NIRT: Fabrication of Functional Architectures through the Directed Assembly of Nanoscale Building Blocks

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Introduction. We are working to build purposeful architectures by the directed assembly of nanoscale building blocks into nanolithographically-patterned arrays. The building block components, including simple and complex wires (core-shell, coaxial, superlattice, hollow, porous, and corrugated), are made from porous templates with a combination of chemical and electrochemical methods. Electron-beam nanolithography can be used for the preparation of a series of patterns with well-defined features. The nanocomponents will then be assembled within the patterned arrays by physical and/or chemical means. The directed assembly of building blocks into these arrays will result in a series of functional architectures. Specific constructs that exploit nanostructured magnetic components are sought for applications in high-frequency tunable filters and magnetotransport arrays. Properties will be investigated as a function of building block materials, dimensions, and geometries as well as the geometries of the patterned arrays. Micromagnetics modeling of individual and collective properties, along with feedback from property measurements, will allow for an active refinement of architectural designs. The educational component of this program provides training for students and teachers in various aspects of nanoscience. We have established an annual summer program for both undergraduates and high school teachers. Both sets of participants receive almost 10 weeks of research experience along with lectures on ethics and proper laboratory techniques. Additionally, we maintain our web page nano.uno.edu, which presents details about our program as well as educational shareware pertaining to our magnetic modeling efforts [1].

Progress. We have synthesized a number of magnetic components both in terms of simple wire and superlattice components for testing of high-frequency properties. The use of nanosized components in the design of passive devices as stopband filters is very effective due to the efficient microwave absorption for dimensions smaller than the skin depth [2]. According to our micromagnetic simulations the microwave response of a single ferromagnetic nanowire contains two ferromagnetic resonance (FMR) absorption peaks: one at low frequency due to the spins from the ends of the wire and a high frequency peak due to the spins in the middle (Figure 1). The high frequency peak is the uniform FMR mode that efficiently can be tuned and used in the stopband filter design.

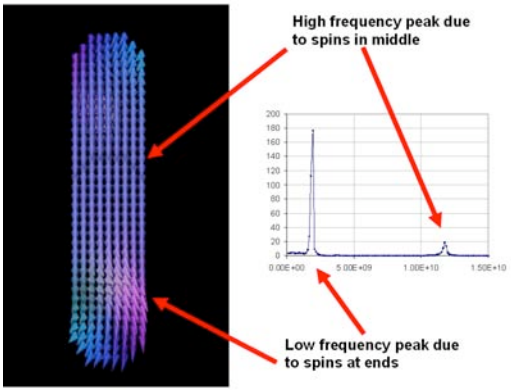

Figure 1. Micromagnetic simulation of the FMR response of a single ferromagnetic nanowire

The tuning of the high-frequency response can be achieved by manipulating the magnetic anisotropy and interactions between assembled components. Thus, shape, unidirectional (exchange bias) or magnetocrystalline anisotropy contributions can be tailored by changing morphology of the nanowires. In order to achieve this control of shape anisotropy, in our work we considered superlattice

wires containing varying-sized ferromagnetic regions separated by nonferromagnetic regions. Superlattice wires of Ni and Cu with a nominal diameter of 150 nm were grown using standard electrodeposition techniques. While the dimension of nonmagnetic Cu segments in the superlattice architectures was kept constant at 150 nm, the length of Ni sections increased as n x 150 nm, where n is the number of ferromagnetic segments. The microwave properties were probed using both, X-band (9.8 GHz) and Q-band (35 GHz) ferromagnetic resonance (FMR) experiments performed at room temperature. In order to investigate the effectiveness of the shape anisotropy on the filter bandwidth the FMR spectrum of superlattice structure is compared to the FMR spectra of four different samples consisting of simple nanowires with constant length of 150nm, 300 nm, 600 nm and 1200 nm. As predicted by micromagnetic simulations the experimental FMR spectra of simple nanowire samples (Figure 2) present two resonance modes: a uniform resonance mode at higher field given by the core of the nanowires and a low field non uniform resonance mode determined by the nanowires extremities. This fact is confirmed by the decrease of the ratio of the uniform mode amplitude to the non-uniform mode amplitude as the length of the nanowire increases. As expected, the resonance field (of the uniform mode) is increasing with the simple nanowire length. However, the observed FMR spectrum of the superlattice nanowire it is not a simple superposition of the individual ferromagnetic segments FMR spectra. This result is explained by the influence of the coupling existing between the different length segments within the superlattice nanowires [3,4].

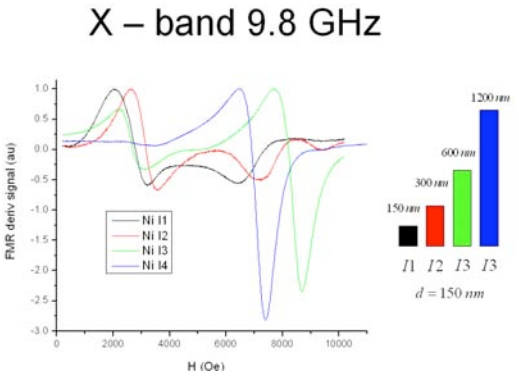

Figure 2. Experimental FMR spectra on nanowires with different aspect ratios

In addition to working towards the development of methods for the assembly of nanoscale components within patterned arrays, we are also looking to pattern the wire arrays directly within the porous membranes. Standard lithographic techniques have been used on the surface of the template prior to electrodeposition. Here we are able to make patterned arrays of vertical wires. Figure 3 shows patterned 200 nm diameter Au wire arrays [5]. Refinement of these techniques should allow us to control the spacing between magnetic wires and consequently control the coupling between adjacent sets of wires.

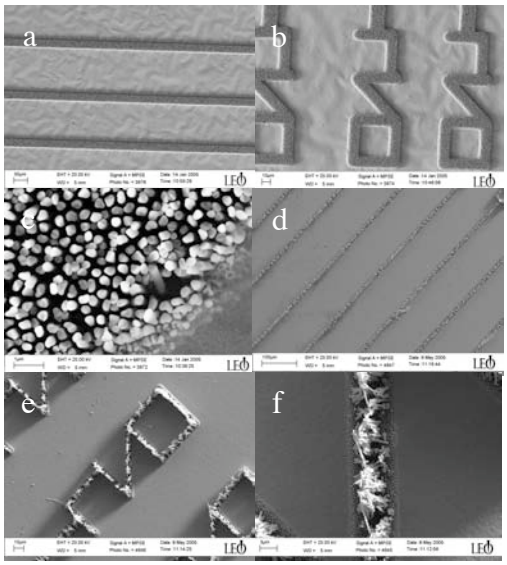

Figure 3. Vertical 200 nm Au wire arrays formed through the patterning of porous templates. In a-c the arrays are about 15 μm wide and 3 μm high; in d-f, 5 μm wide and 15 μm high

Additional efforts have gone towards the development of new building blocks. Here we have formed both square microcapsules [6] and colloidal crystal wires [7,8]. The former float in water and exhibit interesting assembly behavior that depends on their relative orientation in water; edge down capsules assemble end-to-end and face down along their long faces (Figure 4). Colloidal crystal wires can be

prepared by infiltrating silica sphere into a silicon membrane, followed by an annealing step. Both wires and wires encased in a silica sheath can be prepared Figure 5.

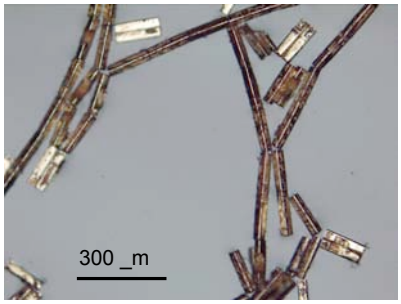

Figure 4. Square microcapsules floating on water, predominately assembling end-to-end.

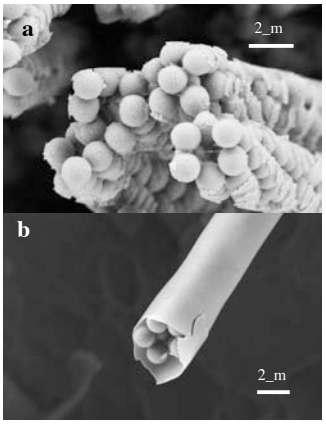

Figure 5. (a) Colloidal crystal wires made of 1 μm silica spheres; (b) colloidal crystal wire encased in silica sheath

[1] For further information about this project link to nano.uno.edu or e-mail **lspinu@uno.edu or jwiley@uno.edu.**

[2] I. Huynen, G. Goglio, D. Vanhoenacker, and A. Vander Vorst, "A novel nanostructured microstrip device for tunable stopband filtering applications at microwaves," *IEEE Microw. Guided Wave Lett.*, vol. 9, pp. 401-403, 1999.

[3] "Study of magnetic interactions in metallic nanowires networks," Ioan Dumitru, Feng Li, John B. Wiley, Dorin Cimpoesu, Alexandru Stancu, and Leonard Spinu, *IEEE Transactions on Magnetics* **2005**, *41*, 3361.

[4] Ioan Dumitru, Feng Li, Dorin Cimpoesu, John B. Wiley, Scott Whittenburg and Leonard Spinu (work in progress).

[5] Feng Li, Mo Zhu, Changgeng Liu, Weilie Zhou and John B. Wiley (manuscript in preparation).

[6] "Fabrication and Assembly Behavior of Square Microcapsules," Feng Li, Xavier Badel, Jan Linnros, Garret Wasserman, Scott L. Whittenburg, Leonard Spinu, and John B. Wiley *Adv. Mater.* **2005**, *17* (accepted).

[7] "Fabrication of Colloidal Crystals with Tubular-like Packings," Feng Li, Xavier Badel, Jan Linnros, and John B. Wiley, *J. Am. Chem. Soc.* **2005**, *127*, 3268. (_Work written up in May 2005 issue of *Materials Today*: "Colloidal Crystals for New Materials," **2005**, *8*, 15.)

[8] "Colloidal Crystal Wires from Directed Assembly," Feng Li, Xavier Badel, Jan Linnros, and John B. Wiley, *Proc. Mater. Res. Soc. Symp.*, **2005** (in press).