Development of energy resource conversion, Chemical industry, Space industry

Custom design of self catalytic reactors using metal 3D printers

Division of Materials and Manufacturing Science, Graduate School of Engineering
Associate Professor Kohsuke Mori
Researchmap https://researchmap.jp/7000018582?lang=en

Abstract

Ni-based multifunctional self-catalytic reactor (SCR) was fabricated by metal 3D printing using Hastelloy X powder as a starting material. Selective electrochemical dissolution of the SCR successfully transformed the original inert surface, which consisted of a Cr- and Fe-based passivation layer, into a Ni-enriched surface that is active as a robust catalyst for CO_2 methanation. Notably, we demonstrate for the first time an SCR that enables a continuous increase in catalytic activity through a simple refreshment process driven by a self-dissolution mechanism. Other important factors, such as the effect of different crystal textures induced by different scan strategies on the selective electrochemical dissolution process and the relationship between the geometric structure of the SCR and its thermal properties, are also investigated.

Background & Results

CO_2 methanation ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$, $\Delta H = -165.0$ kJ mol^{-1}) is of great interest not only as a method to store energy with high density but also as a promising energy source in near-future energy scenarios. This reaction also has the potential to reduce atmospheric CO_2 levels by utilizing CO_2 as an inexpensive, nontoxic, and abundant C1 feedstock and could ultimately provide a carbon-neutral cycle. Thus, the heterogeneous catalysts that exhibit high stability and efficiency are highly desired to accelerate the conversion.

Metal 3D printing is revolutionizing the industry by enabling rapid and cost-effective production of complex metal 3D products with intricate geometries, attracting significant attention in recent years. Particularly, Specifically, this allows for the fabrication of reactors with intricate internal geometries, enabling the production of highly efficient catalysts with high surface area, optimized reactant flow paths, and tuneable selectivity. Moreover, the new concept of integration of catalyst and reactor function as a term of self-catalytic reactor (SCR) is recently proposed and opened the new way of optimizing the usage of metal 3D printing on catalytic field. We developed a multifunctional SCR via metal 3D printing and selective electrochemical dissolution as a method to not only simplify the catalyst development process but also fabricate active catalysts for CO_2 methanation (Fig. 1).

Significance of the research and Future perspective

Metal 3D-printed SCR is the newly emerged research field, and thereby there is a lack of comprehensive information on the SCR. Further research is essential to establish a robust SCR design database containing materials, surface functionalization, geometrical structure, and mechanistic study (Fig. 2). This database enables the creation of various scale-up SCR shapes, i.e. heat exchangers and high-density reactors, for improved cost-effectiveness and industrial application with maximize the advantage of SCR. Despite these challenges, SCR is anticipated to be a technology that explores the potential future advancements in both 3D printing technology and catalytic reactor design.

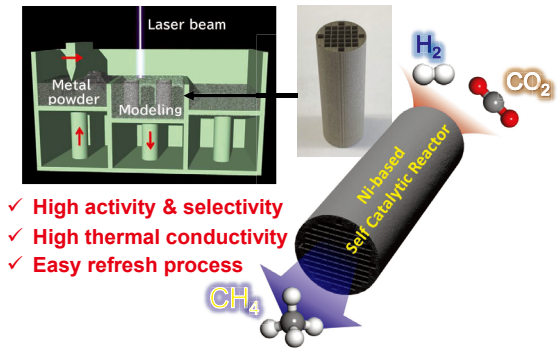

Fig. 1

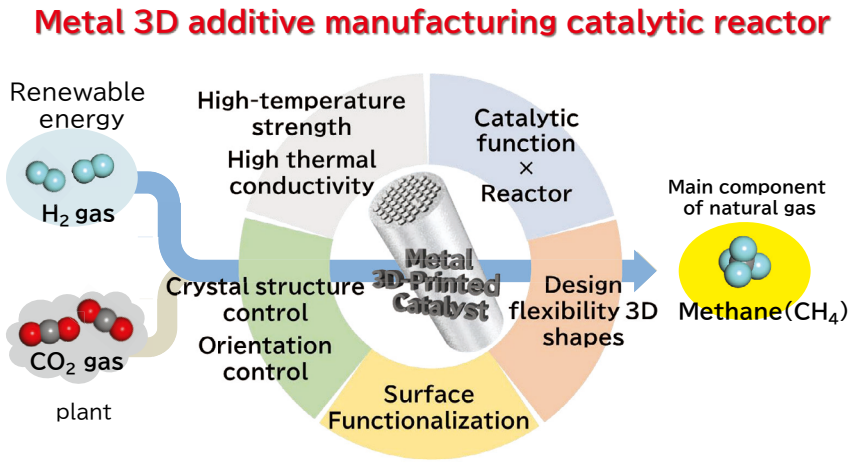

Fig. 2

Patent Japanese Patent Application No. 2024-190103
Treatise Kim, Hyojin; Mori, Kohsuke; Nakano, Takayoshi et al. Robust self-catalytic reactor for CO_2 methanation fabricated by metal 3D printing and selective electrochemical dissolution. Advanced Functional Materials. 2023, 33, 2303994. doi: 10.1002/adfm.202303994
URL
Keyword metal 3D printer, self-catalytic reactor, carbon dioxide, methanation