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Effect of mechanical milling on the magnetic properties of garnets

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Abstract

Rare earth garnets after milling to nanosizes are found to decompose into rare earth orthoferrite and other rare earth and iron oxide phases. The magnetization for the yttrium iron garnet decreases in the nano state due to the formation of antiferromagnetic phases. But for the gadolinium iron garnet when milled up to 25 h, the room temperature magnetization increases despite the formation of antiferromagnetic and non-magnetic phases. This is attributed to the uncompensated moments of the sublattices because of the weakening of the superexchange interaction due to change in bond angles and the breaking of some superexchange bonds on account of the defects and oxygen vacancies introduced on milling. For the 10 h milled gadolinium iron garnet at 5 K, after correcting for the non-magnetic phases present, there is an increase in the magnetic moment of about 10% as compared to the value for the as-prepared garnet. The magnetic hyperfine fields corresponding to the various phases were measured using ^{57}Fe Mössbauer spectroscopy at 16 K. The isomer shift values indicate the loss of oxygen for the samples milled for larger duration.

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Keywords: Gadolinium iron garnet; Yttrium iron garnet; Compensation temperature; Decomposition; Spin canting; Superexchange interaction

1. Introduction

Rare earth iron garnets (RIG) have been extensively studied as they are an important class of ferrimagnetic materials because of their high-frequency applications [1]. The rare earth garnets have three different crystallographic sites with 16 Fe^{3+} ions in the octahedral [a] sites, 24 Fe^{3+} ions in the tetrahedral (d) sites and 24 R^{3+} in the dodecahedral {c} sites. The magnetic contribution arises from the antiparallel alignment of the rare

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earth magnetic moments in the {c} site to the resultant of the antiparallely coupled magnetic moments in the other two sites having Fe^{3+} ions. The net magnetization direction at 0 K is determined by the {c} sublattice magnetization due to its large magnetization at low temperatures. At high temperatures the weak coupling between the magnetic moments decreases the magnetization of the {c} sublattice rapidly. At the compensation temperature (T_{comp}), the {c} sublattice magnetization is equal and opposite to the resultant of the [a] and (d) sublattice magnetizations. The compensation temperature of gadolinium iron garnet (GdIG) is 290 K [2].

Even though sintering is done at a high temperature of 1573 K during the synthesis of garnets [3], a small amount of orthoferrite phase is generally found to be present as an impurity phase [4]. Efforts were made to lower the calcination temperature by milling the precursor oxides [5]. It was observed in ferrites that the reduction of grain size gives rise to changes in cation distribution, magnetization and Néel temperature [6–8]. However, in our knowledge, there was no report on the study of the magnetic properties of the GdIG with nanometer grain sizes. Hence, it is interesting to study the effect of grain size reduction on the structural and magnetic properties of the garnets [9]. In this article, we present a detailed report on the changes in the phase stability and magnetic properties of yttrium and gadolinium iron garnets subjected to milling.

2. Experimental

For our study, as-prepared yttrium and gadolinium iron garnets obtained from the sintered blocks were ball milled in a Fritsch planetary high-energy ball mill (P7) in air. Zirconia balls and vials were used for milling with a ball to sample weight ratio of 10:1. The milled samples were sampled out at different milling times. X-ray diffraction measurements were performed using a Cu target. The average grain size was calculated using the Scherrer formula. The magnetic measurements were done using a vibrating sample magnetometer (VSM) (EG & G, PARC, USA) in the fields up to 560 kA/m and with a quantum design SQUID magnetometer for the fields up to 5.6 MA/m at various temperatures with a stability of ± 5 K. The Mössbauer measurements were performed using a constant acceleration Mössbauer spectrometer (Wiessel, Germany) at 300 K and at 16 K with a ^{57}Co(Rh) radioactive source kept at 300 K.

3. Results and discussion

3.1. Yttrium iron garnet

Fig. 1 shows the XRD pattern of the as-prepared and ball milled yttrium iron garnet (YIG). It is seen from the XRD pattern that the YIG decomposes to $YFeO_3$ and Fe_2O_3 on milling. The grain size of YIG is found to decrease from 91 nm for the as-prepared sample to 20 nm on milling to 15 h. Fig. 2 shows the magnetization and coercivity at 300 and 77 K for the YIG samples milled for various durations. The magnetization at both temperatures shows a decreasing trend with milling, which could be due to the appearance of the antiferromagnetic phases like $YFeO_3$ and Fe_2O_3. With milling, the coercivity at 77 K increases whereas, at 300 K it decreases. The calculated single domain size for the YIG is 300 nm and the maximum coercivity was reported

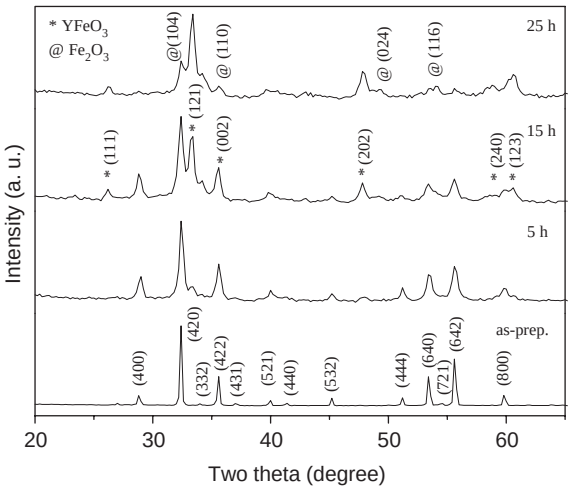

Fig. 1. The XRD pattern of yttrium iron garnet ball milled for various durations.