

Synthesis and Functionalization of Magnetic Nanowires

Dylan Bayerl, University of Wisconsin Eau Claire, Eau Claire, Wisconsin, SURF 2007 Fellow

Faculty Advisors: Dr. Robert Snyder and Dr. Z.L. Wang

Mentor: Jenny Ruth Morber

Introduction

Recently there has been increased interest in magnetic nanostructures for biomedical applications. Such structures can be functionalized with biocompatible coatings and injected into the body, whereupon they can be manipulated by applying an external magnetic field gradient. For *in vivo* applications, it is important that these particles remaining in suspension inside the body and not agglomerate, making ferromagnetic materials with residual intrinsic magnetic fields unsuitable. Thus, paramagnetic materials, especially iron oxides like Fe_3O_4 magnetite, are favored for these purposes.

If paramagnetic structures are of small enough dimensions, a single magnetic domain encompasses an entire particulate object. This results in superparamagnetism, where the particles magnetize strongly in an applied magnetic field, but retain no residual magnetization once the field is removed. This ability to switch magnetic behavior of the nanostructures on and off via an external field leads to a variety of useful applications, especially when the particles are functionalized to bind to specific biological targets.

Currently, the most widely used application of biofunctionalized magnetic nanostructures is as a contrast agent for Magnetic Resonance Imaging. The functionalized particles are injected into the body and bind to a specific type of biological tissue. Their strong response to the applied field of an MRI scan makes the targeted tissue far more visible relative to surrounding tissue.

While most magnetic nanoparticles currently being used for *in vivo* applications are spherical, a wire or rod-like morphology has certain advantages. The higher aspect ratio of elongated shapes gives them a greater dipole moment than spherical particles of the same volume. A wire can also be multi-functionalized to bind to several different types of biological target. The challenge of producing magnetite in wire morphology arises from the tendency of crystals to grow with minimization of surface area to volume ratio.

The synthesis method discussed here circumvents these challenges by growing magnetite crystals on a polyethylene glycol-1000 (PEG-1000) template in a solution-phase approach. Various parameters were examined to determine a simple, repeatable process that can be used to synthesize large volumes of superparamagnetic nanorods.

Procedure

The standard approach was to add 1g ferrous sulfate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$), 0.5g uniformly ground sodium thiosulfate pentahydrate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$), and 2g uniformly ground sodium hydroxide (NaOH) to a Teflon-lined autoclave bomb. 10mL PEG-1000 was heated until liquefied and

added to the bomb, as well as 3mL distilled H_2O . The bomb was then sealed and maintained at 150°C for 24 hours. After cooling to room temperature, the bomb contents were removed and submerged in 95% ethanol with agitation to dissolve PEG-1000. The solution was centrifuged to obtain precipitate, which was then further washed in ethanol and distilled water to remove all PEG-1000 and excess reactants. Washed precipitate was dried in vacuum at 100°C for 3 hours to obtain magnetite nanorods.

Results and Discussion

Dried samples were analyzed with PANalytical X-Ray Diffractometer (XRD) using Cu x-ray tube and LEO Scanning Electron Microscope (SEM). Samples with the best XRD pattern correlations to magnetite were those that were immediately heated in autoclave after mixing and dried in clean furnace tubes. Delay of more than an hour in heating the reactants or drying products in dirty furnace tubes resulted in mixtures of some magnetite with large proportions of undesirable hematite-phase Fe_2O_3 . It is not clear how delaying heating of the autoclave bomb adversely affects the yield. However, it is likely that unknown compounds in the dirty furnace tubes caused oxidation of magnetite into hematite during the drying process. Failure to adequately wash PEG-1000 template from sample also resulted in poor XRD signatures, since any magnetite signature was obscured by the amorphous structure of the PEG-1000.

SEM images confirmed nanowire morphology of samples with magnetite XRD signatures, though amount of visible nanowires varied greatly.

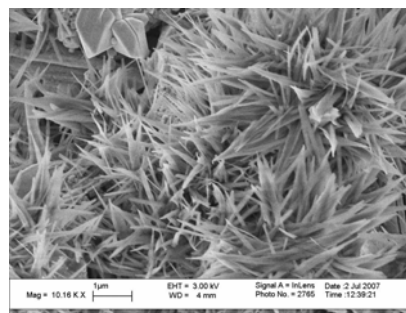


Fig 1. Typical SEM image of magnetite nanowires. Wires appear to be single crystal, with mean length of 2 μm and mean diameters of 80 nm.

Conclusions

Thusfar, this solution-phase approach to magnetite nanowire synthesis shows much promise as a means to produce significant volumes of this material. This enables the next step of this avenue of research, where these nanowires will be functionalized and tested with living cells.