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Magnetic and structural phase transition in iron oxide nanostructures

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Abstract

Among various materials of interest iron oxide is a promising candidate owing to its unique physical and chemical properties. In this research work growth of iron oxide nanostructures is carried out using sol-gel method. The concentration of the sol is varied as 1.8mM, 1.4mM, 1.0mM and 0.6mM. It can be seen that molarity of the sol not only affects the phase transition from magnetite to maghemite but also strongly affects the magnetic properties. Low concentration results in formation of magnetite and maghemite mixed phases whereas high concentration results in phase conversion to pure magnetite phase. Saturation magnetization slightly decreases as the phase conversion from magnetite to maghemite takes place.

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Keywords: Nanostructures; Iron oxide; Phase transition

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1. Introduction

New challenges and opportunities have materialized over the last two decades in order to develop miniaturized electronic devices. This struggle has opened new path in the form of Spintronics (short for Spin Electronics) which exploits the phenomenon of electron spin in addition to its charge. It will lead not only to scaling but also additional functionality in the future devices [1]. This stimulated interest in magnetic and transport properties of multilayered thin films stems from discovery of GMR and superior applications of tunneling magnetoresistance between trilayered structures that are concept base in Spintronic devices [1-3]. In order to fabricate efficient devices based on tunnelling magnetoresistance, iron oxides nanostructures are preferred based on their distinct magnetic and electrical properties [1].

Magnetite is known to mankind since as long as 1000 BC when Chinese discovered the magnetic attraction of lodestone (another name of magnetite). It is one of the most studied magnetic materials. In the current era, interest in magnetite stems from its conducting nature at room temperature, it's high Curie temperature (~ 850 K) and its half metallicity (high spin polarization). Magnetite is a ferrimagnetic material with bulk magnetization of 477 emu/cc [4-6]. The magnetic properties of magnetite arise due to the superexchange phenomenon. Magnetite is predicted to be a half metallic material which means that it possesses a band gap at the fermi level only for minority spins thus achieving 100% spin polarization at the fermi level. The half metallic films having metallic properties for electron spin population and insulating property for the other, making them excellent candidates for spintronic devices like MTJs. Fe_3O_4 exhibits large magnetoresistance at room temperature due to its high curie temperature as compared to other half metals [7-10].

Magnetite has complex cubic structure in which eight small cubes exist within a unit cell having oxygen atom on the four vertices of each of the cube. The tetrahedral (A) sites and octahedral (B) sites are occupied by the metal ions. Eight of the 64 possible tetrahedral sites and 16 out of 32 octahedral sites are occupied in a spinel unit cell. One A site and two B sites are occupied in each formula unit of Fe_3O_4. The divalent (Fe^{2+}) and trivalent (Fe^{3+}) iron ions share the octahedral B sites whereas the trivalent ions sit on the tetrahedral A sites. The moment of Fe_3O_4 is found to be approximately 4μB per formula unit. The contribution to the moment comes from the divalent iron ion on the B sites whereas the trivalent iron ions on A and B sites being antiferromagnetically coupled cancel each other's moment out [1, 11-13].

Iron oxide thin films are more advantageous as compared to their bulk forms. When particle size of these oxides reaches nanometer scale, they exhibit qualities like superparamagnetism and enhanced surface sensitivity that are not observed in the bulk form of oxides. The magnetic properties of magnetite particles strongly depend on their synthesis methods [14-15].

We here report preparation of iron oxide nanostructures using sol-gel method. The concentration of sol was varied as 1.0mM and 2.0mM. It can be seen that variation in concentration of sol resulted in different phases of iron oxide that leads to different magnetic properties.

2. Experimental Details

Sol was prepared using $FeCl_3.6H_2O$ as a precursor, which was then mixed in different organic and inorganic solvents including water and ethanol. The details of sol-gel synthesis have been reported earlier [9, 10]. The selection of appropriate substrate is extremely critical for the production of high quality thin films. The substrate material should be such that no reaction of substrate with thin film occurs even at high temperature along with excellent adhesive properties. It should have a high melting point which is important for the production of films at high temperature. The surface of the substrate should be flat. Furthermore the substrate must have a high dielectric strength. Also the choice of substrate is influenced by the ease of handling during the processing. Copper sheet was cut in 1cm×1cm substrate. Substrates were placed in diluted HCl so that etching of the top layer can take place. Substrates were submerged into a beaker of acetone and then IPA and placed in ultrasonic vibrator. The films were deposited on copper substrate and annealed at 300˚C for 120mins. The films were characterized structurally using