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# Mechanism and Application of Nickel Nano-Cone by Electrodeposition on a Flexible Substrate

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# Mechanism and Application of Nickel Nano-Cone by Electrodeposition on a Flexible Substrate

# Authors

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Xiu-Ren Ni<sup>1</sup>, Ya-Ting Zhang<sup>1</sup>, Guangdong, China; 3. Xiamen Institute of Flexible Electronics Co., Ltd & Xiamen Hongxin  $\frac{1}{2}$   $\frac{1}{2}$  *J. Electrochem.* 2022, 28(7), 2213008 (1 of 11)<br>
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ESS Semiconductor Co., Ltd, Zhuhai 519175,<br>
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power supply, optical Electronics Co., Ltd & Xiamen Hongxin<br>China; 4. Zhuhai Dynamic Technology<br>China; 4. Zhuhai Dynamic Technology<br>N9175, Guangdong, China)<br>wer supply, optical device and electronic manufacturing. In<br>ubstrate by galvanostatic method, as the constrate of the constrained in the existence of the constrained the existence prover supply, optical device and electronic manufacturing. In le substrate by galvanostatic deposition and the corresponding b Affinets<br> **Mechanism and Application of Nickel Nano-Cone by**<br> **Electrodeposition on a Flexible Substrate**<br>
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Xiu-Ren Ni', Ya-Ting Zhang', Chong Wang', Yan Hong'', Yuan-Ming Chen',<br>
Yuan-Zhang Su', Wei He', Xian-Ming Chen', Ben-Xia Hu **Example 19 (Fig. 19)** Electrodeposition on a **Flexible Substrate**<br>
Xiu-Ren Ni<sup>1</sup>, Ya-Ting Zhang<sup>1</sup>, Chong Wang<sup>1</sup>, Yan Hong<sup>1</sup>, Yana-Ming Chen<sup>1</sup>, Yuan-Zhang Su<sup>1</sup>, W **Electrodeposition on a Flexible Substrate**<br>
Xiu-Ren Ni', Ya-Ting Zhang', Chong Wang', Yan Hong'', Yuan-Ming Chen',<br>
Yuan-Zhang Su', Wei He', Xian-Ming Chen', Ben-Xia Huang<sup>2</sup>, Zhen-Lin Xu<sup>3</sup>,<br>
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Yuan-Zhang Su', Wei He', Xian-Ming Chen', Ren-Xia Huang', Zhen-Lin Xu',<br>
Yi-Feng Li', Neng-Bin Li', Yong-Jie Du<sup>4</sup><br>
(*I. School of Materials and* 

**contained** and the minimum of the nicelar and textic-dependence and anary materials have drawn widespread attention. Electrodeposition, as a low to the unique mechanical, optical and electrimethod, has been widely used i

**1 Introduction** stringent device-dependence and low efficiency.

factors involved in the fabrication of nickel nano-cone army was explored. Experimental results showed that a large current density<br>end by main salt concentration were not folloved to the formation of constraicted is true mal low main sult contentration were not favored to the formation of cone nickel structure. It was also found that turmonium chloids, as the crystal modifier, was caucial to deposit the uniform nan-come carry. In addition ride, as the crystal modifier, was crocial to deposit the uniform nano-cone array. In addition, the growth mechanism of nickel<br>nano-cone was further studied by molecular dynamics simulation. The excellent werishing and li nan-cone was further andied by molecular dynamics simulation. The excellent wettability and light absorption of nickel nan-cone<br> **Key words:** nickel algo-cone array, electrodeposition; molecular dynamics simulation; the s 519175, *Guangdong, China*)<br> **Example 1997**, *Guangdong, China*)<br> **Experimental results showed that a large current density<br>
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are diver ano-cone array. In addition, the growth mechanism of nickel<br>e excellent wettability and light absorption of nickel nano-cone<br>the nickel nano-cone array.<br>The nickel nano-cone array.<br>Electrodeposition, as a low cost and con interfaces and display and interfaces and display and  $\mu$  and  $\mu$  and  $\sigma$  **1 Introduction**<br>
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Nano-array materials have drawn widespread atten-<br>
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Nano-array materials have drawn widespread atten-<br>
Electrodeposition, as a low cost and convenient<br>
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 $#E\# (J. Electrochem.) 2022, 28(7), 2213008 (2 of 11)$ <br>formance. Compared with copper, nickel is widely<br>periment was carried out with a constant current of<br>applied in anti-corrosion, decoration and superalloy<br>mechanical stability and **E** *(E. Electrochem.*) 2022, 28(7), 2213008 (2 of 11)<br>
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applied in anti-corrosion, decoration and superally<br>  $\mu_0 \sim 0.5 \sim 0.$ **EVALUATION EXAMORET SET ALL CONSERVATION**<br> **EXAMORET SET ALL CONSERVATIONS** (2 of 11)<br> **Commance.** Compared with copper, nickel is widely<br>
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the perterta mechanical subility and corrosion resistance<sup>[4, 22</sup>]. Ni-<br>magnetic stirring. The flexible CCL was cleaned by<br>eckel foil in nanoscale was prepared in the sulfi-<br>the pretreatment process including alkaline vashing<br>of nickel ckel foil in nanoscale was prepared in the sulfa-<br>
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of nickel nanocrystal were discussed<sup>[29]</sup>. Yin et al. ob-<br>
for incival nanocrystal were discussed<sup>[29]</sup>. Yin et al. te-based electrolyte and the mechanical properties<br>
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melow the oil stain and attachments on the CCL sur-<br>
enchic the h of nickel nanocrystal were discussed<sup>121</sup>. Yin et al. ob<br>
remove the oil stain and attachments on the CCL sur-<br>
tianed the highly ordered parallel hexagonal Ni and<br>
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arrays are insufficient.<br>
In this paper, a uniform nickel nano-cone array<br>
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# 2 Experimental

9. 28(7), 2213008 (2 of 11)<br>
periment was carried out with a constant current of<br>  $0.5 \sim 4.0 \text{ A} \cdot \text{dm}^2$  and the temperature of solution was<br>
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magnetic stirring. The flexible C  $(2.28(7), 2213008 (2 of 11))$ <br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A·dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CCL 28(7), 2213008 (2 of 11)<br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A · dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CCL  $(28(7), 2213008 (2 \text{ of } 11))$ <br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A·dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CC  $28(7)$ ,  $2213008 (2 of 11)$ <br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A·dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CCL 28(7), 2213008 (2 of 11)<br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A · dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CCL 2.2(7), 2213008 (2 of 11)<br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A · dm<sup>-2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible C 28(7), 2213008 (2 of 11)<br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A  $\cdot$  dm<sup>2</sup> and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible 2.2 Molecular Dynamics Simulation<br>Theoryman and Dynamic Simulation of the state of  $0.5 \sim 4.0 \text{ A} \cdot \text{dm}^2$  and the temperature of solution was agitated by magnetic stirring. The flexible CCL was cleaned by the pretreatm  $8(7)$ , 2213008 (2 of 11)<br>
Firment was carried out with a constant current of<br>  $5 \sim 4.0$  A  $\cdot$ dm<sup>2</sup> and the temperature of solution was<br>
"C. The electrodeposited solution was agitated by<br>
"Pertectanent process including 2.2(7), 2213008 (2 of 11)<br>periment was carried out with a constant current of<br>0.5 ~ 4.0 A  $\cdot$  dm<sup>2</sup> and the temperature of solution was<br>30 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible periment was carried out with a constant current of  $0.5 \sim 4.0$  A  $\cdot$  dm<sup>2</sup> and the temperature of solution was agitated by magnetic stirring. The flexible CCL was cleaned by the pretreatment process including alkaline w perment was carried out with a constant current of  $0.5 \sim 4.0 \text{ A} \cdot \text{dm}^2$  and the temperature of solution was  $50 \text{ °C}$ . The electrodeposited solution was agitated by magnetic stirring. The flexible CCL was cleaned by 0.3 ~ 4.0 A cum and the temperature of solution was<br>50 °C. The electrodeposited solution was agitated by<br>magnetic stirring. The flexible CCL was cleaned by<br>the pretreatment process including alkaline washing<br>(OP-200), etc  $\frac{\text{H} \& \frac{\text{W}}{\text{H}}(J. \text{Electrochem.}) 2022, 28(7), 2213008 (2 of 11)}{\text{per, nickel is widely}} \quad \frac{\text{periment was carried out with a constant current of}}{0.5 \sim 4.0 \text{ A} \cdot \text{dm}^2} \text{ and the temperature of solution was} \quad \frac{50 \text{ °C. The electrodeposited solution was adjusted by}}{\text{one resistance}} \quad \frac{50 \text{ °C. The electrodeposited solution was adjusted by } \text{one resistance}}{\text{mean of the cells}}$ 

tained the highly ordered parallel hexagonal Ni and<br>
fine. The etching solution was obtained by adding<br>
Binanowires by cleuroloposition in an organic bath<br>
of dimethyl sulfoxide with metal chloride as the elec-<br>
etching a Bi nanowires by electrode<br>position in an organic bath<br>of  $\frac{60}{2}$  volume fraction sulfuric acid and 5 % ammonium<br>of dimethy sulfoxide with metal elhorics as the clear-<br>conceptration, the crystal modifier and acid monocy of dimethyl sulfoxide with metal ehloride as the cleer<br>
reduybyt<sup>roly</sup>, Eslorica strate, and saccessfully developed nick-<br>
reduyting and eaid washing were 50 °C, 25 °C and 25<br>
electroplating in saccharin-containing electr trolyte<sup>191</sup>. Elsherik et al. successfully developed nick-<br>
electing and acid washing were 50 °C, 25 °C and 25<br>
electroplating in saccharin-containing electroplating<br>
electroplating in saccharin-containing electroplating<br> el nanocrystal with a size of 10 nm ~ 40 nm by pulse<br>
cc. respectively.<br>
esolution. Uniformly distributed nickel nanocrystal<br>
esolution. Uniformly distributed nickel nanocrystal<br>
was obtained by controlling the electropla electroplating in saccharin-containing electroplating<br>
2.2 Molecular Dynamics Simulation<br>
solution. Uniformly distributed nickel ranocorystal<br>
was obtained by controlling the electrophating condi-<br>
tions including the pul solution. Uniformly distributed nickel nanocrystal<br>
"The adsorption behavior of crystal modifier on dif-<br>
was obtained by controlling the cletroplating condi-<br>
tions including the pulse switching time, peak cur-<br>
tions in was obtained by controlling the electroplating condimentation in the assophon netword or tysial modurite on the<br>different diskle group of the plating solution in cluster and theorem in<br>the plating solution in the plating tions including the pulse switching time, peak cur-<br>
lar dynamic (ND) simulation. A simulation hox con-<br>
react anney, pH and temperature of the plaing solu-<br>
tion<sup>19,33</sup>, However, the growth mechanism and theo-<br>
tion<sup>19,3</sup> rent density, pH and temperature of the plating solution and through mattern (MD) simulation. A simulation on cone<br>
tensity However, the growth mechanism and through eric array terms in and the cone<br>
terical calculation o tion<sup>[0,130</sup>]. However, the growth mechanism and theo<br>
six layers of nickel ions is stablished. The results is<br>
retical calculation of nano-<br>
six layers of nickel ions is stablished. The results is<br>
and researches on the ertical calculation of nano-arrays are still inadequate,<br>
and researches on the specific application of nano-<br>
and researches on the specific application of nano-<br>
arrays are insulficent,<br>
to polimization is conducted by In this paper, a uniform nickel nano-cone array<br>
one array the control between metal crystal and additives <sup>[36,11</sup>]<br>
one-surfaction between metal crystal and additives <sup>[36,11</sup>]<br>
direction, sepecially for the crystal mod layer was prepared by one-step electrodeposition<br>
method, and the influences of current density and since the container content method, and the influences of current density in a since the morphology of electrodeposited n methan of the influences of current density and salt in the nickel and the influences of current density functional motopay of electrodeposited nickel nano-cone is used to study the adsorption behavior and the base array the morphology of electrodeposited nickel nano-cone<br>
are ave to value of mickel and the same are stated to you suce that the different proper set as 6-311G (d, p). The summing method<br>
of nickel nano-cone array was studied array were studied. Notably, the growth mechanism<br>
growth scation of inside is set as Fovald electrostatic and Atom based van der<br>
of nickel nano-cone array was studied by multiple<br>
Ehe unique optical and interfacial prop 30 °C. The electroaeposited solution was agriated by<br>magnetic stirring. The flexible CCL was cleaned by<br>the pretreatment process including alkaline washing<br>(OP-200), etching and 5% sulfuric acid washing to<br>remove the oil magnetic surring. The riextible CCL was cleaned by<br>the pretreatment process including alkaline washing<br>(OP-200), etching and 5% sulfuric acid washing to<br>remove the oil stain and attachments on the CCL sur-<br>face. The etchi the pretreament process including aikaline washing<br>(OP-200), etching and 5% sulfuric acid washing to<br>remove the oil stain and attachments on the CCL sur-<br>face. The etching solution was obtained by adding<br>5% volume fractio (OP-200), etcning and 3% suituric acid washing to<br>remove the oil stain and attachments on the CCL sur-<br>face. The etching solution was obtained by adding<br>5% volume fraction sulfuric acid and 5% ammonium<br>persulfate. The tem remove the oil stain and attachments on the CCL sur-<br>face. The etching solution was obtained by adding<br>5% volume fraction sulfuric acid and 5 % ammonium<br>persulfate. The temperatures of alkaline washing,<br>etching and acid w ace. The etcning solution was obtained by adding<br>5% volume fraction sulfuric acid and 5 % ammonium<br>persulfate. The temperatures of alkaline washing,<br>etching and acid washing were 50 °C, 25 °C and 25<br> $C$ , respectively.<br>**2.** 5% volume fraction sulturic acid and 5% ammonium<br>persulfate. The temperatures of alkaline washing,<br>etching and acid washing were 50 °C, 25 °C and 25<br>°C, respectively.<br>**2.2 Molecular Dynamics Simulation**<br>The adsorption beh persuriate. The temperatures or anxame washing,<br>etching and acid washing were 50 °C, 25 °C and 25<br>°C, respectively.<br>**2.2 Molecular Dynamics Simulation**<br>The adsorption behavior of crystal modifier on dif-<br>ferent nickel cry etching and acid washing were 50°C,  $23$ °C and  $25$ °C, respectively.<br> **2.2 Molecular Dynamics Simulation**<br>
The adsorption behavior of crystal modifier on dif-<br>
ferent nickel crystal surfaces is calculated by molecular<br>
dy **2.2 Molecular Dynamics Simulation**<br>
The adsorption behavior of crystal modifier on dif-<br>
ferent nickel crystal surfaces is calculated by molecu-<br>
lar dynamic (MD) simulation. A simulation box con-<br>
taining 100 water mole 2.2 **Molecular Dynamics Simulation**<br>The adsorption behavior of crystal modifier on dif-<br>ferent nickel crystal surfaces is calculated by molecu-<br>lar dynamic (MD) simulation. A simulation box con-<br>taining 100 water molecule The adsorption behavior of crystal modifier on dif-<br>ferent nickel crystal surfaces is calculated by molecu-<br>lar dynamic (MD) simulation. A simulation box con-<br>taining 100 water molecules, six ammonium ion and<br>six layers o ferent nickel crystal surfaces is calculated by molecular dynamic (MD) simulation. A simulation box containing 100 water molecules, six ammonium ion and six layers of nickel ions is established. The results is obtained by lar dynamic (MD) simulation. A simulation box con-<br>taining 100 water molecules, six ammonium ion and<br>six layers of nickel ions is established. The results is<br>obtained by BIOVIA Materials studio and the geome-<br>try optimiza tanning 100 water molecules, six ammonium ion and<br>six layers of nickel ions is established. The results is<br>obtained by BIOVIA Materials studio and the geome-<br>try optimization is conducted by COMPASS force<br>field in Forcite six layers of nickel ions is established. The results is<br>obtained by BIOVIA Materials studio and the geome-<br>try optimization is conducted by COMPASS force<br>field in Forcite tools, which is suitable for simulate the<br>interac obtained by BIOVIA Materials studio and the geometry optimization is conducted by COMPASS force<br>field in Forcite tools, which is suitable for simulate the<br>interaction between metal crystal and additives<sup>[26-31]</sup>.<br>The B3LY try optimization is conducted by COMPASS force<br>field in Forcite tools, which is suitable for simulate the<br>interaction between metal crystal and additives<sup>[26-31</sup>].<br>The B3LYP correlation energy gradient correction<br>function field in Forcite tools, which is suitable for simulate the<br>interaction between metal crystal and additives<sup>[26.31</sup>].<br>The B3LYP correlation energy gradient correction<br>functional method of density functional theory (DFT)<br>is The B3LYP correlation energy gradient correction<br>functional method of density functional theory (DFT)<br>is used to study the adsorption behavior and the base<br>group is set as 6-311G (d, p). The summing method<br>is set as Ewald ctional method of density functional meory (DF1)<br>sed to study the adsorption behavior and the base<br>up is set as 6-311G (d, p). The summing method<br>et as Ewald electrostatic and Atom based van der<br>als parameters, and monte is used to study the adsorption behavior and the base<br>group is set as 6-311G (d, p). The summing method<br>is set as Ewald electrostatic and Atom based van der<br>Waals parameters, and monte Carlo method of the<br>canonical ensemb group is set as 6-311G (d, p). The summing method<br>is set as Ewald electrostatic and Atom based van der<br>Waals parameters, and monte Carlo method of the<br>canonical ensemble (NTV) is used in the simulation.<br>The temperature is

$$
E_{\text{ack}} = E_{\text{complex}} - (E_{\text{Ni}} + E_{\text{additive}}) \tag{1}
$$

$$
E_{\text{binding}} = -E_{\text{ack}} \tag{2}
$$

 $\frac{\text{H}(E^{\omega}(I, Electrochem.) 2022, 28(7), 2213008 (3 of 11))}{\text{surface was tested using X-ray diffractometer (XRD, \n\nRight MINIFLEX 600). The JY-PHa contact angle} \qquad \log F(R_{\omega}) = \log K - \log S = \frac{(1 - R_{\omega})^2}{2R_{\omega}} \qquad (4)$ tester was used to measure the contact angle and the contact angle was obtained by heig  $\frac{\text{E}(E\# (J. Electron) 2022, 28(7), 2213008 (3 of 11))}{\text{Surface was tested using X-ray diffractometer (XRD, \n\nRigaku MINIPLEX 600). The JY-PIa contact angle \n\n log F (R<sub>\infty</sub>) = log K - log S = \frac{(1-R_{\infty})^2}{2R_{\infty}} \n\n (4) \ntester was used to measure the contact angle and the \n\n contact angle was obtained by height measurement \n method<sup>[19]</sup>. The light absorption performance was in-\n established by solid ultraviolet-visible diffuse reflect- **3** Results and Discussion$ the  $\#E \neq (L \nElectrochem.) 2022, 28(7), 2213008 (3 of 11)$ <br>
surface was tested using X-ray diffractometer (XRD,<br>
Rigaku MINIFLEX 600). The JY-PHa contact angle<br>
tester was used to measure the contact angle and the<br>
contact angle was  $\frac{dE}{dt}$ <br>
Electrochem.) 2022, 28(7), 2213008 (3 of 11)<br>
Surface was tested using X-ray diffractometer (XRD,<br>
Rigaku MINIFLEX 600). The JY-PHa contact angle<br>  $\log F(R_*) = \log K \cdot \log S = \frac{(1 \cdot R_*)^2}{2R_*}$  (4)<br>
tester was used to m **EVALUATION**<br> **EXECUTE:** Example 19 X-ray diffract<br> **EXECUTE:** Example 19 X-ray diffract (XRD,<br> **EXECUTE:** EXECUTE: THE DISPTED CONDITIONS (SOFTED THE ABSORPTION PERFORMANCE THE SURFACE USE of the contact angle was obtai **EVALUATION 1989**<br>
Extract was tested using X-ray diffractometer (XRD,<br>
Rigsku MINIFLEX 600). The IV-PH contact angle<br>
tester was used to measure the contact angle and the<br>
contact angle was obtained by height measurement ance spectrometer (Shimadzu UV3600 plus). The light **EVALUATION 1999**<br> **EVALUATION CONTROV**<br> **EVA EVALUATION EXECT (KEN)**<br>
Surface was tested using X-ray diffractometer (XRD,<br>
Rigaku MINIFLEX 600). The JY-PHa contact angle<br>  $\log F(R_*) = \log K \cdot \log S = \frac{(1-R_*)^2}{2R_*}$  (4)<br>
tester was used to measure the contact angle and the<br>
c **EVALUATION 1998**<br> **EVALUATION 1998**<br> **EXECUTE: EVALUATION 1999**<br> **EXECUTE: EXECUTE: EXECUTE:** that can both absorb and reflect light<sup>233</sup>. The K-M<br>
that can both absorb and reflect light and reflect light absorb and reflect light absorb and reflect with the can both absorb and the can both absorption performance w **EVALUATION 1998**<br> **Experimental As the following SY-ray diffractometer (XRD,**<br> **Experimental As the following X-ray diffractometer (XRD,**<br> **Experimentally as the following as the contact angle and the contact angle was o** (4)  $\frac{1}{2}$  (4)  $\frac{1}{2$ **EVALUATION EXAMORE (EVALUATION ACCES)**<br> **Expariation** State of the reflection coefficient of the inf **EVariative CONSTRANG (Example the absorption**) 2022, 28(7), 2213008 (3 of 11)<br>
Rigaku MINIFLEX 600). The JY-PHa contact angle<br>
Dog F' (R<sub>n</sub> ) = log K - log S =  $\frac{(1-R_n)^2}{2R_n}$  (4)<br>
Rigaku MINIFLEX 600). The JY-PHa cont surface was tested using Yard-V*k Eneromena, 2022, 28(v), 2213008 (3 0111)*<br>
Rigaku MINIFLEX 600). The JY-PHa contact angle  $\log F(R_s) = \log K \cdot \log S = \frac{(1-R_s)^2}{2R_s}$  (4)<br>
tester was used to measure the contact angle and the<br>
cont surface was tested using X-ray diffractometer (XRD,<br>
Rigaku MINIPLEX 600). The IV-PH contast angle and the<br>
tester was used to measure the contast angle and the<br>
contast angle was obtained by height measurement<br>
contast a Rigaku MINIFLEX 600). The JY-PHa contact angle<br>
tester was used to measure the contact angle and the<br>
tester was used to measure the contact angle and the<br>
contact angle was obtained by height measurement<br>
emethod<sup>199</sup>. T tester was used to measure the contact angle and the<br>contact angle was obtained by height measurement<br>mechanical  $R_n = 1 + \frac{K}{S} \cdot \left[ \frac{K^2}{S^2} + 2K \right]^{-\frac{1}{2}}$  (5)<br>method<sup>191</sup>. The light absorption performance was in-<br>ses contact angle was obtained by height measurement<br>
nethed<sup>191</sup>. The light absorption performance was in-<br>
serigizate by solid ultraviolet-visible diffuse reflect-<br>
serigizate and Discussion<br>
ences percentrometer (Shimadzu method<sup>1191</sup>. The light absorption performance was in-<br>
vestigated by solid ultraviolet-visible diffuse reflect-<br>
are septerometer (Shimadzu UV3600 plus). The light and Discussion<br>
ance spectrometer (Shimadzu UV3600 plus) spectrometer (Shimadzu UV3600 plus). The light<br>priori means checked hand-ocone at the mickel anno-cone at the mickel and DIS<br>protonmeter (Shimadzu UV3600 plus). The light<br>of the electrodeposited on the<br>priori results were

$$
F(R_{\infty}) = \frac{K}{S} = \frac{(1 - R_{\infty})^2}{2R_{\infty}}
$$
 overlap of the edges of the  
The crystal plane spacing

log F (R<sup>肄</sup> 渊1-R<sup>肄</sup> 冤 2 2R<sup>肄</sup> (4) 电化学渊J. Electrochem.<sup>冤</sup> 2022, 28(7), 2213008 (3 of 11)

28(7), 2213008 (3 of 11)  
\n
$$
\log F(R_{\infty}) = \log K - \log S = \frac{(1 - R_{\infty})^2}{2R_{\infty}}
$$
(4)  
\n
$$
R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}
$$
(5)  
\n**3 Results and Discussion**  
\nThe nickel nano-cone array with width of 200 nm  
\nwas electrodeposited on the flexible copper substrate.

The crystal plane spacing of 0.205 nm was observed, 8 (3 of 11)<br>  $\log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $\left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **S and Discussion**<br>
I nano-cone array with width of 200 nm<br>
eposited on the flexible copper substrate.<br>
deposition parameter was opt 28(7), 2213008 (3 of 11)<br>  $\log F(R_{\infty}) = \log K - \log S = \frac{(1 - R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodep (7), 2213008 (3 of 11)<br>  $g F(R_*) = \log K \cdot \log S = \frac{(1-R_*)^2}{2R_*}$  (4)<br>  $= 1 + \frac{K}{S} \cdot \left[ \frac{K^2}{S^2} + \frac{2K}{S} \right]^{\frac{1}{2}}$  (5)<br> **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
se electrodeposited on the flex 28(7), 2213008 (3 of 11)<br>  $\log F(R_*) = \log K \cdot \log S = \frac{(1 \cdot R_*)^2}{2R_*}$  (4)<br>  $R_* = 1 + \frac{K}{S} \cdot \left[ \frac{K^2}{S^2} + \frac{2K}{S} \right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited o 28(7), 2213008 (3 of 11)<br>  $\log F(R_*) = \log K \cdot \log S = \frac{(1-R_*)^2}{2R_*}$  (4)<br>  $R_* = 1 + \frac{K}{S} \cdot \left[ \frac{K^2}{S^2} + \frac{2K}{S} \right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on 28(7), 2213008 (3 of 11)<br>
log  $F(R_*) = \log K - \log S = \frac{(1-R_*)^2}{2R_*}$  (4)<br>  $R_* = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on th 28(7), 2213008 (3 of 11)<br>
log  $F(R_{\infty}) = \log K - \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{-\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrod 28(7), 2213008 (3 of 11)<br>
log F (R<sub>\*</sub>) = log K - log S =  $\frac{(1-R_*)^2}{2R_*}$  (4)<br>
R<sub>\*</sub> =  $1+\frac{K}{S}$  =  $\left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br> **3. Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrod  $\cos(3 \text{ of } 11)$ <br>  $= \log K - \log S = \frac{(1 - R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $\left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **ts and Discussion**<br>
el nano-cone array with width of 200 nm<br>
eleposited on the flexible copper substrate.<br>
deposited on the fl (4)<br>
(3)<br>
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(5)<br>
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ptimized by<br>
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olution with<br>  $^{-1}$  NH<sub>4</sub>Cl. As<br>
posited nick-<br>
ly and the<br>
height was<br>
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there charac-28(7), 2213008 (3 of 11)<br>  $\log F(R_{\infty}) = \log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} \cdot \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrode 28(7), 2213008 (3 of 11)<br>  $\log F(R_{\infty}) = \log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} \cdot \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{\frac{1}{2}}$  (5)<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrode  $28(7)$ ,  $2213008 (3 \text{ of } 11)$ <br>  $\log F (R_{\infty}) = \log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} \cdot \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodep log  $F(R_{\infty}) = \log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} \cdot \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible copper log  $F(R_{\infty}) = \log K \cdot \log S = \frac{(1-R_{\infty})^2}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} \cdot \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible copper log  $F (R_{\infty}) = 10g \text{ A} - 10g \text{ S} = -\frac{1}{2R_{\infty}}$  (4)<br>  $R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible cop  $R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]^{-\frac{1}{2}}$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible copper substrate.<br>
The electrodeposited on the fl  $R_{\infty} = 1 + \frac{K}{S} - \left[\frac{K^2}{S^2} + \frac{2K}{S}\right]$  (5)<br>
3 **Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible copper substrate.<br>
The electrodeposited on the flexible c **3 Results and Discussion**<br> **3 Results and Discussion**<br>
The nickel nano-cone array with width of 200 nm<br>
was electrodeposited on the flexible copper substrate.<br>
The electrodeposition parameter was optimized by<br>
orthogonal **3 Results and Discussion**<br>The nickel nano-cone array with width of 200 nm<br>was electrodeposited on the flexible copper substrate.<br>The electrodeposited on the flexible copper substrate.<br>The electrodeposition parameter was The nickel nano-cone array with width of 200 nm<br>was electrodeposited on the flexible copper substrate.<br>The electrodeposition parameter was optimized by<br>orthogonal experiment and the uniform nickel<br>nano-cone array was obta



 $\# \# \# (J. Electron) 2022, 28(7), 2213008 (4 of 11)$ <br>which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>the growth direction of [110] (Figure 1d). The XRD uneven distribution. Notab  $\text{#E}\cong (J. Electrochem.) 2022, 28(7), 2213008 (4 of 11)$ <br>which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>the growth direction of [110] (Figure 1d). The XRD uneven distribution. N the  $\frac{1}{2}$  (*Electrochem.*) 2022, 28(7), 2213008 (4 of 11)<br>which corresponds to the (111) plane of nickel and<br>the growth direction of [110] (Figure 1d). The XRD uneven distribution. Notably, the nickel nano-cone<br>patte  $\pm 1$   $\pm 2$   $\pm$  $\#E\ddot{\mathcal{F}}(J. \nElectrochem.) 2022, 28(7), 2213008 (4 of 11)$ which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2c), the<br>
the growth direction of [110] (Figure 1d). The XRD uneven distribution. Notably<br>
patter  $\frac{\pm \sqrt{2^2 + (J. Electrochem.) 2022, 28(7), 2213008 (4 of 11)}}{\pm \sqrt{2^2 + (J. Electrochem.) 2022, 28(7), 2213008 (4 of 11)}}$ <br>
which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2<br>
the growth direction of [110] (Figure 1d). The XRD un

 $\frac{4}{5}$  4.6  $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$   $\frac{4}{5}$  and  $\frac{4}{5}$  a  $\pm (k\ddot{\varphi})(L\text{Elertochem.})$  2022, 28(7), 2213008 (4 of 11)<br>which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>the growth direction of [101] (Figure 1d). The XRD unever distr  $\text{E/}\mathcal{E}/L$  Electrochem.) 2022, 28(7), 2213008 (4 of 11)<br>which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>1</sup> (Figure 2e), the nickel cone appeared<br>the growth direction of [110] (Figure 1d). The XRD uneven Effect of main salt concentration on the morpholo-<br>
Effect of mickel concentration of [110] (Figure 1d). The XRD uneven distribution. Notably, the nickel conce appeared<br>
growth direction of [110] (Figure 1d). The XRD une  $\pm 0.22$  of *Electrodeposited nickel* nano-cone was investi-<br>which corresponds to the (111) plane of nickel and 1.68 mol  $\pm 1$  (Figure 2e), the nickel cone appeared<br>the growth direction of [110] (Figure 1d). The XRD une  $\hfill \text{#R24.}~ \textit{Electrochem.) 2022, 28(7), 2213008 (4 of 11)} \\\hfill \text{which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>-1</sup> (Figure 2c), the nickel cone appeared the growth direction of [110] (Figure 1d), The XRD were distributed in the absence of NHACI (Figure 1e), displaying obvious diffusion peaks of 81). As the nickel crystal modifier, amount in the highest name-one is also included in the absence of NHACI (Figure 1e, displaying obvious diffusion peaks of 81). As the nickel crystal modifier, amount in the nickel vano-conc at 44.5°, 51.8° and 76.4°, correctly, the particles of electrostatic effects$  $\pm$ (*E*) (*Electrochem.*) 2022, 28(7), 2213008 (4 of 11)<br>
sponds to the (111) plane of nickel and 1.68 mol·L' (Figure 2c), the nickel cone appeared<br>
direction of [110] (Figure 1d). The XRD unever distribution. Notably, t the  $22, 28(7), 2213008 (4 of 11)$ <br>which corresponds to the (111) plane of nickel and<br>the growth direction of the (110) plane of nickel and<br>the moven distribution. Notably, the nickel cone appeared<br>patterns of the nickel nano (E2≥(*L Electroletem,*) 2022, 28(7), 2213008 (4 of 11)<br>
which corresponds to the (111) plane of nickel and 1.68 mol·L<sup>+</sup> (Figure 2c), the nickel cone appeared<br>
the growth direction of [110] (Figure 1d). The XRD uncern di  $(28(7), 2213008 (4 of 11))$ <br>
1.68 mol·L<sup>-1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifier, a  $^{1}$  (Figure 2c), the nickel cone appeared<br>ribution. Notably, the nickel nano-cone<br>ained in the absence of NH<sub>4</sub>Cl (Figure<br>nickel crystal modifier, ammonium ion<br> $^{1}$  NH<sub>4</sub>Cl is crucial for fabricating the  $(28(7), 2213008)$  (4 of 11)<br>
1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifier  $(28(7), 2213008)$  (4 of 11)<br>
1.68 mol·L<sup>-1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifie  $28(7)$ ,  $2213008$  (4 of 11)<br>
1.68 mol  $\cdot$  L<sup>-1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
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1.68 mol·L<sup>-1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifier,  $28(7)$ ,  $2213008(4 of 11)$ <br>  $1.68$  mol·L<sup>-1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifie  $28(7)$ ,  $2213008(4 of 11)$ <br>  $1.68$  mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifier  $28(7)$ ,  $2213008$  (4 of 11)<br>  $1.68 \text{ mol} \cdot L^{-1}$  (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal mod  $28(7)$ ,  $2213008(4$  of 11)<br>  $1.68$  mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifi 28(7), 2213008 (4 of 11)<br>
1.68 mol  $\cdot L^{-1}$  (Figure 2c), the nickel cone appeared<br>
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was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
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<sup>-1</sup>, the nickel<br>
um and height<br>
compactly on<br>
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ns refined by  $28(7)$ ,  $2213008$  (4 of 11)<br>  $1.68$  mol  $\cdot L^{-1}$  (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal m  $28(7)$ ,  $2213008(4 of 11)$ <br>1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>uneven distribution. Notably, the nickel nano-cone<br>was not obtained in the absence of NH<sub>c</sub>Cl (Figure<br>S1). As the nickel crystal modifier, ammo  $28(7)$ ,  $2213008 (4 of 11)$ <br>  $1.68 \text{ mol} \cdot L^{-1}$  (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
SI). As the nickel crystal modifi  $\frac{28(7)}{2213008}$  (4 of 11)<br>
1.68 mol·L<sup>1</sup> (Figure 2c), the nickel cone appeared<br>
uneven distribution. Notably, the nickel nano-cone<br>
was not obtained in the absence of NH<sub>4</sub>Cl (Figure<br>
S1). As the nickel crystal modifi 电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (4 of 11)<br>
(a) plane of nickel and  $1.68 \text{ mol} \cdot L^{-1}$  (Figure 2c), the nickel cone appeared<br>
Figure 1d). The XRD uneven distribution. Notably, the nickel nano-cone<br>
is also incl



-1  $(g, h, i)$  4.0 mol $\cdot L^{-1}$  NH<sub>4</sub>Cl.

 $\# \mathcal{H}(L \in \mathbb{R}^{n})$ <br>
adding NiCl<sub>2</sub>  $\cdot$  6H<sub>2</sub>O and the nickel ions could be sup-<br>
plied immediately in the high concentration of NiCl<sub>2</sub> geomerated particles appeared when the current den-<br>
plied immediately in the hi  $\text{H}(k^2/L \text{ }Electrochem.)$  2022, 28(7), 2213008 (5 of 11)<br>adding NiCl<sub>2</sub> · 6H<sub>2</sub>O and the nickel ions could be sup-<br>plied immediately in the high concentration of NiCl<sub>2</sub> ·<br>6H<sub>2</sub>O, which is conductive to the growth of nickel co the  $\mathbb{R}E^{\#}(J. \text{Electrochem.})$  2022, 28(7), 2213008 (5 of 11)<br>
adding NiCl<sub>2</sub> · 6H<sub>2</sub>O and the nickel ions could be sup-<br>
plied immediately in the high concentration of NiCl<sub>2</sub> · sity continued to increase to 4 A · dm<sup>2</sup>. Me  $\text{H}(E\#C)$ . Electrochem.) 2022, 28(7), 2213008 (5 of 11)<br>adding NiCl<sub>2</sub> · 6H<sub>2</sub>O and the nickel ions could be sup-<br>glomerated particles appeared when the current den-<br>plied immediately in the high concentration of NiCl<sub></sub> **EV**<sup>2</sup>€(*L Electrochem.*) 2022, 28(7), 2213008 (5 of 11)<br>
adding NiCl<sub>2</sub> • 6H<sub>2</sub>O and the nickel ions could be sup-<br>
glomerated particles appeared when the current den-<br>
plied immediately in the high concentration of Ni  $\frac{d_1}{d_2}$   $\frac{d_2}{d_2}$   $\frac{d_3}{d_3}$   $\frac{d_4}{d_4}$   $\frac{d_5}{d_5}$   $\frac{d_6}{d_6}$   $\frac{d_7}{d_7}$   $\frac{d_8}{d_8}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9}$   $\frac{d_9}{d_9$ growth.

mol $\cdot$ L<sup>-1</sup> NiCl<sub>2</sub> $\cdot$ 6H<sub>2</sub>O, 4 mol $\cdot$ L<sup>-1</sup> NH<sub>4</sub>Cl and 0.5 mol $\cdot$ L<sup>-1</sup> high concentration of NiCl<sub>2</sub> (6H<sub>3</sub>O provide sufficient ated at high current density, which results in the dif-<br>entity sites to form the nano-cone array was built in the solution with structure of nicelear of nicelear<br>mo

 $\pm$  (*E Fiectrochem.*) 2022, 28(7), 2213008 (5 of 11)<br>adding NiCl<sub>2</sub>-6H<sub>2</sub>O and the nickel ions could be sup-<br>glomerated particles appeared when the current den-<br>plied immediately in the high concentration of NiCl<sub>2</sub>-<br>of  $\pm k \mathcal{F}(J. \text{Eteenvchem}) 2022, 28(7), 2213008 (5 of 11)$ <br>adding NiCl,  $\cdot$  6H<sub>5</sub>O and the nickel ions could be sup-<br>glomerated particles appeared when the current den-<br>plied immediately in the high concentration of NiCl, sity con  $\text{E/CE}(\textit{L} \textit{Electrocheem.}) 2022, 28(7), 2213008 (5 of 11) \text{ adding NicC}_b \cdot 6H_2O \text{ and the nickel ions could be sup-} \text{golomertated particles appeared when the current den-} \text{philed immediately in the high concentration of NicC}_b \cdot \text{sity continued to increase to 4 A·dm<sup>2</sup>. Meanwhile, the 4H_2O, which is conductive to the growth of nickel color of the nickel coding changed into grey white from black. The nickel nuclei formed in the 5 from black. The nickel nucleotee/etepesoticous was accelerated in the 5 mm, and the 5 mm, and the 5 mm, the total mass of the other data is the 4.4 mm,$ the  $\frac{1}{2}$  the  $\frac{1}{2}$  content of current density on the nickel interaction of NiCl<sub>3</sub>.<br>
The effect of current density in the high concentration of NiCl<sub>3</sub>. Stiy continued to increase to 4 A-dm<sup>3</sup>. Meantime, the flow **Example 11**<br> **Example 12**<br> **Example 12** and ing NiCl<sub>+</sub>+6H<sub>2</sub>O and the nickel ions could be sup-<br>
and ing NiCl<sub>+</sub>+6H<sub>2</sub>O and the nickel ions could be sup-<br>
plomerated particles appeared when the current den-<br>
plied immediately in the high concentration of NiC 4 A窑dm-2. The electrodeposited nickel nano-cone  $t_3(E^2\epsilon)$ ,  $t_4Eetonebem$ ,  $2(22, 28(7), 2213008 (5 of 11)$ <br>adding NiCl<sub>2</sub> of H<sub>2</sub>O and the nickel ions could be sup-<br>glomerated particles appeared when the current den-<br>piled immediately in the high concentration of NiCl<sub>3</sub>.<br>F  $\frac{1}{2}$  and the nickel ions could be sup-<br>glomerated particles appeared when the commediately in the high concentration of NiCl<sub>2</sub>. sity cominued to increase to 4 A·dm<sup>2</sup>. Me<br>which is conductive to the growth of nickel **EVALUATE CONSULTERTS (CONSULTERTS ACTES AND THE CONSULTERTS (CONSULTERTS AND THE CONSULTERTS (CONSULTERTS)** of the particles of the animal of the concentration of Nickel I nuclei formed in the form black. The nickel cost adding NiCI: oH:O and the nickel ions could be sup-<br>
glometrical paracited particles appeared when the current den-<br>
plicd immediately in the high concentration of NiCI:<br>  $\frac{1}{2}$  sity continued to increase to  $A \cdot dm^2$ . plied immediately in the high concentration of NiCl<sub>1</sub>-sity continued to increase to 4 A-dm<sup>2</sup>. Meantime, the 6H<sub>2</sub>O, which is conductric to the growth of nickel clear of the nickel catterig change change of the nickel co 6H:O, which is conductive to the growth of nickel color of the nickel coating changed into gry white<br>nano-cone nuclei. The nickel muclei formed in the from black. The nickel electrodeposition was acceler-<br>high coneentrati nano-cone nuclei. The nickel nuclei formed in the from black. The nickel electrodeposition was acceler-<br>high concentration of Nick-1, of Ho provide sufficient at at high current density, which results in the dir-<br>native s  $28(7)$ , 2213008 (5 of 11)<br>glomerated particles appeared when the current density continued to increase to 4 A  $\cdot$ dm<sup>2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrodep  $28(7)$ ,  $2213008(5 \text{ of } 11)$ <br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel ele  $28(7)$ ,  $2213008(5 \text{ of } 11)$ <br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel ele  $28(7)$ ,  $2213008$  (5 of 11)<br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel elec  $28(7)$ ,  $2213008(5 \text{ of } 11)$ <br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel ele  $28(7)$ ,  $2213008(5 \text{ of } 11)$ <br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel ele  $28(7)$ ,  $2213008(5 \text{ of } 11)$ <br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel ele  $28(7)$ ,  $2213008$  (5 of 11)<br>glomerated particles appeared when the current density continued to increase to 4 A  $\cdot$ dm<sup>2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrod  $28(7)$ ,  $2213008$  (5 of 11)<br>glomerated particles appeared when the current density continued to increase to 4 A · dm<sup>-2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrode 28(7), 2213008 (5 of 11)<br>glomerated particles appeared when the current density continued to increase to 4 A  $\cdot$ dm<sup>2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrodepos 28(7), 2213008 (5 of 11)<br>glomerated particles appeared when the current density continued to increase to 4 A·dm<sup>-2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrodepositi  $28(7)$ ,  $2213008$  (5 of 11)<br>glomerated particles appeared when the current density continued to increase to  $4$  A  $\cdot$ dm<sup>-2</sup>. Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel elect  $28(7)$ ,  $2213008$  (5 of 11)<br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into groy white<br>from black. The nickel elec 28(7), 2213008 (5 of 11)<br>glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrod (7), 2213008 (5 of 11)<br>
merated particles appeared when the current den-<br>
y continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>
lor of the nickel coating changed into grey white<br>
m black. The nickel electrodepositi **Examplemental particles appeared when the current density continued to increase to**  $4 \text{ A} \cdot \text{dm}^2$ **. Meantime, the color of the nickel coating changed into grey white from black. The nickel electrodeposition was acceler** glomerated particles appeared when the current density continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the color of the nickel coating changed into grey white from black. The nickel electrodeposition was accelerated sity continued to increase to  $4 \text{ A} \cdot \text{dm}^2$ . Meantime, the<br>color of the nickel coating changed into grey white<br>from black. The nickel electrodeposition was acceler-<br>ated at high current density, which results in the d color of the nickel coating changed into grey white<br>from black. The nickel electrodeposition was acceler-<br>ated at high current density, which results in the dif-<br>ference of nickel ion concentration on the electrode<br>surfac from black. The nickel electrodeposition was acceler-<br>ated at high current density, which results in the dif-<br>ference of nickel ion concentration on the electrode<br>surface and far away from the electrode, leading to<br>the in ated at high current density, which results in the dif-<br>ference of nickel ion concentration on the electrode<br>surface and far away from the electrode, leading to<br>the increasing polarization. Besides, the adsorption<br>behavior 电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (5 of 11)<br>
kel ions could be sup-<br>
glomerated particles appeared when the current den-<br>
poncentration of NiCl<sub>2</sub>· sity continued to increase to 4 A·dm<sup>2</sup>. Meantime, the<br>
the gr



the flat surface. After 10 s of nickel electrodeposition investigate the growth mechanism of nickel nano-cone<br>
(Figure 4b), a large number of nickel unclei were array by calculating the adsorption energy of NH<sub>1</sub> on<br>
(Fig (Figure 4b), a large number of nickel nuclei were<br>
erray by calculating the adsorption energy of NH<sub>L</sub><sup>1</sup> on<br>
generated on the surface of copper and the nucleation<br>
erraces became faster than the nuclear growth pro-<br>
erre generated on the surface of copper and the nuclearion<br>
process became faster than the nuclear growth pro-<br>
eccs in this stage. With the innecesse of nickel cleve-<br>
eccs in this stage. With the innecesse of nickel cleve-<br> process became faster than the nuclear growth process became faster than the nuclear growth process in this stage. With the increase of niletal cloc-<br>tradeposited time, the nickel case of niletal cloc-<br>tradeposited time, coss in this stage. With the increase of nickel electron three crystal planes including the (111), (200) and<br>trodeposited time, the nickel nano-cone mateles grew<br>
When the time of electrodeposited nickel continued<br>
When t trodeposited time, the nickel nano-cone nucleus grew<br>
We and the nano-cone was more distinguishable.<br>
When the time of electrodeposited inickel continued cone are distinguishable.<br>
When the time of electrodeposited inicke

 $\frac{d}{dt}\left(\frac{d}{dt}\right)^2$  =  $\frac{d}{dt}\left(\frac{d}{$  $\# \# \# (J. Electronchem.) 2022, 28(7), 2213008 (6 of 11)$ <br>substrate and the copper particles were observed on<br>the flat surface. After 10 s of nickel electrodeposition<br>(Figure 4b), a large number of nickel nuclei were array by calculatin (Figure 4b), a large number of conception and the interesting of number  $\frac{4}{k^2}$  (*F. Electrochem.*) 2022, 28(7), 2213008 (6 of 11)<br>
substrate and the copper particles were observed on<br>
The molecule dynamic simulation  $\frac{4!}{2!} (L \cdot Electrochem.) 2022, 28(7), 2213008 (6 of 11)$ <br>substrate and the copper particles were observed on<br>the flat surface. After 10 s of nickel electrodeposition investigate the growth mechanism of nickel nano-cone<br>(Figure 4b),  $\frac{4k}{2}(L\text{ Rlectrochem}) 2022, 28(7), 2213008 (6 of 11)$ <br>
substrate and the copper particles were observed on<br>
the flat surface. After 10 s of nickel electrodeposition<br>
(Figure 4b), a large number of nickel electrodeposition<br>
(Fig  $\pm \frac{4\pi}{2}(L\text{~Electrochem.}) 2022, 28(7), 2213008 (6 of 11)$ <br>
substrate and the copper particles were observed on<br>
the flat surface. After 10 s of nickel electrodeposition investigate the growth mechanism of nickel nano-cone<br>
(Fig  $\pm \frac{1}{2}(L\text{~Eecrochem.}) 2022, 28(7), 2213008 (6 of 11)$ <br>substrate and the copper particles were observed on<br>the flat surface. After 10 s of nickel electrodeposition investigate the growth mechanism of nickel nano-cone<br>(Figure 4  $4E/2^2(L \t{Electrochem})$  2022, 28(7), 2213008 (6 of 11)<br>
substrate and the copper particles were observed on The molecule dynamic simulation is performed to<br>
the flat surface. After 10 s of nickel electrodeposition investigate t  $\text{Substrate and the copper particles were observed on} \begin{minipage}{0.9\textwidth} \begin{tabular}{p{0.8cm}} \textbf{#} & \textit{if} \& \textit{if$  $\pm \frac{1}{2}\pi/4$ . *Electrochera*, 2022, 28(7), 2213008 (6 of 11)<br>
substrate and the copper particles were observed on<br>
the flat surface. After 10 s of nickel electrodeposition<br>
investigate the growth mechanism of nickel nan **EVALUATIVE 1989**<br> **EVALUATIVE 1999**<br> **EVALUATIVE 1999**<br> **EVALUATION EXECUTE ARREL 10 SO TRIGERED INTO THE CHEOROFORMOTE INTO THE CHEOROFORMOTE THAN A large number of incided electrodeposition investigate the growth mecha EVALUATION THE TENDEM INTERT (ELECT ACCOND ACCONDUM IN THE STAGE INTERT (ENECT ACCOND THE INTERT (ENECT ACCONDUM INTERT (ELECT A**  $\frac{16}{27}$  (*L. Electrochem.*) 2022, 28(7), 2213008 (6 of 11)<br>
substrate and the copper particles were observed on<br>
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ie surface of all the<br>  $\geq$  (111), (200) and<br>  $\neq$ , bond energy and<br>  $\neq$  (111), (200) and<br>  $\neq$  (111), (200) and<br>  $\neq$  (111), (200) and<br>  $\neq$  (111) array by calculating the adsorption energy of NH<sub>4</sub><sup>+</sup> on<br>different crystal surfaces of nickel. As shown in Fig-<br>ure 5, NH<sub>4</sub><sup>+</sup> can be adsorbed on the surface of all the<br>three crystal planes including the (111), (200) an different crystal surfaces of nickel. As shown in Fig-<br>ure 5, NH<sub>4</sub><sup>+</sup> can be adsorbed on the surface of all the<br>three crystal planes including the (111), (200) and<br>(220) surfaces. The total energy, bond energy and<br>(220) ure 5, NH<sub>4</sub><sup>+</sup> can be adsorbed on the surface of all the<br>three crystal planes including the (111), (200) and<br>(220) surfaces. The total energy, bond energy and<br>non-bond energy of NH<sub>4</sub><sup>+</sup> on nickel (111), (200) and<br>(220) three crystal planes including the (111), (200) and<br>(220) surfaces. The total energy, bond energy and<br>non-bond energy of NH<sub>4</sub><sup>+</sup> on nickel (111), (200) and<br>(220) crystal planes in the simulation box reach sta-<br>ble state (220) surfaces. The total energy, bond energy and<br>non-bond energy of NH<sub>4</sub><sup>+</sup> on nickel (111), (200) and<br>(220) crystal planes in the simulation box reach sta-<br>ble state after 50 ps of simulation, indicating that the<br>adsor The total energy, bond energy and<br>v of NH<sub>4</sub><sup>+</sup> on nickel (111), (200) and<br>nes in the simulation box reach sta-<br>ps of simulation, indicating that the<br>balances within 50 ps (Figure 5c, 5f,<br>of adsorption energies and bindin 电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (6 of 11)<br>les were observed on The molecule dynamic simulation is performed to<br>checkel electrodeposition investigate the growth mechanism of nickel nano-cone<br>f nickel nuclei we





	$E_{\text{binding}}$ (kcal·mol <sup>-1</sup> )	$E_{\text{ads}}$ (kcal·mol <sup>-1</sup> )
$NH4$ on Ni (111)	19.10	$-19.10$
$NH_4^+$ on Ni (200)	18.83	$-18.83$
$NH_4$ <sup>+</sup> on Ni (220)	14.14	$-14.14$

 $E_{\text{total}}$  (200)  $\text{IR}_4$ , and interest and mixed and mixed and mixed and mixed and mixed and  $\text{NH}_4$ , on Ni (200)  $\text{IR}_4$ ,  $\text{Pl.}}$  and  $\text{IR}_4$  and  $\text{$ 

**Example 12**<br> **Example 12 Example 1** The adsorption energies of the NH<sub>4</sub>+ on<br>
different nickel (a+c) (111), (d+f) (200) and (g+j) (220) planes.<br>
Table 1 The adsorption energies of the NH<sub>4</sub>+ on<br>
different nickel crystal surfaces<br>  $F_{\text{total}}$ (on Ni dynamic simulation of NH<sub>4</sub>' on nickel (a-c) (111), (d-f) (200) and (g-i) (220) planes. (color on line)<br>
dynamic simulation of NH<sub>4</sub>' on nickel (a-c) (111), (d-f) (200) and (g-i) (220) planes. (color on line)<br>  $\frac{E_{\text{long}}$ **Figure 5** Molecule dynamic simulation of NH<sub>4</sub>' on nickel (a-e) (111), (d-f) (200) and (g-i) (220) planes, (color on line)<br> **Table 1** The adsorption energies of the NH<sub>4</sub><sup>'</sup> on nickel (a-e) (111), (d-f) (200) and (g-i) ( Figure 5 Molecule dynamic simulation of NH<sub>1</sub> on nickel (a-c) (111), (d-f) (200) and (g-i) (220) planes. (color on line)<br> **Table 1** The adsorption energies of the NH<sub>1</sub> on<br>
there explored. The nickel nano-cone array exhib **Eigare 5** Molecule dynamic simulation of NH<sub>L</sub><sup>+</sup> on nickel (4-0) (111), (d-f) (200) and (g-i) (220) planes. (color on line)<br> **Table 1** The adsorption energies of the NH<sub>L</sub><sup>+</sup> on<br>
the resplored. The nickel nano-cone arra **Figure 5** Molecule dynamic simulation of NH<sub>4</sub><sup>+</sup> on nickel (a-c) (111), (d-f) (200) and (g-i) (220) planes. (color on line)<br> **Table 1** The adsorption energies of the NH<sub>4</sub><sup>-</sup> on<br>
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diffe **Table 1** The sdsoption energies of the NH<sub>4</sub><sup>+</sup> on<br>
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NH<sub>4</sub><sup></sup> mergies of the NH<sub>4</sub><sup>-</sup>on<br>
inter explored. The nickel nano-cone array exhibits<br>
unique optical and interfacial properties. As shown in<br>  $\frac{1 \cdot \text{mol}^4}{10}$   $\frac{1 \cdot \text{mol}^4}{10}$   $\frac{1}{10}$   $\frac{1}{10}$   $\frac{1}{10}$   $\frac{1}{10}$  **Table 1** The adsorption energies of the NII/ on<br>
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and the growth of nickel and interfacial properties. As shown in<br>  $E_{\text{total}}$ , (n Ni (111) 19.10<br>
NH<sub>a</sub>' on Ni (200) 18.83<br>
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18.83<br> **EXECUTE:** and electronic entergies of the rive of the explored interaction and the results of the most of the state of explicit of the state of the state of the most of the uniere interest vipson sumsets<br>  $E_{\text{total}}(\text{kan}^{-1})$ <br>  $E_{\text{total}}(\text{kan}^{-1})$ <br>  $E_{\text{total}}(\text{kan}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{Ric}^{-1})$ <br>  $E_{\text{total}}(\text{R$ The on Ni (111) 19.10 19.10 19.10 19.10 19.10 11, what mickel and nickel nano-cone array were the time of the traction of the weater contact angles of the properties of the intervent of the stresses of the method and the Watter the context of the species of the matter of the species of the context of the species of the matter of the weater contact angles of the PI, Cu and the spe However, the water contact angles of the Pisconsieral<br>
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Figure 6, **Example 1.1** and  $\overline{B}$  are  $\overline{C}$  and  $\overline{C}$ excellent vertable is concerned and operation of the same of the same and one array. The surface ex-<br>contract and interfacial properties. As shown in Figure 6, the water contact angles on polyimide (PI), Cu, Watt nickel a cellent wetter scattering and conductive to the solid-liquid interface reaction<sup>1371</sup>. The surface of the mickel and and an and the solid-liquid-liquid-liquid-liquid-liquid-liquid-liquid-liquid-liquid-liquid-liquid-liquid **Example 12**<br> **Example 10**<br> **Interface reaction**<br> **Interface reacti** due to the initial properties. As shown in<br>the resplored. The nickel nano-cone array exhibits<br>their explored. The nickel nano-cone array exhibits<br>the wide optical and interfacial properties. As shown in<br>Figure 6, the wate <sup>26</sup> <sup>36</sup> <sup>36</sup> <sup>36</sup> <sup>36</sup><br>
36 **cone array** exhibits<br>
ther explored. The nickel nano-cone array exhibits<br>
unique optical and interfacial properties. As shown in<br>
Figure 6, the water contact angles on polyimide (PI),<br>
Cu, Wa b, (d-f) (200) and (g-i) (220) planes. (color on line)<br>ther explored. The nickel nano-cone array exhibits<br>unique optical and interfacial properties. As shown in<br>Figure 6, the water contact angles on polyimide (PI),<br>Cu, Wa Example 1. The nickel nano-cone array exhibits<br>ique optical and interfacial properties. As shown in<br>gure 6, the water contact angles on polyimide (PI),<br>i, Watt nickel and nickel nano-cone array were<br>ted. The water contact ther explored. The nickel nano-cone array exhibits<br>unique optical and interfacial properties. As shown in<br>Figure 6, the water contact angles on polyimide (PI),<br>Cu, Watt nickel and nickel nano-cone array were<br>tested. The w ther explored. The nickel nano-cone array exhibits<br>unique optical and interfacial properties. As shown in<br>Figure 6, the water contact angles on polyimide (PI),<br>Cu, Watt nickel and nickel nano-cone array were<br>tested. The w unique optical and interfacial properties. As shown in<br>Figure 6, the water contact angles on polyimide (PI),<br>Cu, Watt nickel and nickel nano-cone array were<br>tested. The water contact angles of the PI, Cu and<br>Watt nickel w Figure 6, the water contact angles on polyimide (PI), Cu, Watt nickel and nickel nano-cone array were tested. The water contact angles of the PI, Cu and Watt nickel were 76.6°, 68° and 48.8°, respectively. However, the wa Cu, Watt nickel and nickel nano-cone array were<br>tested. The water contact angles of the PI, Cu and<br>Watt nickel were 76.6°, 68° and 48.8°, respectively.<br>However, the water contact angle of the nickel<br>nano-cone array was on **Table 1** The adsorption energies of the  $NH_4$ <sup>+</sup> on the explored. The nickel nano-cone array exhibits Figure 6, the water contact angles on polyimide (PI), Cu, Watt nickel and nickel nano-cone array were

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ties of electrodeposition was tested, and the nickel<br>
nano-cone array electrodeposition at 1.5 A · dm<sup>-2</sup> had<br>
In this pa** <sup>Fi</sup>( $E \cong C$  *Fi*( $E \cong C$  *Fi*  $E \cong C$   $\frac{4}{5}$   $\frac{4}{5}$  **the Width Of 300** nm at the bottom forms the discontinuation of the predominant crowth and concept and discontinue of  $\mathbf{A}$  **Conclusions** concept are array electrodepositied at 1.5 A -dm<sup>2</sup> had and the histoperties of **EVALUATION 1989**<br> **EVALUATION 1999**<br> **EVALUATION Example 19**<br> **Example 199%** near ultraviolet and visible light. It is space, the **EVALUATIVE 1200 EVALUATIVE 12000** (S of 11)<br> **Example 12000 EVALUATIVE 12000 4 4 Conclusions**<br> **Array reduces the light adsorption was tested, and the nickel <b>4 Conclusions**<br> **Array reduces the restrepandence EVALUATION 1998** (Extracken, 2022, 28(7), 2213008 (8 of 11)<br>
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# 4 Conclusions

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## Acknowledgments:

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The authors grat tional Natural Science Foundation of China (Nos.<br>
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12 change O, Lyons T [2] Tong H, Ouyang S X, Bi Y P, Umezawa N, Oshikiri M,  $\begin{tabular}{ll} \hline \textbf{Ref} & \textbf{if} \& \text$  $\frac{\text{H}_{2}}{2}(L\vec{E} + \vec{E} + \vec$ [3] Wong E W, Sheehan P E, Lieber C M. Nanobeam mechang P Y, Ishizaka H, Nimizaka R, Chanical H, Nimizaka R, Nimizaka N, Kimizaka R, Nimizaka R, Nimizaka R, Nimizaka R, Nimizaka R, Theoretics, The Text is a memberika of China (Nos. [12] Humg Q, I, Sma T W, Sisies W D. Ele 11 Through-hole filling by copper cleeropheins; Into Through-hole filling by copper cleeropheins [1]. J. Electrochem State 11 Columbus 21 (12) Humg Q, Lyons 7 W, Sides W.D. Electrochemsion of 27020 and 61974020). The work The authors gratefully acknowledge the support of Natural Science. For a track and Natural Science Foundation of China (Nos. [12] Hung C, Lyons TW, Sides VD. Electrodeposition of China (Nos. 2013). The vork is also suppor al Natural Science Foundation of China (Nos. [12] House TV, Sides WD. Electrodepoision of  $2200$  and 61974020). The work is also supported eigenic Zhina City interviews of the intervent engine of Zhina City eignests of Sc

# References:

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- **EVERICES:** 2014, 151(4): C262-C271.<br>
Wang F, Zao Z C, Li L, He F, Li Y L. Graphdiyne nanoss [14] Zheng L, He VN, Zhu K, Wang C,<br>
1141 Zheng L, He VN, Zhu K, Wang C, Wang C, Wang C, Wang C, Wang C, Wang F, The W, Zhu K, W tructure for high-performance lithium-sulfur hatteries [J].<br>
Chen Y M, Zhou G Y, Mino H, Zhou G P, INSTED TONE H, None Engine To ply (1-my) imiducele couple at the<br>sinustical digited by the plane of the plane of the sinus Nano intergy, 2020, 68: 104307.<br>
Tong II, Ouyung S X, Bi Y P, Umezawa N, Oshikiri M,<br>
Tog II, Ouyung S X, Bi Y P, Umezawa N, Oshikiri M,<br>
Ye J H. Nano-photocatalytic materials: Possibilities and<br>
the left) as levelet for c Tong H, Ouyang S X, Bi Y P, Umezawa N, Oshikiri M,<br>
Yearl H. Nano-photocotalpite materials: New Helme, 1918 Dow W. P, Chin N, 2018, 283: 560-<br>
Yearl H. Nano-photocathylic materials: Possibilities and<br>
Weal P. Electrochim, Ye J H. Nano-photocatalytic materials: Possibilities and<br>
1916[J]. Electrochim. Acta, 2018, 283: 560-567.<br>
13] Yong E W, Sheehan PE, Lieber C M. Nanobeam me-<br>
celectroplating over a Au seed layer modified by a disul-<br>
cha challenges[J]. Adv. Mater, 2012, 24(2): 220-251. [15] Dow W.P, Chiu Y.D. Yen M.Y. Microvia filling by Cu<br>
Warkshare P. E. Liebert C.M. Nanobeam measure entative and layer medified by a distribution of Microsofted Ni nanoc Wong E W, Sheehan P E, Lieber C M. Nanobeam me-<br>
electroplating over a Au seed layer modified by a disal-<br>
education and manufacting, strength, and mangement of manerals<br>
Surface, 1997, 277(5334): 1971-1975.<br>
Surface, 1997
- 
- 
- capacitor(IJ]. Energy Environ. Sci., 2014, 7(8): 2652-2659.<br>
Zhang S C, Du Z J, Lin R X, Jiang T, Liu G R, Wu X M, [18] Walter E C, Zach M P, Fa<br>
Weng D S. Nickel nanocone-array supported silicon anode<br>
for high-performanc
- 
- 
- 1840.
- 

(1), 2213008 (9 of 11)<br>Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>c 电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Elec-<br>
dge the support of Na-<br>
trochem. Soc., 2008, 155(12): D75

- (2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Elec-<br>
trochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition of (exp.), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodepositio 28(7), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating [J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
[12] Huang Q, Lyons T W, Sides W D. Electrodepo (2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating [J]. J. Elec-<br>
trochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition o (2213008 (9 of 11)<br>Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>Huang Q, Lyons T W, Sides W D. Electrochems of cobalt for D721. 28(7), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
[12] Huang Q, Lyons T W, Sides W D. Electrodepos (2), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating [J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition (2) 13008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating [J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>
- 
- 72020 and 61974020). The work is also supported<br>
scheen for interconnect application: Friesc of dimentyl-<br>
he projects of Sci & Tech planning of Zhuhai City<br>
gluoning II. I. Electrochem, Soc., 2016, 163(13): D71:<br>
LEM2017 Fraction and the same of Frederic Columbus (Figure 2010, 163(13): D713-<br>
Frederic SC Tech planning of Zhuhai City<br>
2721.<br>
2711. TH-2017001200032PWC) and Sichuan Science<br>
Technology Program (No. 2022YFS0527).<br>
2711. Howeve ephytecs of science (in particular Capacities of the spectrology Program (No. 2022YFS0527).<br> *CH32017001200032PWC)* and Sichuan Science [13] Mofflur T P, Wheeler D, Josel D. Electrodeposition of<br> **Technology Program** (No. (No. 210012000324PWC) and Sichlin Science [133] Moffier TP, Wheeler D, Josell D. Electrodeposition of<br>
and Technology Program (No. 2022YFS0527).<br> **References:**<br> **References:**<br> **References:**<br> **References:**<br> **References:**<br> Technology Program (No. 2022YFS032/).<br>
respective massenements infunction of massenements infunctions of massenements infunctions of SSUPLI Electrochem. Soc.,<br>
Wang F, Zuo ZC, Li L, He F, Li Y L. Graphdiyne manos-<br>
ray  $F$ for high-performance lithium-ion batteries[J]. Adv. Mater., [1] Wang F, Zuo Z C, Li L, He F, Li Y L. Graphdyne nanos-<br>
tracture for the pheric materials (1). The W, Zhu K, Not G iv, Male H, Zhu K, Not D (1) clumestigation<br>
Nata Energy, 2020, 68: 104907.<br>
[21 Tong H, Ouyay in W, Al (213008 (9 of 11)<br>
213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electr 28(7), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Elec-<br>
trochem. Soc., 2008, 155(12): D750-D757.<br>
[12] Huang Q, Lyons T W, Sides W D. Electrode (1), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition o (1-vinyl), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposi 9. 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[JJ. J. Electroplating<br>
trochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrode (1), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
Huang Q, Lyons T W, Sides W D. Electrodeposition o 28(7), 2213008 (9 of 11)<br>
Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>
Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
[12] Huang Q, Lyons T W, Sides W D. Electrodepo Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>cobalt for interconnect Chuang P Y, Ishizuka H, Sakagawa N, Kimizuka R.<br>Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>Huang Q, Lyons T W, Sides W D. Electrocheposition of<br>cobalt for interconnect Through-hole filling by copper electroplating[J]. J. Electrochem. Soc., 2008, 155(12): D750-D757.<br>
[12] Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>
cobalt for intercomnet application: Effect of dimethyl-<br>
glyoxime trochem. Soc., 2008, 155(12): D750-D757.<br>Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>cobalt for interconnect application: Effect of dimethyl-<br>glyoxime[J]. J. Electrochem. Soc., 2016, 163(13): D715-<br>D721.<br>Moffat T P Huang Q, Lyons T W, Sides W D. Electrodeposition of<br>cobalt for interconnect application: Effect of dimethyl-<br>glyoxime[J]. J. Electrochem. Soc., 2016, 163(13): D715-<br>D721.<br>Moffat T P, Wheeler D, Josell D. Electrodeposition colalt for interconnect application: Effect of dimethyl-<br>glyoxime[J]. J. Electrochem. Soc., 2016, 163(13): D715-<br>D721.<br>[13] Moffat T P, Wheeler D, Josell D. Electrodeposition of<br>corpor in the SPS-PEG-Cl additive system-I. glyoxime[J]. J. Electrochem. Soc., 2016, 163(13): D715-<br>D721.<br>Moffat T P, Wheeler D, Josell D. Electrodeposition of<br>copper in the SPS-PEG-Cl additive system-I. Kinetic<br>measurements: Influence of SPS[J]. J. Electrochem. Soc D721.<br>
Moffat T P, Wheeler D, Josell D. Electrodeposition of<br>
copper in the SPS-PEG-CI additive system-I. Kinetic<br>
measurements: Influence of SPS[J]. J. Electrochem. Soc.,<br>
2004, 151(4): C262-C271.<br>
Zheng L, He W, Zhu K, W [13] Moffat T P, Wheeler D, Josell D. Electrodeposition of<br>
copper in the SPS-PEG-CI additive system-I. Kinetic<br>
measurements: influence of SPS[J]. J. Electrochem. Soc.,<br>
2004, 151(4): C262-C271.<br>
[14] Zheng L, He W, Zhu copper in the SPS-PEG-Cl additive system-I. Kinctic<br>measurements: Influence of SPS[J]. J. Electrochem. Soc.,<br>2004, 151(4): C262-C271.<br>Zheng L, He W, Zhu K, Wang C, Wang S X, Hong Y,<br>Chen Y M, Zhou G Y, Miao H, Zhou J Q. In measurements: Influence of SPS[J]. J. Electrochem. Soc., 2004, 151(4): C262-C271.<br>Zheng L, He W, Zhu K, Wang C, Wang S X, Hong Y, Chen Y M, Zhou G Y, Miao H, Zhou J Q. Investigation of poly(1-vinyl imidazole co 1, 4-butane 2004, 151(4): C262-C271.<br>
Zheng L, He W, Zhu K, Wang C, Wang S X, Hong Y, Chen Y M, Zhou G Y, Miao H, Zhou J Q. Investigation<br>
of poly(1-vinyl imidazole co 1, 4-butanediol diglycidyl<br>
teher) as a leveler for copper electro [14] Zheng L, He W, Zhu K, Wang C, Wang S X, Hong Y,<br>
Chen Y M, Zhou G Y, Miao H, Zhou J Q. Investigation<br>
of poly(1-vinyl imidazole co 1, 4-butanediol diglycidyl<br>
ether) as a levele for copper electroplating of through-<br> Chen Y M, Zhou G Y, Miao H, Zhou J Q. Investigation<br>of poly(1-vinyl imidazole co 1, 4-butanediol diglycidyl<br>ether) as a leveler for copper electroplating of through-<br>hole[J]. Electrochim. Acta, 2018, 283: 560-567.<br>Dow W P,
	-
	-
	-
	-
	-
	- of poly(1-vinyl imidazole co 1, 4-butanediol diglycidyl<br>ether) as a leveler for copper electroplating of through-<br>hole[J]. Electrochim. Acta, 2018, 283: 560-567.<br>Dow W P, Chiu Y D, Yen M Y. Microvia filling by Cu<br>electropl ether) as a leveler for copper electroplating of through-<br>hole[J]. Electrochim. Acta, 2018, 283: 560-567.<br>[15] Dow W P, Chiu Y D, Yen M Y. Microvia filling by Cu<br>electroplating over a Au seed layer modified by a disul-<br>fid hole[J]. Electrochim. Acta, 2018, 283: 560-567.<br>
	Dow W P, Chiu Y D, Yen M Y. Microvia filling by Cu<br>
	electroplating over a Au seed layer modified by a disul-<br>
	fide[J]. J. Electrochem. Soc., 2009, 156(4): D155-D167.<br>
	Dow W Dow W P, Chiu Y D, Yen M Y. Microvia filling by Cu<br>electroplating over a Au seed layer modified by a disul-<br>fide[J]. J. Electrochem. Soc., 2009, 156(4): D155-D167.<br>Dow W P, Lu C W, Lin J Y, Hsu F C. Highly selective<br>Cu ele
- channics: Elasticity, strength, and toughness of nanorods<br>
indel[J]. J. Electrochem. Soc., 2009, 156(4): D155-D167.<br>
and Z. X vang C. Xie B H, Lin Z Y. Ziang Z. X, Liu J P, Li C wie DV. P, Li C W, Lin J Y, Har F C. Highly and nanotubes[IJ]. Science, 1997, 277(5334): 1971-1975.<br>
[16] Dow W.P., Lu C.W., Lin JY, Hsu F.C. Highly selective<br>
[4] PER (X, Ning C.X in D.R. (2) Altang Z X, Lin JP, Lin Designer platinum of Mano<br>
BLI, Kang E.V, Wang C Su Z.1, Yang C, Xie H H, Lin Z Y, Zhang Z X, Lin J P, Li<br>
St H, Kang EY, Woong C P. Scalable fabrication of Moto, The Decorodenosition for filling through silicon halos<br>
1171 Gu, C, Tu J. One-Step fabrication of nanostruc B H, Kang F Y, Wong C P. Scalable fabrication of MnO<sub>2</sub><br>
Hetrochem. Solid Stat Lett, 2011, 14(t): 105-1167<br>
anys for ultrathin, flexible, high-performance micro-super-<br>
equation (1): The C, The J. Obserts fabrication of m ananostrotente deposited on free-standing Ni nanocone ar-<br>
19] Gu C, Tu J. One-step fibrication of nanostructured Ni<br>
equestion(J], Energy Environ. Sci., 2014, 7(8): 2652-2659.<br>
1. Almoy the the method to the quest for fo mys for ultrathin, flexible, high-performance micro-super-<br>
equality of  $\chi$ -Burge EC, doint A, Jung T, Liu G R, We X M,<br>
2014, 2014, 2015, 2014, 2015, 2014, 2014, 2014, 2014, 2014, 2014, 2015, 2014, 2015, 2014, 2014, 2015 [5] Zhoung S C, Du Z J, Lin R X, Jiang T, Liu G R, Wu X M,<br>
Weater F. C, Zach M P, Favier F, Murray H, Imaru K,<br>
weare the minimal properties of Moscore-<br>
2010, 224(7), 5378-5382.<br>
2010, 224(7), 5378-5382.<br>
2010, 224(7), Veng D S. Nickel nanocon-array apported silicon anode<br>
or high-performance liftiminal movies are the first liftiminal movies are the produced by the control of the stable materials and the materials for stable and the stab or high-performance lithium-ion batteries[J]. Adv. Mater.<br>
on the metal amoveire arrays[M]. USA: Sple-Int. Soc. Opti-<br>
on 22(47): 5378-5382.<br>
storage JSM, Names (and Spleeting: 2002). And M. Rabrication<br>
stars (AT) Amoreon [6] Wang X H, Yang Z B, Sam X L, L is X W, Wang D S, Wang<br>
P. J Yin A J, L i J, Jian W, Bennett A J, Xu J M, Fabrication<br>
P. Jie D Y. NiO ameotone army electrode with high care of highly ordered metallic nurewite army by electroplating over a Au seed layer modified by a disul-<br>fide[J]. J. Electrochem. Soc., 2009, 156(4): D155-D167.<br>Dow W P, Lu C W, Lin J Y, Hsu F C. Highly selective<br>Cu electrodeposition for filling through silicon holes [J fide[J]. J. Electrochem. Soc., 2009, 156(4): D155-D167.<br>
[16] Dow W P, Lu C W, Lin J Y, Hsu F C. Highly selective<br>
Cu electrodeposition for filling through silecon holes [J].<br>
Electrochem. Solid State Lett., 2011, 14(6): D Dow W P, Lu C W, Lin J Y, Hsu F C. Highly selective<br>Cu electrodeposition for filling through silicon holes [J].<br>Electrochem. Solid State Lett., 2011, 14(6): D63-D67.<br>Gu C, Tu J. One-step fabrication of nanostructured Ni<br>fi Cu electrodeposition for filling through silicon holes [J].<br>Electrochem. Solid State Lett., 2011, 14(6): D63-D67.<br>Gu C, Tu J. One-step fabrication of nanostructured Ni<br>film with Lotus effect from deep eutectic solvent[J].<br> Electrochem. Solid State Lett., 2011, 14(6): D63-D67.<br>Gu C, Tu J. One-step fabrication of nanostructured Ni<br>film with Lotus effect from deep eutectic solvent[J].<br>Langmuir, 2011, 27(16): 10132-10140.<br>Walter E C, Zach M P, F Gu C, Tu J. One-step fabrication of nanostructured Ni<br>film with Lotus effect from deep eutectic solvent[J].<br>Langmuir, 2011, 27(16): 10132-10140.<br>Walter E C, Zach M P, Favier F, Murray B, Inazu K,<br>Hemminger J C, Pemer R M. film with Lotus effect from deep eutectic solvent [J].<br>
Langmuir, 2011, 27(16): 10132-10140.<br>
[18] Walter E C, Zach M P, Favier F, Murray B, Inazu K,<br>
Hemminger J C, Penner R M. Electrodeposition of porta-<br>
ble metal nano Langmuir, 2011, 27(16): 10132-10140.<br>
Walter E C, Zach M P, Favier F, Murray B, Inazu K,<br>
Hemminger J C, Penner R M. Electrodeposition of porta-<br>
ble metal nanowire arrays[M]. USA: Sple-Int. Soc. Opti-<br>
cal Engineering, 20 Walter E C, Zach M P, Favier F, Murray B, Inazu K,<br>Hemminger J C, Penner R M. Electrodeposition of porta-<br>ble metal nanowire arrays[M]. USA: Sple-Int. Soc. Opti-<br>cal Engineering, 2002.<br>Yin A J, Li J, Jian W, Bennett A J, X Hemminger J C, Penner R M. Electrodeposition of porta-<br>ble metal nanowire arrays[M]. USA: Sple-Int. Soc. Opti-<br>cal Engineering, 2002.<br>Yin A J, Li J, Jian W, Bennett A J, Xu J M. Fabrication<br>of highly ordered metallic nanow ble metal nanowire arrays[M]. USA: Sple-Int. Soc. Optical Engineering, 2002.<br>
[19] Yin A J, Li J, Jian W, Bennett A J, Xu J M. Fabrication<br>
of highly ordered metallic nanowire arrays by electrode-<br>
position[J]. Appl. Phys. cal Engineering, 2002.<br>
Yin A J, Li J, Jian W, Bennett A J, Xu J M. Fabrication<br>
of highly ordered metallic nanowire arrays by electrode-<br>
position[J]. Appl. Phys. Lett., 2001, 79(7): 1039-1041.<br>
Huang B H, Zhang X F, Cai Yin A J, Li J, Jian W, Bennett A J, Xu J M. Fabrication<br>of highly ordered metallic nanowire arrays by electrode-<br>position[J]. Appl. Phys. Lett., 2001, 79(7): 1039-1041.<br>Huang B H, Zhang X F, Cai J N, Liu W K, Lin S. A nove
	-
	-

350.

- 
- the *K'#'* (*J. Electrochem.*) 2022, 28(7), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment., 2<br>
Elsherik A M, Erb U. Synthesis of bulk nanocrystalline<br>
inckel by pulsed electrodeposition[J]. J. Mater. Sci., 1995,<br>
30(22 (25) Electrochem.) 2022, 28(7), 2213008 (10 of 11)<br>
230. (24) Elsherik A M, Erb U. Synthesis of bulk nanocrystalline (33) Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
anickel by pulsed electrodeposition[J]. J. M
- 4 (*Letrochem.*) 2022, 28(7), 2213008 (10 of 11)<br>
2021, 28(7), 2213008 (10 of 11)<br>
2021, 28(7), 2213008 (10 of 11)<br>
2022, 28(7), 2213008 (10 of 11)<br>
2022): 5743-5749. [33] Tang M X, Zhang S T, Qiang Y J<br>
2022): 5743-5749 (a)  $\frac{1}{26}$  Let  $\frac{1}{2$ 102. Lai Z Q, Wang S X, Wang C, Hong Y, Zhou G Y, Chen<br>
(1). 1 Phys. Chen, A, 2002, 106(15): 3885-3890<br>
Y M, He W, Peng Y Q, Xiao D J. A comparison of typi-<br>
cal edulitives for copper electroplaning based on theoreti-<br>
East Z Q
- 
- 
- 7558.
- 
- Wang C, An M Z, Yang P X, Zhang J Q. Prediction of a<br>
new levelet (N-butyl-methyl piperidinium bromide) for<br>
through-hote electrophaling using molecular dynamics<br>
tem's density functional theory study of the chlo<br>
dimulati
- 

- $# \{\&\cong (J. \:Electrochem.)\ 2022, 28(7), 2213008\ (10 of 11)\}\newline \underline{\hspace{1cm}}$ 350. coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
[24] Elsherik A M, Erb U. Synthesis of bulk nanocrystalline [33] Tang M X, Zhang S T, Qiang Y J, Chen S the  $\{E\}^{\infty}(J. Electrochem.) 2022, 28(7), 2213008 (10 of 11)$ <br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Elsherik A M, Erb U. Synthesis of bulk nanocrystalline [33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
nickel (a) 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microv 28(7), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
[33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler fo (a), 2213008 (10 of 11)<br>
(a), 2213008 (10 of 11)<br>
(a), Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia filling with elect (a) 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microv 电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
s of bulk nanocrystalline [33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
on[J]. J. Mater. Sci., 1995
	- then the Help (*Let Tochem,* 2022, 28(7), 2213008 (10 of 11)<br>
	350.<br>
	Elsherik A M, Erb U. Synthesis of bulk nanocrystalline<br>  $[33]$  Tang M X, Zhang S T, Qiang Y 1, Chen B J, Lud L, Gao<br>
	Fickel by pulsed electrodeposition **Electrodeposition** (*B*)  $\frac{1}{24}$  (*Blectrochem.*) 2022, 28(7), 2213008 (10 of 11)<br> **Electrodeposition** (*B*). Synchesis of bulk nanocrystalline (33) Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
	inckel by pul place officient [J]. Dyes Pigment., 2016, 127: 187-188.<br>
	Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
	J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
	dine as a potential leveler for microvia filling with ele 28(7), 2213008 (10 of 11)<br>
	coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
	[33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
	J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
	dine as a potential leveler fo (10 of 11)<br>
	coefficient[J]. Dyes Pigment., 2016, 127: 187-188.<br>
	Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
	J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
	dine as a potential leveler for microvia filling w ), 2213008 (10 of 11)<br>
	coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
	Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
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Elsherik A. M. Erb U. Synthesis of bulk nanoerystalline [33] Tang M X, Zhang S T, Qiang Y J, Ch through-hole electroplating using molecular dynamics  $\frac{10}{25}$ <br>  $\frac{10}{25}$ <br>
Simulations and will have the coefficient (JI, Dyes Pigment, 2016, 127: 187-188.<br>
Elsheink A M, Erb U. Symbesis of bulk nanocrystalline<br>
interactions (133) T mg M, X, Zmag 5, C, Qim 2 1, 46-Dimet 350.<br>
[24] Elsherik A M, Erb U. Synthesis of bulk nanocrystalline [33] Tang M X, Zhung S T, Qiang Y J, Chen S J, Loo L, Goo<br>
mickel by pulsed lecterodeposition(1). 1. Mater. Sci., 1995, J. The L, Com Z J, 4, Demethyl-2 em ectrolication and variable phosphasic of fitsion (13) posterization (13) Tang M. Zhang S. T. Qiang M. Computed and the station in the station of th Eisherik A M, Erb U. Synthesis of bulk nanocystalline [33] Tang M X, Zhang S T, Qiang Y J, Chen 5 J, Luo L, Ga<br>
included electrodeposition[J] J. Mater. Sei, 1995,  $N$ , Feng L, Qio Z 1. 4,6-Durently 2-mercaptoryining of po nicel by pulsed electrodeposition[J]. J. Mater. Sci., 1995,<br>
27 Y. Feng L, Oin Z J. 4, 6-Dimethyl-2-mercaptopyrimi-<br>
29(2): 5743-5749.<br>
29(2): 5743-5749.<br>
2001 Density funcions and policing with electrodeposition [J]. App 30(22): 5743-5749.<br>
Chem. Z, Dial VI. Sti X Y, Li J H. Growth and<br>
compendency transity electrochemental is of redeted neckel nanoeones routed<br>
1340 Oldah J, Van Alsseny C, Samigrahi A B. Condenses<br>
1390 Oldah J, Van Alss morphology tuning of ordered nickel annocones routed<br>
230 John J, Van Alsenoy C, Samigrabi A B, Condesse<br>
2020, 308: 145291.<br>
2020, 308: 145291.<br>
2020, 308: 145291.<br>
2020, 308: 146291.<br>
2020, 308: 146291.<br>
2020, 308: 14629 by one-step pulse electrodeposition[1]. Appl. Surf. Sci.,<br>  $\frac{1}{2}$  finitial functions derived from stockholder elarges: Assess-<br>  $2020$ , 508, 14520, 908 km as Carbon nano-of their performance as local reactions being Y 2020, 508: 145291.<br>
Lai Z Q, Wang S, Yang S, Yang S, Yang C, Hong Y, Zhou G Y, Chen<br>
Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>
Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>
and additives for copper electrophating Y M, He W, Peng Y Q, Xino D J. A comparison of typi-<br>
ed additives for copper cleectoplating based on theoretic and the NK ow NS H, Sun (Y, Chen S, The Copper Content<br>
ed admitterial based on theoretic and the W, St M G W (a). 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microv  $28(7)$ ,  $2213008 (10 of 11)$ <br>
coefficient[J]. Dyes Pigment,  $2016$ ,  $127: 187-188$ .<br>
[33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential level (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia filling wi (19.213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
I Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia (a), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microv ), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dime as a potential leveler for microvia  $28(7)$ ,  $2213008(10 \text{ of } 11)$ <br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
[33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential level (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
1 V, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia filling w ), 2213008 (10 of 11)<br>
coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>
dine as a potential leveler for microvia filling with electro-<br> coefficient[J]. Dyes Pigment, 2016, 127: 187-188.<br>
[33] Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>
J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercarotrynimi-<br>
dine as a potential leveler for microvia filling with elec Tang M X, Zhang S T, Qiang Y J, Chen S J, Luo L, Gao<br>J Y, Feng L, Qin Z J. 4,6-Dimethyl-2-mercaptopyrimi-<br>dine as a potential leveler for microvia filling with electro-<br>plating copper[J]. RSC Adv., 2017, 7(64): 40342-40353 dine as a potential leveler for microvia filling with electro-<br>plating copper[J], RSC Adv., 2017, 7(64): 40342-40353.<br>[34] Oldh J, Van Alsenoy C, Sannigrahi A B. Condensed<br>fukui functions derive df from stockholder charges plating copper[J]. RSC Adv., 2017, 7(64): 40342-40353.<br>Oldh J, Van Alsenoy C, Sannigrahi A B. Condensed<br>tikui functions derived from stockholder charges: Assessment of their performance as local reactivity descriptors<br>[J]. Oldh J, Van Alsenoy C, Sannigrahi A B. Condensed<br>tikui functions derived from stockholder charges: Assessment of their performance as local reactivity descriptors<br>[J]. J. Phys. Chem. A, 2002, 106(15): 3885-3890.<br>Lai Z Q, W fikui functions derived from stockholder charges: Assessment of their performance as local reactivity descriptors<br>[J]. J. Phys. Chem. A, 2002, 106(15): 3885-3890.<br>Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>Hong Y, Zho ment of their performance as local reactivity descriptors<br>
[J]. J. Phys. Chem. A, 2002, 106(15): 3885-3890.<br>
[35] Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>
Hong Y, Zhou G Y, He W, Su X H, Sun Y K, Tao Y G,<br>
Lu X Y. [J]. J. Phys. Chem. A, 2002, 106(15): 3885-3890.<br>Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>Hong Y, Zhou G Y, He W, Su X H, Sun Y K, Tao Y G,<br>Lu X Y. Temperature-dependent inhibition of PEG in<br>acid copper plating: The Lai Z Q, Wang C, Huang Y Z, Chen Y M, Wang S X,<br>Hong Y, Zhou G Y, He W, Su X H, Sun Y K, Tao Y G,<br>Lu X Y. Temperature-dependent inhibition of PEG in<br>acid copper plating: Theoretical analysis and experiment<br>evidence[J]. Mat
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	- 220.
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- cal additives for copper electroplating based on theoretis  $\text{U}_\text{NN}$ . A For W, Tempetature dependent milibition of TEG in  $\text{U}_\text{NN}$ . The energy of bythe milibition of TEG in  $\text{U}_\text{NN}$ . A M F. Tempetature dependen 10. (Comput. Mater. Sci., 2018, 147: 95-<br>
16. X. Y. Temperature-dependent imhibition of PEG in<br>
162. Y. Aming P. X. Zhang J. Q. Prediction of a<br>
163. Computer philing: Theoretical enalysis and copernic results<br>
then used t 102.<br>
waid copper phating: Theoretical analysis and experiment<br>
Wevelvelvelvelvely piperdinium homide) for<br>
New Yevelvelvely (N-huty-methyl piperdinium homide) for<br>
two Vevelvel, (N-huty-methyl piperdinium homide) for<br>
Ho new leveler (N-butyl-methy piperidinium bromide) for<br>
simulation (36) Saraireb S.A, Altaraword M, Taraword M. Nanotye-<br>
simulations[1]. Electrochem Commun, 2012.18: 104-107.<br>
239 Sun H, Ren F, Herior (100) surface[J]. Nano Hong Y, Zhou G Y, He W, Su X H, Sun Y K, Tao Y G,<br>Lu X Y. Temperature-dependent inhibition of PEG in<br>acid copper plating: Theoretical analysis and experiment<br>evidence[J]. Mater. Today Commun., 2020, 24: 100973.<br>Saraireh S H976-H981. acid copper plating: Theoretical analysis and experiment<br>
evidence[J]. Mater. Today Commun., 2020, 24: 100973.<br>
[36] Sarairely functional theory sudvy of the chlorine ad-<br>
soming on the Fe (100) surface[J]. Nanotechnol. Re evidence[J]. Mater. Today Commun., 2020, 24: 100973.<br>Saraireh S A, Altarawneh M, Tarawneh M A. Nanosystem's density functional theory study of the chlorine ad-sorption on the Fe(100) surface[J]. Nanotechnol. Rev., 2021, 10 Saraireh S A, Altarawneh M, Tarawneh M A. Nanosystem's density functional theory study of the chlorine adsorption on the Fe (100) surface [J]. Nanotechnol. Rev., 2021, 10(1): 719-727.<br>Tarasevich Y I. The surface energy of
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# 电沉积纳米锥镍的生长机理及其性能的研究 <sub>电化学(*J. Electrochem.*) 2022, 28(7), 2213008 (11 of 11)<br><br><br>**长锥镍的生长机理及其性能的研究**</sub>

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摘要:本文通过恒电流沉积法在柔性覆铜基板上制备了具有纳米锥阵列结构的黑色镍层,制备的纳米锥镍的底 电化学(*i. Electrochem.*) 2022, 28(7), 2213008 (11 of 11)<br> **电沉积纳米锥镍的生长机理及其性能的研究**<br>
100 nm,养养婴,主种,洪延",陈苑明,苏元章,何为!<br>
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3.厦门集性电子研究废有限公司 &厦门张信电平标准的公 结构形貌的影响,结果表明低电流密度和高主盐浓度有利于纳米锥镍的形成。电沉积过程中保持镍离子的供应 充足是锥镍结构产生的关键因素之一,而高电流密度会影响镍离子浓度的浓差极化,从而影响锥镍的成核过程。 温度、主盐浓度以及结晶调整剂的变化会导致镍颗粒的形貌发生圆包状和针锥状结构的相互转化。温度升高具有 一定的细化晶粒作用,锥镍结构需要在大于 50 ℃ 的条件下生成。结晶调整剂能够改变沉积过程中的晶面择优生 <sup>长</sup>袁且可以调控镍晶粒的形貌袁使得生成的锥结构分布均匀<sup>袁</sup> 颗粒细致<sup>遥</sup> 结果表明袁<sup>在</sup>4.0 mol窑<sup>L</sup> 长,且可以调控镍晶粒的形貌,使得生成的锥结构分布均匀, 颗粒细致。结果表明,在4.0 mol·L<sup>,</sup> NH Cl 和 1.68 mol·L<sup>.1</sup> NiCl<u>.</u>·6H,O 体系中沉积出分布均匀的纳米锥镍阵列结构。本文利用氯化铵作为纳米锥镍的晶体改性剂<sub>,</sub> 通过分子动力学模拟理论上分析了 NH4+ 在镍表面的吸附过程。计算结果表明镍不同晶面上 NH4+吸附能的差异 引起各晶面镍沉积速率的差异,从而导致纳米锥镍阵列的形成。本文呢进一步结合形貌表征,提出了纳米锥镍阵 列的电沉积生长的两步生长机理,包括前期的成核生长和后期的核生长过程,前期成核过程为优势生长,生成大 量的晶核,为锥镍的生长提供了生长位点,而后期的核生长过程表现为锥状镍核的择优生长,最终形成完整均匀 的锥镍阵列结构。本文制备的纳米锥镍结构还具有优异的亲水性和良好的吸光效果,对于近紫外和可见光的吸 收率大于 95%, 具有较好的应用前景。

关键词: 纳米锥镍阵列; 电沉积; 分子动力学模拟; 柔性