Catalytic chemistry, Electrochemistry, Petrochemistry, Carbon neutrality

Electrocatalytic CO_2 valorization using nanostructured carbon catalysts

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Abstract

Concerns over global warming have motivated us to develop material conversion systems that can convert carbon dioxide (CO_2), one of the greenhouse gases, into valuable compounds. Electrochemical CO_2 reduction is attracting interest as an efficient CO_2 conversion technology because it proceeds under ambient temperature and pressure conditions and produces high-value-added organic compounds in a single step. We have found that CO_2 can be electrocatalytically converted to carbon monoxide (CO) with high electron utilization efficiency and selectivity by using a catalyst consisting of active metal species (Co, Ni, etc.) immobilized on unique nanostructured carbon materials with high conductivity and surface area. Although the production of hydrogen (H_2) is unavoidable in this reaction, it can be suppressed by controlling the composition of the carbon material and the chemical state of the active metal species, allowing for highly selective CO production.

Background & Results

CO_2 is considered a major cause of global warming, and the reduction of CO_2 emissions has been a worldwide concern. The Japanese government has set a goal of achieving net zero emissions of greenhouse gases including CO_2 by 2050, and there is a need to develop technologies that can capture CO_2 and convert it into valuable resources. Electrochemical CO_2 reduction is attracting interest as an efficient CO_2 conversion technology because it can proceed under ambient temperature and pressure conditions and synthesize high-value-added organic compounds in a single step. However, the low efficiency of electron utilization for CO_2 reduction and the low selectivity of the products obtained by CO_2 reduction have been issues to be solved, mainly because of the production of H_2 as a byproduct.

We have found that the use of catalysts consisting of active metal species (Co, Ni, etc.) immobilized on unique nanostructured carbon materials with high conductivity and surface area can electrocatalytically convert CO_2 to CO with high electron utilization efficiency and selectivity. CO is industrially valuable because it can be used as a raw material for liquid hydrocarbons such as alcohol, gasoline, and jet fuel. In this reaction, H_2 production is inevitable due to the reduction of water; however, we found that CO can be synthesized with a high selectivity while suppressing H_2 production by controlling the composition of the carbon material and the chemical state of the active metal species. Furthermore, through investigations by structural analysis and computer simulations, we found that differences in the nanostructure of the active metal species affect the adsorption behavior of the molecules and subsequently the CO/H_2 ratio in the resulting gas.

Significance of the research and Future perspective

The mixture of CO and H_2 (synthesis gas) obtained by electrochemical CO_2 reduction reaction can be used as a raw material for liquid hydrocarbons such as alcohol, gasoline, and jet fuel, which is expected to be one of the clean CO_2 conversion technologies for the realization of a carbon neutral society. We aim to develop commercially feasible CO_2 conversion technology in the future by further reducing operating voltage, increasing current density, and improving catalyst durability.

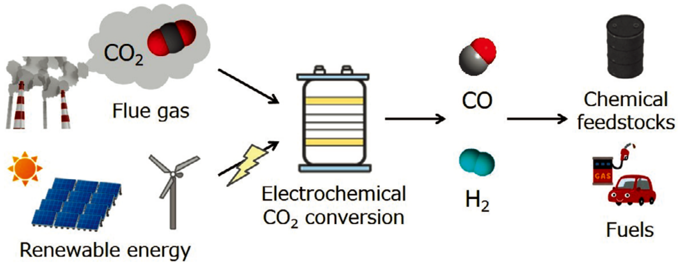

Fig. 1 CO_2 valorization by electrochemical CO_2 reduction

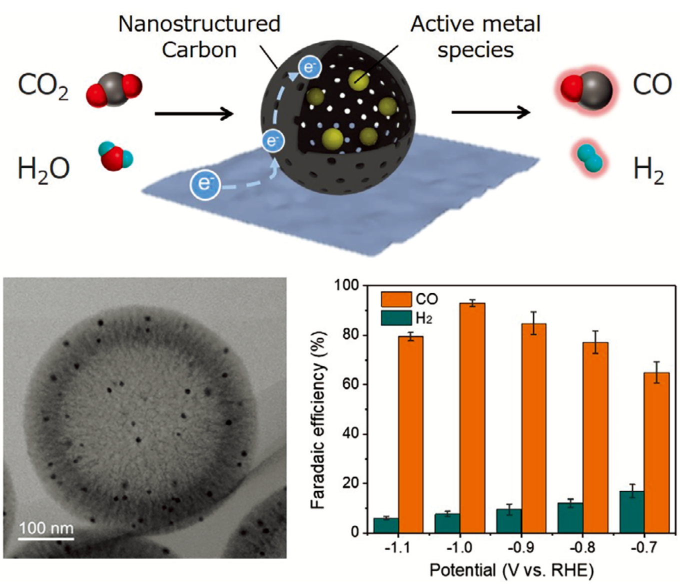

Fig. 2 Production of CO by electrochemical CO_2 reduction using a nanostructured carbon catalyst (top), TEM image of nanostructured carbon catalyst (bottom left), electron utilization efficiency for CO and H_2 (bottom right)

Patent

Treatise

Li, Kaining; Kuwahara, Yasutaka; Yamashita, Hiromi et al. Hollow carbon sphere featuring highly dispersed Co-N_x sites for efficient and controllable syngas electrosynthesis from CO_2. Chemical Engineering Journal. 2024, 488, 150952. doi: 10.1016/j.cej.2024.150952

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URL

Keyword CO_2 capture and utilization, CO_2 valorization, electrocatalysis, carbon materials