Sustainable nitrate wastewater-to-ammonia conversion and energy recovery via a dual-photoelectrode fuel cell

Ying-Yi Liu(劉迎逸)、 Shou -Heng Liu(劉守恒)

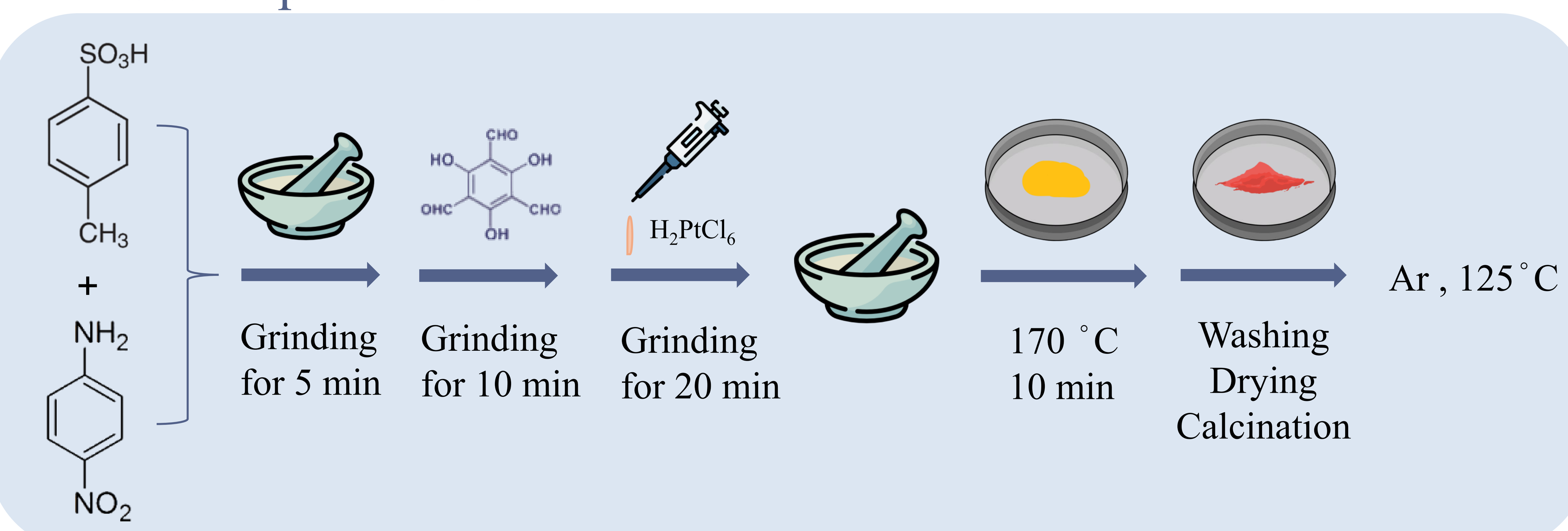
Department of Environmental Engineering, National Cheng Kung University, Tainan 70101, Taiwan

Abstract

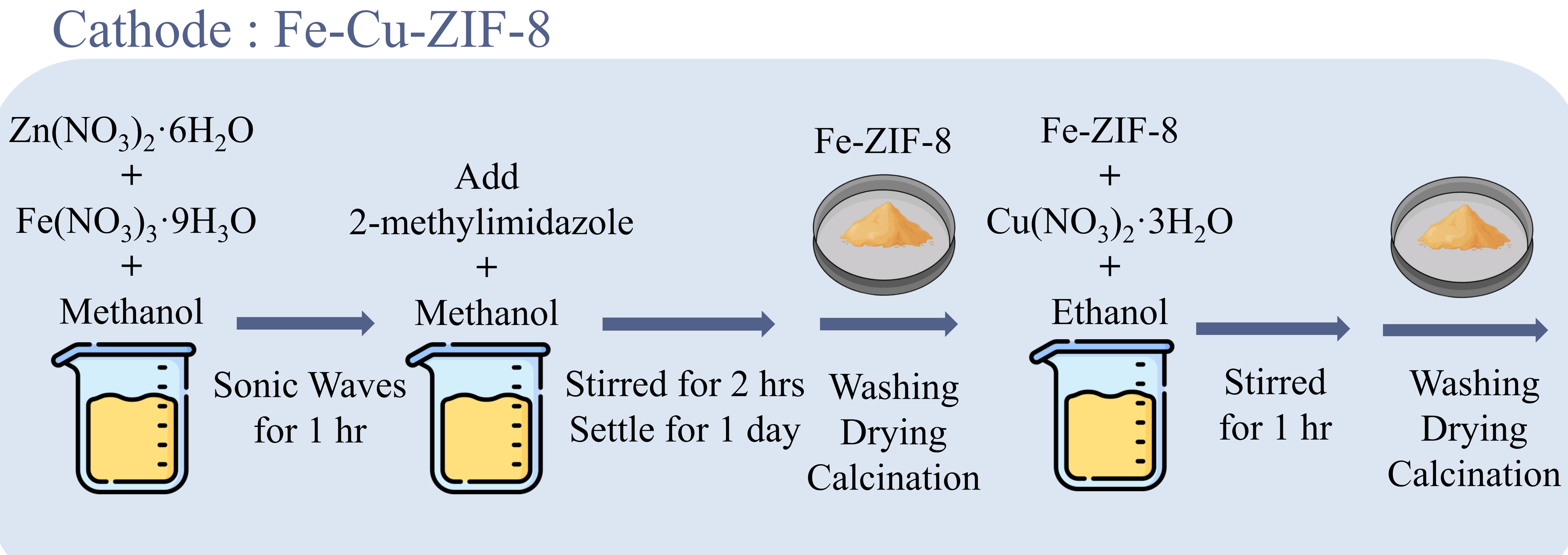
Wastewater treatment and recycling are crucial for achieving the global goal of net-zero carbon emissions by 2050. In this study, a dual-electrode system is employed to convert nitrogen-containing wastewater into ammonia while simultaneously generating electricity(I_{max}: 0.049mA), thereby accomplishing two objectives at once. Covalent organic frameworks (COFs) have emerged as promising catalysts for the nitrogen reduction reaction (NRR). These frameworks are composed of organic molecular units interconnected through strong covalent bonds, forming highly ordered network structures. COFs provide exceptional tunability, well-defined porous architectures, remarkable chemical stability, and abundant active sites, making them highly suitable for catalytic applications. Zeolitic imidazolate frameworks (ZIFs), on the other hand, are known for their structural flexibility, multilayered porous networks, and high surface area. When doped with iron (Fe) and copper (Cu), the resulting Fe–Cu–ZIF serves both as a "porous reactor" and as a carrier for dual-metal active centers. This material combines bimetallic active sites, large surface area, and a conductive carbon framework, thereby enhancing the adsorption and activation of nitrate ions (NO_3^-) and exhibiting excellent catalytic performance in nitrogen reduction reactions.

Experimental Methods

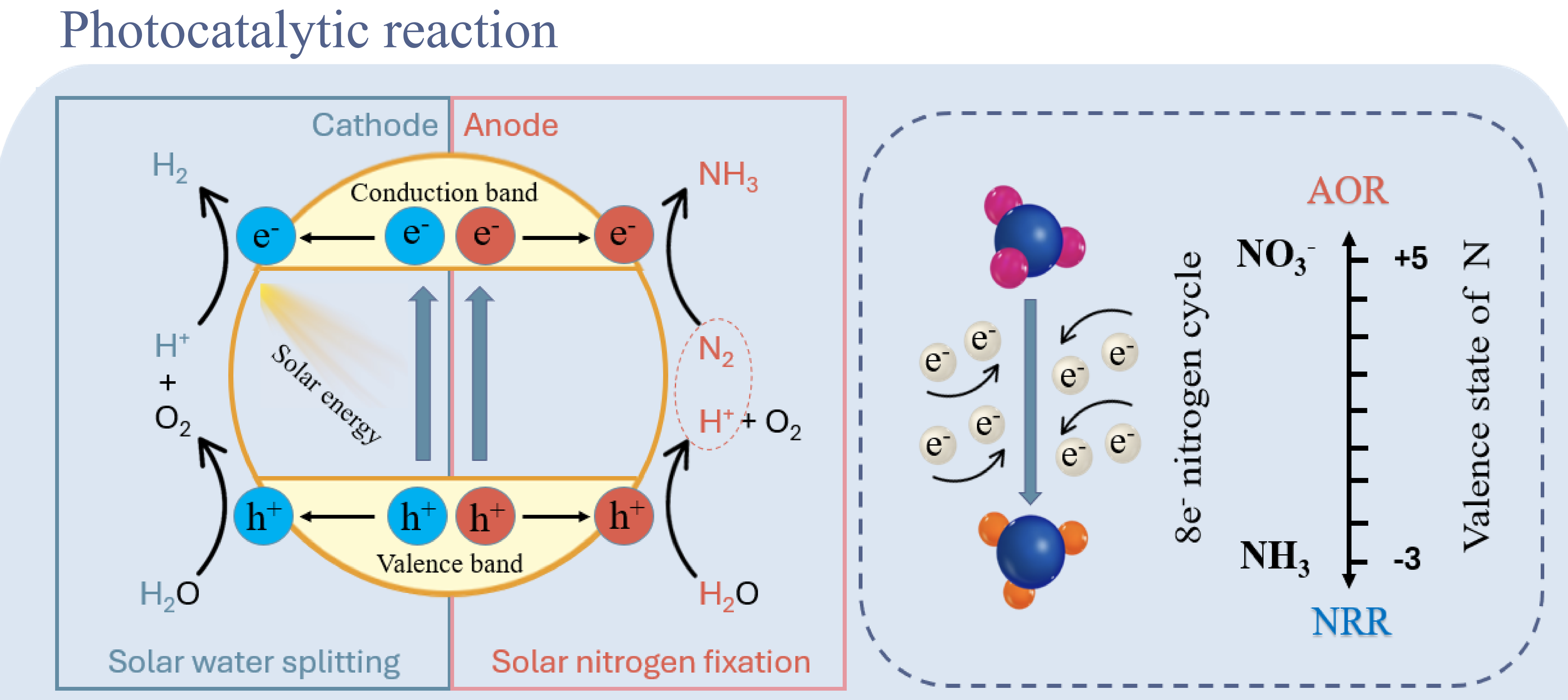
Anode : TpPa-1-COF



Cathode : Fe-Cu-ZIF-8



Photocatalytic reaction

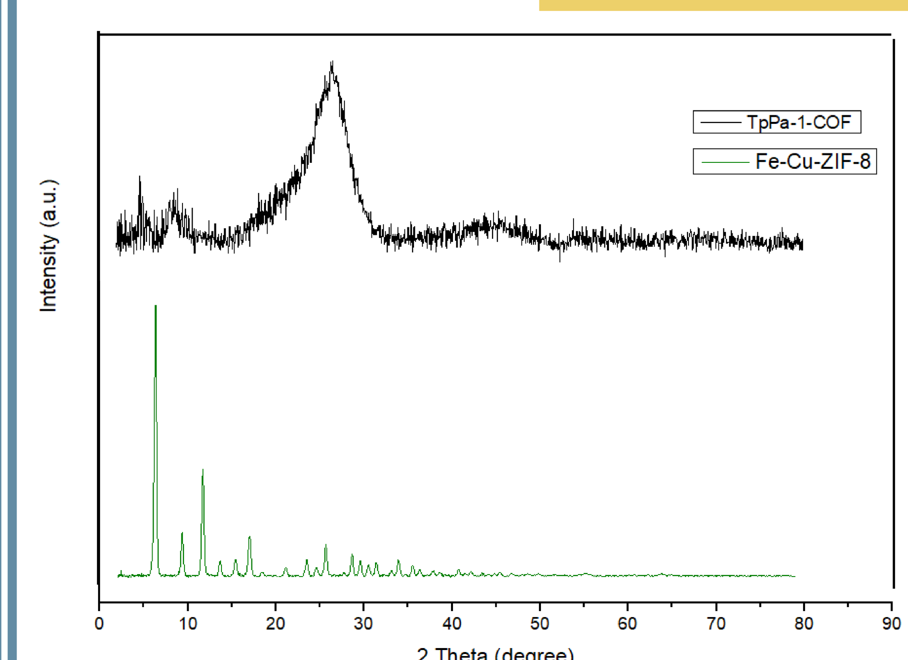


Anode: $4OH^- \rightleftharpoons O_2 + 2H_2O + 4e^-$

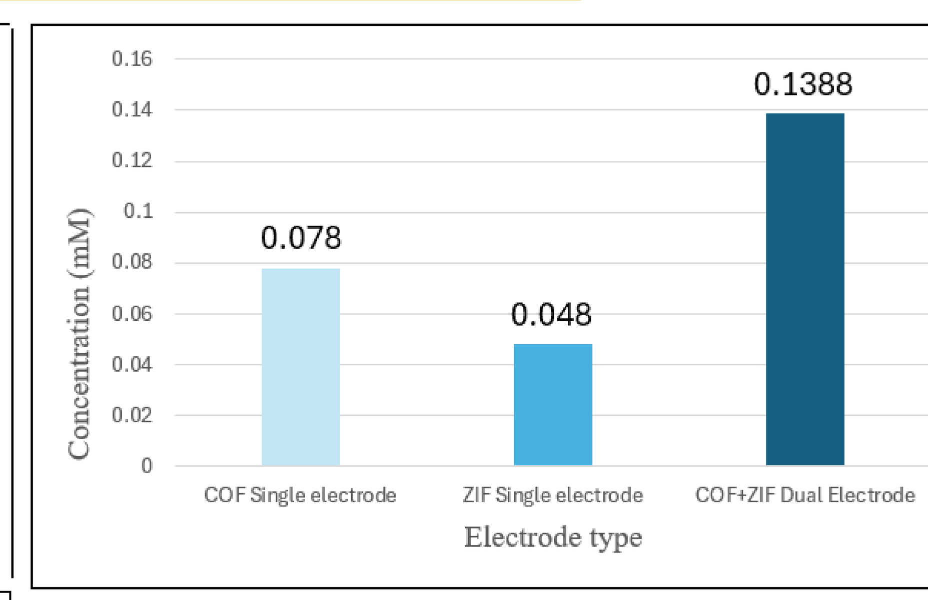
Cathode: $NO_3^- + 6H_2O + 8e^- \rightleftharpoons NH_3 + 9OH^-$

Overall reaction: $NO_3^- + 2H_2O \rightleftharpoons NH_3 + 2O_2 + OH^-$

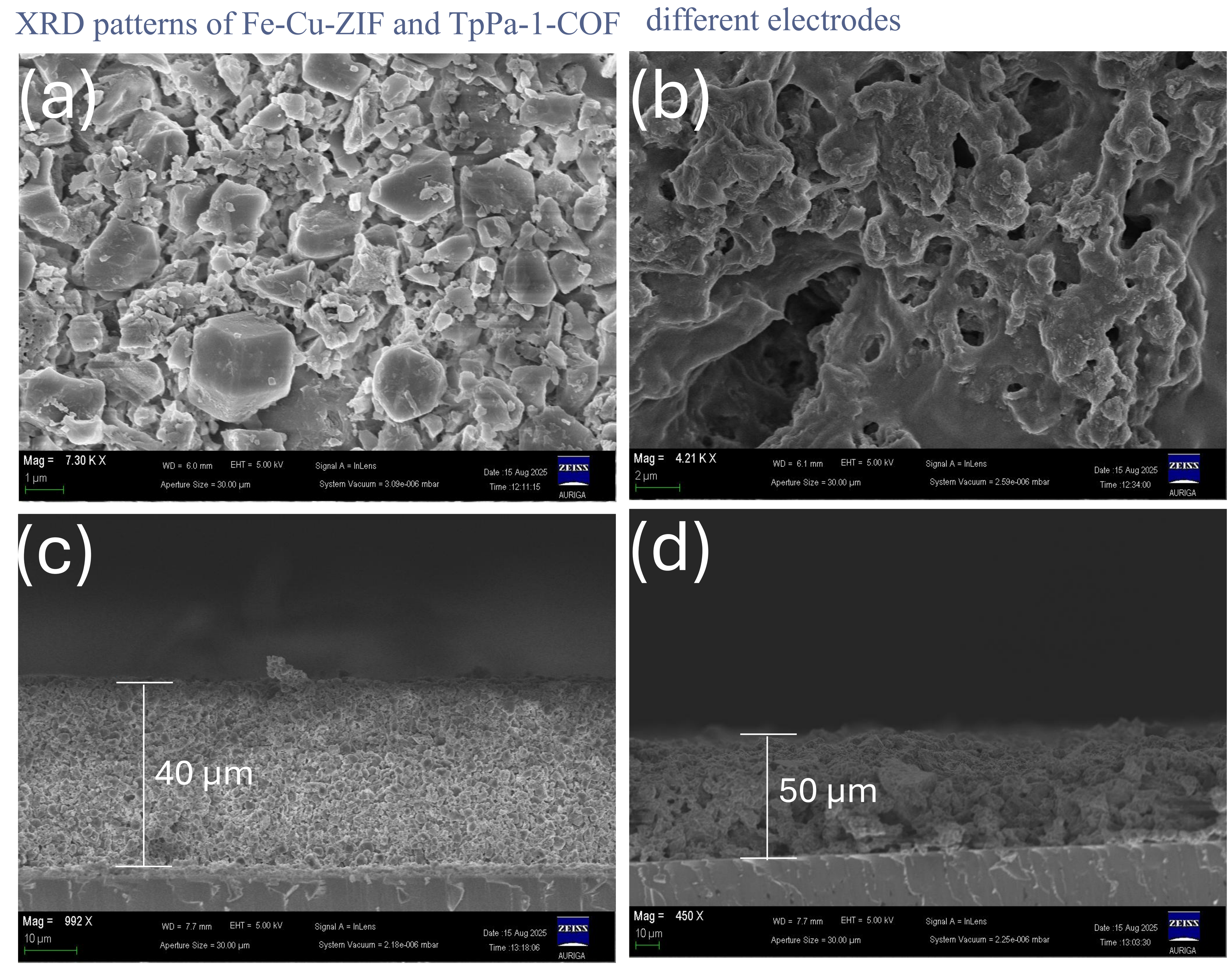
Results and Discussions



XRD patterns of Fe-Cu-ZIF and TpPa-1-COF



Comparison of ammonia concentrations at different electrodes



SEM images of Fe-Cu-ZIF(a)front of Fe-Cu-ZIF (b)front of TpPa-1-COF (c)side of Fe-Cu-ZIF (D)side of TpPa-1-COF

Table 1. IV Test Data of dual-photoelectrode fuel cell

	I_{max}(mA)	V_{max}(mV)	P_{max}(mA)	Time(min)
COF+ZIF dual-photoelectrode	0.049	510	0.249	15

Conclusion

The dual-photoelectrode fuel cell developed in this study reduces nitrogen-containing wastewater into ammonia (conversion efficiency: 44%), and generates electricity (I_{max}: 0.049 mA, V_{max}: 510mV, P_{max}: 0.249mA). Future research will focus on improving the ammonia conversion efficiency by modifying different electrode materials and integrating energy storage materials to capture the generated electricity, thereby enhancing the overall practical value of this work.