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Research articles

Temperature-dependent magnetic properties of YIG thin films with grain size less 12 nm prepared by a sol-gel method

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ABSTRACT

We report on YIG film with small grain size (<12 nm) that has the potential to be used in microwave device application. The nanostructured film has been deposited on quartz substrate by a sol-gel spin coating technique, followed by annealing at temperatures in the range between 700 and 900 °C. The structural and magnetic properties of the film in the range 10–610 K were investigated. The X-ray diffraction results demonstrate that the films formed in a polycrystalline structure with lattice parameter in the range of 12.249–12.359 Å, lower than that of bulk materials. The saturation magnetization decreased not linearly with increasing the temperature from 10 to 300 K, differently from that reported for the bulk YIG. The coercivity value decreased with increasing temperatures (10–300 K), except for the film annealed at 800 °C. The Curie temperature of the film annealed at 700 °C was 554 K, however, other films showed higher Curie temperature values than that reported for bulk YIG. These properties are strongly influenced by the stress in the film's structure due to the different thermal expansion coefficient of the YIG and the quartz substrate.

1. Introduction

Yttrium iron garnet (YIG, $Y_3Fe_5O_{12}$) film is a soft ferrimagnetic material which has a great potential use in microwave devices [1] such as isolators, circulators, phase shifters capacitors and others [2]. The garnet has been used extensively in microwave applications due to its peculiar magnetic and dielectric properties, suitable for microwave technology [3]. Paladino et al. [4] and Saraswati et al. [5] have suggested that single phase garnet structure with smaller grain size can improve the performance of the microwave devices. The small grain size of the garnet is necessary to minimize dielectric field loss in the excitation of spin waves-scattering [4,6]. Meanwhile, the grain size of the garnet must be controlled during its synthesis, as it affects the coercivity. In particular, a low coercivity of the YIG film is required to achieve optimal performance in microwave applications [4,5]. Due to the great interest drawn by small particles in future applications, several reports, (e.g. Sanchez et al. [7], Rajendran et al. [8], Nguyet et al. [9] and Kim & shima [10]) focus on the magnetic properties and their temperature dependence of bulk YIG with small particles sizes: 45–450 nm, 9–60 nm, 22–55 nm, and 10 nm. However, compared to the bulk YIG, the properties of YIG film are very different due to the strong strain effect at the interface between the film and the substrate [11]. To our knowledge, until today, there are few studies focused on the magnetic properties of YIG thin films in the temperature range of 10–610 K.

Many techniques have been reported to obtain YIG thin films, such as radio-frequency magnetron sputtering [12], pulsed laser deposition [1,13], low pressure chemical vapor deposition [14], liquid phase epitaxy, and sol-gel method [15]. In this work, we reported nanostructured YIG thin films growth on quartz substrate with a grain size of <12 nm prepared by a simple sol-gel method. The advantages of using this method are, that it is a simple, inexpensive, and controllable process, and that it allows for a better mixing of the starting material to the final product with excellent chemical homogeneity [16].

This paper was aimed to investigate the magnetic properties of YIG films in the range 10–610 K, and was also devoted to understand the role of the surface effect that can influence the magnetic behavior of YIG films, as compared to the bulk YIG.

2. Experimental procedure

Yttrium iron garnet (YIG) films deposited on quartz substrate were prepared using the sol-gel method. First, the solution of Y $(NO_3)_3 \cdot 6H_2O$) with purity 99.8% (Sigma Aldrich) was dissolved in 2 ml ethanol and iron (III) nitrate nanohydrate $Fe(NO_3)_3 \cdot 9H_2O$ with

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purity 99.99% (Sigma Aldrich) was dissolved in 2 ml ethanol and 1 ml ethylene glycol. These solutions were stirred separately to obtain the homogenous gel. After 1 h, they were mixed and stirred for 2 h, filtered and aged for 2 days at room temperature. A 200 µl of sol was dropped onto a clean quartz substrate for a spin-coating technique at 500 rpm for 15 s and 3500 rpm for 30 s. The total times taken for films spin was 40 s. Then, the film was dried initially at 70 °C for 30 min in ambient atmosphere to burn off the organic solvent. The films were then placed on a plate and transferred to a tube horizontal furnace in presence of a oxygen gas flow of 200 sccm and 1.5 atm pressure. The annealing process has been carried out in three stages: 90 °C for 2 h (to get rid of solvents: ethanol and ethylene glycol residual), 350 °C for 15 min (to remove organic compounds) and further heated at 700, 800 and 900 °C for

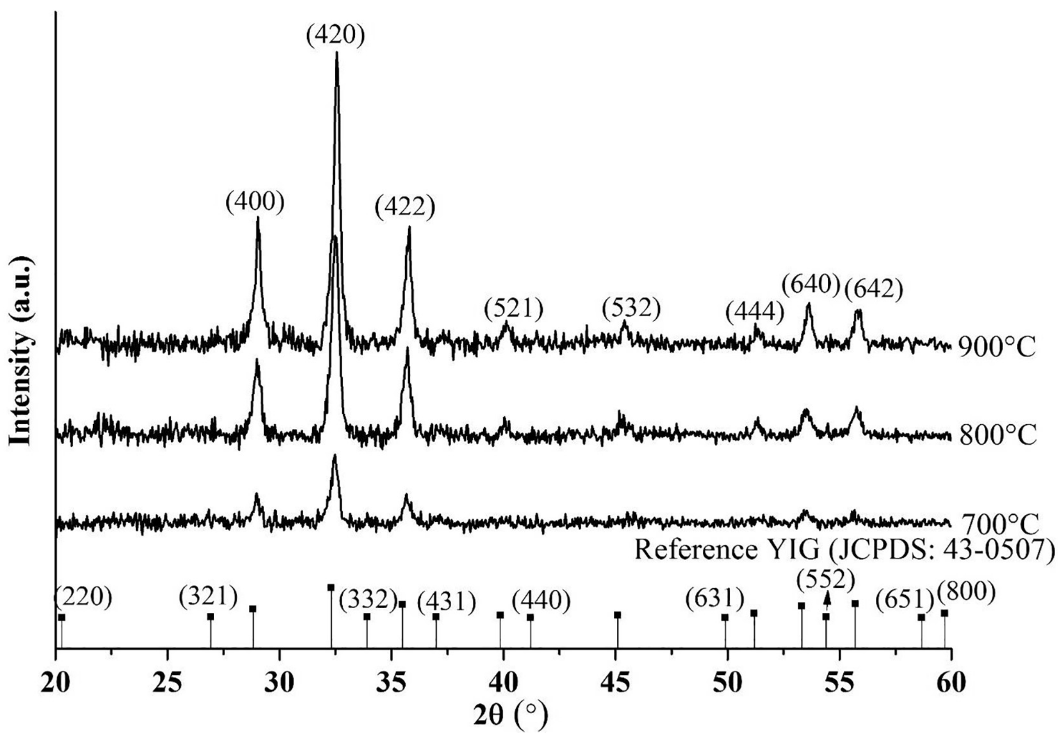

Fig. 1. X-ray diffraction pattern of a bulk YIG standard JCPDS card No. 43-0507 and YIG films with different annealing temperatures.

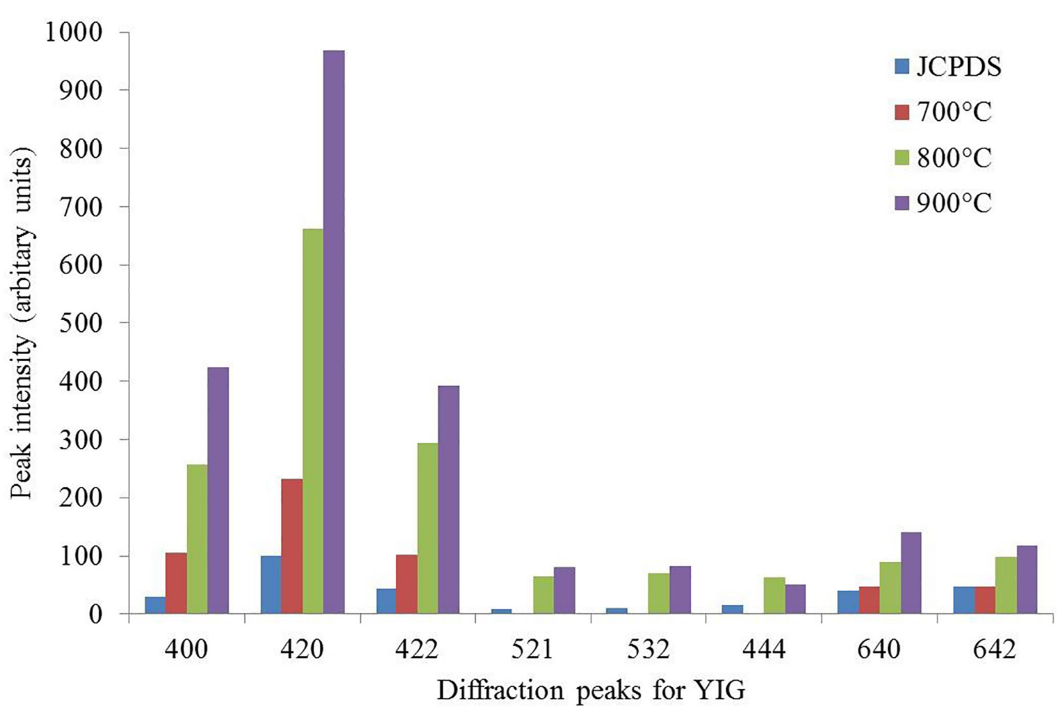

Fig. 2. Relative intensities of the diffraction peaks for YIG films and a bulk YIG (JCPDS).