Development of a New Technology for Energy Storage Material Using Atmospheric-Pressure Plasma

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Abstract—Recently, there is an increasing need for technology to store and transport unstable renewable energy in chemical energy due to environmental problems, depletion of fossil fuels and other factors. In this report, magnesium nitride (Mg_3N_2) is proposed as a new reusable chemical energy carrier. Mg_3N_2 is suitable for storage and transportation and reacts with water to produce NH_3 as a hydrogen carrier. On the other hand, chemically active species generated by atmospheric pressure plasma have high chemical reactivity. Hence, the technique has been developed to synthesize Mg_3N_2 with a dielectric barrier discharge (DBD) treatment.

Keywords—Atmospheric-pressure plasma, non-thermal plasma, dielectric barrier discharge, energy storage material

I. Introduction

There is an increasing need for technology to store and transport unstable renewable energy in chemical energy due to environmental problems, depletion of fossil fuels and other factors. Since hydrogen is an ideal energy carrier, development of hydrogen storage material is a hot topic [1], [2]. Ammonia (NH_3) is considered as a promising hydrogen storage material because of high hydrogen storage density and established mass production technology [3]. However, since ammonia is designated as a deleterious substance, there is a problem that it is necessary to pay attention to safety. Here, magnesium nitride (Mg_3N_2) is proposed as a new reusable chemical energy carrier material. Mg_3N_2 stores about 43 GJ/m^3, which is 10 times of 700 atm hydrogen gas tank. Mg_3N_2 reacts with water to produce NH_3 as shown in (1) [4].

$$\mathrm{Mg_3N_2 + 6\,H_2O \longrightarrow 3\,Mg(OH)_2 + 2\,NH_3} \tag{1}$$

In addition, Mg_3N_2 can also be used as a fuel as follows:

$$\mathrm{Mg_3N_2 + 1.5\,O_2 \longrightarrow 3\,MgO + N_2 + 1576\ kJ} \tag{2}$$

Mg_3N_2 is suitable for storage and transportation because it is chemically stable under dry conditions. Hence Mg_3N_2 can be considered as a new solid NH_3 carrier. When magnesium hydroxide ($Mg(OH)_2$), which is a by-product, is heated up to about 600K, it changes to magnesium oxide (MgO) as follows:

$$\mathrm{Mg(OH)_2 \longrightarrow MgO + 2\,H_2O} \tag{3}$$

Once a technique to synthesize Mg_3N_2 from MgO is developed, magnesium resources can be recycled. In this report, I report the key technology: synthesizing Mg_3N_2 from MgO with a dielectric barrier discharge (DBD) treatment.

II. Experimental apparatus and procedure

Fig. 1 shows the coaxial cylinder type DBD treatment reactor filled with atmospheric-pressure dry nitrogen (N_2, 300K). The inside diameter and thickness of quartz tube were 25 mm and 2 mm, respectively. A metal tube and a metal mesh were used as each DBD electrode. DBD occurred between the closed quartz tube and the metal tube. MgO particles (3 g, Kanto Denka Kogyo Co. Ltd.) with an average particle size of 35 nm were placed in the DBD reactor. The gap between the glass surface and the metal tube was 9.5 mm. A high ac voltage of $V_{\mathrm{p\text{-}p}} = 40$ kV and 1 kHz was applied between the electrodes. The reactor temperature was measured using an infrared camera. After the DBD treatment, MgO samples (0.5 g) were reacted with ultrapure water (20 ml) to produce NH_3.

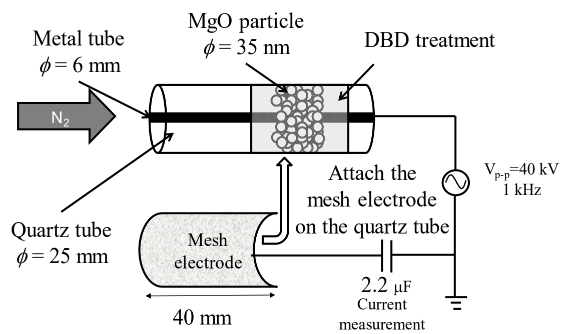

Fig. 1. Dielectric barrier discharge treatment reactor.

Then, a commercially available indophenol blue method (Kyoritsu Chemical-Check Lab. Corp., WAK-NH4, 0.2–10 mg/L) was used to measure the ammonium ion concentration in the solution.

III. Results and discussion

Fig. 2 shows a typical 128 times average Q-V Lissajous waveform during the DBD treatment. X-axis and Y-axis are applied voltage and charge, respectively. The area of the Q-V Lissajous corresponds to the energy consumed during one voltage period. As a result, the power consumption of this DBD treatment can be calculated as 50 W. A photograph of infrared camera immediately after 10 min of DBD treatment

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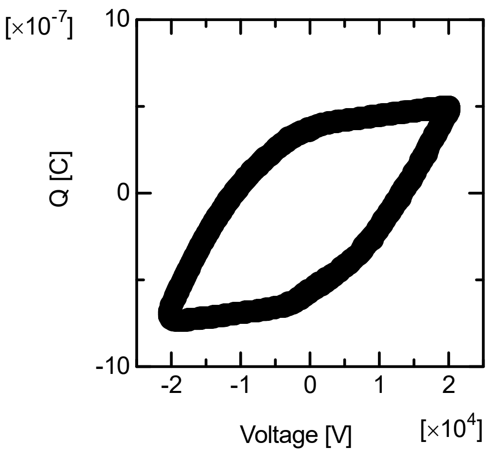

Fig. 2. *Q-V* Lissajous during the DBD treatment.

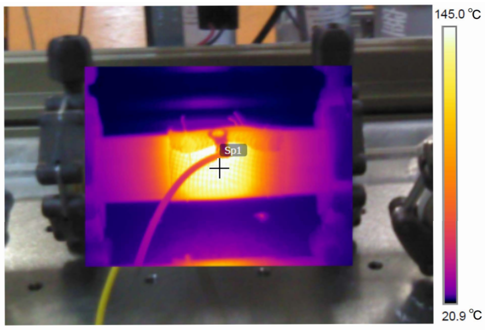

Fig. 3. Photograph of infrared camera immediately after 10 min of DBD treatment.

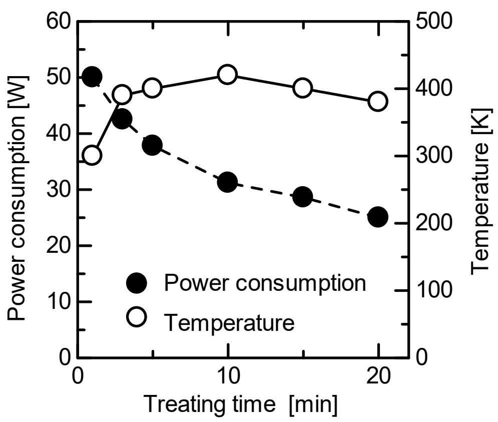

Fig. 4. Changes in power consumption and DBD reactor temperature during the DBD treatmen during the DBD treatment.

is shown in Fig. 3. Since the quartz tube was placed at room temperature, the hot area was the DBD reactor. Fig. 4 shows the changes in power consumption and DBD reactor temperature during the DBD treatment.

The center of DBD reactor temperature was reached to 150°C and saturated after 10 min of DBD treatment. Traditionally, MgO reduction by heat is said to require a very high temperature (exceeding 4000K) [5]. This indicates that DBD

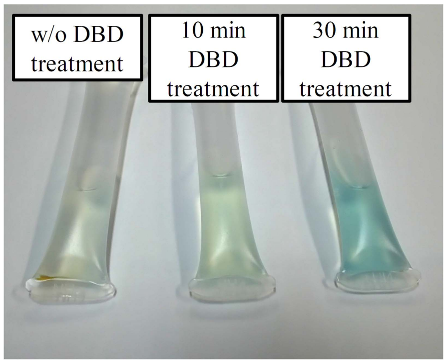

Fig. 5. The ammonium ion concentration in solution for different DBD treatment time.

treatment is a low-temperature process of MgO reduction. On the other hand, the power consumption of DBD treatment was decreasing from 50 W to 25 W. This result indicates that the conditions may be changed during DBD treatment.

Fig. 5 shows the results of the ammonium ion concentration in solution for different DBD treatment time. The absorption spectra of the solution were measured using a spectral photometer. As a result of analyzing the absorption ratio, the ammonium ion concentration of 10 min DBD treated sample and 30 min DBD treated sample were 0.5ppm and 1.5ppm, respectively. Although the energy efficiency is still low, this result indicates that synthesis of Mg_3N_2 from MgO and N_2 takes place via low temperature plasma chemical processes. Chemical active species are considered to promote this chemical reaction instead of heat. N radicals, which is known as a strong reducing agent [6], can be considered as one of the possible chemical active species for this synthesizing process. In the present experiment, a thorough optimization of the DBD treatment is not carried out. Further improvement in energy efficiency by DBD treatment is possible with further optimization of parameters.

IV. Conclusions

In this report, Mg_3N_2 has been proposed as a new reusable carrier of chemical energy. Although the energy efficiency is still low, Mg_3N_2 can be synthesized from MgO and N_2 using a low temperature plasma generated by DBD. N radicals can be considered as one of the possible chemical active species for this synthesizing process. Further improvement in energy efficiency by DBD treatment is possible with further optimization of parameters.

Acknowledgment

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