deposited from a solution of Cu²-(R,P,Hartrate tion of (NH_a)Fe(SO_a)^{n,^{n,a}" and later from a more sta-
gure Sa). These cleared posited chird Cto films be altakine solution of Fe³-critchandamire (TEA)
we specif} (Figure Sa). These electrodeposited chiral CuO films

ble alkaline solution of Fe³-criethanolamine (TEA)

shows a picific solution of consideration of complexes¹⁶⁸-x²⁶.³². In the case of electrodeposition

enantio show specific sclectivity toward the oxidation of complexes^{(10, 2), 83, 31}. In the case of electrodeposition-
e-cuo shows a higher activity toward the oxidation of posited film depends on the applied potential because
C enantiomeric tartrates. As shown in Figure 5h, (S) from the alkaline solution, the phase of the electrode-Cu2 shows a higher activity toward the oxidation of posited film depends on the applied potential because C(S, S)-t //InP(001)[110]. Take the electrodeposition of Cu₂O
on Si as an example, the Cu²⁺ is reduced to epitaxial
Cu₂O seeds by the Si substrates in the initial electro-
less deposition, with the concomitant oxidation of Si the electrodeposition of Cu₂O
the Cu²⁺ is reduced to epitaxial
substrates in the initial electro-
ne concomitant oxidation of Si
trodeposition proceeds on the
igure 5d). Epitaxial Cu₂O films
ed optoelectronic and ph on Si as an example, the Cu²⁺ is reduced to epitaxial Cu₂O seeds by the Si substrates in the initial electro-
less deposition, with the concomitant oxidation of Si
to SiO₂. Then, the electrodeposition proceeds on th Cu₂O seeds by the Si substrates in the initial electro-
less deposition, with the concomitant oxidation of Si
to SiO₂. Then, the electrodeposition proceeds on the
Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O f less deposition, with the concomitant oxidation of Si
to SiO₂. Then, the electrodeposition proceeds on the
Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O films
usually show enhanced optoelectronic and photo-
volta to SiO₂. Then, the electrodeposition proceeds on the Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O films usually show enhanced optoelectronic and photo-
voltaic properties, which is conducive to obtaining higher Cu₂O epitaxial seeds (Figure 5d). Epitaxial Cu₂O films
usually show enhanced optoelectronic and photo-
voltaic properties, which is conducive to obtaining
higher device efficiencies for Cu₂O-based diode and
solar ce usually show enhanced optoelectronic and photo-
voltaic properties, which is conducive to obtaining
higher device efficiencies for Cu₂O-based diode and
solar cells^[99].
Many spinels, including Fe₃O₄ and some ferri voltaic properties, which is conducive to obtaining
higher device efficiencies for Cu₂O-based diode and
solar cells^[99].
Many spinels, including Fe₃O₄ and some ferrites (i.e.,
mixed oxides composed of iron and ano higher device efficiencies for Cu₂O-based diode and
solar cells^[99]. Many spinels, including Fe₃O₄ and some ferrites (i.e.,
mixed oxides composed of iron and another metal),
could be produced by direct electrodepo solar cells^[99]. Many spinels, including Fe₅O₄ and some ferrites (i.e., mixed oxides composed of iron and another metal), could be produced by direct electrodeposition from aqueous solutions without any post-anneali Many spinels, including Fe₃O₄ and some ferrites (i.e.,
mixed oxides composed of iron and another metal),
could be produced by direct electrodeposition from
aqueous solutions without any post-annealing pro-
cess. Epita mixed oxides composed of iron and another metal),
could be produced by direct electrodeposition from
aqueous solutions without any post-annealing pro-
cess. Epitaxial electrodeposition of Fe₃O₄ on low-in-
dex planes o could be produced by direct electrodeposition from
aqueous solutions without any post-annealing pro-
cess. Epitaxial electrodeposition of Fe₅O₄ on low-in-
dex planes of Au was realized initially from a solu-
tion of (aqueous solutions without any post-annealing process. Epitaxial electrodeposition of Fe₃O₄ on low-in-
dex planes of Au was realized initially from a solu-
tion of (NH₄)_{-F}e(SO₄)₂^{[7, 38}] and later from a more cess. Epitaxial electrodeposition of Fe₃O₄ on low-in-
dex planes of Au was realized initially from a solu-
tion of $(NH_t)_2Fe(SO_t)_2^{[7.38]}$ and later from a more sta-
ble alkaline solution of Fe³⁺triethanolamine (TEA) Ily from a solu-

irom a more sta-

iolamine (TEA)

lectrodeposition

of the electrode-

otential because

could lead to the
 Fe^{2+}/Fe^{3+} ions on

vary the mecha-
 s_3O_4 films were

ls whereas ferri-

med at relativel ed the electrodeposition of $Co.Fe_3.O_4^{[8]}$, $Zn.Fe_3.O_4^{[100]}$, \mathbf{I} , $Ni_xFe_{3x}O₄^[34] that could be used in magnetic or catalytic$ H_4 ₂Fe(SO₄)^{r7, 38)} and later from a more sta-
ine solution of Fe³⁺-triethanolamine (TEA)
s_Is^{[18, 21, 32, 85]. In the case of electrodeposition
alkaline solution, the phase of the electrode-
lm depends on the} ble alkaline solution of Fe³⁺-triethanolamine (TEA)
complexes^[18, 21, s2, ss]. In the case of electrodeposition
from the alkaline solution, the phase of the electrode-
posited film depends on the applied potential bec complexes^{[18, 21, 52}, ⁵³]. In the case of electrodeposition
from the alkaline solution, the phase of the electrode-
posited film depends on the applied potential because
the change of the applied potential would lead from the alkaline solution, the phase of the electrode-
posited film depends on the applied potential because
the change of the applied potential would lead to the
change of the concentration ratio of Fe^{2r}/Fe^{3r} ions on

 $#E\# (J. Electrochem.) 2022, 28(7), 2213006 (15 of 24)$
firstly electrochemically reduced into Fe(TEA)²⁺ and of charges passed during each pulse (i.e., by control-
the production of Fe(TEA)²⁺ would trigger the depo ling the curren the production of H(E^* (*L Electrochem*,) 2022, 28(7), 2213006 (15 of 24)

firstly electrochemically reduced into Fe (TEA)²⁺ and of charges passed during each pulse (i.e., by control-

the production of Fe (TEA)² **E** $\{E\}e^{\frac{2\pi}{3}}(J. Electrochem.)$ 2022, 28(7), 2213006 (15 of 24)
 **Sincily electrochemically reduced into Fe(TEA)²⁺ and of charges passed during each pulse (i.e., by control-

the production of Fe(TEA)²⁺ would trigger t** Epitaxial CoxFe3-xO4 films were electrodeposited on \mathbb{R}^m (*LE*^{*} (*LE Electrochem.)* 2022, 28(7), 2213006 (15 of 24)

firstly electrochemically reduced into Fe (TEA)²⁺ and of charges passed during each pulse (i.e., by control-

the production of Fe (TEA)²⁺ wou **EVALUATION**
 EXAMORERT THE MAGE THE MAGE CONTINUATE CONTEX (TEALT AND A THE MAGE THE MAGE THE PROPORTED THE PROPORTED THE MAGE DURING THE MAGE DURING AN ALTERT DURIN $\mathfrak{R} \mathcal{L} \mathcal{L}(\mathcal{I}, E)$ electrodeposited into Fe(TEA)² and of charges passed during each pulse (i.e., by control-
the production of Fe(TEA)² would trigger the depo ing the current density and the dwell time of e $\mathbb{E}(E) = \frac{1}{2} \sum_{i=1}^{n} \frac{1}{2}$ **Example 12**
 Example 12 $#/E^{\#}(L \t\t\t\tEleurochem.) 2022, 28(7), 2213006 (15 of 24)$

firstly electrochemically reduced into Fe(TEA)²⁺ and

the production of Fe(TEA)²⁺ would trigger the depo

ling the current density and he is

sition of M,Fe₅₊O₄ (The method of sternochem, 2022, 28(7), 2213006 (15 of 24)

2Firstly electrochemically reduced into Fe(TEA)³⁺ and

2Fe(TEA)³⁺ would trigger the depo

2Fe current density and the dwell time of each

stiton of M₋Fe_C ${}_{x}Fe^{2+}{}_{1x}Fe^{3+}{}_{2}O_{4} + 3TEA + H_{2}O$ (15) si $\mathbb{H}\{E\neq(1, E(\text{er}(\text{H}^X))\}$ excited into Fe(TEA)^{2,} and of charges passed during each pulse (i.e.,
the production of Fe(TEA)² would trigger the depo
img the current density and the dwell tistion of M_rFe_{st}O₄ **EVALUATION**
 EVALUATION tures with coherent stacking of atomic planes as firstly electrochemically reduced into Fe(TFA)⁵ and of charges passed during each pulse (i.e., by control-
the production of Fe(TFA)⁵ would trigger the depo ling the current density and the dwell time of each
stion of ITSITY electrochementally rearded in to Pet [12A]^x and of nange passed during electro. by control
in the production of Fe(TEA)^x vould trigger the depo ling the current density and the devel time of each
sition of M₋

Superatures are percolarely usered nanostruc-

success the electrodeposition of metal oxise aperation

and coherent stacking of atomic planes as tices¹⁹³⁰. The materials could be deposited as analy-

shown in Figure 5c. more conveniently integrated into electronic devices

that conventional anomonaterials. Superlittices usual-

the specifical and electronic properties, and unique

year of Pb-TI-O superlattices^[602]

optical and electro

4E ($E\neq C$ (*L* Electrochem.) 2022, 28(7), 2213006 (15 of 24)

mically reduced into Fe(TEA)²⁺ and of charges passed during each pulse (i.e., by control-

if Fe(TEA)²⁺ avoid trigger the depo ling the current density $28(7)$, $2213006(15 \text{ of } 24)$
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness o $28(7)$, 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of $28(7)$, $2213006(15 \text{ of } 24)$
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness o $\frac{28(7)}{213006}$ (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of $28(7)$, 2213006 (15 of 24)

of charges passed during each pulse (i.e., by control-

ling the current density and the dwell time of each

pulse). The overall thickness of the superlattices is

determined by the thickness 28(7), 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of eac 28(7), 2213006 (15 of 24)

of charges passed during each pulse (i.e., by control-

ling the current density and the dwell time of each

pulse). The overall thickness of the superlattices is

determined by the thickness of $28(7)$, 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of e $28(7)$, 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of 28(7), 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of eac 7), 2213006 (15 of 24)

charges passed during each pulse (i.e., by control-

g the current density and the dwell time of each

lse). The overall thickness of the superlattices is

termined by the thickness of each bilayer 28(7), 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of eac 28(7), 2213006 (15 of 24)

of charges passed during each pulse (i.e., by control-

ling the current density and the dwell time of each

pulse). The overall thickness of the superlattices is

determined by the thickness of 28(7), 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of eac 28(7), 2213006 (15 of 24)
of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of eac of charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of each bilayer (Λ in
Figure 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (15 of 24)

ed into Fe(TEA)²⁺ and of charges passed during each pulse (i.e., by control-

would trigger the depo ling the current density and the dwell time of each

or Ni) (

the prototom of Tet [LBA]^y would tragger the depote line of the conventions of the superbattices is Figure 3.6 (https://web.com/integrated into the superbattic convention of M,Fe,O, (M = Co, Zn or Ni) (Eqs. 14 and 15). stiton of M_MPe_LO_L(M = Co, *Len* Co, *Len* (Eq. 14 and 15). pulse). It ne overall thredictes is of the superralities of and the superalition of the superalition of the superalition of the MAT(11) from an alkaline Fe(Epitaxial Co. This Were electrodeposited on

Epitaxia Co. The instead of the thickness of each using (A n

Au(11) from an alkaline Fe(TEA)²⁺ and Co(TEA)²⁺ Figure 5e, also known as the modulation wavelength

solution¹ All (11) from an attachmore interaction, the CHAT)⁻ rigure Se, also known as the modulation wellocamplary increases the electrodeposited Co,¹e._CO, epitaxial films could the cyle number of the pulse electrodeposited. soutmove, I. ne magnete and everteral properties of the prelationes of the number of the plus clerchodeposition). The
he conveniently adjusted by controlling the Co:Fe ra-
formation of superlattices could be verified by t the ecoretoeposite Co_{Tex}Ly, eptaxia mins could be more or the pluse electroneposite
of the conveniently adjusted by controlling the Co-Fe ra-
formation of superlattices could be verified by the
tio in Co,Fe₃,O, throug be conventioned by controlling the Co:re associated by controlling the Co:re associated by the convention of superlattices could be vernined by the effect Fe(FEA)²⁺ + c-+ Fe(TEA)²⁺ + xCo(TEA)²⁺ + xCo(TEA)²⁺ + xCo(to no Coe, Q., through the deposition potential. (Signer Sy. The experiment on statilite peaks in the AKD 20 scans

Fe(TEA)²⁺ + x-Fe(TEA)²⁺ + xCo(TEA)²⁺ + 8Ol! Switzer and co-workers have utilized electrodepo-
 \sim Pet $^{1+}$ i e -- $^{1+}$ relation-

Pet (TEA)⁺ $+$ -1-x₁Fe(TEA)² + xCo(TEA)² + 80H (Figure 2g).
 $-3e^{3x}$ Fe($-3e^{3x}$, $-3e$ duced by techniques such as molecular beam epitaxy, \rightarrow Cor μ ; \rightarrow LEA, \rightarrow HEA, \rightarrow HEA, \rightarrow HEA, and to prepare vantos metal otion, and λ chemic since the predictions of the same of the Superbattics of the Superbattics are periodically layeed nanostructions of 4.2.2 eperation Oxide superations and occurrelated was the summy, three enterior are on to saistore of the could be expected at the stepse). Superal transfer the could be deposited as analyshown in Figure 5c. Superlattice tures with connerist suscaying of atomic pianes as these^{ss-ex}; i) the materials could be deposite could
tain the properties of nanomaterials, but also are be changed by varying the applied potential or cur-
more conveni shown in Figure 5e. Superfaites and only can mann-
anomor any tigare of anomaterials, but also are be changed by varying the applied potential or cur-
more conveniently integrated into electronic devices entit, iii) latti tam the properties of nanomaterials, sure is once a measure of the low pro-
time conveniently integrated into electronic devices energy in a properties phenomator current and constrained the low pro-
than conventional nan in conventional nanomaterials. Superlattices suals in the SV should of small to ensure that in materials
thow channel anomaterials, which have been widely applied for various could be grown epitaxially. Epitxial electrode py some transmistal properties, and units

or privarial correction properties compared to bulk of Pb-TI-O superlattices^{yza} on Au(100) was achieved

materials, which have been widely applied for various by periodically p optera and exerceme properties comparates.

and a certome properties compared to built of Figure 3 opter and the deposition and electronics and electronics. For example, the GMR and 5 mA cm³ at room temperature from an materials, which have been welcoly applied to rarioal and the superfect at the superfect the same control between the sum-
ten between the sum-
effect was first observed in Fe/Cr superlatities^[10] and solution of TINO₃ photonics and electronics. For example, the GMK and 3 mathem and the prediute from the statement from an ankaline effect was first observed in Fe/Cr superlattices^{four} and 3 solution of TNO₃ and Pb_{(NO₃). The deposit} effect was lines to
neer the reperatinces^{com} and solution of LINO, and Pb(NO). It is exposite layer
that the layer superlattices have not significant in the layer computer of the layer of the distinguish superlattices s The Although valean migh-achievity data storing. In 11-nen at the two ventred mention were absorbed by techniques such as molecular beam pro-
high current density. FeyO, superlattices could be produced by techniques such Among superratures are transformally ocen pro-

any controlling the concentration ratio of phenomenons of precisely recisely respectively the minical vapor deposition, physical vapor deposition, physical vapor deposition, or charges passed during each pulse (i.e., by control-
ling the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of each bilayer (Λ in
Figure ing the current density and the dwell time of each
pulse). The overall thickness of the superlattices is
determined by the thickness of each bilayer (Λ in
Figure 5e, also known as the modulation wavelength
of superlatt pulse). The overall thickness of the superlattices is
determined by the thickness of each bilayer (Λ in
Figure 5e, also known as the modulation wavelength
of superlattices) and the number of the bilayers (i.e.,
the cyc determined by the thickness of each bilayer (A in
Figure 5e, also known as the modulation wavelength
of superlattices) and the number of the bilayers (i.e.,
the cycle number of the pulse electrodeposition). The
formation rigure 5e, also known as the modulation wavelength
of superlattices) and the number of the bilayers (i.e.,
the cycle number of the pulse electrodeposition). The
formation of superlattices could be verified by the
observat or superiattices) and the number of the bulgers (i.e.,
the cycle number of the pulse electrodeposition). The
formation of superlattices could be verified by the
observation of satellite peaks in the XRD 2 θ seans
(Figur the cycle number of the pulse electrodeposition). The
formation of superlattices could be verified by the
observation of satellite peaks in the XRD 2 θ scans
(Figure 5g).
Switzer and co-workers have utilized electrodepo formation of superlattices could be verified by the
observation of satellite peaks in the XRD 2 θ scans
(Figure 5g).
Switzer and co-workers have utilized electrodepo-
sition to prepare various metal oxide superlattices. observation of satellite peaks in the XKD 20 scans
(Figure 5g).
Switzer and co-workers have utilized electrodepo-
sition to prepare various metal oxide superlattices.
Usually, three criteria need to be satisfied for the
s (rigure 5g).

Switzer and co-workers have utilized electrodepo-

sition to prepare various metal oxide superlattices.

Usually, three criteria need to be satisfied for the

successful electrodeposition of metal oxide supe Switzer and co-workers nave utilized electrodepo-
sition to prepare various metal oxide superlattices.
Usually, three criteria need to be satisfied for the
successful electrodeposition of metal oxide superlat-
tices^[102] sition to prepare various metal oxide superiattices.
Usually, three criteria need to be satisfied for the successful electrode
position of metal oxide superlat-
tices^[102]: i) the materials could be deposited as anhy-
d Usuany, time criteria need to be satisfied for the
successful electrodeposition of metal oxide superlat-
tices^[102]: i) the materials could be deposited as anhy-
drous oxides; ii) the composition of the deposit could
be successiul electrodeposition of metal oxide superlat-
tices^[102]: i) the materials could be deposited as anhy-
drous oxides; ii) the composition of the deposit could
be changed by varying the applied potential or cur-
e tices^[103]: 1) the materials could be deposited as anny-
drous oxides; ii) the composition of the deposit could
be changed by varying the applied potential or cur-
rent; iii) lattice mismatch of the layers A and B (Figdrows oxides; ii) the composition of the deposit could
be changed by varying the applied potential or cur-
rent; iii) lattice mismatch of the layers A and B (Fig-
ure 5e) should be small to ensure that the material
could be changed by varying the applied potential or cur-
rent; iii) lattice mismatch of the layers A and B (Fig-
ure 5e) should be small to ensure that the material
could be grown epitaxially. Epitaxial electrodeposition
of Pb rent; in) lattice mismatch of the layers A and B (rigure 5e) should be small to ensure that the material could be grown epitaxially. Epitaxial electrodeposition of Pb-Tl-O superlattices^[102] on Au(100) was achieved by p ure 5e) should be small to ensure that the material
could be grown epitaxially. Epitaxial electrodeposition
of Pb-Tl-O superlattices^[102] on Au(100) was achieved
by periodically pulsing anodic current between 0.05
and 5 could be grown epitaxially. Epitaxial electrodeposition
of Pb-Tl-O superlattices^[102] on Au(100) was achieved
by periodically pulsing anodic current between 0.05
and 5 mA·cm⁻² at room temperature from an alkaline
solu or Pb-11-O superattices^{scas} on Au(100) was aenieved
by periodically pulsing anodic current between 0.05
and 5 mA \cdot cm² at room temperature from an alkaline
solution of TINO₃ and Pb(NO₃)₂. The deposited layer
i by periodically pulsing anodic current between 0.05
and 5 mA \cdot cm² at room temperature from an alkaline
solution of TINO₃ and Pb(NO₃). The deposited layer
is Tl-rich at the low current density and Pb-rich at the
 mmol \cdot L⁻¹ Zn(II) by pulsing the potentials between A cm⁻ at room temperature from an alkaline
of TINO₃ and Pb(NO₃)₂. The deposited layer
at the low current density and Pb-rich at the
ent density. Fe₃O₄ superlattices could be pro-
y controlling the concentratio solution of 1INO₃ and Pb(NO₃)₂. The deposited layer
is Tl-rich at the low current density and Pb-rich at the
high current density. Fe₅O₄ superlattices could be pro-
duced by controlling the concentration ratio o is 11-ricn at the low current density and Pb-ricn at the
high current density. Fe₅O₄ superlattices could be pro-
duced by controlling the concentration ratio of
 Fe^{2}/Fe^{3+} at the electrode surface through the applied nigh current density. Fe,O₄ superiattices could be produced by controlling the concentration ratio of Fe^{2r}/Fe^{3+} at the electrode surface through the applied potential^[100]. Layers deposited at potentials more posit

 $# \ell \# (J. \text{Electrochem.}) 2022, 28(7), 2213006 (16 of 24)$

ed Co_xFe₃,O₄ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the electrodeposit-

e $\text{E/}E^2$ (*J. Electrochem.*) 2022, 28(7), 2213006 (16 of 24)

ed Co_sFe_{3*}O₄ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the e $# \ell \neq (L \ \text{Electrochem.}) 2022, 28(7), 2213006 (16 of 24)$ ed Co_xFe₃,O₄ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the electrodeposit-

e **EVACUTE 100**
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 EVACUATE $\pm \frac{\mu_2 \mu_3}{\mu_4}$ electrochem.) 2022, 28(7), 2213006 (16 of 24)

ed Co,Fe_l,O₄ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the e **E** the the the tetrochem.) 2022, 28(7), 2213006 (16 of 24)

ed Co,Fe₃,O₁ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the electro $\pm \frac{1}{2}E_{\varphi}^{*}(L)E_{\text{tetrachem.}}$ 2022, 28(7), 2213006 (16 of 24)

ed Co,Fe₅,O₄ epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 15, the el $\#R\mathcal{H}(I. Electrochem.)$ 2022, 28(7), 2213006 (16 of 24)

Co,Fe,,O, epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial electros. As shown in Figure 5h, the electrodeposition of PbS films **E** *W*²² *Ch*, *Electrochem.) 2022, 28(7), 2213006 (16 of 24)

ed Co, Fe, O, epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the elect*

Example 19.1
 Example 19.1 $\mathbb{E}(k^2 \times L \text{Eccrocheem.})$ 2022, 28(7), 2213006 (16 of 24)

ed Co.Fe,.O. epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure Sh, the electrodeposit- $\text{Re}\mathcal{Z}(\mathcal{L} \text{R} \text{t} \text{c} \text{t} \text{m})$

ned Co, Fe₂,O, epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure Sh, the electrodeposit-

rodepos th $\ell\ell\neq 0$. Pieartookem, 2022, 28(7), 2213006 (16 of 24)

ed Co,Fe₁,O, epitaxial layers with two different Co: on the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure Sh, the electrode $\text{#}(E\#(L \text{ *Electrochem*}) 2022, 28(7), 2213006 (16 of 24)$

ed Co,Fe,,O₁ epitaxial layers with two different Co:

for the surface of the Au substrate. The epitaxial elec-

Fe ratios. As shown in Figure 5h, the electrodeposit electrodenomial matrix (*Electrodenom*) 2022, 28(7), 2213006 (16 of 24)

ed Co, Fe, O, epitaxial layers with two different Co:

on the surface of the Au substrate. The epitaxial electrodeposite

From in Figure 5h, the ele of Co,Fe,,O, epitaxial layers with two different Co; on the surface of the Au substrate. The epitaxial electro

Fe ratios. As shown in Figure 5h, the electrodeposit-

evolution of PbS films on Au(100) was triggered Co,Fe, ed Co,Fe₃,O₄ epitaxial layers with two different Co: on the surface of the Au sub-
Fe ratios. As shown in Figure 5h, the electrodeposition of PbS films of
ed Co,Fe₃,O₄ superlattices show abrupt resistance by elect Fe ratios. As shown in Figure 5h, the electrodepositic trodeposition of PbS films on $\Delta u(100)$ was triggered
ed Co_CF_C,O_C, superaltiess show about presistance by electrodehemical reduction of $[Ps(S,0)_1]^2$ to Pb
switc

 $(28(7), 2213006 (16 \text{ of } 24))$
on the surface of the Au substrate. The epitaxial elec-
trodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then rea $(28(7), 2213006 (16 of 24))$

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb

(Eq. 17), which might then react $h(28(7), 2213006 (16 of 24))$

on the surface of the Au substrate. The epitaxial electrocheposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb

(Eq. 17), which might then react (28(7), 2213006 (16 of 24)

(28(7), 2213006 (16 of 24)

(28) on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb . 28(7), 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb

(Eq. 17), which might then rea 213006 (16 of 24)

2213006 (16 of 24)

2213006 (16 of 24)

2213006 (16 of 24)

2213006 (16 of 24)

2215006 of PbS films on Au(100) was triggered

2212 to Pb

2217, which might then react with the adsorbed S

22 + 2H⁺ → $(28(7), 2213006 (16 \text{ of } 24)$

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
 $[Eq. 17)$, which might then re 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (16 of 24)

ith two different Co: on the surface of the Au substrate. The epitaxial elec-

h, the electrodeposit-

we abrupt resistance by electrochemical reduction of $[Pb(S_2O$

$$
S_2O_3^{2+} + 2H^+ \rightarrow S_{\text{colloidal}} + SO_2 + H_2O \tag{16}
$$

$$
[Pb(S_2O_3)_2]^2 + 2e \rightarrow Pb + S_2O_3^2 \tag{17}
$$

Notice the substrate of the Au substrate. The epitaxial elec-
electrodeposition of PbS films on Au(100) was triggered
over different Co: on the surface of the Au substrate. The epitaxial elec-
electrodeposition of PbS fil epitaxial layers with two different Co:

on the surface of the Au substrate. The epitaxial elec-

shown in Figure 5h, the electrodepositi-

trodeposition of PbS films on Au(100) was triggered

supercurbed and with the cha (7) , 2213006 (16 of 24)
the surface of the Au substrate. The epitaxial elec-
deposition of PbS films on Au(100) was triggered
electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
q. 17), which might then react with the ad $5.28(7)$, 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
 $(Eq. 17)$, which might then r 28(7), 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrocleposition of PbS films on Au(100) was triggered

by electrochemical reduction of [Pb(S₂O₃)₂² to Pb

(Eq. 17), which might then . 28(7), 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was trigered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
 $(Eq. 17)$, which might then reac 28(7), 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
 $[Eq. 17)$, which might then reac $28(7)$, 2213006 (16 of 24)
on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then rea $28(7)$, 2213006 (16 of 24)
on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then react 28(7), 2213006 (16 of 24)

on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered

by electrochemical reduction of [Pb(S₂O₃)₂]² to Pb

(Eq. 17), which might then co(*r*), 2210000 (to 012+)
on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then react wi on the surface of the Au substrate. The epitaxial electrodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Pb(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then react with the adsorbed S
to form P trodeposition of PbS films on Au(100) was triggered
by electrochemical reduction of $[Ph(S_2O_3)_2]^2$ to Pb
(Eq. 17), which might then react with the adsorbed S
to form PbS.
S₂O₃² + 2H⁺ → S_{coloidal} + SO₂ + H₂O S films on Au(100) was triggered

1 reduction of $[Pb(S_2O_3)_2]^2$ to Pb

ght then react with the adsorbed S

given then react with the adsorbed S
 $\rightarrow Pb + S_2O_3^2$ (17)

reported the epitaxial electrodepo-

ind $PbTe^{[107]}$ o

 $\#E\#(J. Electron) \ge 2022, 28(7), 2213006 (17 \text{ of } 24)$

of PbSe on InP(100) exhibited a poor epitaxy because the conversion solution. Spec

of weak adsorption of Cd²⁺ on InP (100). For the elec the conversion solution. Spec

tr

 \oplus \oplus $\frac{1}{2}$ (FBSe on InP(100) exhibited a poor epitaxy because

the conversion solution. Specifically, films converted

of PbSe on InP(100) exhibited a poor epitaxy because

the conversion solution. Specifically, films conv **EVALUATION EXAMORE AUTHET SUBARE SET AND THE SUBARE AND THE f** $E^{\infty}(L\text{ *Electochehen.*}) 2022, 28(7), 2213006 (17 of 24)$

of PbSe on InP(100) exhibited a poor epitaxy because

of the electrodeposition of Cd² on InP (100). For the electron absorber than experimentately a [001] orien-
 HEVALUATION
 HEVALUATION (17 of 24)
 HEVALUATION (17 of 24)

of PbSe on InP(100) exhibited a poor epitaxy because

the conversion solution. Specifically, films converted

order and the presence of the presence of So

 $PbI_2^{[22]}$ or $PbO_2^{[9]}$. PbI_2 was electrodeposited on single-4.2.4 Epitaxial Metal Halide Films

Entaxial metal halide semiconductors can serve as

Entaxial metal halide semiconductors can serve as

entaxial metal Rill, could be peeled

enticlent carrier transport layers or light-a Epitaxial metal halide semiconductors can serve as

evan der Waals layered material Bil, could be peeled

efficient earrier transport layers or fight-absorbing

entities or fight-aboustion and the state of the bottom and efficient carrier transport layers or light-absorbing

and the protocolarize estingle-crystal-like and free-standing

layers, which are highly desired for photovolarie cells

and the to the lower transformation, longer di layers, which are highly desired for photovoltaic cells

BiI₁ foils. The epitaxial BiI₁ film

due to the lower trap densities, longer diffusion

econverted into CH_ANH₂),B₁₂₁ (M

lengths, enhanced photoluminesc solution of 0.1 mol \cdot L⁻¹ Pb(NO₃)₂[9,54]. The epitaxial re-
CuI seed crystals are firstly nucleated on the freshly due to the lower trap densities, longer diffusion

lengths, channed photoluminescence, and higher

lengths, only control into CH₂NH₂) Big₀ ((MA)₂Big₄) ty topot-

conversion efficiencies compared to the polycryslengths, enhanced photoluminescence, and higher

eactive transformation, which is a good solar light-ab-

conversion efficiencies compared to the polyerys-

sorbing layer for solar cells. As shown in Figure 6e-f,

lightly conversion efficiencies compared to the polyerys-

sorbing layer for solar cells. As shown in Figure 6c-f,

this ones^{iaming}

incord films of methylammonium lead

in-phase oriented (MA),Bi-I_n films are both out-of-plan talline ones^{[18/h,101}] Fighly ordered flms of methylammonium lead

He converted (MA),Bi₃I, films are both out-of-plane

iodde (MAPh) perovskite could be produced by the

conversion of electrodeposited epitaxial films Highly ordered films of methylammonium lead
ionle (MAPh), prevactive conversion of electrodeposited epitaxial films of
conversion of electrodeposited epitaxial films of
the two man (MA),Bi₃I, and Au(111) substrate is $(M$ iodide (MAPbI₃) perovskite could be produced by the

¹¹ weren the (MA)₃B₁₃I, and Au(111) substrate is (MA)-

pb_I₂²³ or PbO₂⁹³. Pb_I was electrodeposited on single-

Bi₂I(0001)[1100]//Au(111)[16].

e conversion of electrodeposited epitaxial films of

Bi-J(0001)[1100]/Axa(111)[11].

Phy¹²³ or PhO₂². Phy¹ was electrodeposited on single

ergstal Au substrates by electrochemically reducing

Due to the large room-t PbL³⁷⁹ or PbO₂⁸⁹. PbL₃ was electrodeposited on single-

Db 1001)11000111000111000¹201011100¹

expectroleconomically reducing

expectroleconomic molecular iodinc to iodide ions with the presence of

energy (62

 $\# \&\#$ (*J. Electrochem.*) 2022, 28(7), 2213006 (17 of 24)

of PbSe on InP(100) exhibited a poor epitaxy because the conversion solution. Specifically, films converted

of weak adsorption of Cd²⁺ on InP (100). For the the \mathcal{H}_c (*L Electrochem.*) 2022, 28(7), 2213006 (17 of 24)

of PbSe on InP(100) exhibited a poor epitaxy because

of weak adsorption of Cd²⁺ on InP (100). For the elec

at low temperatures have predominately a [$\frac{d}{dt}$ $\frac{d}{dt}$ on InP(100) exhibited a poor epitaxy because the conversion solution. Specifically, films converted of weak ads $\mathbb{E}/E \neq (J. Electrochem.)$ 2022, 28(7), 2213006 (17 of 24)

of PbSe on InP(100) exhibited a poor epitaxy because

of weak adsorption of Cd² on InP (100). For the elec

at low temperatures have predominately a [001] orien-

tro $\frac{16}{12}$ $\frac{16}{2}$ $\frac{16}{2}$ **EVALUATE 1.** The theorem (1.000) exhibited a poor epitaxy because the conversion solution. Specifically, films converted of weak adsorption of Cd^{*} on InP (100). For the election and low temperatures have predominately $\frac{\text{4(}E\#\langle L \text{ } Electrischenm. \rangle 2022, 28(7), 2213006 (17 of 24)}{\text{of PbSe on InP(100) exhibited a poor epitaxy because}}$ the conversion solution. Specifically, films converted of weak adsorption of Cd^{*} on InP (100). For the electrom abut temperatures have predomi $28(7)$, $2213006(17 \text{ of } 24)$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] o $28(7)$, $2213006(17 \text{ of } 24)$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] o $28(7)$, $2213006(17 \text{ of } 24)$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] o $\frac{28(7)}{2213006}$ (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] o 28(7), 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orienta $28(7)$, $2213006(17 \text{ of } 24)$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] o $28(7)$, 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] or $\frac{2213006}{17 \text{ of } 24}$

conversion solution. Specifically, films converted

ow temperatures have predominately a [001] orien-

on, whereas films converted at high temperatures

ve predominately a [110] orientation. The $(28(7), 2213006 (17 of 24)$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orienta $\frac{28(7)}{28(7)}$, 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (17 of 24)

a poor epitaxy because the conversion solution. Specifically, films converted

InP (100). For the election at low temperatures have predominately a [001] orien-

11

ELECT THE CONSOCITET THE CONSOCITET THE CONSOCITED ACCED A $m_{\text{H}}/E\mathcal{P}(L)$ *Electrochem.*) 2022, 28(7), 2213006 (17 o^r24)

of PbSe on InP(100) exhibited a poor epitaxy because the conversion solution. Specifically, films converted

of weak adsorption of Cd² on InP (100). of PbSe on InP(100) exhibited a poor epitaxy because the conversion solution. Specifically, films convert of the conversion solution. Specifically, films convert of the conversion of Cd²⁺ on InP (100). For the elect at BbSc on InP(100) exhibited a poor epitaxy because

the conversion solution. Specifically, films converted

weak adsorption of Cd^{*} on InP (100). For the elect

deposition of PoFt on InP(111), poor epitaxy was

tution, wh of weak adsorption of Cd^{*} on InP (100). For the elec

at low temperatures have predominately a [001] orien-

trodeposition of PBF on InP(111), poor epitaxy was

hation, whereas films converted at high temperatures

PbFe trodeposition of PbTe on InP(111), poor epitaxy was tation, whereas films converted at high temperatures
observed due to the large lattice mismatch between have predominately a [110] orientation. The periaxial
photodure a bestred due to the large lattice mismatch between

brown have predominately a [110] orientation. The epitaxial

For BaM in $\binom{1}{10}$, the same in $\binom{1}{10}$, the larger

structure and its bandgap is ranging from 1.0 to BbTe and InP(111).

Elms of MAPbI, show lower trap densities and high-

SnS is a p-type semiconductor with a layered

structure and is bandgap is ranging from 1.0 to 1.5

falline counterspares iternstites than their polyc SnS is a p-type semiconductor with a layered

structure and its bandgap is ranging from 1.0 to 1.5 aliline counterparts (Figure 6c-d).

structure and its bandgap is ranging from 1.0 to 1.5 aliline counterparts (Figure 6cstructure and its bandgap is ranging from 1.0 to 1.5

talline counterparts (Figure 6c-d),

eV, which makes it potentially an efficient light-ab-

Bi-based perovskite films are

sorbing material for solar cells. SnS nanodi , which makes it potentially an efficient light-ab-

bin gametral of resolution spin sterms are promising alterna-

bin gametral of resolution of back exhibits of the toxic Pb-based percovskites, which could

bin spect ra sorbing material for solar cells. SnS nanodisks with a

integralized provisites, which could

be primaring pro-

high aspect ratio could be periodically electrodeposited by columically percomported by the conversion of Bi high aspect ratio could be epitaxially electrodeposited be obtained by the conversion of Bi-containing pre-
onto Au(100) from an acidic solution of Sn³-tartiste
complexes^[188]. The electrodeposition of Sn³-tartiste
 Au(100) from an acidic solution of Sn²⁻-tartrate cursors such as BiI₃. With the plexes^{[108}]. The electrodeposition of SnS was ac-

tion of molecular iodine to ided by reduction of S in the presence of Sn²⁺¹⁰⁹] from an acidic solution of Sn²-tartrate

The electrodeposition of SnS was ac-

tion of molecular iodine to iodide in the presence of

the electrodeposition of Sn Sura ac-

tion of molecular iodine to iodide in the prese complexes¹⁰⁸⁰. The electrodeposition of SnS was ac-

tip in eelectrochemic of Sn the presence of Sn the presence of Sn the presence of Sn tweet of periods and to-form and und-of-plane contentations of (100) and (301).
 hieved by reduction of S in the presence of Sn²¹¹⁰⁹. metal cations), the epitaxial films of Bil₁ with a high
The electrodeoposited SnS showed two different degree of in-plane and out-of-plane order could be
out-of-p The electrodeposited SnS showed two different

out-cof-phane and out-of-phane order could be

out-of-phane and sut-of-phane and out-of-phane order could be

4.2.4 Epinxial Metal Halide Elims

4.2.4 Epinxial Metal Halide E out-of-plane orientations of (100) and (301).

electrodeposited on inexpensive Au(111)[8i(111) sub-

4.24 Fipinxial Metal Haide Similion distortions can serve as
 219 . These Bil, epitaxial films formed from the

effic 28(7), 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orient 28(7), 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orient 28(7), 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orient $28(7)$, 2213006 (17 of 24)
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orie $\frac{128(7)}{1213006(17 \text{ of } 24)}$
the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orientation, whereas films converted at high temperatures
have predominately a [110] or the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orientation. The epitaxial
films the conversion solution. Specifically, films converted
at low temperatures have predominately a [001] orien-
tation, whereas films converted at high temperatures
have predominately a [110] orientation. The epitaxial
films at low temperatures have predominately a [001] orientation, whereas films converted at high temperatures
have predominately a [110] orientation. The epitaxial
films of MAPbI₃ show lower trap densities and high-
er photo tation, whereas films converted at high temperatures
have predominately a [110] orientation. The epitaxial
films of MAPbI₃ show lower trap densities and high-
er photoluminescence intensities than their polycrys-
tallin have predominately a [110] orientation. The epitaxial
films of MAPbI₃ show lower trap densities and high-
er photoluminescence intensities than their polycrys-
talline counterparts (Figure 6c-d).
Bi-based perovskite fil films of MAPbI₃ show lower trap densities and high-
er photoluminescence intensities than their polycrys-
talline counterparts (Figure 6c-d).
Bi-based perovskite films are promising alterna-
tives to the toxic Pb-based er photoluminescence intensities than their polycrystalline counterparts (Figure 6c-d).

Bi-based perovskite films are promising alterna-

tives to the toxic Pb-based perovskites, which could

be obtained by the conversio talline counterparts (Figure 6c-d).

Bi-based perovskite films are promising alterna-

tives to the toxic Pb-based perovskites, which could

be obtained by the conversion of Bi-containing pre-

cursors such as Bi1, With t Bi-based perovskite films are promising alterna-
tives to the toxic Pb-based perovskites, which could
be obtained by the conversion of Bi-containing pre-
cursors such as BiI₃. With the same trigger (i.e., reduc-
tion of tives to the toxic Pb-based perovskites, which could
be obtained by the conversion of Bi-containing pre-
cursors such as BiI₃. With the same trigger (i.e., reduc-
tion of molecular iodine to iodide in the presence of
me nsols such as Dig. What the same tagget (i.e., i.eductor
of molecular iodine to iodide in the presence of
the largency, the epitaxial films of Bil₃ with a high
gree of in-plane and out-of-plane order could be
extrodepos the convertional mode in the presence of metal cations), the epitaxial films of BiI₃ with a high degree of in-plane and out-of-plane order could be dectrodeposited on inexpensive Au(111))Si(111) substrates^[23]. These mear eatons), the ephaxiar imis of Diry whit a high
degree of in-plane and out-of-plane order could be
electrodeposited on inexpensive Au(111))Si(111) sub-
electrodeposited on inexpensive Au(111)Si(111) sub-
strates^[23] electrodeposited on inexpensive Au(111)|Si(111) sub-
electrodeposited on inexpensive Au(111)|Si(111) sub-
strates^[23]. These BiI_b epitaxial films formed from the
van der Waals layered material BiI₅ could be peeled
o electron of Waals layered materials Bil_s principal films formed from the twates^[23]. These Bil_s pritaxial films formed from the twater wander Waals layered material Bil_s could be preled off to produce single-cryst states \cdot riess Dig ephaziar fills could be pecled
on der Waals layered materal Bil, could be pecled
off to produce single-crystal-like and free-standing
Bil, foils. The epitaxial Bil, fillms could be further
converted

or to produce singe-crystal-like and ree-standing
for photovoltaic cells
Bi₁, foils. The cpitaxial Bi₁, films conducted into CH_ANH₃), films conduct
seconce, and higher
active transformation, which is a good solar $(-1 \cdot S^{-1}),$ vali det waals asyeted machial Binj codu oc pected
off to produce single-crystal-like and free-standing
Bil₃ foils. The epitaxial Bil₃ fillms could be further
converted into (CH₃NH₃),Bi₂I₆ ((MA),Bi₂I₆) by Bil, foils. The epitaxial Bil, fillms could be further

are functional Bil, fillms and the crystal Highren care

are function, which is a good solar light-absorbing layer for solar calls. As shown in Figure 6c-f,

the con Englace into (CH₃NH₃),Bi₃L₃L₃((MA),Bi₃L₃L₃) by topot-
converted into (CH₃NH₃),Bi₃L₃((MA),Bi₃L₃) by topot-
active transformation, which is a good solar light-ab-
sorbing layer for solar cells. A convertica into Crigotriyjstopis₀ ((*VA*ryjstopis₀) oy opposite
is corbing layer for solar cells. As shown in Figure 6e-f,
sorbing layer for solar cells. As shown in Figure 6e-f,
the converted (MA)₃Bi₂I₂, films and state transformation, which is a good solar ingur-ao-
sorbing layer for solar cells. As shown in Figure 6e-f,
sorbing layer for solar cells. As shown in Figure 6e-f,
and the converted (MA)₂Bi₂I₂, filling are both ou solong ager tot sotat cells. As shown in Figure oc-1,
the converted (MA)₃B₁₃I₃I₃ films are both out-of-plane
and in-plane oriented. The epitaxial relationship be-
tween the (MA)₃B₁₃I₃I₃ and Au(111) substra wh in Figure 60-1,
both out-of-plane
I relationship be-
bbstrate is $(MA)_{3}$ -
e exciton binding
 $(43.9 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1})$,
as shown to be a
ics. Epitaxial CuI
n-Si(111) by re-
the presence of
I on Si, epitaxial
ed the converted (*MTXyDFigs*) mins at coun out-or-piane
and in-plane oriented. The epitaxial relationship be-
tween the $(MA)_3Bi_5l_5$ and $Au(111)$ substrate is $(MA)_3$ -
Bi, $J_5(0001)[\overline{11}00]//Au(111)[\overline{11}0]$.
Due to the la and m-phane of chemed. The ephadaan Felatonship be-
tween the $(MA)_3Bi_3I_9$ and $Au(111)$ substrate is $(MA)_3F$
Bi₂I₂(0001)[1100]//Au(111)[110].
Due to the large room-temperature exciton binding
energy (62 meV), high ho Lel the (MET)(D100)//Au(111)] substance is (HET);
L₅(0001)[1100]//Au(111)[110].
Due to the large room-temperature exciton binding
regy (62 meV), high hole mobility (43.9 cm²·V⁻¹·s⁻¹),
l large bandgap (3.1 eV), CuI Bi₂I₃(0001)[1100]//Au(111)[110].
Due to the large room-temperature exciton binding
energy (62 meV), high hole mobility (43.9 cm²·V⁻¹·s⁻ⁱ),
and large bandgap (3.1 eV), CuI has shown to be a
promising candidate in

 $\#E\#(J. Electrochem.)$ 2022, 28(7), 2213006 (18 of 24)

ductor, which can serve as an excellent hole transport

material due to its exceptional optical transporters,

chemical stability, and good hole transport proper-

In this r $\# \ell \# (J. Electrochem.)$ 2022, 28(7), 2213006 (18 of 24)

ductor, which can serve as an excellent hole transport

material due to its exceptional optical transparency,
 5. Summary and Perspectives

chemical stability, and good h $# \&L^{\#}(L \&Electrochem.) 2022, 28(7), 2213006 (18 of 24)$ ductor, which can serve as an excellent hole transport

material due to its exceptional optical transparency,

chemical stability, and good hole transport proper-

the inter **EXAMPLE 123.11.13.** Electrodeposition of CuSCN (18 of 24)
 EXAMPLE 123.13006 (18 of 24)
 EXAMPLE 124.13006 (18 of 24)
 EXAMPLE 124.13006 (The CUSCN (Figure 6h and i).
 EXAMPLE 124.13006 (the common synthetic rout **EVALUATION**
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ductor, which can serve as an exceptional optical transport talline CuSCN (Figure 6h and i).

material due to its exceptional optical transport or this review, the EVALUATION EXECT 10**
 EVALUATION EXECT 10
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chemical stability, and good hole transport pro $\frac{d}{dt}\mathcal{H}^{\#}(J. Electron) = 2022, 28(7), 2213006 (18 of 24)$

ductor, which can serve as an excellent hole transport

talline CuSCN (Figure 6h and i)

material due to its exceptional optical transparency,

talline CuSCN (Figure 6 $\text{#C}(\mu, \mathbb{R}^n) = \text{#C}(\mu, \math$ th \mathbb{R}^n the mass of exceptional in the scattering of the scattering concentrations, in addition, the official theoretical scheme of the perspectives chemical stability, and good hole transport propertical intervalse **Example 11**
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ductor, which can serve as an excellent hole transport

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material due to its exceptional optical transparency,
material due to its exceptional optical transparency,
5 **Summary and Perspectives**
the thin Au substrate ductor, which can serve as an excellent hole transport
material due to its exceptional optical transparency,

for Summarry and Perspectives
chemical stability, and good hole transparency,

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fo ductor, which can serve as an excellent hole transport
matrial to the CuSCN (Figure 6h and j).

metarial data bis excelsional optical transporters, $\frac{1}{2}$ Summary and Perspectives

themical stability, and good hole tra material due to its exceptional optical transparency,

decreasing the derivative, and good hole transpar properties.

the distribution and good hole transpar properties in this review, the common synthetic routes for the
 电化学(*J. Electrochem.*) 2022, 28(7), 2213006 (18 of 24)
ccellent hole transport talline CuSCN (Figure 6h and i).
optical transparency, 5 **Summary and Perspectives**
ole transport proper- In this review, the common synthetic

 $\frac{\text{d}(\hat{R}\#(J \text{ Electrochem.}) 2022, 28(7), 2213006 (18 of 24))}{\text{can serve as an excellent hole transport}}$ can serve as a moccllent hole transport talline CuSCN (Figure 6h and i).

to its exceptional optical transport to the lime CuSCN (Figure 6h and i).

iility $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ $\frac{16}{2}$ as an excellent hole transport talline CuSCN (Figure 6h and i).

Eptional optical transparency,
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talline CuSCN (Figure 6h and i).

5 **Summary and Perspectives**

In this review, the common synthetic routes for the

electrodeposition of different functional materials

and the key experimental $(28(7), 2213006 (18 of 24))$

talline CuSCN (Figure 6h and i).
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In this review, the common synthetic routes for the

electrodeposition of different functional materials

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talline CuSCN (Figure 6h and i).
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electrodeposition of different functional materials

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electrodeposition of different functional materials

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electrodeposition of different functional materials

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talline CuSCN (Figure 6h and i).
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electrodeposition of different functional materials
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talline CuSCN (Figure 6h and i).

5 **Summary and Perspectives**

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In this review, the common synthetic routes for the

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ine CuSCN (Figure 6h and i).

Summary and Perspectives

in this review, the common synthetic routes for the

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1 the key experimental parameters that talline CuSCN (Figure 6h and i).

5 **Summary and Perspectives**

In this review, the common synthetic routes for the

electrodeposition of different functional materials

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 5 Summary and Perspectives

In this review, the common synthetic routes for the

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 5 Summary and Perspectives

In this review, the common synthetic routes for the

electrodeposition of different functional materials

and the key experimental parameters that could be

used to regulate the epitaxial gro

with permission of Ref.^[9], copyright 2015 American Chemical Society. (e) XRD 2 θ scan and (f) pole figure of the (MA).Bi₂I₉ film film

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lower requirements on the equipment and thus leads

to higher scalability. To date, a huge number of mate-

rists have been produced by electrodepos $\exists \mu \mathcal{L} \neq (I. Electrochem.)$ 2022, 28(7), 2213006 (19 of 24)

lower requirements on the equipment and thus leads

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solver requirements on the equipment and thus leads

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Iower requirements on the equipment and thus leads

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Hower requirements on the equipment and thus leads

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to higher scalability. To date, a huge number of mate-
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Hower requirements on the equipment and thus leads
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Stang HS. MeShane CM, Read CG, Seabold JA.

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ies in many characters in electrodepositions causes difficul ever, there are still many challenges for electrodepo-

Electrochemical synthesis of morganic polyerystalline electroches in electroches in the optimization of the deposition. Navay adjustable parameters in electrodeposit sition. Many adjustable parameters in electrodeposi-

actooles with controlled architectures [J]. MRs Bull., 2010,

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R. Allongue P. Electrodeposition of Fe/Au(11) ultrathin

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trions is once of the ways to break through such li trodeposition in ionic liquids instead of aqueous solu-

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tions, but it usually leads to a higher cost and tions is one of the ways to break through such limita-

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low-index planes of gold[1]. J. Am. Chem. Soc., 2002, 1244

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Solut more, it is still challenging to obtain the high-purity

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This work was supported by the Natural Science
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Choi K S, Jang H S, McShane C M, Read C G, Seabold J A.

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电子功能外延薄膜的电沉积 电化学渊J. Electrochem.^冤 2022, 28(7), 2213006 (24 of 24)

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摘要: 电沉积作为一种在温和条件下从溶液中合成材料的技术已被广泛应用于在导体和半导体基底表面合成 各种功能材料。电沉积一般由人为施加于基底的电刺激(如:施加电位/电流)来触发。这种电刺激通过氧化或还原 靠近基底表面的溶液层内部的离子、分子或配合物从而使该溶液层偏离其热力学平衡状态, 随后引起目标产物 在基底表面的沉积。在电沉积过程中,许多实验参数都可能从不同的方面对沉积物的物化性质造成影响。迄今为 止,已通过电沉积制备出多种单质(包括金属和非金属单质)、化合物(例如:金属氧化物、金属氢氧化物、金属硫 化物等)以及复合材料。电沉积制备的这些材料大多为多晶、织构或外延薄膜的形式。其中, 外延薄膜是一种具 有特定的面外和面内晶体生长取向且其晶体取向受基底控制的类单晶薄膜。由于外延薄膜中高度有序的原子排 列,它们常呈现出独特的电磁性质。本文总结了常见的电沉积合成路线及影响沉积物外延生长的关键实验因素。 此外,本文简要介绍了用于表征外延薄膜的技术。最后,本文还讨论了一些采用电沉积制备的具有特殊电子、电 磁及光电特性的功能外延薄膜。

关键词: 电沉积:电镀:薄膜:高度定向