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Phase, microstructure and magnetic evaluation in yttrium iron garnet (YIG) synthesized via mechanical alloying

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Abstract The high electrical resistivity and excellent magnetic properties make ferrites a preferred choice in electronics and telecommunications in higher frequency region (upper MHz and GHz). We chose to investigate experimentally the effect of temperature on a sample's properties which are important to microwave scientists and engineers, after undergoing heat treatments. In this study, yttrium iron garnet (YIG) was prepared via mechanical alloying involving a 24 h milling time of a mixture of yttrium oxide (Y_2O_3) and iron oxide (Fe_2O_3). The samples were then sintered at different temperatures at 900, 1100, 1200 and 1350 °C with 10 h holding time and optimized for microstructure. The microstructure, magnetic and physical properties were studied in order to understand the resulting materials. Starting powders were successfully prepared using high energy ball milling technique for 24 h. The XRD patterns confirmed the formation of the single-phase cubic garnet structure with no extra lines corresponding to any other crystallographic phase or unreacted ingredient. A complete phase of YIG was observed to form at 900 °C sintering temperature due to the high reactivity of the nano-sized starting powder. SEM micrographs showed larger grain size as the sintering temperature increased, consequently increasing the number of multi-domain grains. The permeability values were influenced by several factors which are degree of crystallinity, dominant magnetization process (ease of domain walls movement in multi-domain grains or spin rotation in single-domain grains) and large enough grain size which exceed the critical grain size for transition from single-domain to multi-domain grains. As for magnetic properties, the H_c values were found to increase as the sintering temperature increased from 900 to 1200 °C and subsequently reduced at 1350 °C sintering temperature. The increased value of coercivity for lower sintering was due to shape and magnetocrystalline anisotropy for small enough grains. An integrated analysis of phase, microstructural and hysteresis data pointed to existence of three distinct shape-differentiated groups of B–H hysteresis loops which belong to samples with moderate and strong magnetism.

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1 Introduction

Ferrites, including garnets are magnetic ceramics which have been used in the microwave and non-microwave frequency region for more than eight decades. Ferrimagnetic materials (garnets) have been widely investigated due to their potential applications in various fields [1]. Garnet ferrites with composition ($A_3B_5O_{12}$) structure have unique electromagnetic, magneto-optical, mechanical, and thermal properties [2]. Garnet ferrite comprise of three crystallographic lattice (a, b, and c) sites. Among these lattice sites, the $24Fe^{3+}$, $16Fe^{3+}$, and $24R^{3+}$ ions occupy the [b] tetrahedral, (a) octahedral, and {c} dodecahedral sites, respectively, whereas oxygen ions are distributed to the interstitial sites [3]. However, R is the rare earth ions such as Ce, Gd, Y and Nd. The general formula for rare earth garnets is $R_3Fe_5O_{12}$, whereas the ion distribution in rare earth garnets are $[Fe_2](Fe_3)\{R_3\}O_{12}$ represented tetrahedral, octahedral and dodecahedral sites respectively [4]. The properties of garnet ferrites strongly depend on the phase formation, microstructure fabrication techniques and