Chemical Reaction Under Highly Precise Microwave Irradiation

S. Fujii[1], Y. Wada[2]

[1]Chiba University, Chiba, Japan
[2]Tokyo Institute of Technology, Tokyo, Japan

Abstract

Introduction: Chemical reactions carried out under microwave irradiation often have high reaction rates and high selectivities, which enable compact reactor sizes and energy-conservation processes. Hence, microwave chemical processing and chemical synthesis have attracted considerable interest as they will be employed for greatly improving process efficiencies and conserving energy for realizing "Green Chemistry" or "Green Engineering" [1]. In thermal reactions driven under conventional heating such as the use of electrical heating furnaces and steam heaters, the reactor is heated by heat conduction through the reactor wall. On the other hand, microwave heating provides internal and homogeneous heating of reaction systems. In general, heating with microwave irradiation displays the following features: rapid and high-efficiency heating, rapid thermal response, and selective heating. Furthermore, there have been a lot of works showing unusual enhancement in the reaction rates and selectivities, called "non-thermal effects" [2]. Because of these features, microwave heating has been widely employed in studies on organic synthesis, inorganic synthesis, hydrothermal synthesis, and high-temperature firing.

In order to demonstrate non-thermal effects, we studied the methanol decomposition reaction for extracting hydrogen from methanol using Pd/C as a solid catalyst under highly precise microwave irradiation as a model solid-gas reaction. However, it is often pointed out that microwave irradiated reactions have a very low reproducibility. Our opinion is that one reason for this low reproducibility comes from the broad spectrum of microwave source. Most of chemists usually employed a magnetron as microwave source.

In this study, we developed a microwave irradiation system with a precise and stable high power microwave using a LDMOS-FET and as a diamond surface acoustic wave (SAW) resonator and studied the methanol decomposition reaction for extracting hydrogen from methanol using Pd/C as a solid catalyst under highly precise microwave irradiation as a model solid-gas reaction.

Use of COMSOL Multiphysics®: Electromagnetic (EM) wave and heat transfer simulations of the applicator with an irradiation body were performed using COMSOL Multiphysic®s in order to investigate heat spots. Because chemical reaction rates greatly depend on reaction temperature.

Results: Fig. 1 shows the dependence of the hydrogen generation rate on contact time for hydrogen generated by the methanol decomposition reaction using microwave irradiation and the electrical heating furnace. We can see that the production rate of hydrogen through the methanol decomposition reaction under microwave irradiation was approximately three times greater than that in the case of the electrical heating furnace. It was also found from COMSOL that there was no region of heat spots in the catalyst bed.

Conclusion: With the aim of obtaining high reproducibility of chemical reactions, a microwave high power amplifier (HPA) model with an ultra precise oscillator and elliptical applicator has been successfully developed. We also demonstrated methanol decomposition reaction as a model gas-solid reaction using Pd/C as a catalyst under microwave irradiation. The reaction rate under microwave irradiation was enhanced three-fold as compared with that under electric furnace heating.

Reference

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[2] Microwaves in Organic Synthesis: WILEY-VCH Verlag GmbH & Co., 2006.

Figures used in the abstract

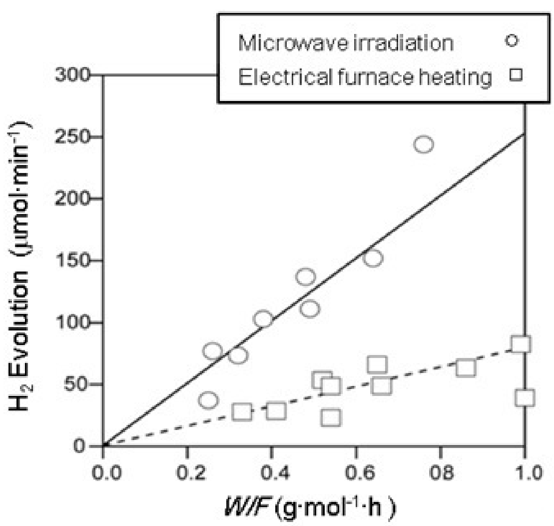

Figure 1: Rate of hydrogen generation by methanol decomposition under microwave irradiation and electrical furnace heating.