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THE EFFECT OF VARIATION OF THE BISMUTH CONTENT ON THE MAGNETIC PROPERTIES OF $Y_{3-X}Bi_XFe_5O_{12}$ SYSTEM

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ABSTRACT

$Y_{3.0-x}Bi_xFe_5O_{12}$ samples were prepared via conventional technique. Four samples of $Y_{3.0-x}Bi_xFe_5O_{12}$ were prepared (x = 0.2, 0.4, 0.6, 0.8). The samples were then studied for general variation of Curie temperature and initial permeability with bismuth content. All the compounds prepared were identified by X-Ray Diffraction. Sample with the highest content of bismuth, sample $Y_{2.2}Bi_{0.8}Fe_5O_{12}$, recorded the highest Curie temperature and the highest initial permeability. The bismuth is speculated to give rise to the strong super-exchange interaction and this results in the increase of Curie temperature. Additionally, the bismuth content works as a sintering aid to assist grain growth during sintering and hence enhances the initial permeability.

INTRODUCTION

Yttrium iron garnet (YIG) has been studied intensively by researchers for decades now. It prides itself as being one of the most well known soft ferrites hitherto. Its grandeur can be justified by its application in microwave devices such as spatial light modulators, guided wave optical isolators [1], optical Faraday rotator [2], phase shifters, switches and sensors [3, 4].

Doped YIG were also subjected to scrutiny. The magnetic and electric properties of these compounds YIG changed slightly or drastically based on the type and quantity of dopant employed. Recent studies involve the work of Miroslav Marysko [5] who studied the properties of cobalt doped YIG films and the work of Jiehui Yang *et al.* that focused on the magneto-optical properties of Nd substituted YIG [6]. This paper reports the findings of the variation of the Curie temperature of bismuth doped on single phase YIG.

METHODOLOGY

Four samples of $Y_{3.0-x}Bi_xFe_5O_{12}$ (x = 0.2, 0.4, 0.6, 0.8) were prepared via the conventional oxide technique. Firstly, stoichiometric oxides of yttrium, iron and bismuth were added together. Then, wet milling process was carried out to obtain highly uniform samples. After being filtered and left to dry for one day, the samples were dried in an oven at 120^oC for four hours. Next, the samples were pre-sintered at 1250 ^oC for 10 hours. Consequently, the samples were crushed by a porcelain mortar. They were then crushed via wet milling process. The samples were dried in an oven at 120^oC for four hours after being filterd via a funnel and left to dry under normal atmospheric conditions. The samples were then sieved, bound with PVA, added with zinc stearate (a lubricant), moulded into both toroid and pellet shape and sintered at 1350 ^oC for 10 hours in air. Finally, the samples were characterised.

The pellet shaped samples were characterised by Siemens D5000 (Cuα radiation with λ = 1.5418 Å) XRD machine. All the samples were scanned from 20 to 80 degree.

The toroidal samples were wound with 10 turns of 0.3 mm diameter insulated copper wire. They were then placed in a furnace and series of inductance values at equal intervals of temperature increment was recorded using HP 4291 LCR meter. The Curie temperature was obtained by plotting an inductance versus temperature. The sharp fall of the inductance indicates the weakening of the exchange interaction. The initial permeability were recorded using Agilent 4291 RF Impedance analyser.

RESULTS AND DISCUSSION

From Figures 1 and 2, it can be observed that the XRD pattern of the samples pre-sintered at 1150°C and sintered at 1250°C exhibit the highest peak respectively. Other weak peaks do appear which could attribute to small volume of maghaemite, hematite, orthoferrite and others. The highest peak indicates the intensity of $Y_{3.0-x}Bi_xFe_5O_{12}$ phase with x = 0.2, 0.4, 0.6 and 0.8. This sharp Bragg peaks are characteristics of crystalline $Y_{3.0-x}Bi_xFe_5O_{12.}$ It is consistent with the crystallisation angle at which amorphous garnet phase appear.

Table 1: The X-Ray Diffraction main peak of samples with different bismuth substitution measured at room temperature

Code	Sample	Pre-sintering (2θ)	Sintering (2θ)
S1	$Y_{2.8}Bi_{0.2}Fe_5O_{12}$	32.3	32.41
S2	$Y_{2.6}Bi_{0.4}Fe_5O_{12}$	32.3	32.25
S3	$Y_{2.4}Bi_{0.6}Fe_5O_{12}$	32.1	32.29
S4	$Y_{2.2}Bi_{0.8}Fe_5O_{12}$	32.3	32.17

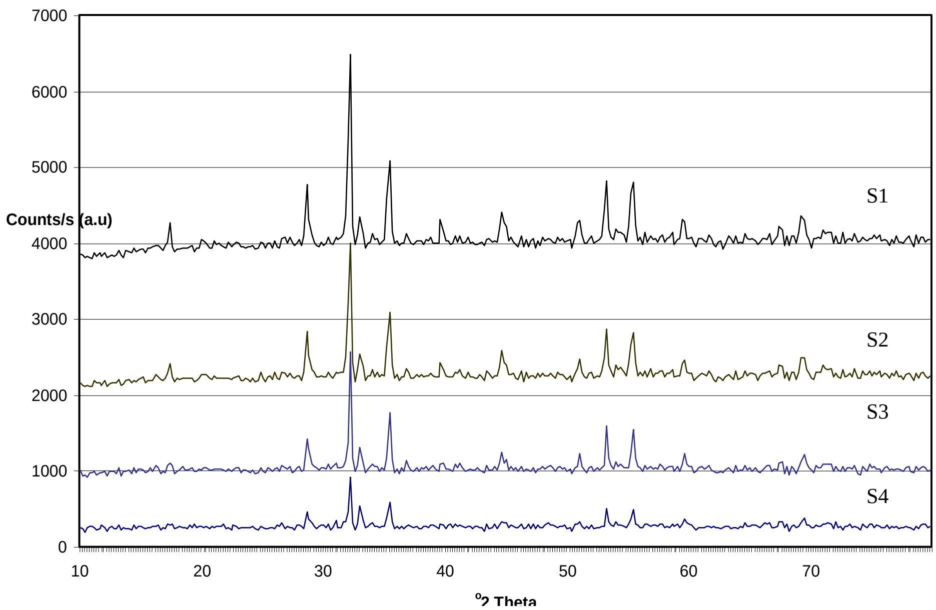

Figure 1: X-Ray Diffraction profiles for samples presintering at 1150°C for 10 hours

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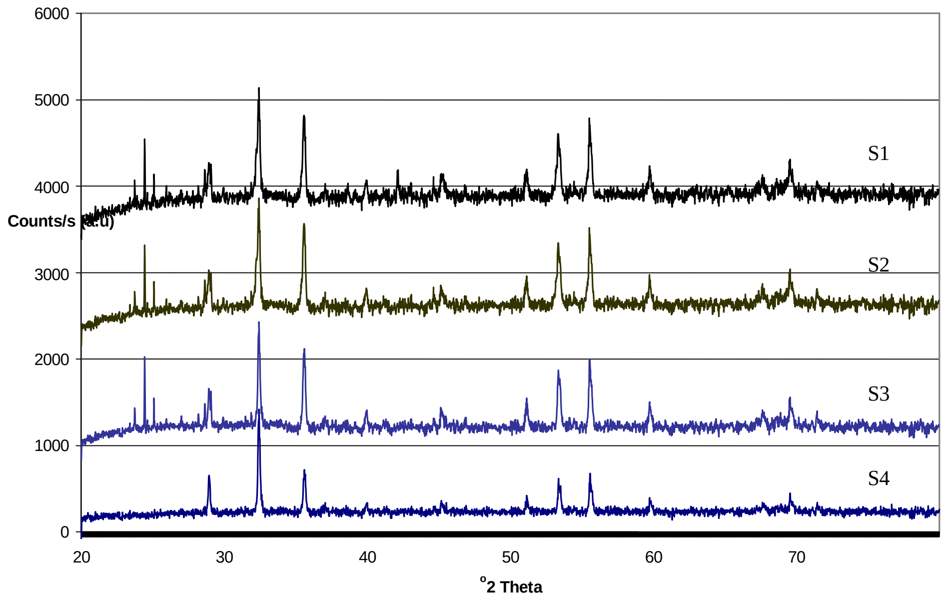

Figure 2: X-Ray Diffraction profiles for samples sintering at 1250°C for 10 hours

The XRD pattern after sintering at 1250°C for 10 hours does not differ much from the pre-sintered samples at 1150°C. Table 1 elicits the angles at which highest peaks were recorded. From Table 1, we can see that the XRD pattern for pre-sintering at 1150°C is better than the XRD pattern at1250°C as its value of each peak is closer to the Miller Index (420). The highest peak for pure YIG is at 32.317°. Sample S3 ($Y_{2.4}Bi_{0.6}Fe_5O_{12}$) was observed to have the maximum deviation from this value. This could be due to measurements error. From here, we can conclude that 1150 °C is the better sintering temperature for the samples. Sample S4 ($Y_{2.2}Bi_{0.8}Fe_5O_{12}$) recorded the highest Curie temperature at 352.5°C (refer to Table 2). Figure 3 shows the Inductance vs. Temperature curve. It elicits that Sample S4 recorded the highest curie temperature. This may be due to a stronger exchange interaction present in the sample. Super exchange interaction describes the interaction between the moments on ions that is too far apart to be connected by direct exchange but coupled over a relatively long distance through a non-magnetic material. The ferric ion in the sample has a half 3d shell and so has a spherically symmetric charge distribution (s state ion). Yttrium, a triply rare earth ion, is not symmetric and thus has a strong spin orbit coupling to its moment. The ion's moments are coupled via super exchange, so turning the Fe moment alters the quantity of overlap of Yttrium cation in the molecule. This results in changes of the magnitude of both the Coulomb and exchange interactions between the cations. This phenomenon will lead to a coupling which depends on the moment's orientation.

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Table 2: The Curie temperature (^{0}C) in different ratio (x) of samples

Code	Sample	Curie Temperature ('C)
S1	$Y_{2.8}Bi_{0.2}Fe_5O_{12}$	316.5
S2	$Y_{2.6}Bi_{0.4}Fe_5O_{12}$	332.5
S3	$Y_{2.4}Bi_{0.6}Fe_5O_{12}$	342.5
S4	$Y_{2.2}Bi_{0.8}Fe_5O_{12}$	352.5

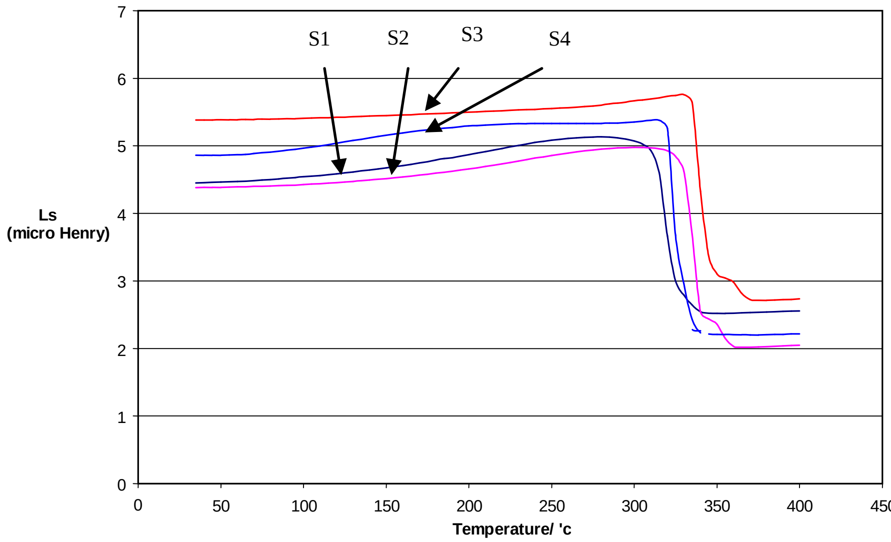

Figure 3: Inductance versus temperature

Figure 4 shows the general variation of Curie Temperature against bismuth content in $Y_{3.0-x}Bi_xFe_5O_{12}$. It can be said that the increased proportion of bismuth content causes a linear increase in the Curie Temperature. The Curie temperature for the $Y_3Fe_5O_{12}$ was reported to be less then 250^{0}C for sample that was prepared via convectional technique [9].

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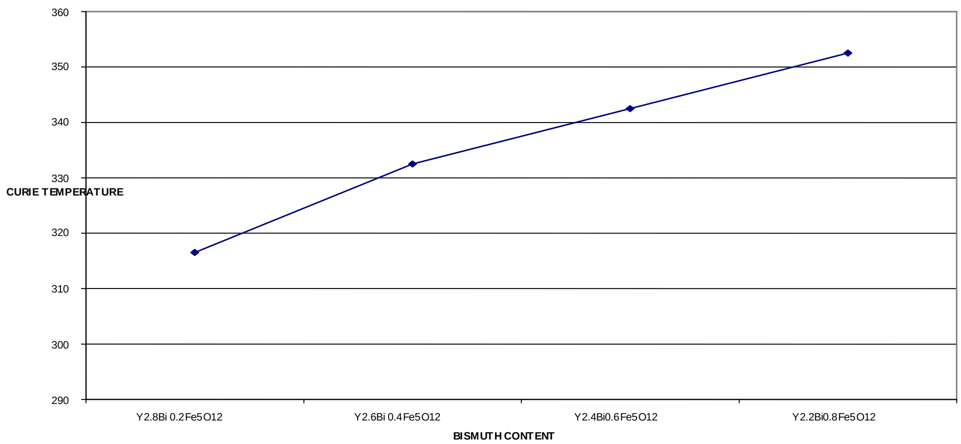

Figure 4: The graph of Curie temperature versus bismuth content

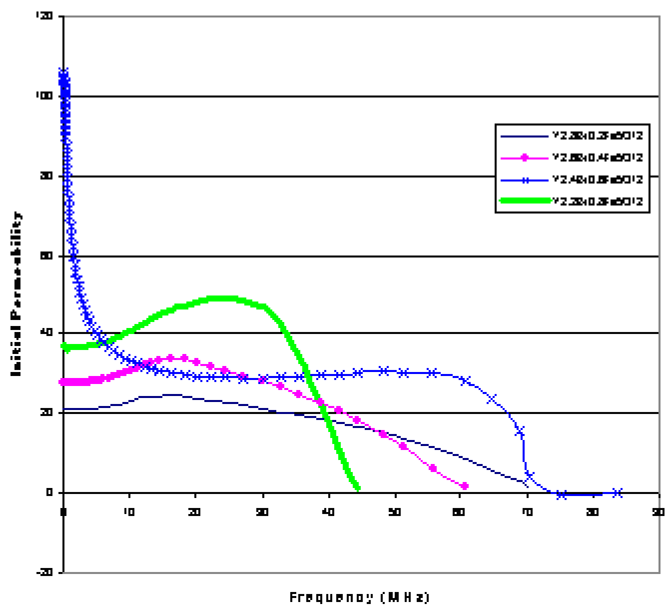

Figure 5: Initial permeability versus frequency (MHz) for all the samples measured at room temperature

The initial permeability for all the samples decreased with the increased frequency. Sample S4 gives the highest initial permeability, but lowest resonance frequency. This means that the Snoek equation below [7] is obeyed.

$$f_r(\mu - 1) = 4/3\ (\gamma M_s) \quad (1)$$

where f_r = loss resonance frequency

γ = gyromagnetic ratio

M_s = saturation magnetization

Initial permeability is the one of the important parameters used in evaluating magnetic material. It is strongly dependent on microstructure, stress and strain, crystal structure and composition [8]. Referring to Figure 6, the SEM image for sample S4 ($Y_{2.2}Bi_{0.8}Fe_5O_{12}$) has a good microstructure with clear grain boundary(Figure 6). Besides, sample S4 also has the highest initial permeability at 10MHz, which is 40.7931 (Figure 5) comparing to the other samples. This is due to the fact that large grain sizes with poreless microstructure allow domain walls to move easily hence giving rise to a higher initial permeability. The force with which a domain wall is fixed to a grain boundary becomes weaker due to the decrease in the total grain boundary area as the grain size increase, thus movements of domain walls appear to be easier. Besides grain sizes, grain boundaries and porosity also would affect the initial permeability. Microstructure defects caused by vacancies may be biggest factor contributing to reduction of initial permeability. This is maybe there is a lot of pores were trapped within the boundaries and effects the domain wall motion [10]. The increase of initial permeability may also been contributed by other factor such as internal stress, σ. When the internal stress decreases, the initial permeability will increase. From the XRD pattern (Figure 1 and 2), it is obvious that the crystallization of all samples are clearly shown. Initial permeability can also be affected by the magnetic anisotropy. When magnetic anisotropy increase, it will cause the spin of the magnetic ions to have less freedom to rotate and their orientation is bounded to a specific crystallographic direction [7]. The increasing bismuth content results in the weakening of anisotropic effect . This is due to the fact that bismuth is a non magnetic element. As a result, the initial permeability may be decrease.

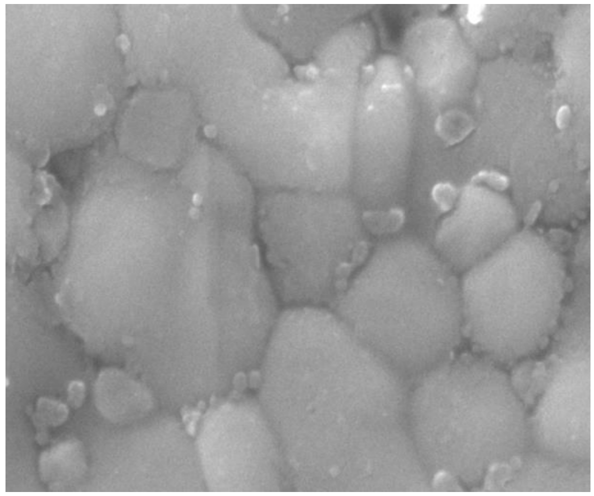

Figure 6 : Scanning electron micrograph of sample S4 ($Y_{2.2}Bi_{0.8}Fe_5O_{12}$)

CONCLUSIONS

The highest content of bismuth in $Y_{3.0-x}Bi_xFe_5O_{12}$, gives the highest Curie temperature and the highest initial permeability. The role of bismuth as the sintering aid gives the best microstructure and thus sample S3 exhibit better magnetic properties. This makes YIG with high bismuth doping a suitable candidate for wave absorbers, stamped core for low powered transformers and magnetic materials which has to operate in a maximum temperature of about 300^{o}C and below. The bismuth is speculated to give rise to the strong super-exchange interaction and this results in the increase of Curie temperature. Besides this bismuth also assists in the sintering process that results in large large grain size.

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