Oxygen partial pressure dependence of the structure of RF sputtered Strontium Ferrite

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Abstract

Strontium hexaferrite ($SrFe_{12}O_{19}$) is a prime candidate in the application of magnetic memory devices and microwave devices. The structure of rf sputtered Strontium ferrite strongly depends on the oxygen partial pressure during sputtering according to X-ray diffraction (XRD) measurements. The optimum oxygen partial pressure and the best target composition suitable to synthesize the Strontium hexaferrite have been investigated. A non-magnetic phase of Strontium ferrite ($SrFe_2O_4$) was completely crystallized at 10% of oxygen, as the oxygen partial pressure was increased from 0% (pure Ar) to 10%.

Introduction

The magnetic anisotropy and the coercivity of Strontium hexaferrite are higher compared with those of soft cubic ferrites such as Nickel ferrite and Lithium ferrite, since hexaferrites such as Barium ferrite and Strontium ferrite are magnetically uniaxial. The easy-axis of magnetization of Strontium hexaferrite directs along the C-axis of hexagonal lattice, although the easy axis of cubic ferrites can direct along any of the body diagonal of cubic lattice. Previously the films of Barium ferrite has been synthesized on ZnO[1], sapphire[2,3], Si/SiO_2[4,5,6] and fused quartz[7,8] substrates using rf[2,4,6], dc[2,7] and target facing sputtering[1,5], laser ablation[3], and arc discharge evaporation[8] by some other researchers.
Strontium and Barium hexaferrites have nearly identical properties, although the crystal anisotropy constant of Sr ferrite is higher than that of Ba ferrite.[9] Nevertheless the interest of Sr hexaferrite thin films has been developed in the late 1993. The easy-axis oriented thin films of Sr hexaferrite has been deposited on Si(111)[10] substrates and fused quartz[11] substrates using rf sputtering. Previously we have sputtered non-epitaxial Sr hexaferrite films on polycrystalline Al_2O_3 substrates. Changing the deposition temperature could orient the easy-axis on the plane of the film.[12] The coercivity of these Sr hexaferrite films increased with increasing temperature similar to the Nickel ferrite films deposited by us previously.[13,14] These Sr hexaferrite films could be crystallized only above some minimum deposition temperature similar to the sputtered rare earth-transition metal (RE-TM) films.[15]

Experiment

At the beginning the chamber was pumped down to a pressure of 10^{-7} Torr using a system of mechanical pump, cryo-pump and ion pump. All these films were deposited on Al_2O_3 polycrystalline substrates using rf sputtering at deposition temperature of 600 ^{0}C and total pressure of 100 mTorr of Ar/O_2, subsequently annealed under 500 Torr of oxygen at 550 ^{0}C for 30 minutes to improve the peaks of XRD patterns. Electronic flow controllers controlled the ratio between the oxygen and Ar. For example, the oxygen and Ar partial pressures during sputtering at 10% of oxygen were 10 mTorr and 90 mTorr, respectively. Commercially available bar targets of Strontium hexaferrite with stoichiometric compositions could not crystallize the Strontium hexaferrite phase in thin film form due to the bombardment of negatively charged oxygen ions. Therefore the customary made bar targets of size 1cmx1cmx4cm with the composition of Sr:Fe:O=1:4:7 were used to deposit the stoichiometric Strontium hexaferrite films described in this report. The distance between the target and the substrate was fixed to 6 cm.
Cu-Kα has been used to obtain the XRD patterns of rf sputtered Sr hexaferrite films. The vibrating sample magnetometer (VSM) performed the magnetic hysteresis loops. The Scanning electron microscope (SEM) coupled to the PGT System 4 Plus unit measured the composition and the thickness of these films.

Results and discussion

The XRD patterns of the film deposited at various oxygen partial pressures are shown in figure 1. At 0% of oxygen (in pure Ar), the Sr hexaferrite phase could be crystallized. Up to 2% of oxygen partial pressures, the films were found to be single phase. Above 2% of oxygen, the secondary phase began to crystallize. At 10% of oxygen this secondary phase completely crystallized, and XRD did not show any

peak of Sr hexaferrite. The peaks indicated with letter "s" are substrate peaks. This secondary phase was found to be SrFe2O4 by comparing with standard powder patterns.

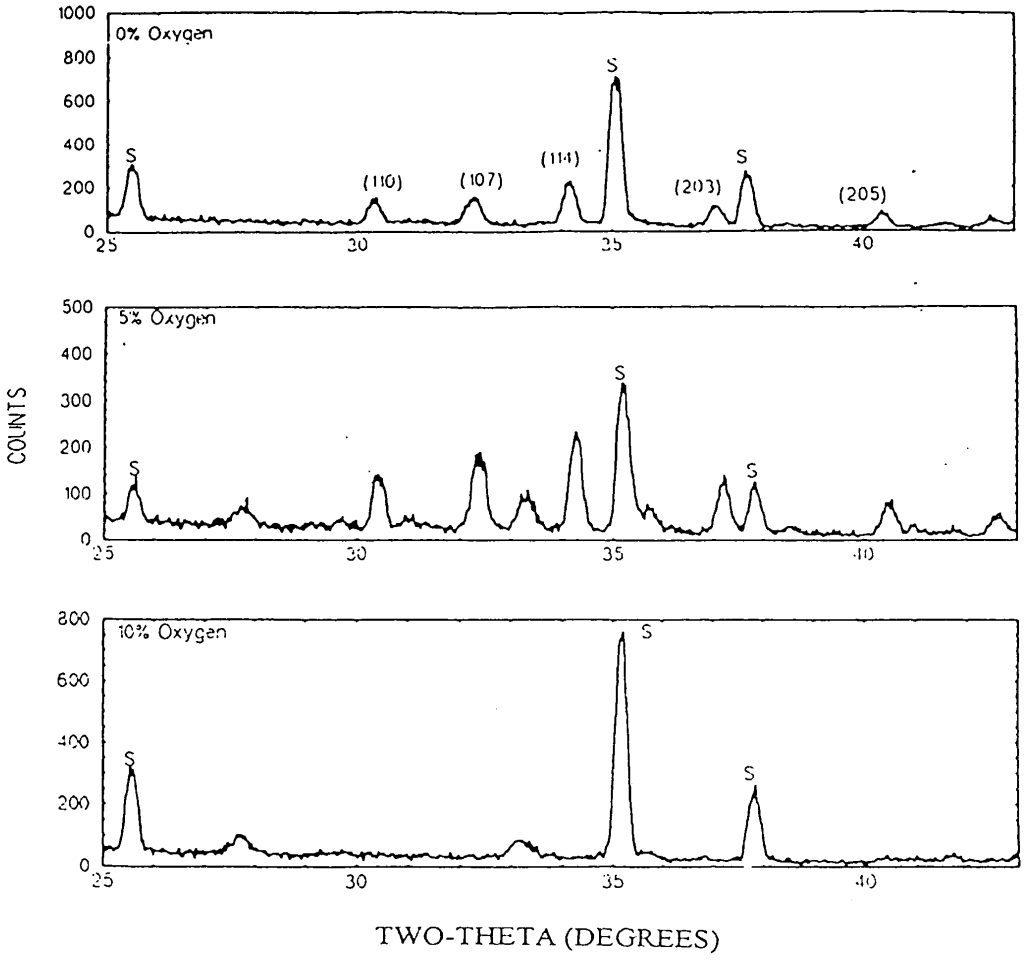

Figure 1. XRD patterns of the Strontium hexaferrite films synthesized at 0%, 5% and 10% of oxygen partial pressures at total pressure of 100 mTorr of Ar/O2 and 600 0C, and subsequently annealed under 500 Torr of oxygen at 550 0C for 30 min.

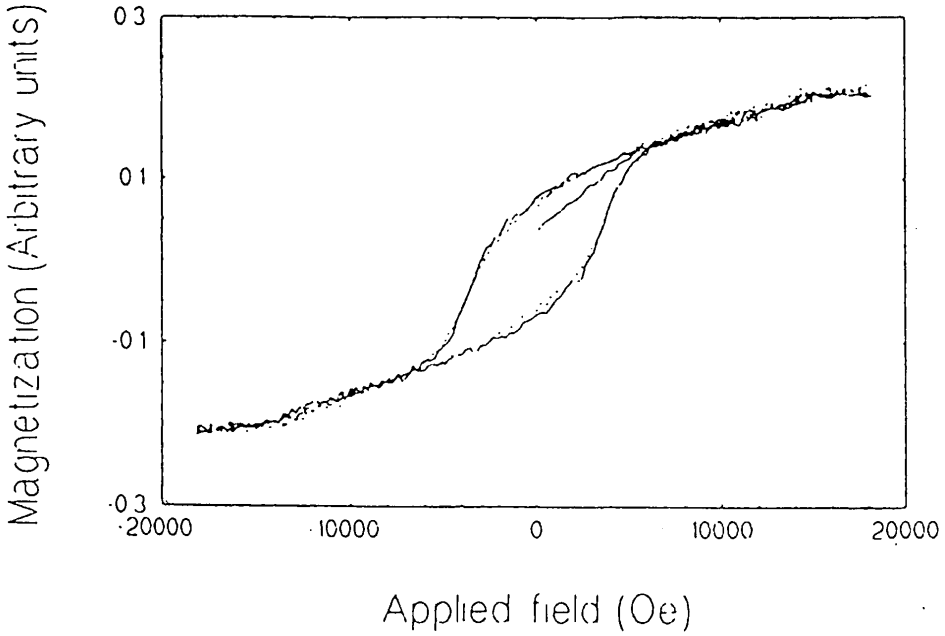

Figure2. In plane (dashed) and perpendicular (solid) magnetic hysteresis loops of Strontium hexaferrite film deposited at 625 ^{0}C and 100 mTorr of pure Ar, and subsequently annealed at 550 ^{0}C under 500 Torr of oxygen for 30 min.

The in-plane and out-of-plane magnetic hysteresis loops of a film deposited at 625 ^{0}C are given in figure 2. The magnetic hysteresis loops have been given with the substrate correction after taking the effect of diamagnetic properties of substrate into account. The remanent to saturation flux density ratio of this film is 0.5 for both in-plane and perpendicular loops indicating that the film is magnetically isotropic. The saturated magnetic moment of the films gradually decreased with the oxygen partial pressure indicating that the secondary phase is nonmagnetic. Only Fe^{+3} ions with magnetic moment of 5 Bohr magnetrons contribute to the magnetization in Sr hexaferrite. Because the magnetic moment of Sr^{+2} is zero due to the lack of unpaired electrons, the calculated value of total magnetic moment per spinel $SrFe_2O_4$ cubic unit cell is zero.

Conclusion

The best oxygen partial pressure and target composition required for synthesizing Strontium hexaferrite have been studied in detail during this project. The Strontium hexaferrite phase could be crystallized only up to 2% oxygen partial pressure according to our studies. Above that pressure the crystallization of secondary nonmagnetic phase was identified according to XRD patterns and magnetic hysteresis loops. The amount of this secondary nonmagnetic phase gradually increased up to 10%.

Acknowledgement

I especially thank Professor F. J. Cadieu at Queens College of CUNY, NewYork, U.S.A. for his continuous support during this project.

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