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Effect of Al doping on the Structural and Magnetic Properties of Iron Oxide Thin Films

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ABSTRACT

During the past few decades iron oxide nanostructures are gaining worldwide attraction due to its applications in various industrial and medical areas. This is due to the unique structural, magnetic and electrical properties of iron oxide that it has found its usage in water purification, biosensors, magnetic resonance imaging, drug delivery etc. In addition iron ion in iron oxide can be replaced by other metals to enhance its certain properties for different practical applications. Al doped iron oxide thin films are prepared by thermal evaporation method. The concentration of aluminum was varied from x=0 to x=1 in $Fe_{2-x}Al_xO_4$. XRD results show the formation of highly crystalline iron oxide undoped and thin films. The ionic radii of iron Fe^{+3} is 0.069nm and Al^{+3} is 0.0675nm thus, incorporation of aluminum in iron oxide lattice caused slight shrinkage of unit cell thus leading to very little decrease in lattice parameter. No peaks corresponding to Al_2O_3 was observed in XRD indicating that aluminum is successfully incorporated within the host lattice in the concentration range studied with decrease in peak intensities with increasing Al^{+3} content. The band gap of the films was studied using Variable Angle Spectroscopic Ellipsometer (VASE) and is found in the range of 2.14 to 2.55eV. Moreover, aluminum doping also strongly affect the magnetic and dielectric properties of iron oxide thin films.

1. INTRODUCTION

During the past few years, the controlled growth of spinel nanostructures with desired morphology is of technological interest due to its exciting properties like Giant MagnetoResistive (GMR) tunneling and electric field effects (Yanagihara 2013, Wu 2012). These properties have found wide applications in spintronic devices (e.g. Magnetic Tunnel Junctions (MTJ's)), humidity sensors, in Magnetic Resonance Imaging, targeted drug delivery, magnetic recording etc. Spinel oxides appear flexible due to their complex structure and the resulting high degrees of freedom (Ikeda 2007). The crystal structure of spinels XFe_2O_4 (X= Co, Mg, Mn, Ni etc) is cubic. There are 8 corner

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atoms in cubic unit cell. Each corner is occupied by ferrite molecules and resulting in eight ferrite unit cells. Therefore, there are 8 ferrous (Fe^{+2}) ions, 16 ferric (Fe^{+3}) ions and 32 oxygen (O^{-2}) ions in a ferrous ferrite unit cell. If oxygen atoms are considered alone it constitutes a FCC structure. There are sixteen octahedral sites and 8 tetrahedral sites in a spinel ferrite unit cell (Liu 2013, Teresa 2000).

To date various spinel structures of the form XFe_2O_4 has been reported including $CoFe_2O_4$ (Cui 2010), $MgFe_2O_4$ (Chandradass 2013), $MnFe_2O_4$ (Vamvakidis 2013), $NiFe_2O_4$. Soderlind (2009) found the presence of impurity garnet $Gd_3Fe_5O_{12}$ phase in perovskite $GdFeO_3$ films. The magnetization of GdFeO3 was attributed to two factors one arising from iron sublttice and other from gadolinium sublattice. Gupta (2011) prepared $MgFe_2O_4$ using Pulsed Laser deposition and obtained ferromagnetic behavior of the films at room temperature.

Among the inverse spinel structures of the form XFe_2O_4 (where X= Co, Mg, Mn, Ni etc.) very little attention has been given to $AlFe_2O_4$. $AlFe_2O_4$ is a normal spinel oxide in which Fe^{+2} cations occupy 1/8th of the tetrahedral sites and Al^{+3} occupy ½ of the octahedral sites. The distribution of charges on octahedral and tetrahedral changes depending on the synthesis conditions as octahedral sites can also be occupied by Fe^{+2} cations.

We here prepared the much neglected spinel ferrite $AlFe_2O_4$ using thermal evaporation of iron and aluminum followed by oxidation under at 10sccm at 150˚C-450C.

2. EXPERIMENTAL DETAILS

Preparation of $AlFe_2O_4$ was done using thermal evaporation method in Edward 306 coating unit. Before deposition of thin films the corning glass substrates were placed in acetone in ultrasonic bath for ten minutes followed by ultrasonication in Isopropyl Alcohol (IPA) for 15mins. Iron and aluminum were evaporated by sequential elemental layer technique at a base pressure of 10^{-6} torr and working pressure of 1.5×10^{-5} torr and then oxidized in the presence of oxygen flow of 10sccm at 150˚C, 250˚C and 350˚C for 60min. The flow rate of oxygen is chosen on the basis of work done earlier by Riaz (2013). Structural characterization and optimization is done by XRD (Rigaku D-MAX II A Diffractometer) and magnetic properties are studies by VSM (Lake Shore 7407 Magnetometer).

2. RESULT AND DISCUSSIONS

Fig. 1 show XRD patterns for $AlFe_2O_4$ thin films deposited on glass substrate and annealed at 150˚C, 250˚C and 350˚C. The films show amorphous behavior under as deposited conditions where as annealing does not affect the crystalline structure of the films. However the presence of very small diffraction peaks indicates the formation of the required $AlFe_2O_4$ phase at oxygen flow rate of 10sccm. The spinel ferrites of the form XFe_2O_4 (where X=Co, Mg, Mn, Ni etc.) is of technological importance owing to its spintronic applications. However the spinel ferrite $AlFe_2O_4$ is long neglected and to the best of our knowledge there are no reports so far on $AlFe_2O_4$ spinel ferrite.

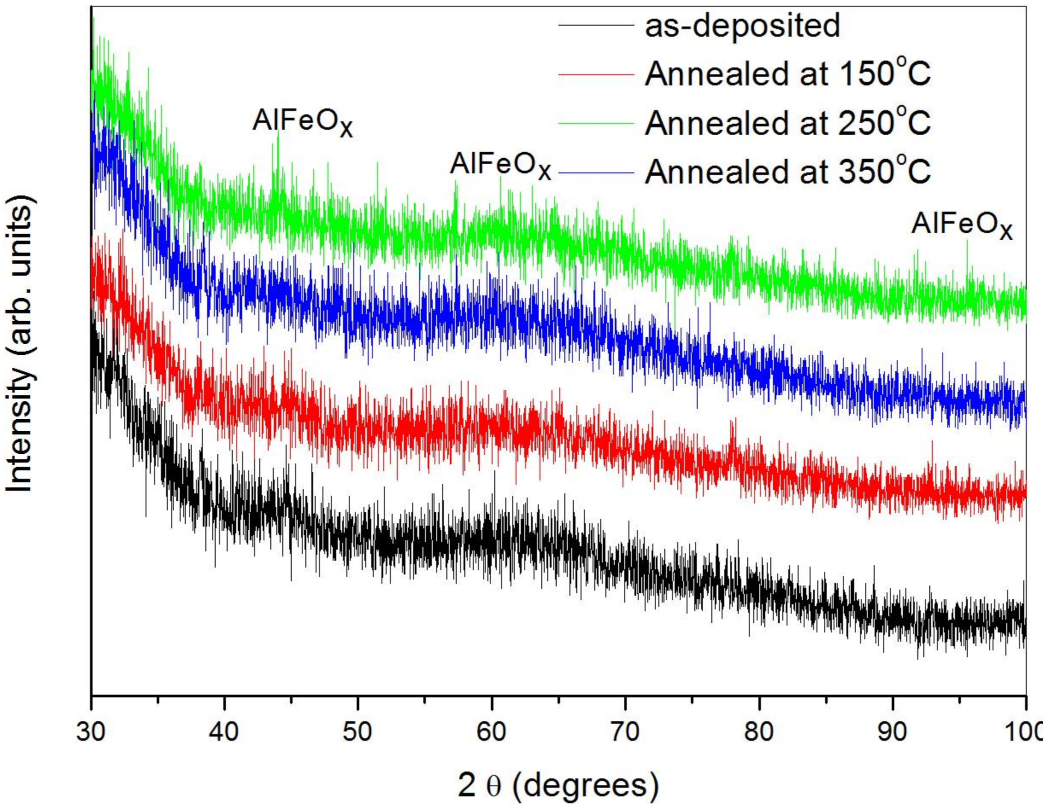

Fig. 1 XRD pattern of $AlFe_2O_x$ thin films oxidized at oxygen flow rate of 10sccm and annealed at 150˚C, 250˚C and 350˚C.

Fig. 2 show XRD room temperature in-plane and out-plane magnetization curve of $AlFeO_x$ film annealed at 350˚C. The film show ferromagnetic behavior with high coercivity. The saturation magnetization of the film for in-plane and out-plane applied field is 0.002 and 0.0015 respectively. The coercivity of the films for in-plane and out-plane field is 1980Gauss and 1995Gauss respectively.

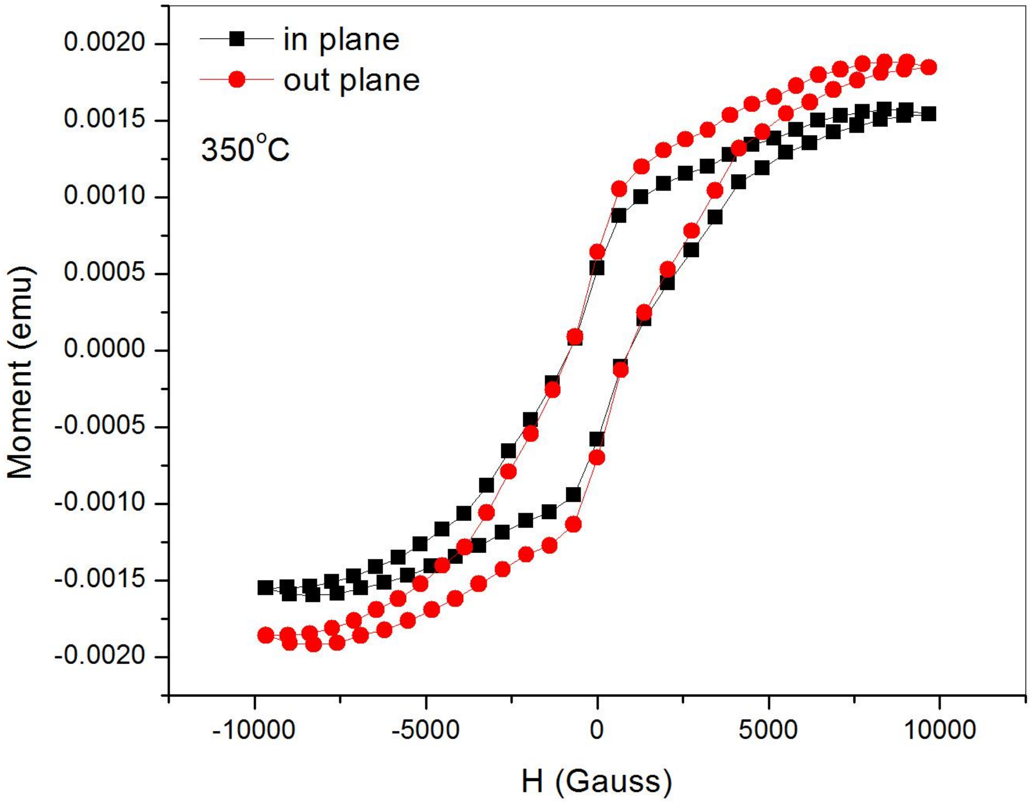

Fig. 2 Room temperature M-H curve for $AlFeO_x$ thin film annealed at 350˚C.

3. CONCLUSIONS

Spinel oxide $AlFeO_x$ has been investigated for its structural and magnetic properties. The films are deposited using thermal evaporation of iron and aluminum followed by annealing at 150˚C, 250˚C and 350˚C in an oxygen flow of 10sccm. XRD results show that films exhibit amorphous behavior with very small diffraction peaks. The film show ferromagnetic properties of film annealed at 350˚C.

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