

SYNTHESIS AND PATTERNING OF MAGNETIC NANOSTRUCTURESL. Fu¹, V.P. Dravid¹, K. Klug¹, X. Liu² and C.A. Mirkin²¹ Dept. of Materials Science and Engineering, Northwestern University, IL, 60208² Dept. of Chemistry, Northwestern University, IL 60208

The recent developments in biocompatible, functionalized magnetic nanoparticles show considerable promise for both enhanced and novel applications in biomedical and diagnostic fields, ranging from targeted drug delivery to MRI contrast enhancement. Magnetite (Fe_3O_4) and related oxides, which are chemically stable, nontoxic, non-carcinogenic and have attractive magnetic properties, have been pursued for many years [1,2]. As an alternative, we are also exploring synthesis and properties of graphite or SiO_x encapsulated superparamagnetic (ESP) nanoparticles. The ESP nanoparticles provide exciting prospects of not only biocompatibility but also the robust protection of inert graphite coating, which permits encapsulation of otherwise toxic high magnetic moment metals/alloys such as Ni-Pd, FePt, Co-Sm [3-5].

In our group, two approaches have been applied to synthesize magnetic nanoparticles. Magnetite, magnetic ferrites, Co, FePt nanoparticles were prepared by standard wet chemical method but using procedural and surface chemical control for narrow size distribution. Graphite and SiO_x encapsulated Ni/Co/Fe nanoparticles were prepared by arc evaporation and the CVD coating approach [3, 6-8].

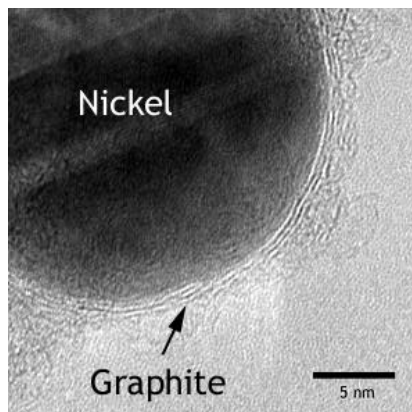


Fig. 1. TEM image of graphite encapsulated Ni nanoparticle.

Figures 1 to 3 show the morphology of the nanoparticles of graphite encapsulated Ni and SiO_x encapsulated Ni nanoparticles and monodispersed Fe_3O_4 .

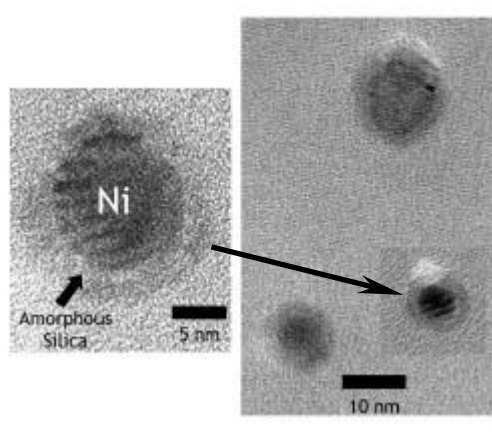


Fig. 2. TEM images of silica encapsulated Ni nanoparticles.

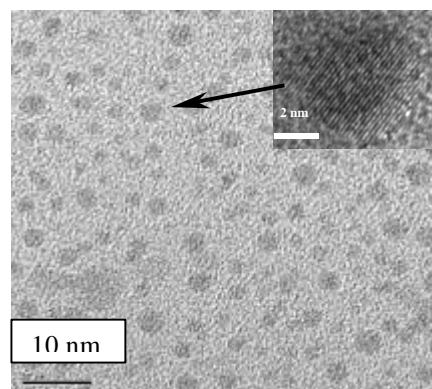


Fig. 3. TEM images of monodispersed magnetite (Fe_3O_4) nanoparticles.

The magnetic properties of monodispersed magnetite nanoparticles have been measured by SQUID (Figures 4 and 5). The results indicated that the monodispersed magnetite nanoparticles show superparamagnetic behavior at room temperature. The blocking temperature decreased with increasing strength of the magnetic field.

There has been considerable interest in developing methods for patterning nanostructured magnetic particles because of their potential applications for biomarkers and biosensors. Herein we present a new and straightforward strategy, based on Dip-pen nanolithography (DPN), for preparing nanometer scale magnetic structures with precise feature size control [9,10].

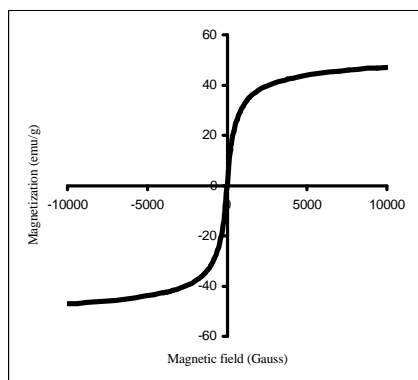


Fig. 4. Fe_3O_4 nanoparticles magnetization.

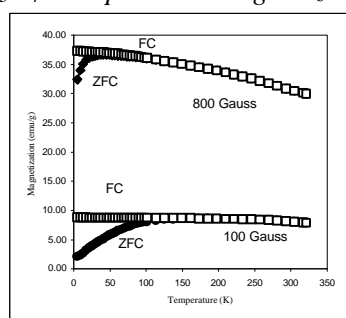


Fig. 5. Zero-field cooled and field cooled measurements at different magnetic fields.

To confirm the concept, nano-scale Fe_3O_4 and $MnFe_2O_4$ have been patterned successfully via Dip-pen nanolithography. Figures 6 and 7 show the patterns of the magnetic nanostructures. Patterning of metal nanoparticles with precise control will be done later in the project. The objective is to use biochemical markers (e.g. DNA/proteins) as templates for nanoparticle assembly and vice versa.

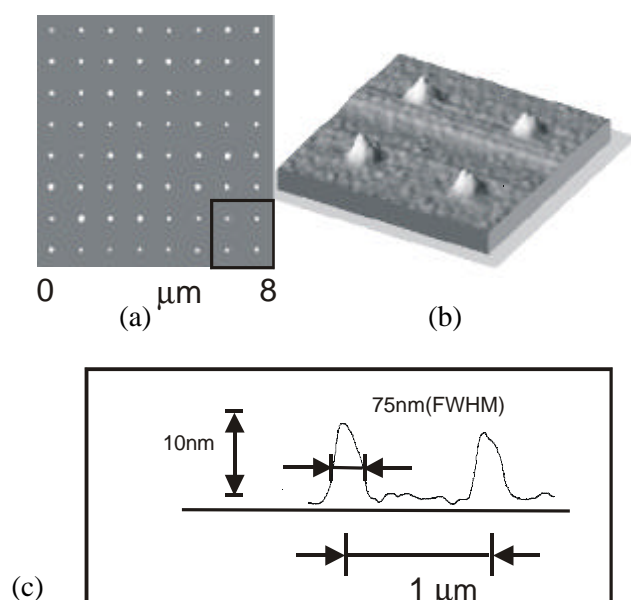


Fig. 6. An array of magnetite dots patterned by Dip-pen nanolithography. (a) AFM topography image of the dots. (b) Three dimension

topography image for a selective area (marked square). (c) Cross section topography of the dots.

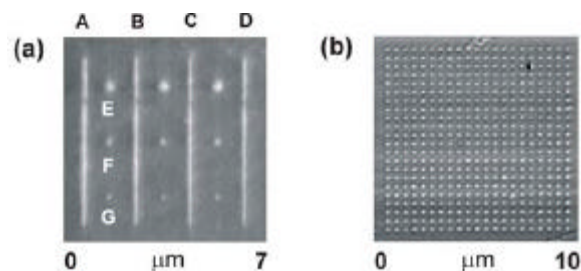


Fig. 7. Manganese ferrite nanostructures patterned via Dip-pen nanolithography. (a) AFM image of patterned dots and line. (b) AFM image of an array of dots.

In summary, metal, nonmetal and encapsulated magnetic nanoparticles have been synthesized by chemical and arc evaporation methods. We have presented a versatile new method for generating magnetic nanostructures down to sub-100 nm with precise control, allowing a major step towards biodiagnostics at nanoscale.

REFERENCES: ¹B. Bonnemain (1998) *J. Drug Targeting* 6:167. ²U. Hafeli, W. Schutt, J. Teller, et al, *Scientific and Clinic Applications of Magnetic Microspheres*, Plenum Press, New York, 1997. ³L. Fu, V.P. Dravid and D.L. Johnson (2001) *Applied Surface Science* **181**:173-178. ⁴W.F. Parron, J. Kim, B.S. Jacobson (1985) *Biochem. Biophys., Acta* **83**:816. ⁵P.K. Gupta, C.T. Hung (1989) *Life Sci.* **44**:175. ⁶X.W. Li, A. Gupta, V.P. Dravid et al. (1998) *Applied Physics Letters* **73**: 3282-3284. ⁷V.P. Dravid, J. J. Host, et al. (1995) *Nature* **374**: 602-602. ⁸Hwang, J. H., V. P. Dravid, et al. (1997) *Journal of Materials Research* **12**: 1076-1082. ⁹S. Hong, J. Zhu, C.A. Mirkin (1999) *Science*, **283**:661. ¹⁰X. Liu, L. Fu, V.P. Dravid et al (2002) *Advanced Materials*, **14**: 231-234.