Development of a 300 GHz material processing system

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***Abstract*— The effective characteristics of high frequency and strong electric field processing were observed. One of the interesting effects is so called non-thermal effect or microwave effect. In order to widely study the non-thermal effect of ceramics sintering, we developed a material processing system by using a 300 GHz gyrotron. Successful submillimeter wave sintering of partially stabilized zirconia ceramics was obtained.**

I. Introduction And Background

THE millimeter and Submillimeter-wave power in continuous wave region of about ten kilowatts, which can be of interest for industrial applications, can be produced by gyrotron. Such progress in high frequency and high power radiation source technology stimulates the electromagnetic wave sintering technology [1]. The effective characteristics of high frequency and strong electric field processing were observed. One of the interesting effects is so called non-thermal effect or microwave effect [2,3]. In order to widely study the non-thermal effect of ceramics sintering, we developed a submillimeter wave material processing system by using a 300 GHz gyrotron.

II. Submillimeter Wave Material Processing System

A submillimeter wave material processing system (SMMW-MPS) consists of a 300 GHz, 3.5 kW, CW gyrotron (Gyrotron FU CW I) with a cryogen-free 12 T superconducting magnet, a corrugated circular waveguide and an applicator, as shown in Fig. 1.

Gyrotron FU CW I had been developed in conjunction with the Institute of Applied Physics (IAP), Russia. A 12 T cryogen free superconducting magnet is used for the generation of main magnetic field. The gyrotron has a quasi-diode electron gun and operates on the $TE_{22,8,1}$ cavity mode. This gyrotron is designed so that the output power can be smoothly varied in the range from 0.5 kW to 3.5 kW by a change of electron beam voltage.

The submillimeter wave beam from gyrotron has to be transmitted to the applicator by a low-loss transmission line. To achieve the low-loss transmission at the frequency of 300 GHz, the over-coupled corrugated waveguide (i.d.=6.35 cm) has a fine structure with a corrugated period and a depth of 254 μm.

The applicator was designed with a cylindrical sample processing space of diameter ϕ 450 × length 880 mm. Both volumetric heating by uniformly distributed microwave energy and surface heating by a high intensity focused wave beam can be performed in this applicator.

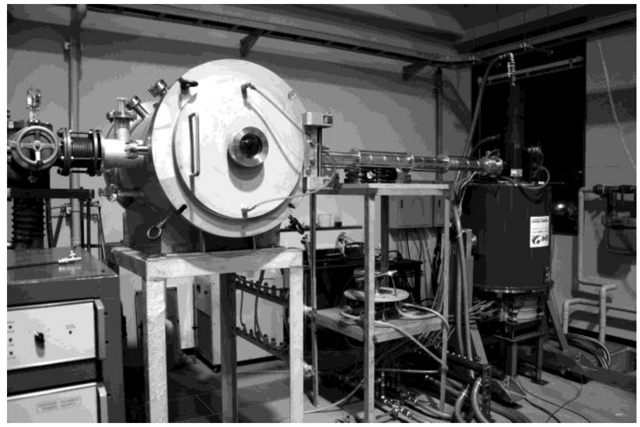

Fig. 1 A Submillimeter wave material processing system.

III. Submillimeter Wave Sintering of Zirconia

Submillimeter wave sintering of zirconia (ZrO_2 – 3 mol % Y_2O_3, TOSOH TZ-3Y) had been performed by SMMW-MPS. Green sample was formed by slip casting into a plate with the size of 20 mm diameter by 6 mm high and was calcined by keeping at 600 ^oC. The zirconia green bodies were settled in the thermal insulator (DENKA ALCEN) without the susceptor and were heated from the room temperature to 1250 ^oC at the average heating rate of 60 ^oC/min. Successful submillimeter wave sintering of zirconia ceramics were obtained with the density of 5.9 g/cm^3 as shown in Fig. 2.

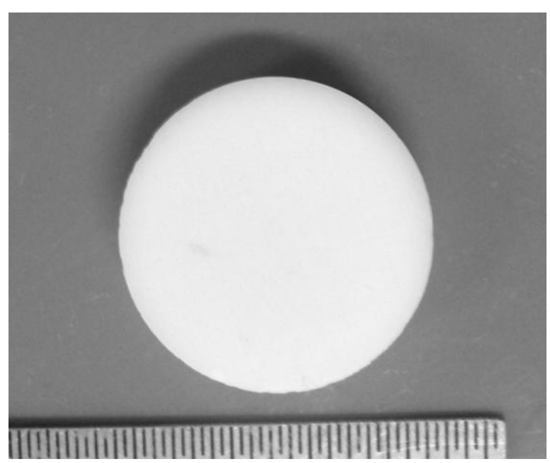

Fig. 2 Successful submillimeter wave sintering of zirconia ceramics.

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Figure 3 shows typical sintering processes. Each sample was heated from the room temperature to the appropriate temperature (●:1000 °C, ×: 1100 °C, □: 1300 °C) at the heating rate of 60 °C/min. After the holding time of 10 min, the irradiation of the sub-millimeter wave was stopped. The sintered sample was naturally cooled. The millimeter wave (28 GHz) sintering of zirconia was also performed up to the appropriate temperature at the heating rate of 30 °C/min with the holding time of 10 min.

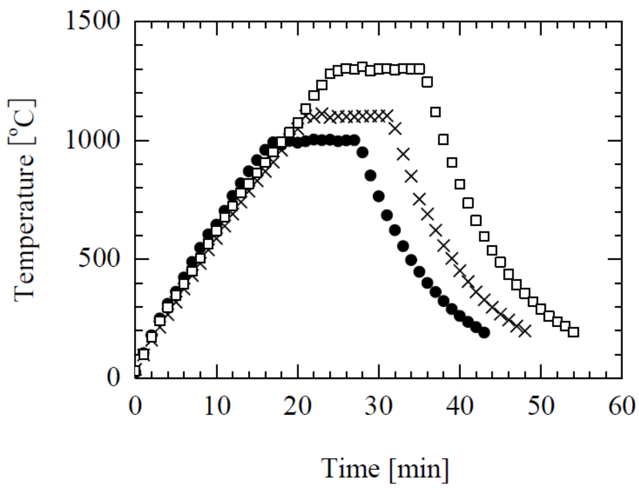

Fig. 3 The measured temperature as function of time. (●: 1000 °C , ×: 1100 °C, □: 1300 °C)

Figure 4 shows sintering curves for the millimeter wave (×: 28 GHz), the sub-millimeter wave (●: 300 GHz) and the conventional (□) sintering of zirconia in terms of sintered density vs. temperature. The sintering curve of conventional sintering is plotted from previous reports [4]. Both of millimeter wave and sub-millimeter wave sintering curves show the acceleration of densification. The sintering curve of millimeter wave sintering is in good agreement with previous report [4]. In the case of sub-millimeter wave sintering, a sintering curve is located at intermediate temperature between millimeter wave and conventional sintering. From the previous reports, as the electromagnetic wave frequency increase, the acceleration is also increase. However, the sub-millimeter wave sintering curve shows decreasing of the acceleration of densification.

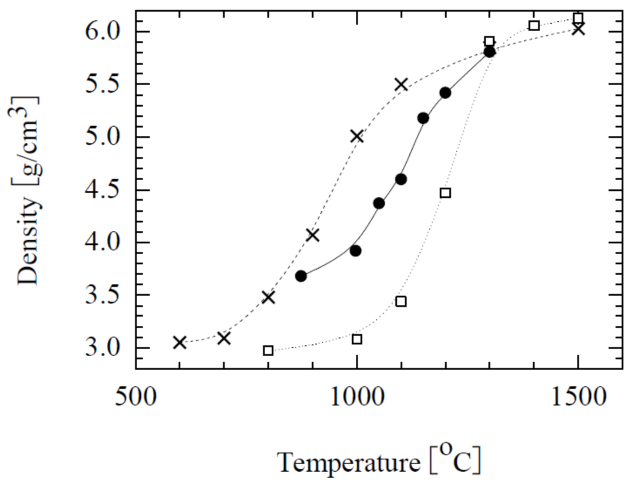

Fig. 4 The sintering curves of zirconia. (●: 300 GHz SMMW, ×: 28 GHz MW, □: Conventional sintering)

IV. Conclusion

A submillimeter wave material processing system consists of a 300 GHz, 3.5 kW, CW gyrotron (Gyrotron FU CW I) had been developed successfully. The SMMW-MPS was applied for a very rapid sintering (heating rate: 60 °C/min) of zirconia ceramics. Successful submillimeter wave sintering of zirconia ceramics were obtained with the density of 5.9 g/cm^3. The temperature dependence of the density of the zirconia ceramics was also obtained in the submillimeter wave processing. The enhancement of densification was observed. The millimeter (28 GHz) and the sub-millimeter (300 GHz) wave sintering of zirconia had been performed. The sub-millimeter wave sintering curve shows the sintering slower at the same temperature, for sub-millimeter wave processing as compared to millimeter wave processing. In order to know whether it is general tendency or not in electromagnetic wave sintering, further research is needed in sub-millimeter wave materials processing.

References

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