Feasibility on a Microwave-Heating for the Volumetric Heating of Li_2TiO_3 Pebbles

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1. Introduction

Microwave is an electromagnetic wave with the frequency range of 300 MHz to 300 GHz. Microwave is utilized in telecommunication (wireless LAN, Bluetooth, Wi-Fi), microwave oven, radar, and spectroscopy. Microwave heating is a process in which materials couple with microwaves, absorb the electromagnetic energy, and transform into heat. Materials produce thermal energy from their entire volume (i.e., volumetric heating). The surface of materials will receive heat produced from the interior core directly. In comparison, the materials' surface is first heated by the heat source and then transferred inwardly through conduction in the conventional heating techniques.

Tritium breeding process involves a neutron capture and α decay reaction:

$$^{6}Li + n \rightarrow \alpha + T + E(4.78\ MeV)$$

This process results in the volumetric heating of a material. A feasible way to the volumetric heating is to apply a microwave heating method. In this presentation, the microwave was irradiated on Li_2TiO_3 pebbles to investigate the applicability of the microwave as a source for the volumetric heating.

2. Methods and Results

Microwave heating is applicable to limited ceramics, which possess high dielectric loss – generating the heat via the absorption behavior. To the best of our knowledge, Li_2TiO_3 has not been tested in microwave heating. However, manufacturing of Li_2TiO_3 pebbles using microwave sintering was reported by Chinese researchers [1,2]. They utilized microwave with 2.45 GHz in frequency and 2.5 kW of maximum power to sinter the Li_2TiO_3 ceramic pebbles. This sintering of Li_2TiO_3 provides the first indication that the microwave is applicable to heat up Li_2TiO_3 pebbles.

2.1 Li2TiO3 Crystal Structure

The lattice structure of Li_2TiO_3 (monoclinic phase, C2/c space group) is presented in Fig. 1 [3]. Li_2TiO_3 lattice consists of TiO_6 layer (gray octahedron) and Li layer (green), alternatively. From the lattice structure, Li_2TiO_3 is anisotropic in physical properties. Li atoms on TiO_6 octahedron layer can induce a dielectric property due to their asymmetric locations. Li_2TiO_3 is a promising material for low-temperature co-fired ceramic (LTCC) technology because it has a good dielectric performance as well as sinterable at low temperature. Generally, a doping with various oxides is required to attain a higher performance and stability in Li_2TiO_3 [4-7]. The dielectric constant of Li_2TiO_3 was reported as $\varepsilon_r = 22–23$ [4,5]. The dielectric loss, however, varied quite extensively depending on reports. The quality-factor of Li_2TiO_3 was varied from 15,000 to 63,000 GHz [4,5]. The quality-factor was increased when Li_2TiO_3 had been doped [4,5]. The low quality-factor is connected to a high dielectric loss and a high possibility of microwave heating.

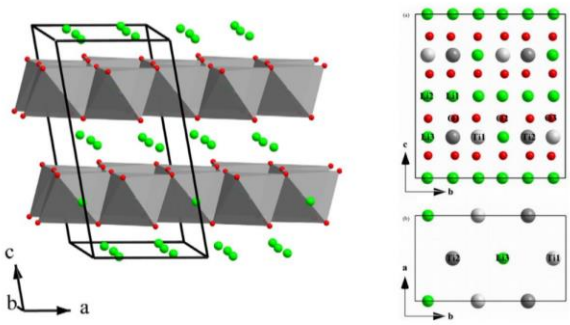

Fig. 1. Lattice structure of Li_2TiO_3 [3]

2.2 Microwave Irradiation

Interaction between microwave and materials are determined by the materials nature; however, the appearance (recognition by the observer) is highly depend on the density of the microwave. The microwave with 2.45 GHz is used in kitchenware oven as well as wireless fidelity (Wi-Fi) transmission signal. The frequency of the microwave is same each other. We're exposed to the Wi-Fi signals without health problems; however, it would be crucial if exposed to microwave oven. The only difference in these circumstances is the density (power) of microwave.

Microwave ovens for household use are operated at 700–1000 W in power. The first experiment of microwave irradiation had been performed using a 700 W equipment. Fig. 2 shows the appearance of pebbles before and after the irradiation. The pebbles maintained same color and shape during the microwave irradiation. The temperature of the pebble bed could not be measured because of the microwave interaction with the thermocouple. However, the surface temperature of the crucible was measured by using a pyrometer attached the outside of the microwave chamber, as shown in Fig. 3. The temperature increased to about 90°C in 1.5 h of microwave heating. The measured temperature of pebbles after shutting off the microwave was 74°C. Although the temperature is increased, it is too low (inefficient) to do the volumetric heating of the pebbles.

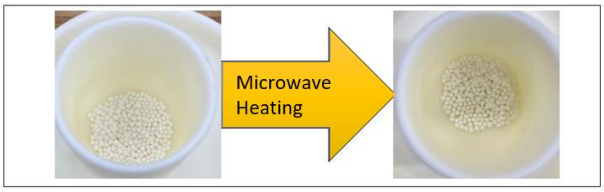

Fig. 2. Li_2TiO_3 Pebbles before and after the microwave irradiation for 1.5 h at 700 W.

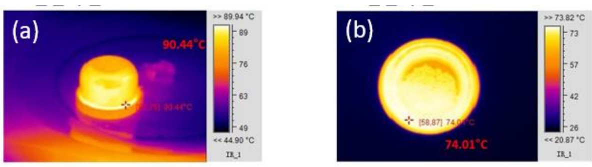

Fig. 3. Temperature of (a) crucible surface during microwave heating and (b) the Li_2TiO_3 pebbles right after shutting the microwave off. (1.5 h at 700 W, 2.45 GHz)

The second experiment was conducted using a high power microwave facility operated at 2.5 kW and 5 kW. The irradiation was lasted until to reach the designated temperatures of 800, 900, and 1000°C – these are the crucible surface temperature measured by the pyrometer. When applying the high power microwave, it was possible to reach the target temperatures by the irradiation lasted at least 10 min. Fig. 4 shows the pebbles after the microwave heating at 800–1000°C., The pebbles were intact after heating at 800 and 900℃; however, they were sintered at 1000℃ (specifically, 1st stage sintering that forming necking).

It should be confirmed further where the heat come from: the pebbles themselves or the crucible. Base on the former experiments, the empty crucible did not heat up to these temperatures. Thus, it is concluded that the pebbles can be heated via microwave, and it is feasible to apply the microwave for the volumetric heating of the pebble bed.

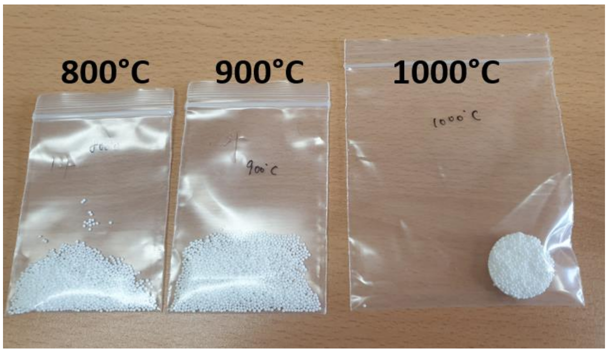

Fig. 4. Li_2TiO_3 Pebbles after microwave heating at 800, 900, and 1000°C. (2.5 and 5 kW, 2.45 GHz)

3. Conclusions

Microwave was utilized to heat up the Li_2TiO_3 pebbles in order to investigate the applicability of the volumetric heating. The pebbles was heated up to 1000°C by using a 2.45 GHz microwave chamber operated at 2.5–5 kW power. It is expected that the microwave can be utilized in the pebble thermo-mechanic experiment by providing the volumetric heating of the pebbles.

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