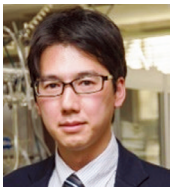
Energy conversion, Carbon-neutral, Green transformation

Multiscale design of high-rate CO_2 electrolysis systems



Research Center for Solar Energy Chemistry, Graduate School of Engineering Science
Associate Professor Kazuhide Kamiya
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Abstract

We have successfully increased the partial current density for electrochemical CO_2 reduction reactions to multicarbon products (C_{2+}) over Cu nanoparticles on gas diffusion electrodes in neutral electrolytes to a record value of 1.8 A/cm^2. Furthermore, a hybrid gas diffusion electrode coated with tin oxide on metal foam was developed, achieving efficient CO_2 reduction to formate with a current density surpassing 1 A/cm^2.

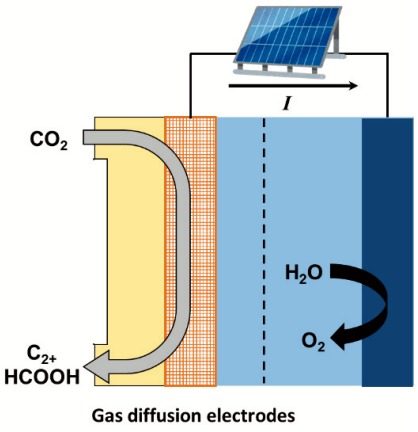
Background & Results

The electrochemical CO_2 reduction reaction (CO_2RR) is a promising strategy for closing the carbon cycle. Increasing the current density (J) for CO_2RR products is a critical requirement for the social implementation of this technology. There are many factors with different size scales, such as catalysts, electrodes, and electrolysis cells, that determine the activity of CO_2 electrolysis. However, many studies have focused only on single elements, with little research on how to harmonize their functions as a whole. Based on our philosophy of appropriately selecting and arranging these elements to function in harmony and maximize the potential of each material, we carried out research and successfully achieved high reaction rates for CO_2RR.

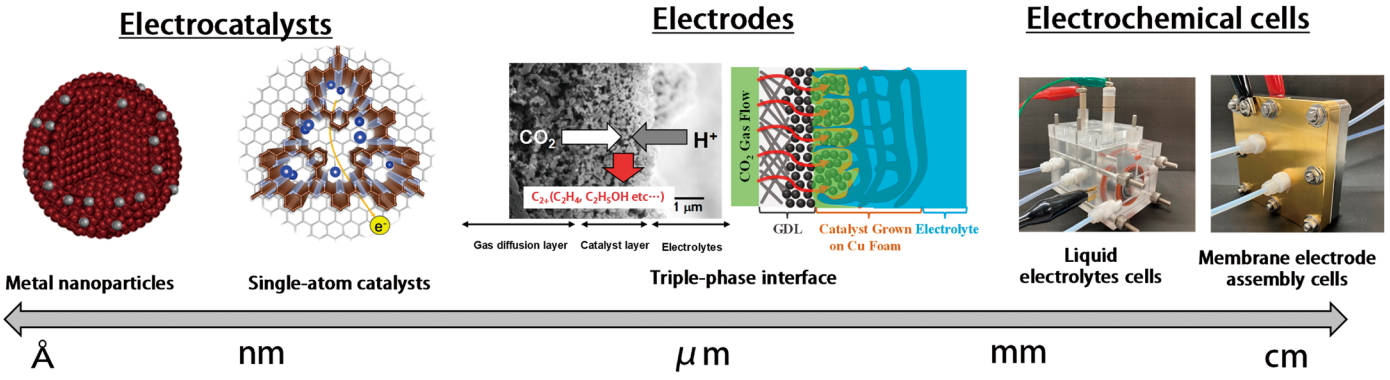
Specifically, nanoscale tin-oxide-modified copper-oxide foam was hybridized with a carbon-based gas-diffusion electrode (GDE). Using the resultant electrode, we increased the $J_{formate}$ to 1.1 A/cm^2 at −1.2 V vs. RHE in 1 M KOH, which is the highest value for CO_2-to-formate electrolysis. In addition, we have successfully increased the partial current density for gaseous CO_2 reduction reactions to multicarbon products (C_{2+}) over Cu nanoparticles on gas diffusion electrodes to a record value of 1.8 A/cm^2 in KOH solutions.

Significance of the research and Future perspective

Our work demonstrated the relevance of consistent design from the micro to the macro scale, and would be expected to become a general guideline for future energetic device studies. This can be seen as a fusion of research across different scales, and the principles and materials derived here are expected to be significantly different from those derived from single-scale research. Additionally, as the current density for the production of high value-added products is correlated with the capital cost of the employed electrodes, these ultra-high current electrolysis will become important cornerstones for their social implementation.



Schematic illustration of gaseous CO_2 electrolysis



Multiscale design of CO_2 electrolysis systems

Patent

Treatise
Inoue, Asato; Nakanishi, Shuji; Kamiya, Kazuhide et al. Ultra-high-rate CO_2 reduction reactions to multicarbon products with a current density of 1.7 A/cm^2 in neutral electrolytes. EES Catalysis. 2023, 1, 9–16. doi: 10.1039/D2EY00035K
Liu, Tengyi; Nakanishi, Shuji; Kamiya, Kazuhide et al. A tin oxide-coated copper foam hybridized with a gas diffusion electrode for efficient CO_2 reduction to formate with a Current density exceeding 1 A cm^{-2}. Small. 2022, 18, 2205323. doi: 10.1002/smll.202205323
Kato, Shintaro; Nakanishi, Shuji; Kamiya, Kazuhide et al. Selective and high-rate CO_2 electroreduction by metal-doped covalent triazine frameworks: A computational and experimental hybrid approach. Chemical Science. 2023, 14, 613–620. doi: 10.1039/D2SC03754H

URL

Keyword CO_2 electrolysis, net zero emissions, multi-scale simulation, artificial photosynthesis