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The magnetic and dielectric properties of microwave sintered yttrium iron garnet (YIG)

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Abstract

Yttrium iron garnet (YIG) material is widely used in microwave devices. Experiments show that microwave sintering (MS) treated YIG materials possess excellent properties with a saturation magnetization of 14.60 emu/g and coercive force 34.82 Oe. In the frequency range of 1 MHz–1.8 GHz, the relative dielectric constant is from 6.5 to 7.0, the line-width is 105 Oe, dielectric loss less than 0.09 and magnetic loss less than 0.7. Furthermore, the sintering time and temperature were significantly reduced from 20 h and 1300 °C for the conventional sintering (CS) process to 2 h and 900 °C for MS technique, respectively.

Keywords: Magnetic materials; Ceramics; Microwave sintering; YIG material; Dielectric loss; Magnetic loss

1. Introduction

With the development of low temperature co-fired ceramic (LTCC) technology, multilayer ceramic microwave devices have attracted extensive attention due to the overwhelming trend for miniaturization of microwave communication equipment. YIG materials, in both bulk and film forms, have been widely used for magnetic microwave devices, such as circulators, oscillators and phase shifters [1–3] for it smallest linewidth (ΔH) in magnetic resonance [4–7] and controllable saturation magnetization. However, high sintering temperature (>1350 °C) and long sintering time (>10 h) are required to synthesize the YIG materials in conventional technology. Meanwhile, in multilayer ceramic microwave devices, other ceramic materials (magnetic or dielectric) and the electrode materials (silver or gold) require the development of low temperature sintering technology. The CS technique is hard to satisfy these new requirement.

Sintering of ceramics by MS is advantageous over the CS because it has very fast heating rate and thus reduces processing time [8–11].The magnetic and dielectric properties of CS YIG materials have been intensively investigated [12–14]. However, only a few studies on MS YIG materials have been performed [15]. In this paper, the polycrystalline YIG was synthesized using MS technology and the magnetic and dielectric properties were investigated and compared with CS samples.

2. Experiment

YIG ferrite powders having stoichiometric compositions of $Y_3Fe_5O_{12}$ were prepared by the solid state reaction method. The raw materials, Fe_2O_3 (99.9% purity) with the particle size of about 1.5 μm and Y_2O_3 (99.9% purity) with the particle size of about 1.0 μm, were mixed with a ball mill for 10 h, and the particle size is about 1.2 μm. After added with 8 wt.% polyvinyl alcohol as a lubricant, the powder were pressed into disks with diameter of 18.6 mm and thickness of 2.2–3.0 mm, and rings with inner diameter of 8.4 mm, outer diameter of 18.6 mm, and thickness of 2.2–3.0 mm, the pressure is 40,000 N/m^2. The disk and ring samples were both divided into two batches: one was processed with CS process while another with the microwave sintering process. In CS process, the powders were sintered in electrical furnace at 1300 °C for 6 h with heating and cooling

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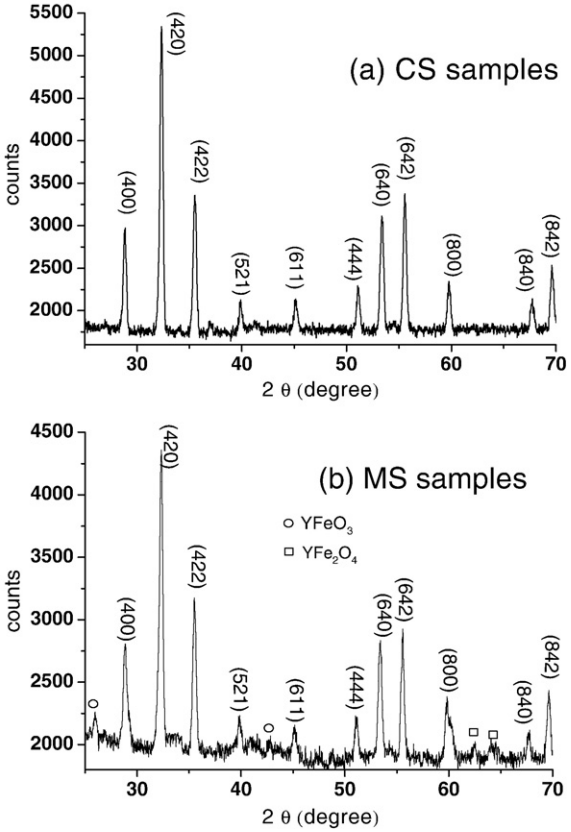

Fig. 1. XRD patterns of YIG samples treated by (a) CS process (1300 °C for 6 h) and (b) MS processes (900 °C for 20 min).

rates of 2 °C/min. In MS process, a 2.45 GHz microwave stove (NL75) was applied. The samples were heated at a rate of 8 °C/min, soaked at 900 °C for 20 min in air, and then cooled at a rate of 30 °C/min. The phase structure for both batches of samples were characterized by X-ray diffraction (XRD) with Cu Ka radiation. The density of the materials was measured using Archimedas method. The microstructure of the fracture surface was studied by JSM-6301F scan electronic microscopy (SEM). The magnetic characteristics were measured with VSMVT-800 vibrating sample magnetometer (VSM); An HP4291B impedance analyzer was used to measure the frequency dependence of relative dielectric constant (ε_r), dielectric loss tangent ($\tan\delta_e$) and magnetic loss tangent ($\tan\delta_m$) from 1 MHz to 1.8 GHz; The ferromagnetic resonance line-width (ΔH) was measured with electron-spin resonance apparatus.

3. Results and discussion

Fig. 1(a) and (b) shows the XRD pattern of YIG samples treated by CS and MS process, respectively. As it can be seen from Fig. 1 (a), the CS sample was single garnet phase without any evidence of other phases. In Fig. 1 (b), the material was crystallized completely at 900 °C with MS method, which is 400 °C lower than the CS method. In MS sample, the garnet phase is dominant with a few other phases.

The microstructures of YIG samples prepared by CS and MS technology are shown in Fig. 2. It can be seen that the grains size of CS samples is 3.0–5.0 μm, while that of MS samples is about 1.5 μm. This phenomenon has also been observed previously [15,16]. The probable explanation is that: with MS technology, the crystallize process, can be completed at lower temperature and shorter time; at the same time the

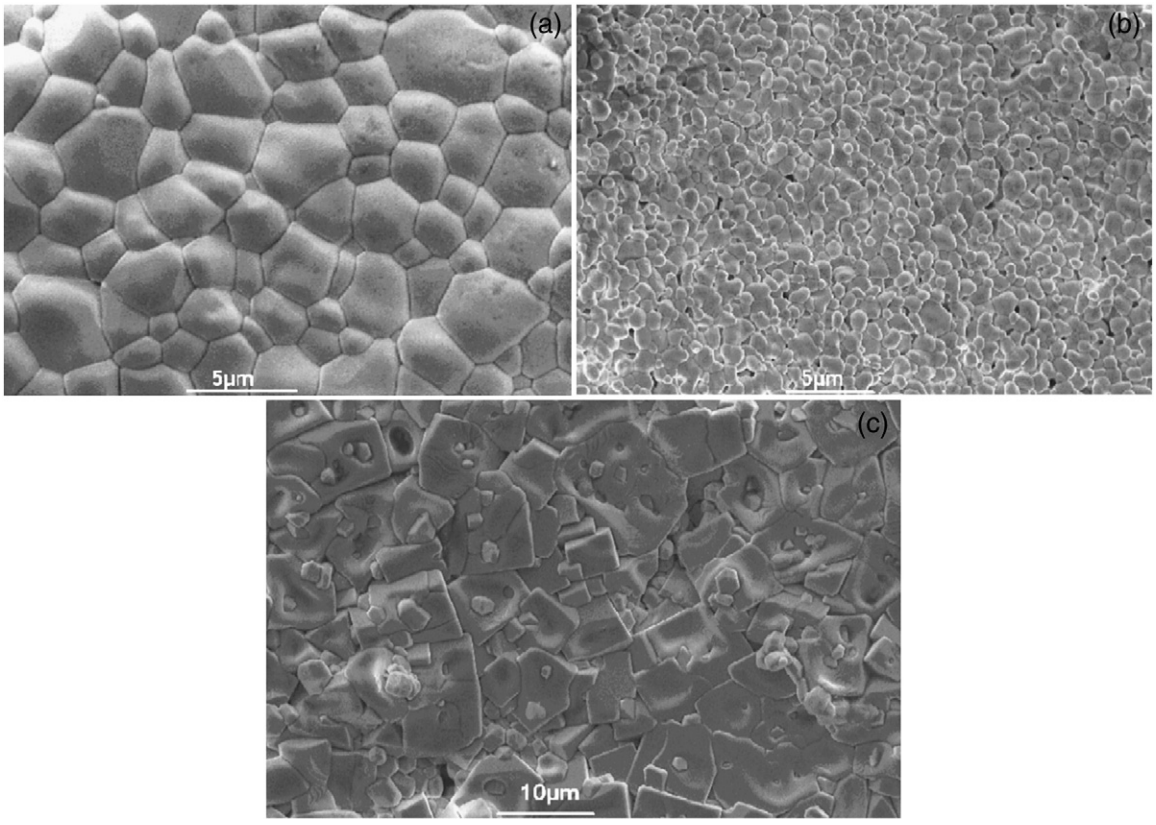

Fig. 2. SEM photograph of YIG materials processed by (a) CS process (1300 °C for 6 h) and (b) MS process (900 °C for 20 min) (c) MS processes (1000 °C for 30 min).