[Journal of Electrochemistry](https://jelectrochem.xmu.edu.cn/journal)

[Volume 28](https://jelectrochem.xmu.edu.cn/journal/vol28) | [Issue 1](https://jelectrochem.xmu.edu.cn/journal/vol28/iss1)

2022-01-28

A High-Performance Continuous-Flow MEA Reactor for Electroreduction CO2 to Formate

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Recommended Citation

Pei-Xuan Liu, Lu-Wei Peng, Rui-Nan He, Lu-Lu Li, Jin-Li Qiao. A High-Performance Continuous-Flow MEA Reactor for Electroreduction CO₂ to Formate[J]. Journal of Electrochemistry, 2022, 28(1): 2104231. DOI: 10.13208/j.electrochem.210423 Available at:<https://jelectrochem.xmu.edu.cn/journal/vol28/iss1/3>

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[Article] DOI: 10.13208/j.electrochem.210423 Http://electrochem.xmu.edu.cn

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 **Ph-Performance Continuous-Flow MEA Reactor for

Electroreduction CO₂ to Formate

Pei-Xuan Liu¹⁴, Lu-Wei Peng^{1#}, Rui-Nan He¹, Lu-**, Lu-Lu Li1 $\frac{1}{2}$ *L. Electrochem,* 2022, 28(1), 2104231 (1 of 9)
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 A High-Performance Continuous-Flow MEA Reactor for
 Electroreduction CO₂ to Formate

Pei-Xuan Liu¹⁸, Lu-Wei Peng¹⁸

2. *L. Electrochem.* 2022, 28(1), 2104231 (1 of 9)
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Pei-Xuan Liu¹⁶, Lu-Wei Peng¹⁶, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qia ISITACE:** The isotenchemical cantom dioxide reduction reaction (CORR) is a promising approach to produce liquid fuels and

Instituted chemical by utilizing intermittent renewable electricity for mitigating environmenta **Abstract:** The electrochemical carbon dioxide reduction reaction (CORR) is a promising approach to product liquid fitels and

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industrial chermicals by utilizing intermitient renewable electricity for mitigating encoronn industrial chemicals hy utilizing intermittent renewable electricity for mitigating environmental problems. However, the traditional

H-type reactors steriously limits the electrochemical performance of CO,RR due to the l H-spe reactor seriously limits the electrochemical performance of COAR due to the low CO, solubility in electrolyte, and high obmit resistance counter (we observe the bow content of the above problems. Herein, we demonstr bimic resistance caused by the large distance hetween two electrodes, which is unbeneficial for industrial application. Herein, we
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demonstrated a high-percell, the microscopy of the microscopy of the demonstrate concerning CO, to forma g, *conguta Untrersary*, *stangaat 201020, Cnina;*

ological Security, Shanghai 200092, China)

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r mitigating environmental problems. However, the traditiona orogical security, shangiata 200092, Chinta)

1 (CO_SRR) is a promising approach to produce liquid fuels and

CO_SRR due to the low CO₂ solubility in electrolyte, and high

es, which is unbeneficial for industrial app α (CO₃RR) is a promising approach to produce liquid fuels and
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CO₂RR due to the low CO₂ solubility in electrolyte, and high

es, which is unbene r mitigating environmental problems. However, the traditional CO₂RR due to the low CO₂ solubility in electrolyte, and high stock the is unbeneficial for industrial application. Herein, we orde assembly (MEA) reactor b **Absortigate:** The electrochemical carbon dioxide reduction reduction reduction reduction reduction reduction \mathbf{A} **Hitp://electrochem.xmu.educm**
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Pei-Xuan Liu^{te}, Lu-Wei P **Example 1**
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Jin-Li Qiao^{1,2*}

hanghai 201620, China;

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 Solubility in electrolyte, and high

solubility in electrolyte, and high

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 Http:/ μ^{18} , Lu-Wei Peng^{1#}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qiao^{12*}
 M Science and Engineering, Donglua Universit **OOF 10.1526831atenvielm.210425** Interviewent current **A High-Performance Continuous-Flow MEA Reactor for**
 Electroreduction CO₂ to Formate

Pei-Xuan Liu^{te}, Lu-Wei Peng^{te}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qiao¹²

(*I. College of Environmental Science and Engineer* **A High-Performance Continuous-Flow MEA Reactor for**
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Pei-Xuan Liu^{te}, Lu-Wei Peng^{te}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qiao¹²

(*I. College of fractromental Science and Engineer* **EA Reactor for**

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ity, Jin-Li Qiao^{1,2*}

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hanghai 200092, China)

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v CO₂ solubility in electrolyte, a **Example 1.12 College of 2.11 V. The Study Provides a provide Section CO₂ to Formate

Pei-Xuan Liu¹⁴, Lu-Wei Peng^{ti}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qiao¹²⁶

(***I. College of Environmental Science and Engineerin* **Electroreduction CO₂ to Formate**

Pei-Xuan Liu^{lg}, Lu-Wei Peng^{lg}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qia

(*I. College of Environmental Science and Engineering, Donghua University, Shamghai 201

2. Shanghai Institut* Pei-Xuan Liu^{li}, Lu-Wei Peng^{ie}, Rui-Nan He¹, Lu-Lu Li¹, Jin-Li Qiao¹²
(*I. College of Fanitrommental Science and Engineering, Donghua University, Shamghai 200620, China;
2. Shamghai Institute of Pollution Control*

The excessive consumption of fossil thel by an-

dtropological behavior has caused be increasing CO₃ CH_CH_OH), while formate or formic acid, due to its

dtropological behavior in the atmosphere, thus, intrigu-

ingle

I Introduction

The excessive consumption of fossil fuel by an-

ducts (CO, formate, CH_OH) and C₅ products C₁pro-

hropological behavior has caused the interessing CO₂ CH₂CH_OH), while formate or formic acid, **roduction**
 conduction
 **complementing¹⁸¹. The products of CO₂RR include C₁pro-

gigal behavior has caused the increasing CO₂ CH₅CH₂OH), while formate or formic acid, due to its

tain level in the atmospher 1** Introduction temperature^[6]. The products of $CO₂RR$ include $C₁$ pro-Innexilie electrochary in the smooth of the controlling and since the catalytic and the smooth and these protocols and the smooth o CO2007 man as near was won a control of the production at the cost of the control of the production. Surprisingly, the production rate of formic reached 163 µmol-h''-em'ni-0.91 V_{SB} with the edl voltage of 3.17 V. This s of 3.17 V. This study provides a promising path to overcome mass transport imitations of the electrochemical CO₂RR and to separate liquid from gas products.
 Key words: electrochemical reduction; carbon dioxide; flow me liquid from gas products.
 Key words: electrochemical reduction; carbon dioxide; flow MEA reactor; electrolyzer
 Chemical CO-REA include C, pro-
 The excessive consumption of fossil fuel by an-
 dues (CO, format Key words: electrochemical reduction; carbon dioxide; flow MEA reactor; electrolyzer
 1 Introduction

The excessive consumption of fossil fuel by an-

thropological behavior has caused the increasing CO₂. CH₅CH₅ CO₂RR due to the low CO₂ solubility in electrolyte, and high
ss, which is unbeneficial for industrial application. Herein, we
rode assembly (MEA) reactor based on a self-growing Cu/Sn
o formate. Compared with an H-typ es, which is unbeneficial for industrial application. Herein, we
rode assembly (MEA) reactor based on a self-growing Cu/Sn
o formate. Compared with an H-type cell, the MEA reactor not
 V_{w} , but also maintains high Far rode assembly (MEA) reactor based on a self-growing Cu/Sn

o formate. Compared with an H-type cell, the MEA reactor not
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designed the new CO₂RR system t o formate. Compared with an H-type cell, the MEA reactor not V_{ww}), but also maintains high Faraday efficiency of formate designed the new CO₃R system to effectively separate the reached 163 μ mol·h⁻¹·cm² at -0. V_{well} , but also mantams high Faraday efficiency of formate
elesigned the new CO₂RR system to effectively separate the
tecacher is reached 163 µmol·h¹·cm³ at-0.91 V_{bulk} with the cell voltage
ensport limitatio designed the liew Co_SKK system to encetively separate the reached 163 μ mol·h⁻¹·cm⁻at-0.91 V_{BB} with the cell voltage anasport limitations of the electrochemical CO_SRK and to separate may about the developm EA reactor, electrolyzer

EA reactor, electrolyzer

EA reactor, electrolyzer

EA reactor, electrolyzer

temperature^[6]. The products of CO₂RR include C₁ pro-

ducts (CO, formate, CH₃OH) and C₂, products (C₂H₄ EA reactor; electrolyzer

EA reactor; electrolyzer

temperature^[6]. The products of CO₃RR include C₁ pro-

ducts (CO, formate, CH₃OH) and C₂¹ products (C₂H₄,

CH₃CH₂OH), while formate or formic acid, d EA reactor; electrolyzer
temperature^[6]. The products of CO₂RR include C₁ pro-
ducts (CO₂ formate, CH₃OH) and C₂, products (C₂H₄,
CH₂CH₂OH), while formate or formic acid, due to its
high hydrogen conte

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 $4k\mathcal{Z}cL$ *Electrochern*, 2022, 28(1), 2104231 (2 of 9)

Hysts due to its simple fabrication¹¹⁹. However, the tracke (GDF), which can allow CO₂ molecules to be di-

H-type reactor has certain limitations, such as l $H_0 \gg H_0 \gg H_0 \gg H_0 \gg H_0 \gg H_0$

by the case of this simple fabrication¹⁰¹. However, the troto (GDE), which can allow CO₂ molecules to be di-

H-type reactor has certain limitations, such as large

electrode divariants $4E\div(L\,Electrochem, 2022, 28(1), 2104231, 2 of 9)$

flysts due to its simple fabrication¹⁽⁹⁾. However, the

trole (GDE), which can allow CO₂ molecules to be di-

H-type reactor has certain limitations, such as large

recelly re Iysis due to its simple fabrication ¹²¹. However, the tree of GDE), which can allow CO₃ molecules to be di-
H-type reactor has cretain limitations, such as large reedty reduced to various products. Nevertheless, the
el lysts due to its simple fabrication¹¹⁰. However, the trode (GDF), which can allow CO₂ molecules to be di-
H-type reader has eartian limitations, such as large predly reduced to various products. Nevertheless, the
H-typ H-type reactor has certain limitations, such as large
electrode distance, low Co₂ sabability in the electrode distance, low Co₂ sabability in the electrode, which definitely by the
electrode, which definitely esses th electrode distance, low CO₂ solubility in the electro-

electrode, which definited by and large of H gas-literate of solution of the gas-liquison layer and the various

electrode, which definitely causes the limitation lyte and large pH gradient close to the surface of the flooding of the gas diffusion layer and the evapora-
electrode, which definitely causas the limitation of tion of the catholyte, therefore, water management is
eCO, m etectrode, which definitely causes the limitation of

colones transfer in the questosial to keep a stuble gas-liquid of GDP²⁰²¹³. Thus,

performance of CO_SR.

It is necessary to design a new type of reaction

In order CO₂ mass transfer in the aqueous and the inferior essential to keep a stable gas-liquid of GDE^{na, 21}. Thus,

In order to meet to meet the denands of industrial applica-

it is necessary to design a new type of reactio performance of CO₃RR.

it is necessary to design a new type of reaction do-

In order to meet the deneands of industrial applica-

it is necessary to design a new type of reaction for CO₅RR, developing the reaction sy In order to meet the demands of industrial applieas

trices to enable the widely used of CO_JRR for practi-

trice to FO/RR, developig the reaction system is an each applications.

transport is one calculated membrane cl tion for CO_RR, developing the reaction system is an cal applications.

argent job to achieve sufficient rate of CO_C conver-

considering all the challenges of an H-type

sion and high current density^{tha}. As the core urgent job to achieve sufficient rate of CO₁ convertional and the challenges of an H-type
sion and high current density¹⁰² As the core part of re-
equivalent, the interval associated configuration and a
setionsystem while the anolyte and eatholyte are continuously vir-

collated by peristalite pumps. CO, dissolved in the catalytis. From the other point, MF.A reactor can

continuous catholyte can be transported to the inter-

cation-e culated by peristaltic pumps. CO₂ dissolved in the catalysts. From the other point, MEA reactor can
encontinuous catholyte can be transported to the inter-

frace of gas-liquid-catalyst, where CO₂ is reduced to oming continuous eatholyte can be transported to the inter-
largely shorten the internal resistance and reduce
the face of gas-liquid-catholy, where CO, is reduced to
diminipolarization between cathode and anode. As a
various p face of gas-liquid-catalyst, where CO, is reduced to

ominic polarization between cathode and anode. As a

various products, namely formic acid, methanol, CO,

erluging entity formic acid, methanol, CO, is center formic s various products, namely formic acid, methanol, CO, result, the as-designed flow MEA reactor showed cx-
ethylene, etc. This H-type flow-cell can enhance eellent formate selectivity (89.56%), high current den-
ethylene, ac ethylene, etc. This H-type flow-cell can can
hance ellent formate selectivity (89.56%), high current den-
gas-liquid mass transfer of CO₂ by circulating sity (47.56 mA - cm⁻ at -0.91 V_{art}) and durable stabil-
cathol gas-liquid mass transfer of CO₂ by circulating

sity (47.56 mA·cm² at -0.91 V_{ww}) and durable stabil-

centbayte, however, the products of CO₃R might

cross over the segnated membrane from cathode to

any come cross eatholyte, however, the products of CO_RRR might

ity (20 h), which is superior to the H-type reactor ow-

eroses over the separated membrane from cathode to

and do¹⁷. Noticing this problem, Yang et al.¹⁹⁴ designed
 cross over the separated membrane from eathode to

and the higher solubility of CO₂ shorter distance

and a 3-compartment cell configuration to produce formic

and and \sim 6.1¹⁶ absigned between the electrodes, lower anode¹⁷¹¹, Noticing this problem, Yang et al.¹⁹ designed between the electrodes, lower ohmic resistance and
a³-compartment cell configuration to produce formic
calce between the electrodes, lower ohmic resistance an a 3-compartment cell configuration to produce formic

eincid directly. The 3-comparement cell configuration

econsisted of a cathode compartment, an anode com-

econsisted of a cathode compartment, an anode com-

exparemen acid directly. The 3-comparement cell configuration

such, we also explore the influence of different elec-

consisted of a carbote compartment, an anode comparement as

partment and a center flow compartment. In this sys

 $\#E\# (L \n{Electrochem.}) 2022, 28(1), 2104231 (2 of 9)$

lysts due to its simple fabrication^[15]. However, the trode (GDE), which can allow CO₂ molecules to be di-

H-type reactor has certain limitations, such as large retly redu then \mathbb{R}^n (*J. Electrochem.*) 2022, 28(1), 2104231 (2 of 9)
Jysts due to its simple fabrication^[15]. However, the trode (GDE), which can allow CO₂ molecules to be di-
H-type reactor has certain limitations, such $\# \# \#$ (*L Electrochem.*) 2022, 28(1), 2104231 (2 of 9)
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Ilysts due to its simple fabrication^[15]. However, the

Irat-other anallow CO₂ molecules to be di-

H-type reactor has certain limitations, such as large

electrod $\pm \frac{\mu_0 \cdot \mu_0 \cdot \mu_0}{\mu_0 \cdot \mu_0 \cdot \mu_0}$ (*L Electrochem.*) 2022, 28(1), 2104231 (2 of 9)

Hysts due to its simple fabrication¹¹³¹. However, the trode (GDE), which can allow CO₂ molecules to be di-

H-type reactor has $\text{H}(E^{\omega})$ (*L Electrochem.*) 2022, 28(1), 2104231 (2 of 9)

Its due to its simple fabrication^[15]. However, the trode (GDE), which can allow CO₂ molecules to be di-

representor has certain limitations, such as l \pm (*E Eternehem.*) 2022, 28(1), 2104231 (2 of 9)
Jysts due to its simple fabrication¹¹⁹). However, the trode (GDE), which can allow CO₂ molecules to be di-
H-type reactor has certain limitations, such as large reet \pm 6. Electrochem, 2022, 28(1), 2104231 (2 of 9)

Uysts due to its simple fabrication¹⁹¹. However, the trode (GDE), which can allow CO₂ molecules to be di-

H-type reactor has certain limitations, such as large rect the method is simple fabrication¹¹⁹¹. However, the trock (GDE), which can allow CO; molecules to be di-
H-type reactor has certain limitations, such as large rectly reduced to various products. Nevertheless, the
electro $\pm \frac{1}{2}$ ($\pm \frac{1}{2}$))) abyts due to its simple fabrication¹⁹¹! However, the trotode (ODE), which can allow CO, molecules to be distinge 2, 28(1), 2104231 (2 of 9)
trode (GDE), which can allow CO_2 molecules to be di-
rectly reduced to various products. Nevertheless, the
channel of CO_2 transport would be prohibited by the
flooding of the gas diffusion l 2, 28(1), 2104231 (2 of 9)
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rectly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
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rectly reduced to various products. Nevertheless, the
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channel of CO₂ transport would be prohibited by the
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rectly reduced to various products. Nevertheless, the
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rectly reduced to various products. Nevertheless, the

channel of CO₂ transport would be prohibited by the

flooding of the gas diffusi 2, 28(1), 2104231 (2 of 9)
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channel of CO₂ transport would be prohibited by the
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rectly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion l (1), 2104231 (2 of 9)

le (GDE), which can allow CO₂ molecules to be di-

ly reduced to various products. Nevertheless, the

nnel of CO₂ transport would be prohibited by the

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trode (GDE), which can allow CO₂ molecules to be di-
rectly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
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channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion lay 2, 28(1), 2104231 (2 of 9)
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channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion lay 2, 28(1), 2104231 (2 of 9)
trode (GDE), which can allow CO₂ molecules to be directly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion lay 电化学(*J. Electrochem.*) 2022, 28(1), 2104231 (2 of 9)

on^[15]. However, the trode (GDE), which can allow CO₂ molecules to be di-

rectly reduced to various products. Nevertheless, the

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to the s

sion and high current density¹⁶⁰. As the core part of re-

actionsystem, the clearboyser includes H-type membrane electrodic assembly (MEA) reactor, in this

actionystem, the electrodic assembly (MEA) reactor. An H-type actionsystem, the electrolyzer includes H-type membrane electrode assembly (MEA) reactor, in this flow-cell, 3-compartment cell configuration and mem-
voice, we designed a novel MEA-based flow cell by thome electrode asse How-cell, 3-compartment cell configuration and mem-

brow elesigned a novel MEA-based flow cell by

brow-cell is based on the traditional H-type reactor, An H-type thoromianton of H-type flow-cell and MEA reac-

brow-cell brane electrode assembly (MFA) reactor. An H-type

the combination of H-type flow-cell and MEA reac-

dhow-cell is based on the traditional H-type reactor, tore. From one side, the critotation of catholyte can

while the flow-cell is based on the traditional H-type reactor,

which the analysis cross-minuous stably terms. To dissimilate the diffusion of CO₂ to the surface of electr-

while the analysis are comituated by peristalic pumps. 2, 28(1), 2104231 (2 of 9)
trode (GDE), which can allow CO₂ molecules to be di-
rectly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion l frode (GDE), which can allow CO₂ molecules to be directly reduced to various products. Nevertheless, the channel of CO₂ transport would be prohibited by the flooding of the gas diffusion layer and the evaporation of t trode (GDE), which can allow CO₂ molecules to be directly reduced to various products. Nevertheless, the channel of CO₂ transport would be prohibited by the flooding of the gas diffusion layer and the evaporation of t rectly reduced to various products. Nevertheless, the
channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion layer and the evapora-
tion of the catholyte, therefore, water management is
essent channel of CO₂ transport would be prohibited by the
flooding of the gas diffusion layer and the evapora-
tion of the catholyte, therefore, water management is
essential to keep a stable gas-liquid of GDE^[21,22]. Thus, flooding of the gas diffusion layer and the evapora-
tion of the catholyte, therefore, water management is
essential to keep a stable gas-liquid of GDE^{p1,22}. Thus,
it is necessary to design a new type of reaction de-
vi tion of the catholyte, therefore, water management is
essential to keep a stable gas-liquid of GDE^{p1,22}. Thus,
it is necessary to design a new type of reaction de-
vices to enable the widely used of CO₂RR for practi-
 essential to keep a stable gas-liquid of GDE^{pt, 24}. Thus,
it is necessary to design a new type of reaction de-
vices to enable the widely used of CO₂RR for practi-
cal applications.
Considering all the challenges of a it is necessary to design a new type of reaction de-
vices to enable the widely used of CO₂RR for practi-
cal applications.
Considering all the challenges of an H-type
flow-cell, a 3-compaertment cell configuration and vices to enable the widely used of CO₂RR for practical applications.
Considering all the challenges of an H-type flow-cell, a 3-compaertment cell configuration and a membrane electrode assembly (MEA) reactor, in this wo cal applications.
Considering all the challenges of an H-type
flow-cell, a 3-compaertment cell configuration and a
membrane electrode assembly (MEA) reactor, in this
work, we designed a novel MEA-based flow cell by
the co Considering all the challenges of an H-type
flow-cell, a 3-compaertment cell configuration and a
membrane electrode assembly (MEA) reactor, in this
work, we designed a novel MEA-based flow cell by
the combination of H-typ flow-cell, a 3-compaertment cell configuration and a
membrane electrode assembly (MEA) reactor, in this
work, we designed a novel MEA-based flow cell by
the combination of H-type flow-cell and MEA reac-
tor. From one side membrane electrode assembly (MEA) reactor, in this
work, we designed a novel MEA-based flow cell by
the combination of H-type flow-cell and MEA reac-
tor. From one side, the circulation of catholyte can
facilitate the dif work, we designed a novel MEA-based flow cell by
the combination of H-type flow-cell and MEA reac-
tor. From one side, the circulation of catholyte can
facilitate the diffusion of CO₂ to the surface of electr-
catalysts the combination of H-type flow-cell and MEA reac-
tor. From one side, the circulation of catholyte can
facilitate the diffusion of CO₂ to the surface of electr-
catalysts. From the other point, MEA reactor can
largely s for. From one side, the circulation of catholyte can
facilitate the diffusion of CO₂ to the surface of electr-
catalysts. From the other point, MEA reactor can
largely shorten the internal resistance and reduce
ohmic po facilitate the diffusion of CO₂ to the surface of electr-
catalysts. From the other point, MEA reactor can
largely shorten the internal resistance and reduce
ohmic polarization between cathode and anode. As a
result, th catalysts. From the other point, MEA reactor can largely shorten the internal resistance and reduce ohmic polarization between cathode and anode. As a result, the as-designed flow MEA reactor showed ex-
cellent formate se largely shorten the internal resistance and reduce
ohmic polarization between cathode and anode. As a
result, the as-designed flow MEA reactor showed ex-
cellent formate selectivity (89.56%), high current den-
sity (47.56 cellent formate selectivity (89.30%), fight current density (47.56 mA·cm² at -0.91 V_{BHE}) and durable stability (20 h), which is superior to the H-type reactor owing to the higher solubility of CO₂, shorter distance $Y(t)$ on the case of the H-type reactor condition, which is supprior to the H-type reactor owers to the higher solubility of CO₅, shorter distance tween the electrodes, lower ohmic resistance and arge transfer resistanc (KHCO₃), which is superior of the H-type relation of the higher solubity of CO₂, shorter distance the electrodes, lower ohin resistance and behave the electrodes, lower ohin resistance and otharge transfer resistance mg to the melectrodes, lower ohmic resistance and
between the electrodes, lower ohmic resistance and
charge transfer resistance of flow MEA reactor. As
such, we also explore the influence of different elec-
trolytic envir between the betweenes, between the distance and
sharp transfer resistence of flow MEA reactor. As
such, we also explore the influence of different elec-
trolytic environments in the flow MEA reactor, such
as bubbling CO₂ stands unance of now *influence* of different elec-
trolytic environments in the fluore of different elec-
trolytic environments in the fluore of different elec-
trolytic environments in the flow MEA reactor, such
as bubb

2 Experimental

 $\#E\#(J. Electron, 2022, 28(1), 2104231 (3 of 9)$
Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-
chased from Phychemi (HK) Limited Company. All
the chemicals were analytical grade and used in ex-
periments without further purific $\mathbb{E}(\mathbb{K} \neq L \text{ } \text{Electrochem.})$ 2022, 28(1), 2104231 (3 of 9)

Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

Externe the Areactor, several Teflon plates, two peristaltic

chased from Phychemi (HK) Limited Company. All the chemical grade and the method reported in our previous work^[23]. (Nation 117, DuPont) and Pti film. The effective Cu/Sn theoretical grade and used in ex-
 Example and used in ex- and electrolyte circuited company **E** *(Exerioriem.)* 2022, 28(1), 2104231 (3 of 9)
 E Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-
 EXECUTE: MEA reactor, several Teflon plates, two periments without further purification.
 EXECUTE: and electro ^{ELEC}[≠](*L Electrochem.*) 2022, 28(1), 2104231 (3 of 9)

Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

chased from Phychemi (HK) Limited Company. All pumps, a gas-liquid separation device for cat

the chemicals $#R\mathcal{L}(L\text{ }R\text{ }let\text{ }m)$
 $\frac{1}{2}$ agent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltic

assed from Phychemi (HK) Limited Company. All

pumps, a gas-liquid separation de (*k)*²²(*k) kleetnochem.*) 2022, 28(1), 2104231 (3 of 9)

Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltic

chased from Phychemi (HK) Limited Company. All

pumps, **EVALUATION**
 Example 12.5 (1.1 Carbon cloth (WOS 1009) was pur-

MEA reactor, several Tellon plates, two peristalic

chased from Phychemi (HK) Limited Company. All

pumps, a gas-liquid separation device for cathode

th **Example 1.1**
 CAUS Consider the chemical swere analytical grade and used in ex-
 Example 1.1
 C Hence C. Ltd. Carbon cloth (WOS 1009) was pur-

Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltic

chased from Phychemi (HK) Limited Company. All

pumps, a gas-liquid (d) *C*. Ltd. Carbon eloth (WOS 1009) was pur-

Reagent Co. Ltd. Carbon eloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltie

chased from Phychemi (HK) Limited Company. All pumps, a gas-liquid **EVALUATION**
 EXECUTE US ALLA CALUAT EXECUTE US ALLA CALUAT EXECUTE US ARE THE CONDICTON CONDICT THE PROPERTION (ITCL LIMITED CONDICTON THE PROPERTION CONDICTON THE PROPERTION OF THE PROPERTION OF THE PROPERTION CONDICTO $\frac{\text{td}(E\# (L \text{ Hetermchem}) 2022, 28(1), 2104231 (3 of 9)}{\text{Hence of the chemical system}}$

Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltic

chased from Phychemi (HK) Limited Company. All

pumps, a was stirred to a transparent solution and sonicated for **EVERTUAL EXAMPLE (1.** *Bimetalic* Cu/Sn (199)
 Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur- MEA reactor, several Teflon plates, two peristaltic

chased from Phychemi (HK) Limited Company. All

pumps, a gas-liquid Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon plates, two peristaltic

classed from Phychemi (HK) Limited Company. All

pumps, a gas-liquid separation device for cathode

the chemicals wer Reagent Co. Ltd. Carbon cloth (WOS 1009) was pur-

MEA reactor, several Teflon phlates, two peristaltic

chased form Phyehenii (IK) Limited Company. All pumps, a gas-liquid separation device for eached

the chemicals were chased from Phychemi (HK) Limited Company. All pumps, a gas-liquid separation device for cathode

the elementals were analytical grade and used in ex-

ore MEA reactor with a sandwich structure was
 2.2 Preparation of th the chemicals were analytical grade and used in ex-

exact correct correct to the same of A reactor with a sambivel structure was

2.2 **Preparation of the Electrodes** ends of Cu/Sn electrode, an anion-exchange mem-

Nitro periments without further purification. core MEA reactor with a sandwich structure was

2. Preparation of the Electrodes and core Cu/Sn electrodes, an amio-exchange mem-

Virtue-particle and the method reported in our pre 2.2 **Preparation of the Electrodes**

made of Cu/Sn electrode, an anion-exchannel wis the method reported in our previous work¹²³! brane (FAD, German) or a cation-exchange mode Specifically, 2.941 g Na,C_aH,O₂ 2H,O (0 Nitrogen doped carbon cloth (N-CC) was prepared

brane (FAD, Germen) or a cation-exchange mem

via the method reported in our previous work^[23]. (Nafion 117, DuPont) and Pt film. The effective

Specifically, 2,941 g Na, the method reported in our previous work¹³¹. (Nafion 117, DuPont) and Pr film. The effective Cu/Sn

eigicinally, 2.941g No₁₆/L4,0, 24HQ (0.01 mol) and 0.0684 g CuCl₃ - 2H₂O (0.01 mol) and 0.0684 g CuCl₃ - 2H₂O Specifically, 2.941 g Na,C,H,O, 21:L(O (0.01 mol) and electrode area is 2 cm² and the distance between

of S. CH,N,O (0.01 mol) were mixed with 0.39 g working electrode and outnit clerctode is 4 mm. It

SnCl, 2EH,O (0.0 0.6 g CHN:O (0.01 mol) were mixed with 0.39 g

working electrode and counter electrode is 4 mm. It

SnCL: 2H(0,01 mol) and 0.0684 g CuCl; 2H(0

mol) and 0.0684 g CuCl; 2H(0

mol) in 100 mL deionized water stirring for

ME SnCl_z-2H₅O (0.01 mol) and 0.0684 g Cucl₃-2H₅O was worth noting that, CO₂ gas can bubble inside the (0.01 mol) in 100 mL deionized water stirring for MEA reactor. In addition, CO₂ gas was also continuate comple (0.01 mol) in 100 mL dcionized water stirring for MEA reactor. In addition, CO₁ gas was also continuous
complete dissolution. Then, 0.68 g CFNaO₂ (10 μ ma) ously purged into the KHCO, solution (150 ml). at
was added complete dissolution. Then, 0.68 g CHNaO-(10 µmol) ously purged into the KHCO, solution (150 mL) at
was sidered in the mentioned elear solution, which least 30 min, and then the CO_r-saturated 0.5 mol -1.¹
was sitred t was added in the mentioned clear solution, which

was sitred to a transparent solution and Somical dof ref. CMCO, solution was circulated into MEA reactor by

was core-lectrodeposit-

using a perisaltic pump (HUXI, HL-25) was stirred to a transparent solution and sonicated for

26 mm. The binentalic Cu/Sn was circletrodeaposite

and onto the pronous N-CC at the constant voltage (-0.75 and of the electrolyte was 13 mL ·min¹. After CO₂
 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

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and electrolyte circulation device for anode, while the

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core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

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and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

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and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2. 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich -1 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich 2, 28(1), 2104231 (3 of 9)

MEA reactor, several Teflon plates, two peristaltic

pumps, a gas-liquid separation device for cathode

and electrolyte circulation device for anode, while the

core MEA reactor with a sandwich rate of the electrolyte of the electrolyte correlation of the electrolyte circulation device for candode and electrolyte circulation device for anode, while the core MEA reactor with a sandwich structure was made of Cu/Sn pumps, a gas-liquid separation device for cathode
and electrolyte circulation device for anode, while the
core MEA reactor with a sandwich structure was
made of Cu/Sn electrode, an anion-exchange mem-
brane (FAD, Germen) and electrolyte circulation device for anode, while the
core MEA reactor with a sandwich structure was
made of Cu/Sn electrode, an anion-exchange mem-
brane (FAD, Germen) or a cation-exchange mem-brane
(Nafion 117, DuPont core MEA reactor with a sandwich structure was
made of Cu/Sn electrode, an anion-exchange mem-
brane (FAD, Germen) or a cation-exchange mem-brane
(Nafion 117, DuPont) and Pt film. The effective Cu/Sn
electrode area is 2 c made of Cu/Sn electrode, an anion-exchange mem-
brane (FAD, Germen) or a cation-exchange mem-brane
(Nafion 117, DuPont) and Pt film. The effective Cu/Sn
electrode area is 2 cm² and the distance between
working electrode nion-exchange mem-
exchange mem-brane
The effective Cu/Sn
ne distance between
electrode is 4 mm. It
an bubble inside the
as was also continu-
plution (150 mL) at
aturated 0.5 mol·L¹
into MEA reactor by
HL-25), and the f brane (FAD, Germen) or a cation-exchange mem-brane
(Nafion 117, DuPont) and Pt film. The effective Cu/Sn
electrode area is 2 cm² and the distance between
working electrode and counter electrode is 4 mm. It
was worth not (Nafion 117, DuPont) and Pt film. The effective Cu/Sn
electrode area is 2 cm² and the distance between
working electrode and counter electrode is 4 mm. It
was worth noting that, CO₂ gas can bubble inside the
MEA react electrode area is 2 cm² and the distance between
working electrode and counter electrode is 4 mm. It
was worth noting that, CO₂ gas can bubble inside the
MEA reactor. In addition, CO₂ gas was also continu-
ously pur is 2 cm² and the distance between

ode and counter electrode is 4 mm. It

mg that, CO₂ gas can bubble inside the

n addition, CO₂ gas was also continu-

to the KHCO₃ solution (150 mL) at

and then the CO₂-satura working electrode and counter electrode is 4 mm. It
was worth noting that, CO₂ gas can bubble inside the
MEA reactor. In addition, CO₂ gas was also continu-
ously purged into the KHCO₃ solution (150 mL) at
least 30 anode. MEA reactor. In addition, CO₂ gas was also continuously purged into the KHCO₃ solution (150 mL) at least 30 min, and then the CO₂-saturated 0.5 mol·L¹ KHCO₃ solution was circulated into MEA reactor by using a pe purged into the KHCO₃ solution (150 mL) at
30 min, and then the CO₂-saturated 0.5 mol·L¹
O₃ solution was circulated into MEA reactor by
a peristaltic pump (HUXI, HL-25), and the flow
of the electrolyte was 13 mL·m st 30 min, and then the CO₂-saturated 0.5 mol \cdot L⁻¹

ECO₃ solution was circulated into MEA reactor by

mg a peristaltic pump (HUXI, HL-25), and the flow

e of the electrolyte was 13 mL \cdot min⁻¹. After CO₂

se KHCO₃ solution was circulated into MEA reactor by
using a peristaltic pump (HUXI, HL-25), and the flow
rate of the electrolyte was 13 mL · min⁻¹. After CO₂
was electrochemically reduced in the MEA reactor,
the liqui 电化学(*J. Electrochem.*) 2022, 28(1), 2104231 (3 of 9)
WOS 1009) was pur-
mited Company. All pumps, a gas-liquid separation device for cathode
rade and used in ex-
and electrolyte circulation device for anode, while the
cat

 $#E\# (J. Electrochem.) 2022, 28(1), 2104231 (4 of 9)$ (Shanghai Chenhua). Before the electrochemical test

of CO₂ reduction, the cathode electrolyte solution

was saturated with highly-pure nitrogen (99.999%) in

was saturated with h **EACTE CO2** reduction, the cathode electrochemical test working electrode.

(Shanghai Chenhua). Before the electrochemical test working electrode.

of CO₂ reduction, the cathode electrolyte solution Gaseous products wer $\# \&\# \langle I. \text{ \textit{Electrochem.}} \rangle$ 2022, 28(1), 2104231 (4 of 9)

(Shanghai Chenhua). Before the electrochemical test

of CO₂ reduction, the cathode electrolyte solution

was saturated with highly-pure nitrogen (99.999%) in chr ^t[1](*k^{to}* (*L Electrochem.*) 2022, 28(1), 2104231 (4 of 9)

(Shanghai Chenhua). Before the electrochemical test

of CO₂ reduction, the cathode electrolyte solution

(Gaseous products were collected by the online ga metry (CV) and linear sweep voltammetry (LSV) were (Shanghai Chenhua). Before the electrochemical test

(Shanghai Chenhua). Before the electrochemical test

of CO₂ reduction, the cahote electrochemical test

was saturated with highly-pure nitrogen (99.999%) in

chromato **in Alteration** in the determination of the sectometerm $\hat{H}_{\text{grav}}(t)$ and $\hat{H}_{\text{grav}}(t)$ are about **Example 16.** Electrochemical test working electrode.
 (Shanghai Chenhua). Before the electrochemical test working electrode.

of CO₂ reduction, the cathode electrodyte solution Gaseous products were collected by the 50 and 5 mV窑^s $\pm 2k \neq 0.1$ at $k \neq 0.999996$ and $k \neq 0.000999996$ and the *C* is the system. Therefore, the system of the system (SC-2014C, Shimadzu), assess transled with highly-pure nitrogen **Examplaia Chembus).** Before the electrochemu, 2022, 28(1), 2104231 (4 of 9)

(Shamphai Chembus). Before the electrochemical test working electrode.

of CO₂ reduction, the cathode electrolyte solution Gaseous products (Shanghai Chembua). Before the electrochemical test working electrode.

(Shanghai Chembua). Before the electrochemical test working electrode.

(of Oc, reduction, the cathode electrodytre solution Gaseous products were co (Shanghai Chenhua). Before the dectree
hour potentios of the control of the potential conducts of the potention
of the control of the activate experiment of the case of the control of the case of the calibratic experiment (Shanghai Chenhua). Before the electrochemical test

(Shanghai Chenhua). Before the electrochemical test

or of Co, reduction, the cathode electrolyte solution. Gaseous products were collected by the online gas

was satur **Example 1** ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$ ($\frac{4\pi}{3}$) (Shanghai Chenhua). Before the electrochemical test
of CO₂ reduction, the cathode electrolyte solution
of CO₂ red anghai Chenhua). Before the electrochemical test working electrode.

CO₂ reduction, the cathode electrolyte solution Gaseous products were collected by the online gas

staturated with highly-pure nitrogen (99.999%) in c (Shanghai Chenhua). Before the electrochemical tst working electrode.

of CO₂ reduction, the calnote electrolyte solution Caseous products were collected by the online gas

was saturated with highly-pure nitrogen (99.99 2 reduction, the cathode electrolyte solution

Gascous products were collected by the online gas

corsele oxygen in thing the pH of 2.2014C, Shimadzu, as-

corsele oxygen from the solution. Cyclic volumm-

sembled with TC was saturated with highly-pure nitrogen (99.999%) in

order to capcing metholout Cyclic voltam-

sembled with TCD-2014C, Shimadzu, as-

order to capcing metholout Cyclic voltam-

employed to confirm the difference of curr order to expel oxygen from the solution. Cyclic voltam-

sembled with TCD-2014C and FID-2014C. Before

memployed to confirm the difference of current density

gas chromatography system, the gas samples were

im N₂ and C metry (CV) and linear sweep voltammetry (LSV) were the CO₂ carrying gas products were injected into the memboved to confirm the difference of current density gas chromotography system, the gas samples were piled potenti ployed to confirm the difference of current density gas chromatography system, the gas samples were

N₂ and CO₂ saturated condition upon different ap-

elementary of exaction defined by a filter bundle kit. The Farada N₃ and CO₂ saturated condition upon different ap-

dehumidified by a filter bundle kit. The Faradaic effi-

and S mV·s³ at room temperature in a three-elec-

according to the following equation.

and S mV·s³ at ro plied potentials. The scan rates of CV and LSV were ciency for gas products (CO and H₃) can be calculated

50 and 5 mV-s⁻² at room temperature in a three-clee-

trode system. Electrochemical impedance spectro-
 $F_{\nu_{$

mol \cdot L¹) at a pH of 7.5. Without further explanation,

equation. E) = E(vs. SCE) + 0.19/2 + 0.0991pH (1)

ine SEM images were used it

in e. EM images were used it

in e. EM images were used it

for user an orphology by a S-4800 field-

the twenty-hour electrolysis experiment

is the s ysis was carried on a Philips PW3830 X-ray diffrac-

3D-multilayered microstructure showe

tometer by using a Cu K_a radiation at 40 mA and 40

ties on the surface (Figure 2(A)), which

kV. Before the XRD test, all the s

$$
FE_{\text{HCOO}}(%) = \frac{2 \times n \times F}{Q} \times 100\% \tag{2}
$$
100%

2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products w 8(1), 2104231 (4 of 9)

orking electrode.

Gaseous products were collected by the online gas

romatography system (GC-2014C, Shimadzu), as-

mbled with TCD-2014C and FID-2014C. Before

c CO₂ carrying gas products were in 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 2, 28(1), 2104231 (4 of 9)

working electrode.

Gaseous products were collected by the online gas

chromatography system (GC-2014C, Shimadzu), as-

sembled with TCD-2014C and FID-2014C. Before

the CO₂ carrying gas prod 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 2, 28(1), 2104231 (4 of 9)
working electrode.
Gaseous products were collected by the online gas
chromatography system (GC-2014C, Shimadzu), as-
sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products 8(1), 2104231 (4 of 9)

orking electrode.

Gaseous products were collected by the online gas

romatography system (GC-2014C, Shimadzu), as-

mbled with TCD-2014C and FID-2014C. Before
 ϵ CO₂ carrying gas products were (1), 2104231 (4 of 9)

iking electrode.

Gaseous products were collected by the online gas

omatography system (GC-2014C, Shimadzu), as-

bled with TCD-2014C and FID-2014C. Before

CO₂ carrying gas products were injecte of 9)

...

.. ets were collected by the online gas

system (GC-2014C, Shimadzu), as-

CD-2014C and FID-2014C. Before

gas products were injected into the

ohly system, the gas samples were

filter bundle kit. The Faradai 1), 2104231 (4 of 9)

ing electrode.

succes products were collected by the online gas

matography system (GC-2014C, Shimadzu), as-

led with TCD-2014C and FID-2014C. Before
 CO_2 carrying gas products were injected into 2, 28(1), 2104231 (4 of 9)

working electrode.

Gaseous products were collected by the online gas

chromatography system (GC-2014C, Shimadzu), as-

sembled with TCD-2014C and FID-2014C. Before

the CO₂ carrying gas prod working electrode.

Gaseous products were collected by the online gas

chromatography system (GC-2014C, Shimadzu), as-

sembled with TCD-2014C and FID-2014C. Before

the CO₂ carrying gas products were injected into the
 chromatography system (GC-2014C, Shimadzu), assembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products were injected into the
gas chromatography system, the gas samples were
dehumidified by a filter bu sembled with TCD-2014C and FID-2014C. Before
the CO₂ carrying gas products were injected into the
gas chromatography system, the gas samples were
dehumidified by a filter bundle kit. The Faradaic effi-
ciency for gas pr O₂ carrying gas products were injected into the
hromatography system, the gas samples were
indified by a filter bundle kit. The Faradaic effi-
y for gas products (CO and H₂) can be calculated
ding to the following equ 电化学(*J. Electrochem.*) 2022, 28(1), 2104231 (4 of 9)

electrochemical test working electrode.

electrolyte solution Gaseous products were collected by the online gas

itrogen (99.999%) in chromatography system (GC-2014C,

\n- s chromatography system, the gas samples were humidified by a filter bundle kit. The Faradaic efficiency for gas products (CO and H₂) can be calculated cording to the following equation.
\n- $$
FE_{gas}-(\%) =
$$
\n $\frac{v}{60 \text{ s} \cdot \text{min}^{-1}} \times \frac{c}{24000 \text{ cm}^3 \cdot \text{mol}^{-1}} \times n \times F$ \n $\times 100\%$ \nWhere, v is the CO₂ flow rate, *n* is the number of
\n
	\n- cctrons transferred from one CO₂ molecule to
	\n- /CO, *c* is the molar concentration of the gaseous
	\n\n
\n- **Results and Discussion**
\n- **1 Characterization and Formation Mechanisms of Electrode**
\n- The SEM images were used to analyze the misstructure and morphology of the electrode during
\n
	\n- is twenty-hour electrolysis experiment, as shown in
	\n- gure 2(A-E). The bimetallic Cu/Sn electrode with a
	\n\n
\n

product.

50 and 5 mV·s' at room temperature in a three-elec-

stroction geneter expective pectro-

scopic (EIS) test was conducted at -0.91 V_{isa} with the

scopic (EIS) test was conducted at -0.91 V_{isa} with the

amplitude of 0. trode system. Electrochemical impedance spectro-

scopic (ERS) test was conducted at -0.91 V_{ass} with the intermediates of reduced and the one and the stems intermediate and the stems of J_{total}

amplitude of 0.11 V ov scopic (EIS) test was conducted at -0.91 V_{pau} with the

unplitted of 0.1 V over the frequency range from 0.1 $\frac{60 \text{ s} \cdot \text{min}^{-3}}{4} \times \frac{24000 \text{ cm}^3 \cdot \text{mol}^{-1} \times n \times F}{24000 \text{ cm}^{-3} \cdot \text{mol}^{-1} \times 100\%}$

to 100 kHz. On-bo amplitude of 0.1 V over the frequency range from 0.1

to 100 s-mm² 24000 cm² cm² 2400

20-hour stability test were conducted by using the

20-hour stability test were conducted by using the

20-hour stability test w to 100 kHz. One-hour potentiostatic experiment and 9 one 9 one and the amprometric mode (*i-i* curve).

20 honor sability test were conducted by using the 18 one amprometric mode (*i-i* curve).

In electrochem 20-hour stability test were conducted by using the

undercontrie and the correspondent of U_1 curve).

In electrochemical CO₂ reduction reaction, the

electrons transferred from one CO₂ molecule to

candode electrol amperometric mode (*i*-t curve).

In electrons was even in the carbon then the carbon intervalse carbon and Co₂ reduction reaction carbon the electrons transferred from one CO₃ melectrons can

and L⁺L⁺) at a pH of In electrochemical CO₂ reduction reaction, the
 $\frac{1}{2}$ eractions denotes contrastion of the gasous

candbed electrolyte was CO₂-staps and the computer and the diversion of the gasous

and $\frac{1}{2}$ at a pH of 7.5. eathode electrolyte was CO₂-saturated KHCO₁ (0.5 recove) the unitariation of the gasoots

moli-L³) at a pH of 7.5. Without further explanation and the specified into the potential described below will be versus reve mol (L²) at a pH of 7.5. Without further explanation,

the potential described below will be versus reversible

by drogen electrode (RHE) that can be converted ag-

23. Characterization and Formation Mec-

intission of the potential described below will be versus reversible

by the canvered ag-

and DISCUSSION and DISCUSSION

and SCE by using the following equation.

E(vs. RHE) = E(vs. SCE) + 0.1972 + 0.0591pH (1) The SFM images were us hydrogen electrode (RHE) that can be converted ag-

ains SCE by using the following equation.

Leves RHE) = E (vs. SCE) + 0.1972 + 0.0591pH (1) The SEM images were used to analyze the mi-

The seaming electron microscope 0.1972 + 0.0591pm (1) The SEM images were used to analyze the min-
second (SEM) was used crostratuture and morphology of the electrode during
liftraction (XRD) anal-
figure 2(A-E). The bimetallic CwSn electrode with a
W38 analyze the surface morphology by a S-4800 field-

ission at 5 kV. The X-ray diffraction (XRD) and

ission at 5 kV. The X-ray diffraction (XRD) and

if eigence 2(A-F). The bimedilic CuS nelectrons were

served and this sp emission at 5 kV. The X-ray diffraction (XRD) anal-

Eigure 2(A-E). The bimetallic Cu/Sn electrode wit

sysis was carried on a Philips PW3830 X-ray diffrac-

3D-multilayered microstructure showed some cord

to retect by u on (XRD) anal-

Figure 2(A-E). The bimetallic Cu/Sn electrode with a

X-ray diffrac-

3D-multilayered microstructure showed some cavi-

40 mA and 40 ties on the surface (Figure 2(A)), which could pro-

ples were kept vide is PW3830 X-ray diffrac-
3D-multilayered microstructure showed some cavi-
diation at 40 mA and 40 ties on the surface (Figure 2(A)), which could pro-
vide a large dectrochemical surface area and confine
the intermediates tometer by using a Cu K, radiation at 40 mA and 40

ties on the surface (Figure 2(A)), which could pro-

kV. Before the XRD test, all the samples were kept vide a large electrochemical surface area and confine

in a littl dehumidified by a filter bundle kit. The Faradaic effi-
ciency for gas products (CO and H₂) can be calculated
according to the following equation.
 FE_{gas} -(%) =
 $\frac{v}{0.0 \text{ s} \cdot \text{min}^{-1}} \times \frac{c}{24000 \text{ cm}^3 \cdot \text{mol}^{-1}} \times n \times F$ ciency for gas products (CO and H₂) can be calculated
according to the following equation.
 FE_{gas} -(%) =
 $\frac{v}{0.0 \text{ s} \cdot \text{min}^+} \times \frac{24000 \text{ cm}^3 \cdot \text{mol}^+}{J_{total}} \times n \times F \times 100\%$
(3)
Where, *v* is the CO₂ flow rate, *n* i according to the following equation.
 FE_{gas} -(%) =
 $\frac{v}{60 \text{ s-min}^{1}} \times \frac{c}{24000 \text{ cm}^{3} \cdot \text{mol}^{1}} \times n \times F$ × 100%
 J_{total} (3)

Where, *v* is the CO₂ flow rate, *n* is the number of

electrons transferred from one CO₂ FE_{gas} -(%) =
 $\frac{v}{60 \text{ s-min}^{1}} \times \frac{c}{24000 \text{ cm}^{3} \cdot \text{mol}^{1}} \times n \times F$ x 100%
 J_{total} (3)

Where, *v* is the CO₂ flow rate, *n* is the number of

electrons transferred from one CO₂ molecule to

H₂/CO, *c* is the mo $\frac{v}{60 \text{ s-min}^{1}} \times \frac{c}{24000 \text{ cm}^3 \cdot \text{mol}^{1}} \times n \times F$
 $\frac{1}{J_{\text{total}}}$ (3)

Where, *v* is the CO₂ flow rate, *n* is the number of

electrons transferred from one CO₂ molecule to

H₂/CO, *c* is the molar concentration $\frac{60 \text{ s} \cdot \text{min}^4$ $24000 \text{ cm}^3 \cdot \text{mol}^{-1}$ $\times 100\%$
(3)
Where, *v* is the CO₂ flow rate, *n* is the number of
electrons transferred from one CO₂ molecule to
H₂/CO, *c* is the molar concentration of the gaseous *A_{toul}* (3)

Where, *v* is the CO₂ flow rate, *n* is the number of

electrons transferred from one CO₂ molecule to

H₂/CO, *c* is the molar concentration of the gaseous

product.
 3 Results and Discussion
 3.1 HCOO. It can be observed that this 3D-multilayered (3)

here, v is the CO₂ flow rate, n is the number of

as transferred from one CO₂ molecule to

c is the molar concentration of the gaseous

i.
 ESUILS and Discussion
 haracterization and Formation Mec-
 ensity a Where, v is the CO₂ How rate, n is the number of
electrons transferred from one CO₂ molecule to
H₂/CO, c is the molar concentration of the gaseous
product.
3 Results and Discussion
3.1 Characterization and Format electrons transferred from one CO_2 molecule to H_2/CO , c is the molar concentration of the gaseous product.
 3 Results and Discussion
 3.1 Characterization and Formation Mechanisms of Electrode

The SEM images we H₂/CO, *c* is the molar concentration of the gaseous
product.
3 Results and Discussion
3.1 Characterization and Formation Mec-
hanisms of Electrode
The SEM images were used to analyze the mi-
crostructure and morp **3 Results and Discussion**
 3.1 Characterization and Formation Mechanisms of Electrode

The SEM images were used to analyze the mi-

crostructure and morphology of the electrode during

the twenty-hour electrolysis expe **3 Results and Discussion**
 3.1 Characterization and Formation Mechanisms of Electrode

The SEM images were used to analyze the microstructure and morphology of the electrode during

the twenty-hour electrolysis experim **3.1 Characterization and Formation Mechanisms of Electrode**
The SEM images were used to analyze the microstructure and morphology of the electrode during
the twenty-hour electrolysis experiment, as shown in
Figure 2(A-E) **hanisms of Electrode**
The SEM images were used to analyze the mi-
crostructure and morphology of the electrode during
the twenty-hour electrolysis experiment, as shown in
Figure 2(A-E). The bimetallic Cu/Sn electrode wit The SEM images were used to analyze the mi-
crostructure and morphology of the electrode during
the twenty-hour electrolysis experiment, as shown in
Figure 2(A-E). The bimetallic Cu/Sn electrode with a
3D-multilayered mic structure and morphology of the electrode during
twenty-hour electrolysis experiment, as shown in
que $2(A-E)$. The bimetallic Cu/Sn electrode with a
-multilayered microstructure showed some cavi-
son the surface (Figure 2(the twenty-hour electrolysis experiment, as shown in
Figure 2(A-E). The bimetallic Cu/Sn electrode with a
3D-multilayered microstructure showed some cavi-
ties on the surface (Figure 2(A)), which could pro-
vide a large e Figure 2(A-E). The bimetallic Cu/Sn electrode with a
3D-multilayered microstructure showed some cavi-
ties on the surface (Figure 2(A)), which could pro-
vide a large electrochemical surface area and confine
the intermedi 3D-multilayered microstructure showed some cavi-
ties on the surface (Figure 2(A)), which could pro-
vide a large electrochemical surface area and confine
the intermediates of reduced CO₂ in order to generate
HCOO: It c yered microstructure showed some cavi-
surface (Figure 2(A)), which could pro-
gelectrochemical surface area and confine
ediates of reduced CO₂ in order to generate
can be observed that this 3D-multilayered
ture was almo crostructure showed some cavi-
(Figure 2(A)), which could pro-
hemical surface area and confine
reduced CO₂ in order to generate
bserved that this 3D-multilayered
almost unchanged in the first 10 h
20-h electrolysis, it ture showed some cavi-
2(A)), which could pro-
surface area and confine
CO₂ in order to generate
that this 3D-multilayered
nchanged in the first 10 h
ectrolysis, it can be found
ce of electrode were part-
also appeared ed some cavi-
ich could pro-
rea and confine
der to generate
D-multilayered
in the first 10 h
it can be found
rode were part-
ared along the
). These might
morphology of
flushing of the
electrode were
uring 20-h sta-
the s ties on the surface (Figure 2(A)), which could pro-
vide a large electrochemical surface area and confine
the intermediates of reduced CO₂ in order to generate
HCOO¹. It can be observed that this 3D-multilayered
micro

The XRD patterns of the Cu/Sn electrode were at 32.108 °, 44.902 °, 55.33 °, 64.576 ° and 79.47 ° as-

the two diffraction peaks at 30.126° and 42.971° be-**EXERCT: EXERCT: Example 19** Example 1001) and (110) planes of alter Co, and Solution (B) 5 h, (C) 10 h, (D) 15 h and (E) 20 h. (F) XRD patterns

behavior behavior behavior and after different interestingly, To our through the N₃ and C **Eigure 2** SEM images: (A) before and alter different electrolysis time. (B) 5 h, (C) 10 h, (D) 15 h and (E) 20 h, (F) XRD patterns
obtained before and alter different time. (color on line)
of Sn (JCPDS card no. 04-0673), **Figure 2** SEM images: (A) before and ster different electrolysis time. (B) 5 h, (C) 10 h, (D) 15 h and (E) 20 h. (F) XRD patterns
obtained before and after different time. (color on line)
of Sn (JCPDS card no. 04-0673), **Figure 2** SFM images: (A) before and sthe different electrolysis time, (B) 5 h, (C) 10 h, (D) 15 h and (F) 20 h. (F) RRD patterns

obtained before and sthe different time. (color on line)

solution patterns of Cu/Sn elec obtained betore and atter diteretion time. (color on this)

of Sn (JCPDS card no. 04-0673), respectively. To our

through the N₃ and CO₂-saturation KHCO₂. From Fig-

surprise, the diffraction patterns of Cu/Sn elect of Sn (JCPDS card no. 04-0673), respectively. To our
surprise, the diffraction patterns of Cu/Sn clectrode
tier S2, the current densities
the two diffraction patterns of Cu/Sn clectrode
the S2, the current densities
the t of Sn (JCPDS card no. 04-0673), respectively. To our

surprise, the diffraction patterns of Cu/Sn electrode

ure S2, the current densities at diffrerent apple

after 15-h electrodysis showed no changes. However, tentials prise, the diffraction patterns of Cu/Sn electrode ure S2, the current densities at different applied po-

115-he decreases howed an edungers. However, tentials in CO-saturated electrolyte was obviously

115-he defined in after 15-h cleartolysis showed no changes. However,

tentials in CO₂-saturated electrochyic was obviously

the two diffraction peaks at 30.126° and 42.971° be- much larger than those in N₂-saturated condition.

canne the two diffraction peaks at 30.126° and 42.971° be-

emch larger than those in N_r-saturated condition.

electrode for (101) and (110) planes of alloy Cu_{ta},Sn, in considering that the working electrode for dhe (101) a earme predominant after 20-h electrolysis, well in-

considering that the working electrode and the

dexel to the (101) and (110) planes of alloy Cu_{ca}, So₁, counter electrode as in close contact, the distance

(JCPDS dexed to the (101) and (110) planes of alloy Cu₆₂₈S_{Bs} counter electrode are in electroDS card no. 47-1575), which could affirm that between an anode and a cat
the (101) and (110) planes of alloy Cu₆₂₈S_{B₃} cen the

The CONSERV CONSERV ARE CONSERV ARE CONSERV ARE CONSERV ARE CONSERVATIONS (CONSERVATION CONSERVATION CONSERVATION CONSERVATION CONSERVATION (CONSERVATION CONSERVATION CONSERVATION CONSERVATION (CONSERVATION CONSERVATION EXAMPLE 1998
 EXAMPLE 2019 IDENTIFY (CO2P) $\frac{1}{20}$ and $\frac{1}{20}$ Example 120 pm

Franchical Constrainers and the working distributions

Consider the working of the working electron and the N₂ and CO₂-saturation KHCO₃. From Figure 32, the current densities at different applied pot Example and the stress contact in close contact of the stress contact of the stress contact of the distance o **between anotage and CD**-saturation KHCO₃. From Figure S2, the current densities at difference or a so open and captural shortened, the same shortened, the same of the same shortened, the same of the same of the shorten **EXERCT AND ACTED TO THE CALL AND THE C** Electrodes. Besides and the context of electrodes. Besides and the circulation of electrodes. The circulation of electrolyte by peristalite pumps is favorable for mass transition of electrodes. The context of the context **PERIOR ON THE CALCE SET ON SURVEY CONTROLLED SET ON SURVEY ON SURVEY (201)**
 PERIOR ON SURVEY AND PARTIME CONTROVER ON SURVEY AND PARTICLE SURVEY ON THE SET ON SURVEY ON SURVEY ON SURVEY AND PARTICLE SURVEY ON SURVEY AN EXECUTE:
 CO2 EXEC io 20 30 40 50 60 70 80 90

ne. (B) 5 h, (C) 10 h, (D) 15 h and (E) 20 h. (F) XRD patterns

through the N₂ and CO₂-saturation KHCO₃. From Fig-

ure S2, the current densities at different applied po-

tentials in CO 60 70 80 90

(Free)

(E) 20 h. (F) XRD patterns

on KHCO₃. From Fig-

different applied po-

rolyte was obviously

r-saturated condition.

gelectrode and the

contact, the distance

e is greatly shortened,

ance between bubbling CO₂ into MEA

below the Hyperactor Consideration CHCO₃. From Fig-

through the N₂ and CO₂-saturation KHCO₃. From Fig-

ure S2, the current densities at different applied po-

tentials in CO₂-saturated (B) 5 h, (C) 10 h, (D) 15 h and (E) 20 h. (F) XRD patterns

cough the N₂ and CO₂-saturation KHCO₃. From Fig-

s2, the current densities at different applied po-

trials in CO₂-saturated electrolyte was obviously
 through the N₂ and CO₂-saturation KHCO₃. From Figure S2, the current densities at different applied potentials in CO₂-saturated electrolyte was obviously much larger than those in N₂-saturated condition. Conside through the N₂ and CO₂-saturation KHCO₃. From Figure S2, the current densities at different applied potentials in CO₂-saturated electrolyte was obviously much larger than those in N₂-saturated condition. Conside through the N₂ and CO₂-saturation KHCO₃. From Figure S2, the current densities at different applied potentials in CO₂-saturated electrolyte was obviously much larger than those in N₂-saturated condition.
Conside ure S2, the current densities at different applied po-
tentials in CO₂-saturated electrolyte was obviously
much larger than those in N₂-saturated condition.
Considering that the working electrode and the
counter elect tentials in CO₂-saturated electrolyte was obviously
much larger than those in N₂-saturated condition.
Considering that the working electrode and the
counter electrode are in close contact, the distance
between an anod

11) and (110) planes of alloy Cu_{Ga}Sn₃ counter electrode are in close contact, the distance

147-1575), which could affirm that between an anotele and a cataboei is greatly shortened,

1401 planes of alloy Cu_{Ga}Sn₅ (ICPDS card no. 47-1575), which could affirm that between an anode and a cathode is greatly shortened,
the (101) and (110) planes of alloy Cu_{sa},Sa, are the units, reducing the chimic resistance between the two
main acti the (101) and (110) planes of alloy $Cu_{62}Sn_8$ are the thus, reducing the ohmic resistance between the two main active cystal planes for CO_RR. The disappear-
electrodes. Besides, the cruiculation of electrolyte by
ance main active crystal planes for CO₃RR. The disappear-
electrodes. Besides, the circulation of electrolyte by
ance of the Sn peak may be caused by the loss of Sn eperistalic purms is fivorable for mass transfer of
particl ance of the Sn peak may be eassed by the loss of Sn

peristatic pumps is favorable for mass transfer of

particles from the electrode sartheo. Interestingly, CO, to the surface of Cu/Sn electrode and promotion

the intens much larger than those in N₂-saturated condition.
Considering that the working electrode and the
counter electrode are in close contact, the distance
between an anode and a cathode is greatly shortened,
thus, reducing t Considering that the working electrode and the
counter electrode are in close contact, the distance
between an anode and a cathode is greatly shortened,
thus, reducing the ohmic resistance between the two
electrodes. Besi counter electrode are in close contact, the distance
between an anode and a cathode is greatly shortened,
thus, reducing the ohmic resistance between the two
electrodes. Besides, the circulation of electrolyte by
peristal between an anode and a cathode is greatly shortened,
thus, reducing the ohmic resistance between the two
electrodes. Besides, the circulation of electrolyte by
peristaltic pumps is favorable for mass transfer of
CO₂ to thus, reducing the ohmic resistance between the two
electrodes. Besides, the circulation of electrolyte by
peristaltic pumps is favorable for mass transfer of
CO₂ to the surface of Cu/Sn electrode and promotion
of CO₂ electrodes. Besides, the circulation of electrolyte by
peristaltic pumps is favorable for mass transfer of
CO₂ to the surface of Cu/Sn electrode and promotion
of CO₂ solubility in 0.5 mol·L⁴ KHCO₃ by directly
bubb peristaltic pumps is favorable for mass transfer of CO₂ to the surface of Cu/Sn electrode and promotion of CO₂ solubility in 0.5 mol \cdot L⁻¹ KHCO₃ by directly bubbling CO₂ into MEA assembly. Figure 3(A) provide

tor with CO, bubbling inside can acquire higher cell
then, maintained more than 90% alter reaching the
flictiency and current density than the H-type cell.
In constraint level of 90.24% at -1.01 V_{MB}. Further-
In order t efficiency and current density than the H-type cell.

In order to further investigate the working principle

In order to further investigate the volume of the FL $_{1000}$ of Cu/Sn electrode in the flow

V_{ten}, are shown In order to further investigate the working principle

and a core, the FF $_{\text{recoo}}$ of Cu/Sn electrode in the flow

of the flow MEA reactor, the Nyguist Jobs at -0.91

V_{Ros} are shown in Figure 3(B). The ohmic resistanc of the flow MEA reactor, the Nyquist plots at -0.91

VmEA reactor without bubbling CO₂ inside was

VmE are shown in Figure 3(18). The ohmic resistance

of EIS curve. From Figure 3(8), the ohmic resistance

of EIS curve. $V_{\text{H/E}}$ are shown in Figure 3(B). The ohmic resistance

81.49% at -0.91 $V_{\text{H/E}}$ lower and the value of dosines according to the strain point of is the value of abscissa according to the starting point
 ${}^{81.499}$ at -0.91 v_{urrent} content durature and two the bisis of the flow MEA reactor

of FIS curve. From Figure 3(B), the obmic resistance

of the flow MEA re of EIS curve. From Figure 3(B), the ohmic resistance

of the flow MEA reactor was merely 0.957 Ω , near

of the flow MEA reactor was merely 0.957 Ω , near

three times bover than that of the H-type reactor

cation of of the flow MEA reactor was merely 0.957 Ω , near

three than that of the H+type reactor

than that of the H+type reactor

diffusion of CO₂ toward the surface of Cu/Sn electroding the

three times lower than that of t ee times lower than that of the H-type reactor

So f3), implying that the former has better CO_SR diffusion of CO₃ toward the surface of Cu/Sn archeof

for different ap-taxe of Cu/Sn accession components that the funct (3.05 Ω), implying that the former has better CO_SRR diffusion of CO₂ toward the surface of Cu^xSn electrom-
performance than the latter due to the reduced clear-
tode distance. Moreover, the charge transferresista performance than the latter due to the reduced elec-
trode. For gaseous products, there were only CO and
trode distance. Moreover, the charge transferrestistance
 H_2 detected by the online gas chromatography in the
CCT

ELET ELECT EXECT EXECT ALCOCED
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 ELECT ALCOCED without bubbling CO2 showed the onset potential of $\# \# \# (J. Electrochem.)$ 2022, 28(1), 2104231 (6 of 9)

cell. In addition, the Cu/Sn electrode in MEA reactor

without bubbling CO₂ showed the onset potential of

due to the rapid consumption of CO₂¹²⁵. Under the

-0.64 V_{RH} **E** *(L Electrochem.*) 2022, 28(1), 2104231 (6 of 9)

cell. In addition, the Cu/Sn electrode in MEA reactor

without bubbling CO₂ showed the onset potential of

due to the rapid consumption of CO₂¹²⁵¹. Under the

- $\frac{q_1 R^2 (L \t{E}_{letrocheem}) 2022, 28(1), 2104231 (6 of 9)}{q_1 R^2 (L \t{E}_{letrocheem}) 2022, 28(1), 2104231 (6 of 9)}$

Seall. In addition, the Cu/Sn electrofe in MEA reactor

without bubbling CO₂ showed the onset potential of the tote rapi $\pm \frac{\text{Re}2\pi (L \text{ *Electrochem.}) 2022, 28(1), 2104231 (6 \text{ of } 9)}{\text{cell.} \ln \text{ addition, the C}u/\text{Sn}}*$ electrode in MEA reactor
without bubbling CO₂ showed the onset potential of the to the rapid consumption of CO₂¹²⁵¹. Under the
-0.64 V **Effective CET II** (*Electrochem.*) 2022, 28(1), 2104231 (6 of 9)

recll. In addition, the Cu/Sn electrode in MEA reactor

without bubbling CO₂ showed the onset potential of

due to the rapid consumption of CO_2^{123} . \pm *RE* \neq (*L Electrochem.*) 2022, 28(1), 2104231 (6 of 9)

II. In addition, the Cu/Sn electrode in MEA reactor transport of CO₂ intermediate at high overpotentials

thout bubbling CO₂ showed the onset potential the flow MEA reactor (μ New The Figure 3(B), The other center of the flow MEA reactor (μ SHA) at a the Nypus are strengthen the Ministon MEA reactor, the Nypus ame conditions, the FE $_{\text{LQO}}$ of the H-type reactor **EVALUATION**
 EVALUATION (EVALUATION \mathcal{H}_H are shown in Figure 3(B). The ohmic resistance

Similar to the DEVA reactor in MEA reactor in any of CO₂ intermediate at high overpotentials

without bubbling CO₂ s **EVALUAT CONTENT (FOC ABSCEDENT (FOC ABSCEDENT (SOLUTE ACT CONTENT) (SOLUTE ON A VALUAT COLUTE OF A VALUAT COLUTE ON THE VALUAT COLUTE START (FOR EVALUAT THE CONDUMER CONTENT CONTENT (FOR THE SUPPLE TO A SUPPLE THE ACT (FOR THE SUPPLE THE UNIT CO, into MEA CO, into MEA CO, into** ¹¹1(*E*²*F*</sup>*(L <i>Electrochem,*) 2022, 28(1), 2104231 (6 of 9)

cell. In addition, the Cu/Sn electrode in MEA reactor transport of CO₂ intermediate at high overpotentials

without bubbling CO₃ into the H-type r **EVALUAL TEL AS CONDED**
 EVALUAT THE CONDEND THE CONDENDIGATE CONDENDIGATE:

THE CONDENDIGATE CONDENDIGATE THE CONDENDIGATE THE CONDENDIGATE THE CONDENDATE THE CONDENDED ON NOTE VALUAT THE CONDENDED THE CONDENDED THE CO the $\mu_E \gg 222, 28(1), 2104231$ (6 of 9)

cell. In addition, the Cu/Sn electrode in MEA reactor transport of CO₂ intermediate at high overpotentials

without bubbling CO₂ showed the onset potential of due to the rapid performance that the CO₂ interests and the reduced in MEA reader of the reduced in t cell. In addition, the Cu/Sn electrode in MEA reactor

without bubbling CO₃ showed the costs potential of due to the rapid consumption of CO₂¹⁸³. Under the

without bubbling CO₃ involved the costs potential of due without bubbling CO₂ showed the onset potential of due to the rapid consumption of $CO_2^{1/3}$. Under the $-0.64 \text{ V}_{\text{BH}}$ (similar to the H-type reactor), implying same conditions, the FE_{recoO} of the H-type reac -0.64 V_{max} (similar to the H-type reactor), implying same conditions, the FE_{ncero} of the H-type reactor in Equal throubbiling CO₂ into MEA assembly can reduce the guare S5 firstly showed a similar tendency as the than bubbling CO₂ into MEA assembly can reduce the

gas diffusion resistance. Overall, the flow MEA reactor between -0.61 and -0.81 V_{Rue}

gas diffusion resistance. Overall, the flow MEA reactor between -0.61 and -0.81 gas diffusion resistance. Overall, the flow MEA reac-

flow MEA reactor between -0.61 and -0.81 Van-

for Cro, bubbling inside can acquire higher cell

efficiency and current density than the H-type cell

then, maintained 2, 28(1), 2104231 (6 of 9)
tra nsport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂^[25]. Under the
same conditions, the FE_{HcOO} of the H-type reactor in
Figure S5 firstly showed a s 2, 28(1), 2104231 (6 of 9)
transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂^[25]. Under the
same conditions, the FE_{HCOO} of the H-type reactor in
Figure S5 firstly showed a si overpotentials
^[25]. Under the
type reactor in
mdency as the
d -0.81 V_{RHE} ,
r reaching the 2, 28(1), 2104231 (6 of 9)
transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂^[25]. Under the
same conditions, the FE_{HCOO}' of the H-type reactor in
Figure S5 firstly showed a s the at high overpotentials

on of $CO_2^{[25]}$. Under the

of the H-type reactor in

similar tendency as the

n -0.61 and -0.81 V_{RHE},

190% after reaching the 2, 28(1), 2104231 (6 of 9)
transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂^[25]. Under the
same conditions, the FE_{HCOO} of the H-type reactor in
Figure S5 firstly showed a si 2, 28(1), 2104231 (6 of 9)

transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂¹²⁵¹. Under the

same conditions, the FE_{HCOO} of the H-type reactor in

Figure S5 firstly showed 2, 28(1), 2104231 (6 of 9)
transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂¹²⁵. Under the
same conditions, the FE_{HCOO} of the H-type reactor in
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transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂^[25]. Under the

same conditions, the FE $_{\text{HCOO}}$ of the H-type reactor in

Figure S5 firstly sh f 9)

Intermediate at high overpotentials

consumption of $CO_2^{[25]}$. Under the

he FE_{HCOO} of the H-type reactor in

showed a similar tendency as the

r between -0.61 and -0.81 V_{RHE},

more than 90% after reaching the
 2, 28(1), 2104231 (6 of 9)
transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂^[25]. Under the
same conditions, the FE_{IICOO} of the H-type reactor in
Figure S5 firstly showed a s 2, 28(1), 2104231 (6 of 9)

transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂^[25]. Under the

same conditions, the FE_{1cOO} of the H-type reactor in

Figure S5 firstly showed 2, 28(1), 2104231 (6 of 9)

transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂⁽²⁵⁾. Under the

same conditions, the FE_{*HCOO}* of the H-type reactor in

Figure S5 firstly showe</sub> 2, 28(1), 2104231 (6 of 9)

transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂¹²⁵!. Under the

same conditions, the FE_{HcOO} of the H-type reactor in

Figure S5 firstly showed 2, 28(1), 2104231 (6 of 9)

transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂¹²⁵!. Under the

same conditions, the FE_{BCOO} of the H-type reactor in

Figure S5 firstly showed at high overpotentials
of $CO_2^{[25]}$. Under the
the H-type reactor in
nilar tendency as the
0.61 and -0.81 V_{RHE} ,
0% after reaching the
-1.01 V_{RHE} . Further-
electrode in the flow
ng CO_2 inside was
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transport of CO₂ intermediate at high overpotentials

due to the rapid consumption of CO₂¹²⁵¹. Under the

same conditions, the FE_{1cOO} of the H-type reactor in

Figure S5 firstly showe 2, 28(1), 2104231 (6 of 9)
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Figure S5 firstly showed a transport of CO₂ intermediate at high overpotentials
due to the rapid consumption of CO₂¹²⁵¹. Under the
same conditions, the FE_{HCOO} of the H-type reactor in
Figure S5 firstly showed a similar tendency as the
flo due to the rapid consumption of CO_2^{125} . Under the same conditions, the FE_{HCOO} of the H-type reactor in Figure S5 firstly showed a similar tendency as the flow MEA reactor between -0.61 and -0.81 V_{HHE} , then, maint same conditions, the FE_{HCOO} of the H-type reactor in Figure S5 firstly showed a similar tendency as the flow MEA reactor between -0.61 and -0.81 V_{HHE} , then, maintained more than 90% after reaching the maximum level o Figure S5 firstly showed a similar tendency as the
flow MEA reactor between -0.61 and -0.81 V_{RHE} ,
then, maintained more than 90% after reaching the
maximum level of 90.24% at -1.01 V_{RHE} . Further-
more, the FE _{HCOO} Figure 35 msary showed a shimal chiedry as the
flow MEA reactor between -0.61 and -0.81 V_{RHE} ,
then, maintained more than 90% after reaching the
maximum level of 90.24% at -1.01 V_{RHE} . Further-
more, the FE $_{\text$ how MEA reactor between -0.01 and -0.01 V_{RHE}.

then, maintained more than 90% after reaching the

maximum level of 90.24% at -1.01 V_{RHE}. Further-

more, the FE _{HCOO} of Cu/Sn electrode in the flow

MEA reactor withou then, maniform level of 90.24% at -1.01 V_{BHE}. Furthermore, the FE _{Hcoo} of Cu/Sn electrode in the flow MEA reactor without bubbling CO₂ inside was 81.49% at -0.91 V_{BHE}. lower than that with bubbling CO₂ into elec Example 10 1903.2470 at -1.01 VREE. Funder-

The FE $_{\text{HCOO}}$ of Cu/Sn electrode in the flow

A reactor without bubbling CO₂ inside was

49% at -0.91 V_{RHS} lower than that with bubbling

2 into electrolyser (Figure 3(mole, the TE_{Hcoo} of Carsin electrode in the flow
MEA reactor without bubbling CO₂ inside was
81.49% at -0.91 V_{RHS} lower than that with bubbling
CO₂ into electrolyser (Figure 3(D) and Figure S6),
demonstrating furt MEA reactor without bubbling CO₂ inside was 81.49% at -0.91 V_{RHE}, lower than that with bubbling CO₂ into electrolyser (Figure 3(D) and Figure S6), demonstrating further that bubbling CO₂ into MEA assembly can prom 81.49% at -0.91 V_{Ritis} lower than that with bubbling CO₂ into electrolyser (Figure 3(D) and Figure S6), demonstrating further that bubbling CO₂ into MEA assembly can promote FE _{iccoo} by accelerating the diffusion CO₂ into electrolyser (Figure 3(D) and Figure S6),
demonstrating further that bubbling CO₂ into MEA
assembly can promote FE $_{\text{ECOO}}$ by accelerating the
diffusion of CO₂ toward the surface of Cu/Sn elec-
trode. Fo by ser (Figure 3(D) and Figure S6),
urther that bubbling CO₂ into MEA
romote FE $_{\text{HCOO}}$ by accelerating the
2 toward the surface of Cu/Sn elec-
us products, there were only CO and
he online gas chromatography in the
 straining infinite that balooning CO_2 into WEA
dy can promote FE _{IICO0}^b by accelerating the
on of CO₂ toward the surface of Cu/Sn elec-
For gaseous products, there were only CO and
teted by the online gas chromato 电化学(*J. Electrochem.*) 2022, 28(1), 2104231 (6 of 9)

rode in MEA reactor transport of CO₂ intermediate at high overpotentials

he onset potential of due to the rapid consumption of CO₂^[25]. Under the

e reactor),

trode distance. Moreover, the charge transfer resistance

IFs decleted by the online gas chromatography in the

CCTR) is related to the radius of semicircle in EIS flow MEA reactor. In contrast, the lower HER of the Given CTR) is related to the radius of semicircle in EiS alow MEA reactor. In contrast, the lower HER of the curve. The CTR of the flow MEA reactor was 0.996 alow MEA reactor than the H-type reactor (4.85 to -1.1 Curels and the curve. The CTR of the flow MEA reactor was 0.996

0. much small pri change re- drop is the higher local pH close to the singlar beat to fit. An much small products displayed to the surface of CwSn

10), demonstrating tha markable changes along with potentials. The FE_{HCOO} of changes in surface morphology of Cu/Sn electrode in Ω), demonstrating that the flowing electrolyte does

increase the diriusion rate of electros. Actually, the be weakened in the flow MEA reactor¹⁸⁰. The energy

increase the diriusion rate of electros. Actually, the be increase the diffusion rate of electrons. Actually, the be weakened in the flow MEA reactor²⁵⁰. The energy CIR has a close relation with current density, which efficiency (EE) approached 3^{1%}.

can be observed in Figur CTR has a close relation with current density, which

efficiency (EE) approached 31%.

with a lower CTR showed a higher S3. The reactor system \sim In order to inset the industrial demand for

with a lower CTR showed a hi can be observed in Figure S3. The reactor system μ and reder to meet the industrial demand for
with a lower CTR showed a higher total current den-
CO, RR, the statistivy of the flow MEA reactor was
eight, manifesting a with a lower CTR showed a higher total current den-

89. At a stability of the flow MEA reactor was

sidy, mantissing a higher CO₂ consumption rate. In evaluated at -0.91 V_{Reat} in Figure 3(E). During the

addition, th sity, manifesting a higher CO, consumption rate. In

evaluated at -0.91 V_{mg} in Figure 3(E). During the

addition, the current density of the flow WEA reactor is 112 h, the flow MEA reactor showed a relative-

with CO, in demonstrating that the active Cu_e addition, the current density of the flow MEA reactor

inst 12 h, the flow MEA reactor showed a relative-

with CO, purging inside was unsulable, possibly due

to the precipitation of carbonate in the system PE_{reco} FE_{HCOO} became a slight oscillation due to the rapid diffusion of CO₂ toward the surface of Cu/Sn electrode. For gaseous products, there were only CO and H₂ detected by the online gas chromatography in the flow MEA reactor. In contrast, the lower HER of the flow MEA rea drilation of CO₂ toward the surface of Cu/Sn electrode. For gaseous products, there were only CO and H₂ detected by the online gas chromatography in the flow MEA reactor. In contrast, the lower HER of the flow MEA rea FE_{HCOO} was 80% at the current density near 50 mA \cdot cm⁻² For gascous products, there were omy CO and
ected by the online gas chromatography in the
HEA reactor. In contrast, the lower HER of the
HEA reactor than the H-type cell may be due to
gher local pH close to the surface of flow MEA reactor. In contrast, the lower HER of the
flow MEA reactor than the H-type cell may be due to
the higher local pH close to the surface of Cu/Sn
electrode, and thus, hydrogen binding energies would
be weakened in HER of the
ay be due to
e of Cu/Sn
rrgies would
The energy
demand for
reactor was
During the
demand for
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50 mA·cm⁻²
and the in-
and the in-
attributed to flow MEA reactor than the H-type cell may be due to
the higher local pH close to the surface of Cu/Sn
electrode, and thus, hydrogen binding energies would
be weakened in the flow MEA reactor¹⁵⁶. The energy
efficiency (E the higher local pH close to the surface of Cu/Sn
electrode, and thus, hydrogen binding energies would
be weakened in the flow MEA reactor^[26]. The energy
efficiency (EE) approached 31%.
In order to meet the industrial electrode, and thus, hydrogen binding energies would
be weakened in the flow MEA reactor^[26]. The energy
efficiency (EE) approached 31%.
In order to meet the industrial demand for
CO₂RR, the stability of the flow MEA be weakened in the flow MEA reactor^[26]. The energy
efficiency (EE) approached 31%.
In order to meet the industrial demand for
CO₂RR, the stability of the flow MEA reactor was
evaluated at -0.91 V_{RHE} in Figure 3(E) efficiency (EE) approached 31%.

In order to meet the industrial demand for CO₃RR, the stability of the flow MEA reactor was

evaluated at -0.91 V_{RME} in Figure 3(E). During the

first 12 h, the flow MEA reactor showe In order to meet the industrial demand for CO_SRR, the stability of the flow MEA reactor was evaluated at -0.91 V_{RME} in Figure 3(E). During the first 12 h, the flow MEA reactor showed a relative-ly stable FE_{HCOO}^o CO₃RR, the stability of the flow MEA reactor was
evaluated at -0.91 V_{RHE} in Figure 3(E). During the
first 12 h, the flow MEA reactor showed a relative-
ly stable FE_{HCOO} of ~89%. The current density and
 $FE_{\text{HCOO$ of the flow MEA reactor was
 E_{E} in Figure 3(E). During the

EA reactor showed a relative-
 29% . The current density and

and the excessive accumulation

surface of the Cu/Sn electrode.

urrent density near 50 mA IEA reactor was

(E). During the

nowed a relative-

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ive accumulation

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rnear 50 mA·cm⁻²
 E_{HCOO} and the in-

ially attributed to

u/Sn electrode in

s, suggesting evaluated at -0.91 V_{RME} in Figure 3(E). During the
first 12 h, the flow MEA reactor showed a relative-
ly stable FE_{HCOO} of ~89%. The current density and
 FE_{HCOO} became a slight oscillation due to the rapid
con first 12 h, the flow MEA reactor showed a relative-
ly stable FE_{1coo}· of ~89%. The current density and
FE_{1coo}· became a slight oscillation due to the rapid
consumption of CO₂ and the excessive accumulation
of format

From the minimized and the stability of the stability of $\frac{2}{3}$ and $\frac{2}{3}$ **Formation Also can be verified by LSV**
 Figure 3 (A) LSV results of the different MEA assemblies (with without bubbling CO₃ in 2 + 6 **F**_{an O}₂ in the verified by C₃ in 2 + 6 **F**_{an O}₂ in the streamency name 0 **EXERCISE THE SET IN THE SET IN THE SET IN THE SET INTERFERENCE CO.** THE RESPONDING THE SET IN THE S **Figure 3** (A) LSV results of the different MEA assemblies (with without bubbling CO, inside; using Nafon/anion-exchange FAD

remembrane) and H-lype reactor: (B) LSI curves for the different MEA assemblies (n) S mol L' KI **Figure 3** (A) LSV results of the different MEA assemblies (with without bubbling CO₃ inside; using Nufion/anion-exchange FAD
membrane) and H-type reactor. (B) EIS curves for the different MEA assemblies in 0.5 mol-L¹ **Eignes 3** (b) LSY results of the directric MEA assembles (with wathout bubbling Cb, insign-babyling Prince (b) ES curves for the different MEA assemblise in 0.5 mol - "KICO, solation at -0.91 V_{BE} with a frequency range memotion yard re-type reactor. (b) LE of the uniteral with assume in to 2 more. The home-mate the Home-mate the Home-mate flow MEA reactor of the flow MEA reactor of the flow MEA reactor of the flow MEA reactor at the con

teriality angles of the constrained for the constrained for the current density of the Cu/Sn electrode by using
continuously 20-h electrolysis. The total production
the current density of the Cu/Sn electrode by using
con continuously 20-h electrolysis. The total production
the current density of the Cu/Sn electrode by using
rate of formate during 20-h electrolysis had a slight the AME as a separator was 47.56 mA cm⁻ at -0.97
decrease fr continuously 20-h electrolysis. The total production
the current density of the Cu/Sn electrolys hysing
rate of formate during 20-h electrolysis had a slight the AMF as a separator was 47.56 mA·cm² at -0.97
decrease fro continuously 20-h electrolysis. The total production
the current density of the Cu/Sn electrode by using
rate of formate during 20-h electrolysis had a slight the AME as a separator was 47.56 mA·-en⁻³ at 0.97
decrease f c of formate during 20-h electrolysis had a slight
the AME as a separator was 47.56 mA-em³ at -0.97

For an -177 µmol com² at the initial stage to V_{max} , which is obviously higher than that by using the

63 µmol decrease from ~177 μ mol·em² at the initial stage to
 V_{HT5} which is obviously higher than that by using the
 -163 μ mol·em² after 20-h decretolysis, but still -2 CEM (2.3.51 mA cent;). Figure 3(C) and Fi ~163 µmol·em² after 20-h electrolysis, but still ~2 CEM (23.51 mA·cm²). Figure 3(C) and Figure 59
times higher than those in the case for the Figure (show the FE₁₆₀₀ values of the AEM and CEM, the
renctor (51.14 µmo times higher than those in the case for the H-type

show the FE₁₈₇₀₀ is also of the AFM and CFM, the

reactor (51.14 µmol) and without bubbling inside

(69.64 µmol) and without bubbling inside

(69.64 µmol). In addition reactor (51.14 µmol) and without bubbling inside

fromer realized a FE₁₀₀₀ up to 89.56% at -0.96

(69.64 µmol). In addition, the stability of CO,RR per-

of membrane also can be verified by LSV curves which

were, which (69.64 µmol). In addition, the stability of CO_SRR per-

V_{sue,} which is higher than 84.87% of the later. Al-

formance also can be verified by LSV curves which-

whough the ion conductivities of the membranes are

were formance also can be verified by LSV curves which

"though the ion conductivities of the membranes are

were collected after each one-hour potentionistic cx-

Naffon 117 > FAD, the current density and FE of for-

persence Potential / V vs. RHE
 $\frac{2}{3.85}$
 $\$ From the strengtheness of the CI/Sn electrode by using
the Fig. 2.3. The strengtheness of the CI/Sn electrode by using
the Fig. 3.1 metallical as a separator was 47.56 mA cm² at 0.3 molecular strengtheness of the Cu/Sn ¹⁰⁰

³³

³⁵

³⁵

⁴⁶

⁴⁹

⁴⁹ **For the CEAL CALC CONSET (23.51 mA** cm²). Figure 3(C) and Figure Sphere realized a FE $_{\text{IICO}}$ values of the AEM and CEM, the former realized a FE $_{\text{IICO}}$ in the share which is higher than 84.87% of the later. Also - up to 89.56% at -0.96 **EVALUATE ANTIFIES AND SET UP AND ADDED**
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 matrix and the CO₂ inside; using the AME are better than the AME are basemblies in 0.5 mol·L¹ KHCO₃ solution at -0.91 V_{RHE} with a branched for different MEA assemblies (E) Stability performance ron line)
the curre ithout bubbling CO₂ inside; using Nafon/anion-exchange FAD
assemblies in 0.5 mol·L¹ KHCO₃ solution at -0.91 V_{BIE} with a
ormate for different MEA assemblies (E) Stability performance
ro inee)
the current density of memore and any cover and symmetric and symmetric and symmetric and symmetric of different MEA assemblies (E) Stability performance on line)
the equation of the Cu/Sn electrode by using the equation at -0.91 V_{ne} with a b Frame for different MEA assemblies (E) Stability performance
or on line)
the current density of the Cu/Sn electrode by using
the AME as a separator was 47.56 mA \cdot cm⁻² at -0.97
V_{RWE}, which is obviously higher than 2.1 The set of the p to 89.56% at -0.96
4.756 mA · cm⁻² at -0.97 er than that by using the ree 3 (C) and Figure S9 he AE r on line)
the current density of the Cu/Sn electrode by using
the AME as a separator was 47.56 mA·cm⁻² at -0.97
V_{RWE}, which is obviously higher than that by using the
CEM (23.51 mA·cm⁻²). Figure 3(C) and Figure S9
 the current density of the Cu/Sn electrode by using
the AME as a separator was 47.56 mA·cm⁻² at -0.97
V_{RWE}, which is obviously higher than that by using the
CEM (23.51 mA·cm⁻²). Figure 3(C) and Figure S9
show the FE the current density of the Cu/Sn electrode by using
the AME as a separator was 47.56 mA \cdot cm⁻² at -0.97
V_{RWE}, which is obviously higher than that by using the
CEM (23.51 mA \cdot cm⁻²). Figure 3(C) and Figure S9
s u /Sn electrode by using
47.56 mA · cm⁻² at -0.97
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the AME as a separator was 47.56 mA \cdot cm⁻² at -0.97
V_{RWE}, which is obviously higher than that by using the
CEM (23.51 mA \cdot cm⁻²). Figure 3(C) and Figure S9
s the AME as a separator was 47.56 mA \cdot cm⁻² at -0.97
V_{RWE}, which is obviously higher than that by using the
CEM (23.51 mA \cdot cm⁻²). Figure 3(C) and Figure S9
show the FE_{IICOO} values of the AEM and CEM, the
for V_{RIBs} which is obviously higher than that by using the CEM (23.51 mA · cm²). Figure 3(C) and Figure S9 show the FE $_{\text{HCOO}}$ values of the AEM and CEM, the former realized a FE $_{\text{HCOO}}$ up to 89.56% at -0.96 V_{\text CEM (23.51 mA · cm²). Figure 3(C) and Figure S9
show the FE_{IICOO}' values of the AEM and CEM, the
former realized a FE_{IICOO}' up to 89.56% at -0.96
V_{RIE3}, which is higher than 84.87% of the later. Al-
though the ion show the FE $_{\text{HCOO}}$ values of the AEM and CEM, the
former realized a FE $_{\text{HCOO}}$ up to 89.56% at -0.96
V_{RWE}, which is higher than 84.87% of the later. Al-
though the ion conductivities of the membranes are
Nafion 1 mer realized a FE_{11coo} up to 89.56% at -0.96

^{2HE}_{2HE}, which is higher than 84.87% of the later. Al-

2HEE at cathodes the membranes are

fion 117 > FAD, the current density and FE of for-

atte by using the AME are _{HHB}, which is higher than 84.87% of the later. Al-

bugh the ion conductivities of the membranes are

fion 117 > FAD, the current density and FE of for-

atte by using the AME are better than using the

EM. The reason 2014 the interest of the members are applying the ion conductivities of the membranes are afform $117 > FAD$, the current density and FE of fortate by using the AME are better than using the EM. The reasons can be from diffe

$$
CO2 + 2e2 + H2O \rightarrow HCOO2 + OH
$$
 (1)
2H₂O + 2e² \rightarrow H₂ + 2OH (2)

- And the state of the state of the state of the state of the

 $HCO_3 + OH \rightarrow CO_3^2 + H_2O$

 $# \# \# (J. \: \: Electrochem.) 2022, 28(1), 2104231 (8 of 9)$ CO₂ + OH → HCO₃

HCO₃² + H₂O (4) Zhu J J. Electrode materials engine

To further explore the difference between the AEM (4) Zhu J J. Electrode materials engine

d CEM $# \&L \# (J. \tElectrochem.) 2022, 28(1), 2104231 (8 of 9)$
 $\cdot \text{OH} \rightarrow \text{HCO}_3$
 $\cdot + \text{OH} \rightarrow \text{CO}_3$ ² + H₂O (3) [2] Song R B, Zhu W, Fu J, Chen Y, Liu
 $\cdot + \text{OH} \rightarrow \text{CO}_3$ ² + H₂O (4) Zhu J J. Electrode materials engineer

ther $\text{#E} \left\{ \frac{\mu_0 \mu_0}{\mu_0} \right\} \text{ where } \mu_0 \text{ is the$ **Example 1998** $($ *J.* $$ *Co* $₂ + OH → Co₃⁵ + H₂O

 $\text{HCO}_3 + \text{OH} \rightarrow \text{CO}_3^2 + \text{H}_2\text{O}$ (4) Zhu J J. Electrode materials engineering in electrocatalytic

To further explor$ 49. $\frac{1}{2}$ Electrochem.) 2022, 28(1), 2104231 (8 of 9)

CO₂ + OH → HCO₃

CO₂ + OH → CO₃² + H₂O

(4) Zhu J J. Electrode materials engineering in electrocatalytic

To further explore the difference between t **EXAM And CEM** $\overline{O}_2 + \overline{O}H \rightarrow \overline{O}$ (3) [2] Song R B, Lin V, Lin L, Zhang J R, Lin V,
 $\overline{E}O_2 + \overline{O}H \rightarrow \overline{C}O_3^2 + H_2O$ (3) [2] Song R B, Zhu W, Fu J, Chen Y, Liu L, Zhang J R, Lin V,
 $\overline{E}O_3 + \overline{O}H \rightarrow \overline{C$ $\begin{array}{l} \vspace{0.2cm} \begin{tabular}{ll} \multicolumn{3}{l}{{\bf H}}&\vspace{0.2cm}{{\bf H}}&\$ $\begin{tabular}{ll} \multicolumn{3}{l}{{\textbf{#6: }}\mathbf{F}(\mathbf{F}) = \mathbf{F}(\mathbf{F})\left(\mathbf{F}(\mathbf{F})\right)} & \text{if $\mathbf{F}(\mathbf{F})$ is the same value of the T-space level.} \\ \hline \multicolumn{3}{l}{\begin{tabular}{l} $\mathbf{C}O_2$+OH$}\rightarrow $\mathbf{H}(\mathbf{C})$} & $\mathbf{C}(\mathbf{F})$& $\mathbf{F}(\mathbf{F})$& $\mathbf{C}(\mathbf{F})$& $\mathbf{F}(\mathbf{F})$& $\mathbf{F}(\mathbf{F})$$ the CEM (3.7 V) in Figure S8. The analysis [4] Al-Manoori A, Krishnamurtiy A, Rownsight A. Here C. The CHM (3.7 V) in Figure S8. The analysis [4] A. Co., exposition: energy input and convession efficiency [1]. The convex **EDENT (ELECTION AND THE SET ALT AND ANDEL AT ALT AND THE SET AND AND THE SET AND AND THE SET AND A SHOW THE SET AND A LOTE SHOW THE SHOW IN THE SHOWER (CO.) FO** ^赘) of the AEM than that of the CEM (1.136 ^赘). Overall, the AEM exhibited better CO2RR performance **EVALUATION 1992-28(1), 2104231 (8 of 9)**

CO₂ + OHF -- HCO₃ + OHF -- HCO₃ + OH -- HCO₃ + OH -- HCO₃ + OH -- CO₂ + HC and CFM, the cost potentials of the Custom case of the CEM in the cost potentials of the CE smaller resistance and lower cell voltage in our $\begin{tabular}{ll} \multicolumn{3}{l}{{\bf \# }} \mathcal{L}^{\mathcal{L}}(L \: {Electrochen}, 2022, 28(1), 2104231 (8 of 9)\\ \hline \multicolumn{3}{l}{\bf CO}_1 + OH^- \to CO_1^+ + H_2O &\text{(3)} \: \begin{tabular}{ll} \multicolumn{3}{l}{\bf \# } \mathcal{L}^{\mathcal{L}}(L \: {Electroche}~{\bf m}, 1011, 1111, 1111, 1111, 1111, 1111, 1111, 1111, 1111, 1111$ CO₂⁺ OH⁻ + HCO₃⁺ OH- + HCO₃⁺ (3)⁻ 12 (3)⁻ 12 (3)⁻ 12 (3)⁻ 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3)- 12 (3 CO₂ 1 OH^T → HCO₃ (3) [2] Song R B, Zhu W, Fu J, Chen Y, Liu L, Zhang J R, Lin Y,

HCO₃ + OH^T → CO₂ + OHT → CO₂ cradicion cometimals organization emission emission emission emission emission emission emission $\text{HCO}_5 + \text{OH} \rightarrow \text{CO}_5^2 + \text{H}_5\text{O}$

To further acplore the difference between the AEM (C), reduction: energy input and conversion efficiency]

To further acplore the difference between the AEM of CEUS and to Adv. Muter To further explore the difference between the AEM

of Adv. Mater., 2020, 27(32): 1902106.

and CFM, the enset potentials of the CusSn electroched

by using the AFM and CFM were -0.57 V_{ires} and -0.62

by using the AFM an and CEM, the onset potentials of the Cu/Sn clectrode
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V_{BR} as v_x respectively (the instead in Figure 3(A)). Addition-

VH. Eksetcokencied synthesis of amonoin from inforgen

VH, the celectrolic plane (3(A)). Addition-

4 Conclusions

V_{non}, respectively (the inset in Figure 3(A)). Addition

under mild conditons: current status and challenges, elec-

ulty, the cell voltage of the AEM (3.17 V) was lower CTR (0.996 for AEM (4.13 and N-type Rev., 2000, 3 tor owing to the higher solubility of CO2, shorter disthan that of the CEM (3.7 V) in Figure S8. The analysis

(i) Al-Manoori A, Krishnamurthy A, Rownaghi A A, Rezaei

f EdS in Figure 3 (18) showed a lower CTR (0.996 F. Carbon caputure and utilization update[J]. Energy Techof EIS in Figure 3 (B) showed a lower CTR (0.996 F . Curbon cupture and ulikanion update[J]. Energy Tech-

and the AEM charge that of the CEM (1.136 G). Over

and the AEM charge that of the CEM (1.136 G). Over

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10. Integrals and its AEM in the Kim technology. 2017, 5(6): 834-849.

11, 1h ACM chall the ACEM in the kinetic records performance of Fixed remains G, Mal J, Larmachal all, the AEM exhibited better CO_SRR performance

than the Kinchi excelsion is V_1 , baltmagina is V_2 , the smaller resistance and lower cell voltage in our

smaller resistance and lower cell voltage in our

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1.1 this work, a high-performance continuous flow

MEA reactor based a self-growing Cu/Sn bimetallite

MEA reactor based **CONCLUSIONS**

In this work, a high-performance continuous flow the the Secure term and the same of CA in useful deconderest name, remaining

EX reactor based a self-growing Cu/Sn bimetallic deallenges, and finare opportu In this work, a high-performance continuous flow

MEA reactor based a self-growing Cu/Sh bimetallite

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excellent formate selectivity (89.56%), great current

byt, reaction mechanism, and process engineering[1]. Namo

dencity is may can be the fundamental control of the Funda excellent formate sclectivity (89.56%), great current

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density (47.56 mA · cm² at -0.91 V_{nes}) and durable

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Acknowledgements:

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Lin Y. Tuning Sn.O, for CO. reduction to formate with ulbetter CO-RR performance than CEM in the ki-

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or exterto due to the smaller resistance (0.996 ft) [10] ii QQ, Rao X F, Sheng J W, Xu J, Yi J, Liney Y, Zhang

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一种用于电还原 $CO₂生成甲酸的$ 高性能连续流动式 MEA 反应器

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摘要: 电化学二氧化碳还原反应(CO,RR)是一种利用间歇性可再生电力缓解环境问题,并且生产液体燃料和工 业化学品的有前途的方法。然而,传统的 H 型反应器由于在电解液中较低的 CO2 溶解度以及两电极之间较大的 极距而导致高欧姆电阻,严重限制了 CO2RR 的电化学性能,不利于 CO2RR 在工业应用的发展。在本文中,我们设 mass flows and membrane cross-over in CO₂ reduction at i6(27): 138-149.
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3.18.48大环境将学与工程学院上海201620;2.上海市污染控制与生态实行所,上海200 甲酸的生产率为 163 μmol·h-1·cm²。本文为克服电化学 CO₂RR 的传质限制以及分离液体和气体产物提供了一条 新途径。

关键词: 电化学还原:二氧化碳:流动式 MEA 反应器:电解槽