3D Printing Porous Electrode with Functional Coating for CO_2 Reduction

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Project Highlights and Results

This project successfully combined 3D printing and advanced functional coatings and mass transfer to enhance the selectivity of CO_2 electrochemical reduction. The functional Mo(x)S(x+1) substrate significantly improved the selectivity of CO_2 reduction compared to flat Mo electrodes, leading to a selective electrochemical conversion. The 3D-printed porous structure provided an increased specific surface area, facilitating improved reaction kinetics. The optimized pore geometry controls mass, which ultimately tunes the process towards particular products.

Electrochemical testing revealed distinct performance differences between the Mo and on the other hand Mo(x)S(x+1) electrodes. While Mo electrodes primarily produced hydrogen and methane, the Mo(x)S(x+1)-coated electrodes demonstrated the ability to generate diverse hydrocarbons, including C1 to C5 species. The product distribution varied significantly with applied potential, with methane and isobutane dominating at higher and lower potentials, whereas intermediate potentials favoured the production of a wider range of hydrocarbons.

These results underline the critical role of both electrode architecture and functional coatings in determining CO_2 reduction efficiency and product selectivity.

The project leveraged key advancements reported in the literature, such as the scalability and design flexibility of 3D printing (Padinjareveetilet et al., *Advanced Materials Interfaces*, 2023) and the catalytic potential of molybdenum-based coatings (Alinejadian et al., *Materials Today Chemistry*, 2022). Together, these approaches have demonstrated a promising pathway for scalable, cost-effective, and highly efficient CO_2 conversion technologies.

Advantages of the Approach

The integration of 3D printing and functional coatings offers several unique advantages. The complex geometry achievable through 3D printing allows for precise control over pore architecture, enabling tailored designs that minimize mass transfer limitations and maximize reaction efficiency. The approach is highly versatile, allowing for easy adaptation to a wide range of electrochemical systems. Furthermore, 3D printing ensures scalability and replicability while minimizing waste during production, making it a cost-effective solution for large-scale applications.

Conclusion

This project has demonstrated the transformative potential of combining 3D printing with functional coatings for CO_2 electrochemical reduction. By addressing critical challenges in selectivity, efficiency, and scalability, the findings pave the way for future interdisciplinary collaborations and large-scale industrial applications. Continued efforts will focus on advancing catalytic performance, expanding the product range, and ensuring the feasibility of these technologies for widespread use. This project serves as a steppingstone for developing sustainable, high-impact solutions to address global energy and environmental challenges.

Plan for follow-ups

Building on the achievements of this project, further research is focused on optimizing the electrode structure and functional coatings to tube the pore size and surface composition. Detailed investigations into the effects of hierarchical pore sizes on Faradaic efficiency and product selectivity will be conducted. Additionally, the functional coatings will be refined to enhance the generation of multicarbon hydrocarbons, which are critical for achieving higher-value products. Electrochemical testing will be expanded by selecting two or three critical potentials for extended experiments. These tests will provide insights into the long-term stability of the electrodes and their performance under varying operational conditions. The impact of co-catalysts integrated into the electrode system will also be explored to further improve product selectivity and efficiency. This project aims to foster collaborations with materials scientists, electrochemists, and industry partners. Interdisciplinary research will enable a deeper understanding of the electrode architecture's impact on catalytic performance, while industrial partnerships will support the scaling up of these technologies. Beyond CO_2 reduction, the methodologies developed here will be adapted to other critical electrochemical systems, such as water splitting and nitrogen reduction, broadening the scope of this research.