Fabrication of Novel Magnetic Nanostructures towards Efficient Power Generation

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Introduction

Magnetic nanoparticles (NPs) and their broad range of applications is one of the most useful aspects of nanotechnology. They are a class of nanoparticles which are typically less than 100 nm in all dimensions.[1]. Magnetic nanoparticles have been the focus of much research recently because they possess attractive properties for potential use in catalysis, biomedicine, magnetic resonance imaging, magnetic particle imaging, data storage, environmental remediation and especially in energy consuming sectors of the industry, such as power generation, conversion and conditioning as well as electromagnetic motors.[2-4] Improvement in the efficiency of functional magnetic materials achieved by reducing their size and production costs and increasing their magnetic moment will have significant impact by consuming less energy. One route to improve the technical properties of magnetic nanoparticles is to synthesize them in a nanocomposite form. The intensity of the applied magnetic field required to reduce the magnetization of that material to zero after the magnetization of the sample has been driven to saturation is called the coercivity of that material. It has been known[5] that at the interfaces of bilayers or multilayers of hard (coercivity higher than 1 kOe) and soft (coercivity less than 300 Oe) magnetic materials a shift in the magnetization curve of the material is observed. This shift is a signature of the quantum mechanical exchange coupling at the phase interface and is called exchange bias. As a result of this phenomenon, the magnetic energy stored in the material can dramatically increase. In this research, fabrication and study of novel magnetic core-shell multiphase nanoparticles is pursued, with particular focus on understanding the magnetic exchange coupling between the core and the shell. The goals of the proposed research will be achieved by fabricating pure-phase FeCo nanoparticles with a high saturation magnetization – low coercivity, which serve as the core, covered by a layer of pure-phase, high coercivity Co_xC as the shell. A chemical process in which the metals precipitate in an alcohol containing multiple hydroxyl groups (polyol) is used to synthesize the materials. Core-shell nanostructures will be made by utilizing the FeCo particles as the nuclei to form Co_xC shells around them. In this presentation, the fabrication of FeCo nanoparticles is delivered.

Experimental Details

FeCo NPs were synthesized using the polyol method[5], in which stoichiometric quantities of iron chloride; cobalt acetate and sodium hydroxide were mixed and added to 100 mL of ethylene glycol. The mixture was stirred and heated to reflux to 200 °C to form NPs. Then it was cooled to room temperature by removing the heat source. The nanoparticles were then separated from the mixture by means of magnetic separation and ultrasonication for 1.5 hours. After removing the supernatant, the precipitate was rinsed with methanol and centrifuged at 5000 rpm for 5 min several times. Finally, the precipitate was dried in an oven overnight at 50 °C. The particles were characterized by Vibrating Sample Magnetometry (VSM), X-Ray Diffraction and Transmission Electron Microscopy (TEM). TEM was carried out by our collaborators at the University of Delaware and at Virginia Commonwealth University.

Results and Discussion

Up to 6 grams/batch pure phase iron-cobalt nanoparticles with magnetic moments of up to 219 emu/g were fabricated. FeCo particles were successfully obtained from reduction of their salts at high temperatures[5] (usually at the boiling temperature of the solvent; in this case 200 ^{0}C). We examined two possible synthesis conditions: adding the reactant to the cold solution and then heating the solution or, injecting the reactants into a pre-heated solution at 200 ^{0}C. The VSM and XRD results show that in latter condition particles have higher moments than the former one (219 emu/g vs. 149 emu/g). Additionally, in the first condition, some secondary phases were detected by X-ray diffraction. The effects of two important parameters were then investigated: the reaction time and the salt: metal precursor concentration ratio. An increase in reaction time from 1 min to 60 min causes an increase in magnetic moment at about 30 min and then a decrease is noted. It is speculated that the reason for this behavior is particle oxidation. XRD data confirmed this hypothesis as it is noted that cobalt oxide and iron oxide form when the reaction time exceeds 40 min. Simultaneously, FeCo Bragg diffraction peaks begin to weaken and disappear at longer reaction times. The other synthesis processing parameter that was varied was the salt concentration. According to the literature [6], hydroxyl ions provide active sites for nucleation and growth of the FeCo nanoparticles. At low salt/metal concentration ratio (12:1), the obtained nanoparticle moment was much lower than expected. It is believed that it is due to the low amount of nuclei formed and the formation of immature particles less than 10 nm in diameter which have a low moment. With an increasing salt: metal ratio, the nanoparticle moment increases. At the salt: metal ratio of 27:1 the nanoparticles moment reaches its highest value at 219 emu/g. This value may be compared with that of bulk FeCo which is 240 emu/g. At this ratio, we obtained uniform particles with 15-25 nm diameters, as determined by Scherrer's formula. On the other hand, as salt: metal ratio exceeded 40, the nanoparticles magnetic moment begins to decrease. It is believed that this effect is due to the high amount of hydroxyl and oxygen ions that facilitates other reactions such as oxidation.

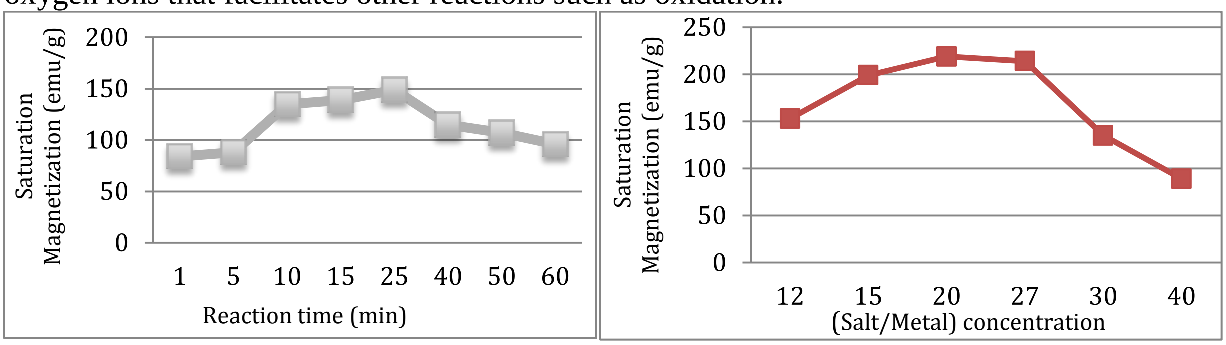

Figure1.Effect of reaction time (left) and salt/metal concentration ratio (right) on magnetic moment

In conclusion, FeCo nanoparticles were successfully obtained with the highest magnetic moment found at a salt: metal ratio at 27: 1 with 30 minutes reaction time. As the reaction time increased to greater than 40 min, formation of iron and cobalt oxides decreases the nanoparticle magnetic moment. Future work includes study and fabricating Co_xC nanoparticles and coating FeCo particles with them to make FeCo-Co_xC core-shell nanostructures.

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