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INFLUENCE OF SINTERING TEMPERATURE ON THE DIELECTRIC PROPERTIES OF YTTRIUM IRON GARNET (YIG)

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ABSTRACT

Yttrium Iron Garnet (YIG) is widely used in microwave applications. In this study, the samples were synthesized at three different sintering temperatures which were 1300 °C, 1350 °C, and 1400 °C by conventional solid-state method. The samples were characterized by XRD and SEM to determine the crystalline structure and microstructure of the samples. The dielectric properties of the sample were measured using Novocontrol High Resolution Dielectric Analyzer in the frequency range 10 mHz to 1 MHz at different temperatures. YIG sample sintered at 1400 °C produced better grain growth of crystalline structure with higher dielectric constant and dielectric loss. The dielectric measurement revealed that the dielectric constant decreases with increasing frequency for all samples.

Keywords: yttrium iron garnet; solid-state; microstructure; dielectric properties;

INTRODUCTION

Yttrium Iron Garnet (YIG) is a magnetic material which can be prepared by many different methods, such as conventional solid-state [1], sol-gel [2-4], co-precipitation [5-6], combustion [7], sol-gel combustion [8], floating zone [9], and full linearized potential augmented plane wave (FLAPW) [10]. YIG in both bulk and film forms can highly be used in microwave applications. They are mostly used as insulators, circulators, dephasers, etc [1-5]. Since multimedia applications are expanding slowly, YIG is mostly used in amplifier chains in the range 1-2 of GHz. This is to produce a smaller size and lower value of intermodulation (IMD) which can reduce the processing costs [11].

Homogeneous powder is needed to possess good magnetic characteristics. However, homogeneous powder needed prolonged grinding and heating process to reduce the impurities of the samples [1, 5].

There are few studies which have been discussed about the dielectric properties of YIG. In this research, we prepared the YIG using conventional solid-state method. The microstructure and dielectric properties of polycrystalline YIG were investigated.

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EXPERIMENTAL DETAILS

YIG samples were prepared using conventional solid-state reaction method. Stoichiometric amounts of the starting materials, Y_2O_3 (99.9%) and Fe_2O_3 (99.9%) were weighed. These powders were dry milled and calcined in air at 1150 ˚C for 10 hours. The powders were grinded and sieved to ensure the particles size of the powders were homogenous. These powders were then pressed into pellets and sintered in air at 1300 °C, 1350 °C, and 1400 °C for 10 hours then cooled to room temperature in the furnace.

All the samples were examined using XRD to determine the crystalline structure of the sample. The morphologies of the samples were examined using FESEM. The dielectric properties of the samples were determined using Novocontrol High Resolution Dielectric Analyzer in the frequency range 10 mHz to 1 MHz at 27 °C, 50-250 °C at 50 °C intervals.

RESULTS AND DISCUSSION

Figure 1 shows the XRD pattern of YIG after sintering at 1300 °C, 1350 °C, and 1400 °C. The samples are obtained as a highly pure YIG crystal in single garnet phase with cubic structure with high peaks at 2θ = 32.3°, 35.5° and 55.5° without other phases. This series correspond to 01-083-1027 of the ICDD database.

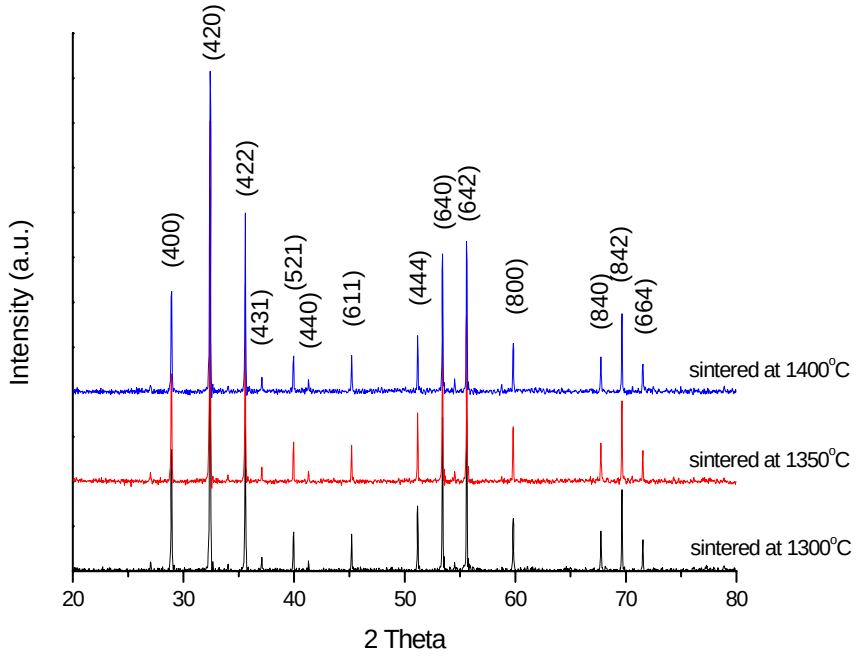

Figure 1: XRD patterns for YIG at different sintering temperatures

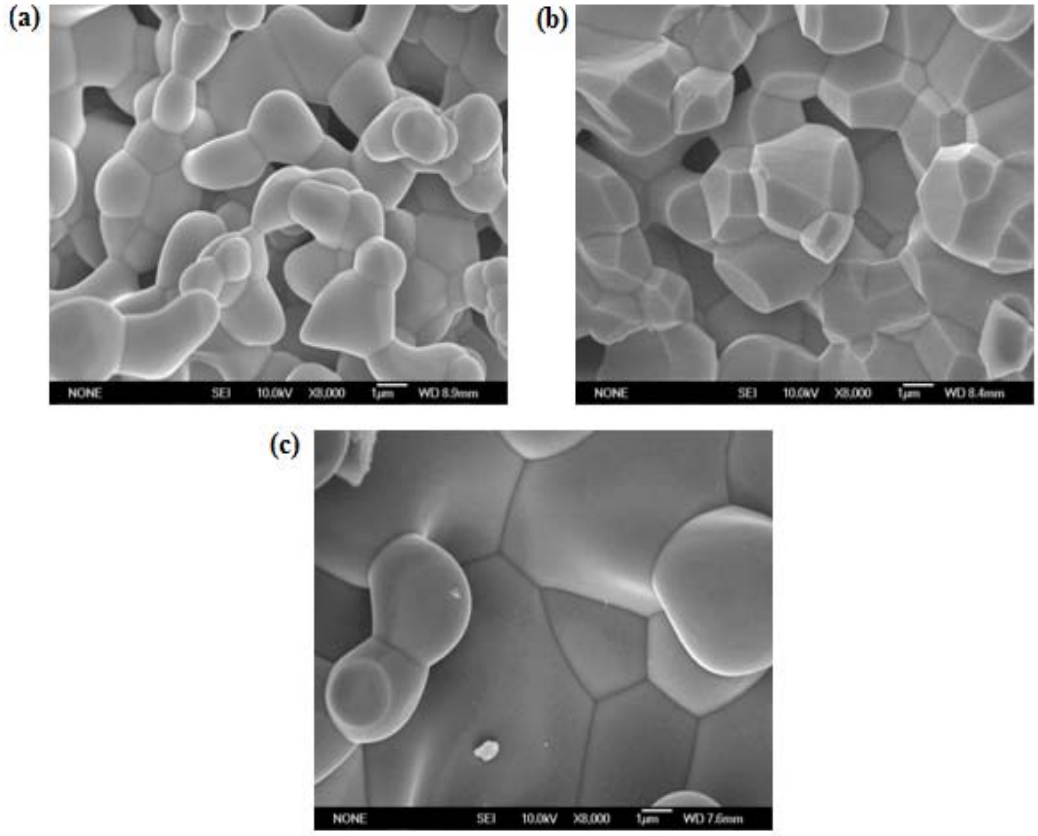

Figure 2: SEM photograph of YIG sintered at (a) 1300 °C, (b) 1350 °C, and (c) 1400 °C

SEM photographs of the grain growth of crystalline structure of YIG sintered at 1300 °C, 1350 °C, and 1400 °C are shown in Figure 2. The necking parts between crystal grains of YIG sintered at 1300 °C are partially formed. There are some voids occurring in between the crystal grains. YIG sintered at 1350 °C has better grain growth where the necking parts are more perfect than before. The crystalline structure is the most perfect at 1400 °C where majority of the grains are fully joined together to form bigger grains. This shows that the grain growth of YIG increases as the sintering temperature is increased. This means that the diffusion of ions between lattices is improving as sintering temperature is increased [1].

The density of YIG sintered at different sintering temperatures is tabulated in Table 1. The density of samples increases with increasing sintering temperatures [5]. This is due to the improvement of diffusion ions between lattices as sintering temperature increases. YIG sintered at 1400 °C has the best grain growth which nearly achieved the theoretical density of YIG which is 5.170 gm^{-3} [12].

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Table 1: Density of YIG sintered at different sintering temperatures

Sample	1300 °C	1350 °C	1400 °C
Density (gm^{-3})	4.9735	5.0212	5.0358
% of theoretical density	96.2%	97.1%	97.4%

The dielectric constant of YIG with respect to temperature at selected sintering temperatures of 1 kHz and 1 MHz are shown in Figures 3 and 4. YIG are temperature dependent where the dielectric constant increases as the temperature increases as shown in Figures 3 and 4. YIG sintered at 1400 °C has the highest dielectric constant. This may be due to the effectiveness of polarization occurring due to increased thermal agitation of atoms in the sample. YIG sintered at 1300 °C has higher dielectric constant at 1 kHz while lower at 1 MHz compared to YIG sintered at 1350 °C. These most probably is due to the combination of polarizations occurring among the grain boundaries and electrodes at low frequency range.

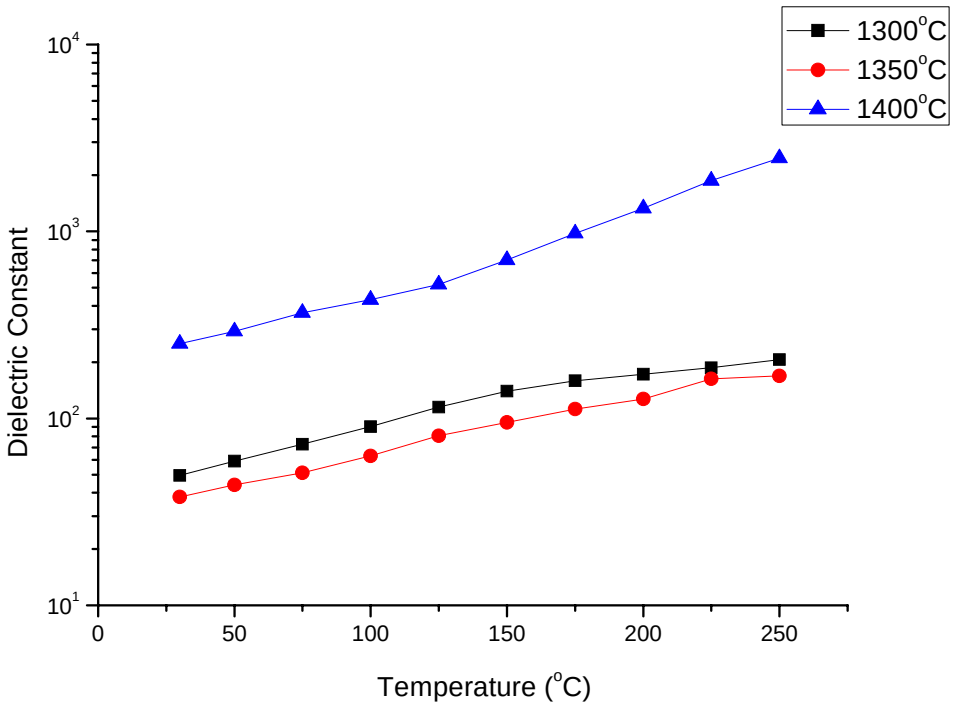

Figure 3: Dielectric constant of YIG with respect to temperature at selected sintering temperatures at 1 kHz

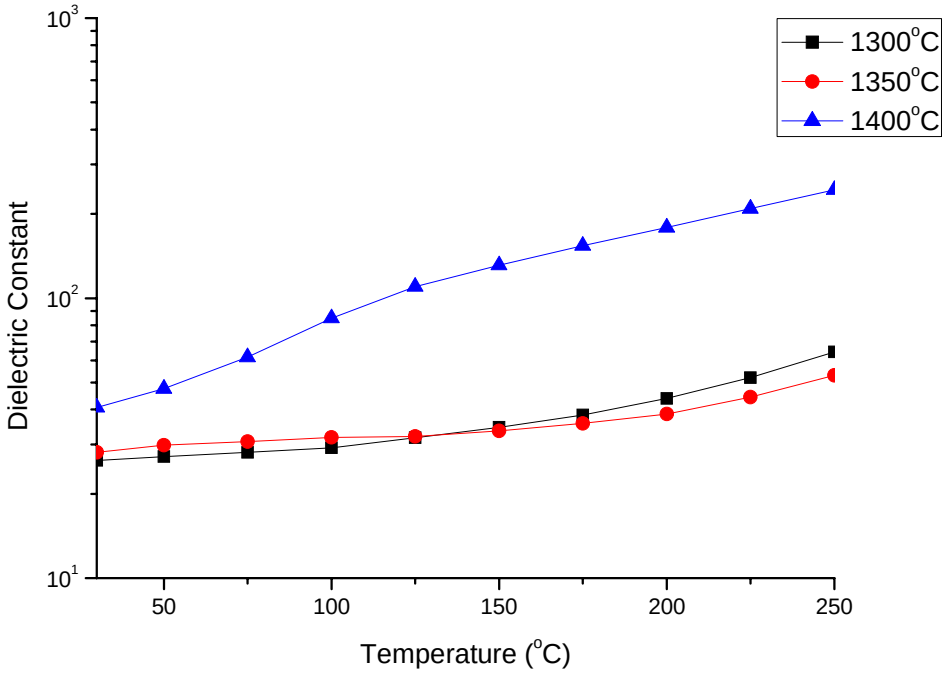

Figure 4: Dielectric constant of YIG with respect to temperature at selected sintering temperatures at 1 MHz

Figures 5 and 6 show the dielectric loss factor of YIG with respect to temperature at selected sintering temperatures at 1 kHz and 1 MHz. The dielectric loss factor increases as temperature increased. YIG sintered at 1400 °C shows the highest dielectric loss factor for both figures. This may be due to the ineffectiveness of polarization occurring and existence of pores among the grain boundaries of the sample. As shown in Figure 6, the dielectric loss factor for YIG sintered at 1350 °C is nearly stable. This means that there is no extra loss of heat during the polarization process at different measuring temperatures. The dielectric loss factor is increased for YIG sintered at 1300 °C where the heat loss is released from the voids appearing between the crystal grains.

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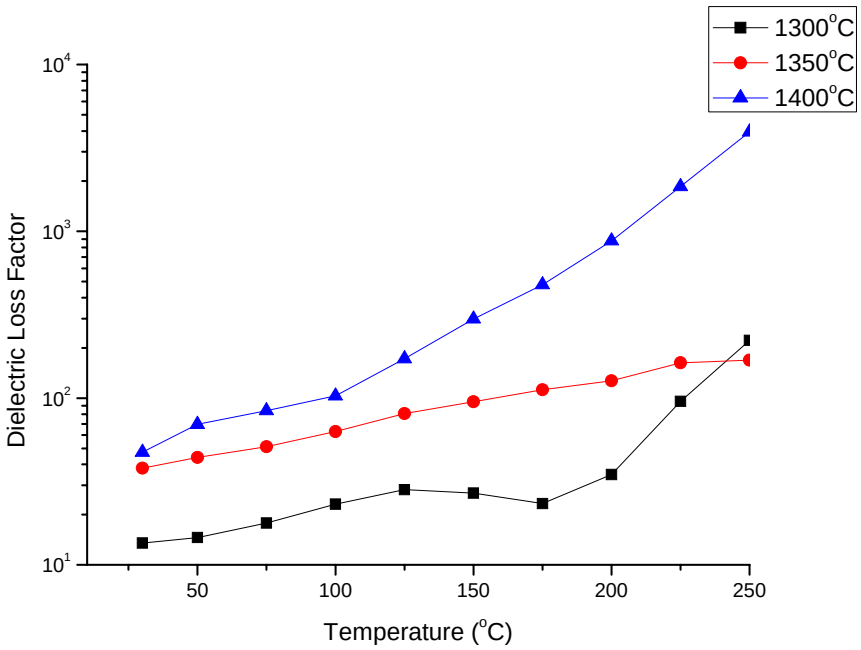

Figure 5: Dielectric loss factor of YIG with respect to temperature at selected sintering temperatures at 1 kHz

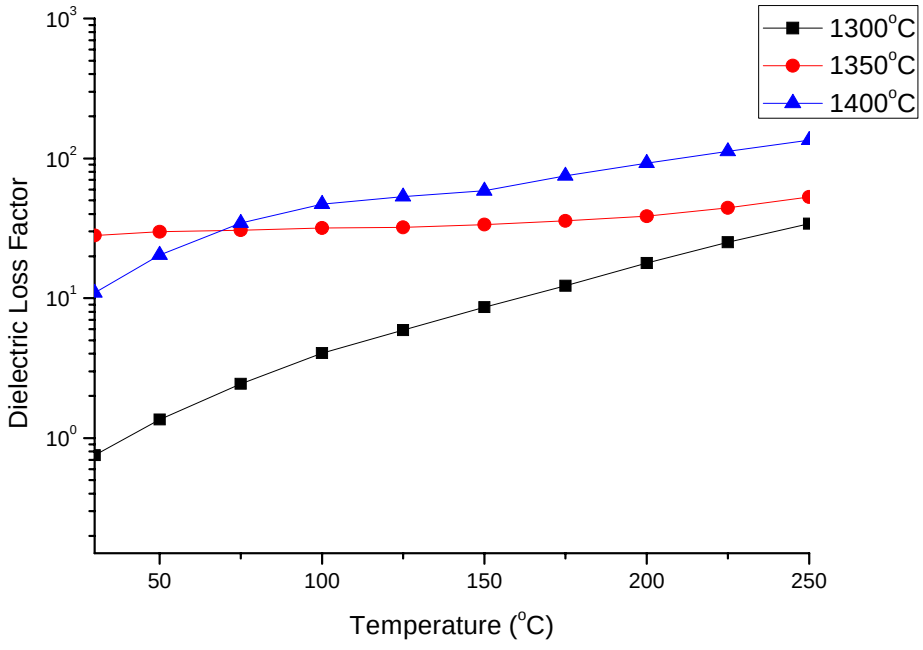

Figure 6: Dielectric loss factor of YIG with respect to temperature at selected sintering temperatures at 1 MHz

The dielectric constant and dielectric loss factor of YIG with respect to frequency at selected sintering temperatures at 1 kHz and 1 MHz are shown in Figure 7 and 8. YIG are frequency dependent where the dielectric constant decreased as the frequency increased as shown in Figure 7. YIG sintered at 1400 °C has the highest dielectric constant due to the greater ease of dielectric polarization occurring in the better grain growth among the crystal grains. At low frequency region, the impedance of grain boundaries are bigger than of crystal grains, therefore YIG sintered at 1300 °C has higher dielectric constant than YIG sintered at 1350 °C due to its fine crystal grains which provide more grain boundaries compared to the others [1]. The dielectric constants decreased and almost reach a stable value. This is because of better polarization occurring within the crystal grains compared with the grain boundaries.

In Figure 8, a small dispersion occurred at the high frequency region for YIG sintered at 1400 °C. This shows the relaxation behavior of the sample. Generally, the dielectric relaxation effects are observed resulting from the lower Fe^{2+} content in the material [1]. YIG sintered at 1300 °C has higher dielectric loss factor may due to the ineffectiveness of polarization occurring among the grain boundaries and electrodes and also the appearance of pores inside the grains.

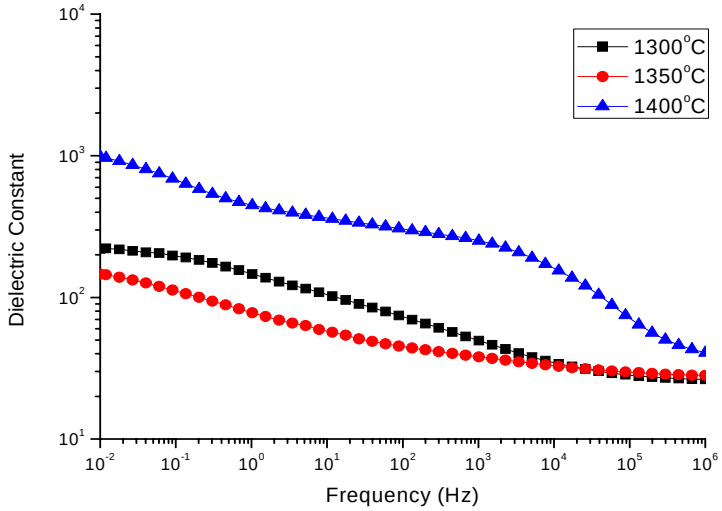

Figure 7: Dielectric constant of YIG with respect to frequency at selected sintering temperatures at 1 kHz

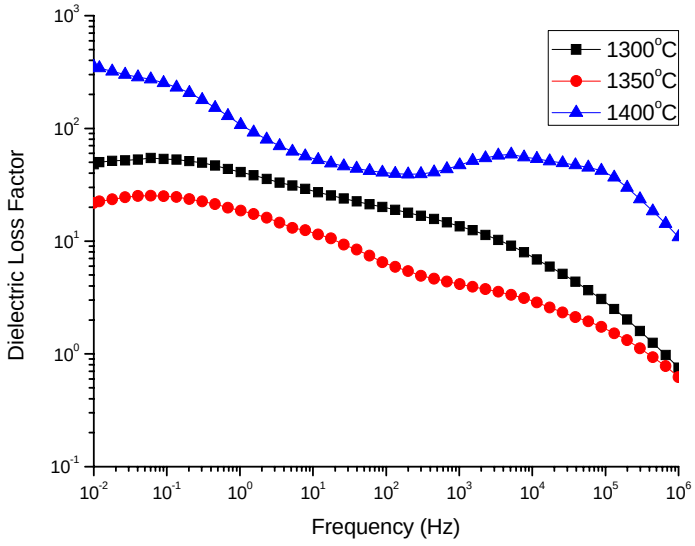

Figure 8: Dielectric loss factor of YIG with respect to frequency at selected sintering temperatures at 1 MHz

CONCLUSIONS

In this paper, the dielectric properties of YIG were measured at 10 mHz to 1 MHz. They exhibited frequency dependence and temperature dependence. YIG sintered at 1400 °C has the best grain growth of crystalline structure and higher density which produced the highest dielectric constant and dielectric loss factor.

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