TOP 10 RESEARCH ACHIEVEMENTS

Rare-earth-platinum alloy nanoparticles for catalysis

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Metal nanocatalysts are a vital component in chemical processes. Particularly, controlling the catalytic properties by alloying 2 or more metal components in the form of nanoparticles is highly important. However, rare-earth elements could not be formed in the form of metal nanoparticles due to their low chemical reduction potential. Prof. Ryoo and his group members established a route to disperse rare-earth elements in the form of single atomic species using the surface of mesoporous zeolite. This increased the chemical reduction potential of the rare earth elements, thereby allowing the formation of rare-earth-platinum alloy nanoparticles. The alloy nanoparticle catalysts exhibited an outstanding performance in a petrochemical reaction producing propylene. This result provides a new concept in the field of heterogeneous catalysis and will greatly contribute to the pioneering of basic research and application in this field.

1. Background

Professor Ryong Ryoo has performed research on the synthesis of mesoporous materials over the past two decades at KAIST. Prof. Ryoo published 5 papers in Nature and 1 paper in Science regarding the synthesis of various porous materials, including the CMK-series mesoporous carbons which was named after KAIST. In the last semester before his retirement, Prof. Ryoo published a paper in Nature as the first author and corresponding author, which is titled "rare-earth-platinum alloy nanoparticles in mesoporous zeolite for catalysis". Upon expansion of his research direction from the synthesis of mesoporous materials to the exploration of surface chemical properties, Prof. Ryoo has newly discovered a phenomenon (that is, dispersing rare-earth elements on the mesopore surface in a single atomic state) and explored the possibility of its application in the field of catalyst synthesis. This research has opened up the opportunity of applying the mesoporous zeolite pioneered by KAIST as a propane dehydrogenation catalyst. Propane dehydrogenation is a reaction that converts propane in shale gas and natural gas to propylene and is currently the most important research topic in the field of petrochemical industry.

2. Contents

Rare-earth elements are difficult to reduce into a metallic state due to their low chemical reduction potential, making them difficult to form into metal nanoparticles or alloy nanoparticles with other elements. Prof. Ryong Ryoo's research team succeeded in dispersing rare-earth elements on the surface of the zeolite as single atomic species by controlling the surface properties of the mesoporous zeolite.

The single atomically dispersed rare-earth elements exhibited higher chemical reduction potential compared to that of the conventional rare-earth oxides, allowing them to be easily reduced. Using this strategy, the research team could successfully generate intermetallic compound nanoparticles between rare-earth elements (La, Ce, Y) and platinum, which were previously considered impossible. The Pt-La, Pt-Y, and Pt-Ce nanoparticles obtained in this manner were intermetallic compounds having an L12 structure, as seen in the atomic-resolution STEM image of Fig. 1a. The rare-earth-platinum nanoparticles showed excellent catalytic activity and stability in the propane dehydrogenation reaction. The catalytic activity of rare-earth-platinum catalysts was maintained for as short as 7 days to as long as 20 days, as seen in Figure 1b and 1c. This is several times to tens of times longer than the catalytic lifetime of the commercial Pt-Sn catalyst supported on alumina.

3. Expected effects

The principle of the atomistic alloying process discovered in this study would be applicable for the formation alloys not only between platinum and rare-earths but also between platinum and other transition metals. It is expected that the synthesis strategy would be helpful for the design of other alloy catalysts for not only propane dehydrogenation but also other industrially important chemical reactions.

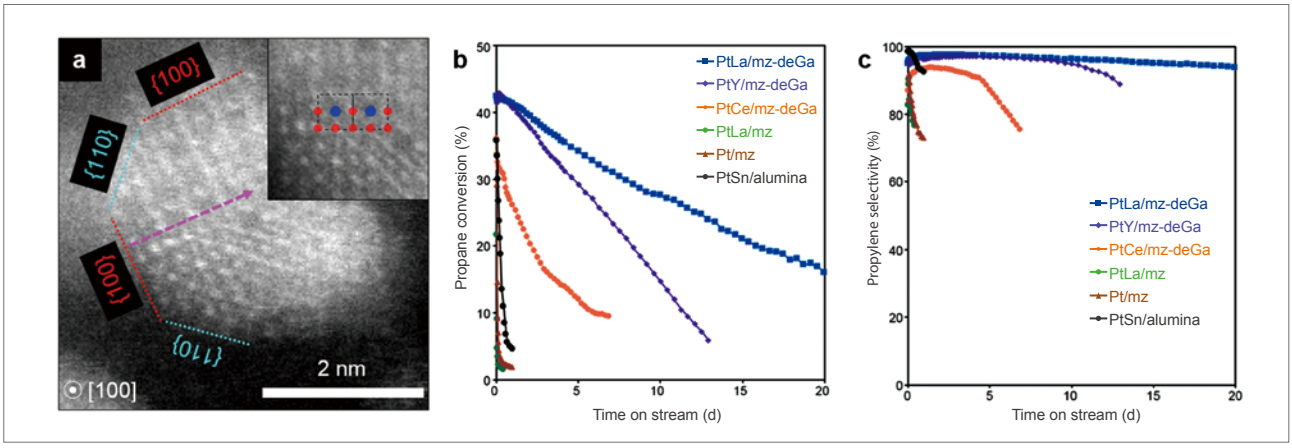

Figure. (a) Atomic resolution STEM photograph of Pt3Y intermetallic compound alloy nanoparticles with L12 structure supported on mesoporous zeolite. (b) Propane conversion and (c) propylene selectivity over time of various platinum-based catalysts in propane dehydrogenation

Research outcomes

[Paper] R. Ryoo,* J. Kim, C. Jo, S. W. Han, J.-C. Kim, H. Park, J. Han, H. S. Shin, and J. W. Shin, "Rare-earth–platinum alloy nanoparticles in mesoporous zeolite for catalysis", Nature 585, 221–224 (2020) [2019 Impact Factor = 42.778].
[Patent] R. Ryoo, J. Kim, C. Jo, J.-C. Kim, in preparation
[Press release] Prof. Ryong Ryoo at KAIST develops Pt-REE alloy nanocatalysts, Yonhap News, September 10, 2020
KAIST develops propylene production technology from shale gas, Chosun Biz, September 10, 2020

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