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Structure and Magnetic Properties of Polycrystalline $Y_{3-x}La_xFe_5O_{12}$ Garnets

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Abstract. La substituted polycrystalline $Y_{3-x}La_xFe_5O_{12}$ ($x = 0.0 - 0.5$) garnets were manufactured by ceramic method and the structure and magnetic properties of the garnets were studied by X-ray diffractometry, magnetometry, ferromagnetic resonance and permittivity and permeability measurement. Saturation magnetization and Curie temperature of the garnets increase slightly with increasing La content. Resonance linewidth decreases with increasing La concentration x . Complex permittivity and permeability of the garnets are reported.

I. INTRODUCTION

YIG has been widely used because of its small resonance linewidth in many devices such as isolator, circulator and gyrators[1-2]. The saturation magnetization, gyromagnetic resonance linewidth, microwave permeability and permittivity are properties which are of fundamental importance in determining the performance of the devices in the microwave region. Several types of substituted magnetic garnets for high frequency applications were developed to tailor and to improve their magnetic and microwave properties recently.

In this paper, we have investigated the structure and magnetic properties of La substituted polycrystalline $Y_{3-x}La_xFe_5O_{12}$ ($x = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5$) garnets. Furthermore, we have measured magnetic resonance linewidth(ΔH), microwave permittivity and permeability in microwave range.

II. EXPERIMENT

Polycrystalline $Y_{3-x}La_xFe_5O_{12}$ samples were prepared by conventional ceramic method. Mixed high purity Y_2O_3 , La_2O_3 and Fe_2O_3 powders were fired at 1200 °C for 2 hrs and then sintered at 1400 °C for 2 hrs in the air. For structural characterization of the resulting samples, XRD experiment was carried out with Cu K α radiation. Temperature dependence of saturation magnetization of the polycrystalline $Y_{3-x}La_xFe_5O_{12}$ garnets was measured by vibrating sample magnetometry (VSM) from room temperature to 600 K with an external field of 5 kOe. Ferromagnetic resonance line width (ΔH) of the polycrystalline garnets was measured at 9.44 GHz by using spherical sample of 0.5 mm in diameter. Also microwave permittivity and permeability of the polycrystalline garnets were measured by using the cavity perturbation method at TE₁₀₁ and TE₁₀₄ mode respectively. The measurement was performed by using rectangular samples of about 0.5×0.7×10.2 mm in a rectangular cavity.

III. RESULT AND DISCUSSION

The experimental condition was found after several pre-experiments. The prepared garnet samples showed densities of about 97% of X-ray densities. XRD trace from $Y_{3-x}La_xFe_5O_{12}$ samples showed diffraction peaks corresponding to cubic garnet structure and a weak peak corresponding to perovskite phase, indicating a presence of small amount of perovskite phase. Lattice constant of the cubic structure increased linearly from 12.382 to 12.443 Å with increasing La from $x = 0.0$ to $x = 0.5$, indicating a formation of homogeneous solid solution. Microstructure of the sample was observed by scanning electron microscopy (SEM). Grain size of the garnet increased from about 8 μm to 25 μm with increasing La from $x = 0.0$ to $x = 0.5$. A grain boundary phase was observed in the specimen with high La content $x = 0.5$, even though volume fraction is

too low to be detected by XRD experiment. It was difficult to find a variation in porosity with La content.

Fig. 1 shows temperature dependence of saturation magnetization of the $Y_{3-x}La_xFe_5O_{12}$ garnets as a function of temperature. The saturation magnetization decreased with increasing temperature as expected. The saturation magnetization at room temperature increased slightly from about 1700 to 1780 G with increasing La content from 0 to 0.4. Also the Curie temperature for $Y_{3-x}La_xFe_5O_{12}$ garnets increased slightly from about 570 to 576 K. The slight changes in saturation magnetization and Curie temperature with La content may be related with the increase in lattice constant with increasing La content. Because magnetic property of La^{3+} ion is same as that of Y^{3+} ion.

Fig 2 shows a variation of ferromagnetic resonance linewidth, ΔH , with La content (x) for $Y_{3-x}La_xFe_5O_{12}$ sintered at 1400°C. ΔH is decreased slightly from about 90 Oe to 65 Oe with increasing x from 0.0 to 0.4. The decrease seems to be due to the increased grain size with increasing La content. The large ΔH value at x=0.5 is due to the presence of grain boundary phase.

Fig.1 Temperature dependence of saturation magnetization as a function of temperature.

Fig. 2 Ferromagnetic resonance linewidth as a function of x for sintered $Y_{3-x}La_xFe_5O_{12}$ at 1400°C.

Table 1. shows the complex permittivities and permeabilities measured by cavity perturbation method at TE_{101} and TE_{104} mode, respectively, for sintered $Y_{3-x}La_xFe_5O_{12}$ at 1400°C. Permittivity and permeability were measured at 6.8 GHz and 10.0 GHz respectively. It was difficult to find a relationship between La content and permittivity of the substituted garnet. The values of the ϵ_r are in the range of 15.0 - 17.5. The value of ϵ_i / ϵ_r of $Y_{3-x}La_xFe_5O_{12}$ sample was larger than typical value of 10^{-3} in polycrystalline YIG. The real part of the microwave permeability μ_r was about 1, which is slightly larger than the value of 0.9 in pure YIG [3]. The imaginary part of the permeability μ_i varied in the range of 6.5×10^{-3} - 51×10^{-3} .

x	ϵ_r	ϵ_i	μ_r	μ_i	x	ϵ_r	ϵ_i	μ_r	μ_i
0	17.10	0.49	0.98	8.3×10^{-3}	0.3	14.95	0.09	1.02	11.7×10^{-3}
0.1	16.81	0.15	1.01	7.9×10^{-3}	0.4	15.04	0.25	1.02	39.7×10^{-3}
0.2	15.76	0.28	1.01	6.5×10^{-3}	0.5	17.54	0.80	0.98	51.2×10^{-3}

Table 1. Complex permittivity(ϵ) and permeability(μ) measured by cavity perturbation method at TE_{101} and TE_{104} mode, respectively for sintered $Y_{3-x}La_xFe_5O_{12}$ at 1400°C.

IV. CONCLUSIONS.

Single phase La substituted polycrystalline $Y_{3-x}La_xFe_5O_{12}$ (x = 0.0 - 0.4) garnets were manufactured by ceramic method. Saturation magnetization and Curie temperature of the garnets increased slightly with increasing La content. Resonance linewidth decreased with increasing La concentration x. Complex permittivity and permeability were measured by cavity perturbation method at TE_{101} and TE_{104} mode.

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