

Nanomanufacturing Strategy and System Design for Nanoscale Patterned Magnetic Recording Medium

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The long-term goal of this project is to demonstrate ultra-high density magnetic data storage using nanoscale patterned magnetic recording medium, a single-grain-per-bit recording paradigm, where the randomness inherent to conventional polycrystalline magnetic recording medium is eliminated through lithographic patterning and self-assembly methods. The program combines several diverse research efforts to explore the fundamentals of nanomagnetism, recording physics of patterned media, nanoscale self-assembly, and the limits of resists and lithography. The specific objectives are: 1) to develop patterned magnetic recording media design guidelines for "next generation" information storage systems; 2) to develop highly exchange-coupled patterned media materials using combinatorial materials synthesis; 3) to develop manufacturing strategies at the nanometer scale using a combination of Atom/Ion Beam Lithography and Step-and-Flash Imprint Lithography; 4) to demonstrate a prototype of a functional patterned medium at the scale of 25 nm/bit or 1 Terabit/in²; and 5) to extend the technology to the superparamagnetic limit at 3-4 nm/bit using a novel patterning approach based on self-assembled nanomask lithography.

Prototype recording systems will be built to evaluate the functionality (e.g., write/read efficiency, signal-to-noise ratio, bit error rates) of the patterned media. The proposed technology is expected enable the \$23 billion information storage industry to continue its record-setting growth rate for the next 7-15 years. It should also lead to dramatic storage device miniaturization, acting as a catalyst for a wealth of new mobile computing applications. The nanofabrication toolset will offer an immediate benefit to magnetic random access memory and magnetic quantum cellular automata, and thus has the potential to transform the integrated circuit industry. The toolset can be applied to molecular and nanoelectronic integrated systems as well.

Nanoscale Patterned Magnetic Recording Medium:

Among the recent achievement of our NIRT team is a large area (1 x 1 cm²) N-PMR prototypes fabricated using atom/ion-beam lithography with an average bit size of 50 nm (see Figure 1). High anisotropy exchange coupled (Co/Pd)₁₀ magnetic multilayers developed by the team were used for patterning. The M-H curves of the multilayer films measured before and after patterning (see Figure 1) show, *for the first time*, more than a 10x increase in the coercivity in ultra-high anisotropy magnetic multilayers due to the creation of artificial

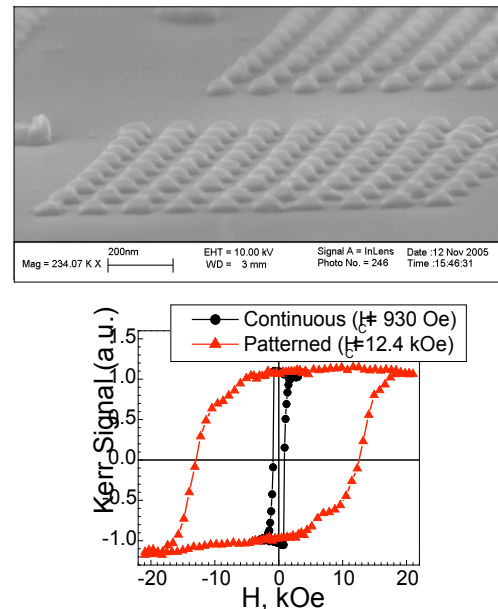


Figure 1: (top) Electron micrograph of a patterned medium test sample based on exchange coupled (Co/Pd)₁₀ multilayer stack; (bottom) magnetization curves of continuous and patterned multilayers.

barriers to domain wall motion. In addition to serving as a probe of fundamental nanomagnetic concepts, these experiments demonstrate the potential of atom/ion beam lithography patterned medium fabrication and the suitability of the developed magnetic multilayers for ultra-high density patterned recording medium applications.

Ultra-Thin Atom/Ion Scattering Masks: We have demonstrated the feasibility of using ultra-thin objects as atom beam lithography scattering masks. Two micrographs shown in Figure 2 demonstrate a nearly perfect replica in silicon dioxide of a 20nm carbon nanotube. This result is highly non-trivial since the stopping range of the 30 keV helium atoms used to print the image is 0.4 μm , which is more than 200 times larger than the nanotube diameter at its center. This ratio is even larger at the edges. Preliminary modeling data indicate that indeed the intensity in the shadow region may drop to below 1 % of that in the areas with direct illumination. Thus, ultra-thin foils can serve as masks in atom beam lithography.

Ultra-high resolution resist development: We have a critical

need for an ultra-high resolution negative resist for fabricating magnetic islands. HSQ, the common resist for these applications, requires HF for removal. This is not usually compatible with glass hard-disk substrates. We have been exploring the potential of plasma-deposited polymers to alleviate this problem. While not yet fully optimized for this application, we have been able to fabricate 50 nm lines and 100 nm dots in plasma polymerized methylmethacrylate (see **Error! Reference source not found.**). Significantly, exposure times are 50 % of those for negative tone PMMA. Moreover, the resist can be removed in an oxygen plasma. Work is ongoing to further improve exposure sensitivity.

Development of Self-Assembled Nanomasks: MnFe_2O_4 nanoparticles with vinyl group have been successfully immobilized on a hydrogen terminated

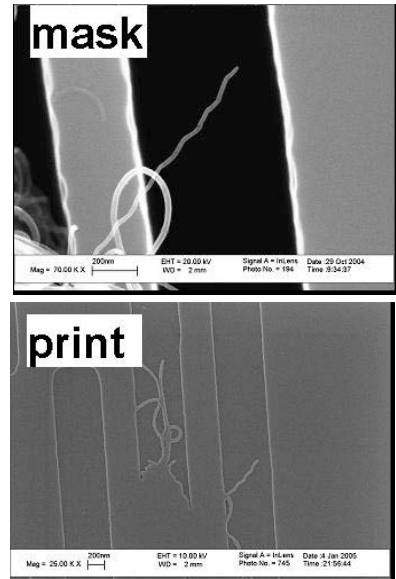


Figure 2. Electron micrographs of (top) 20nm carbon nanotube overlaid on top of a silicon stencil mask; (bottom) atom beam lithography print of a 20nm carbon nanotube in silicon dioxide.

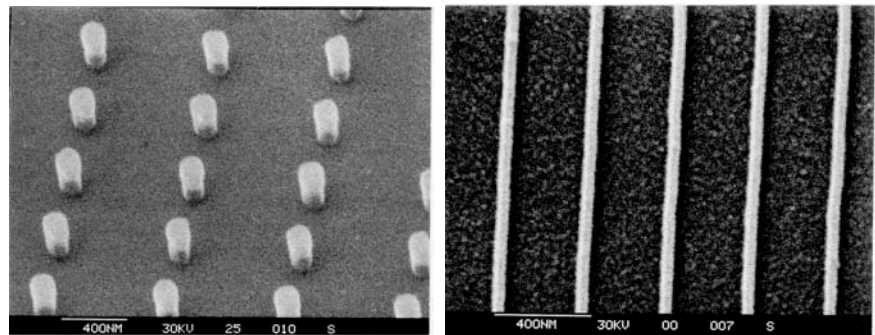


Figure 0: (left) An array of PPMMA dots, 100 nm in diameter and 300 nm in height, exposed by IBP, and (right) a series of PPMMA lines, 50 nm wide and 300 nm tall, exposed by electron beam lithography.

plasma polymerized methylmethacrylate

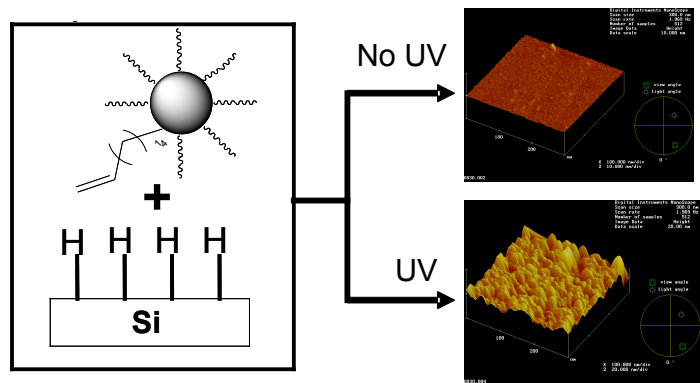


Figure 4: Nanoparticles anchoring scheme

silicon wafer via UV irradiation; in case of no UV irradiation, unbound nanoparticles are easily removed from the silicon surface. The ability to anchor nanoparticles to surfaces, where nanoparticles are to be used as hard nanomasks, is essential for achieving patterned medium capable of supporting densities at the superparamagnetic limit.

Nanomagnetic Design: We have developed a nanomagnetic formalism to describe magnetization switching during the write process in patterned medium recording. This work is necessary to design patterned medium system. Figure to the right shows the dependence of the switching field on head-bit misregistration, one of the critical parameters in a patterned medium recording system. The tolerance to head-bit misregistration defines the lithography precision required for patterned medium fabrication.

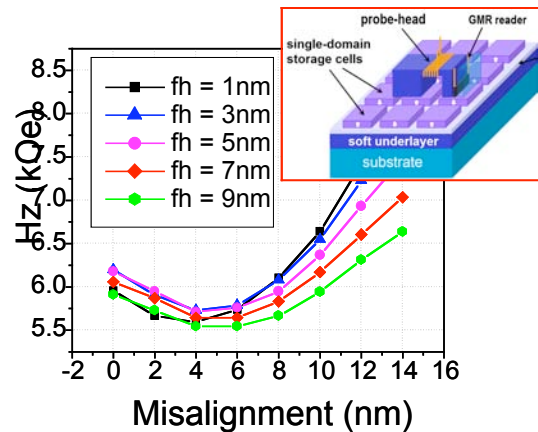


Figure 5: Dependence of the switching field on writer-bit misregistration.

Student learning: Two advanced courses have been developed by the NIRT team related to this research: “Introduction to Design and Fabrication of Nanoscale Materials and Devices” (undergraduate/graduate) and “Ferromagnetic Materials and Devices” (graduate). The cumulative enrollment in the Fall 2004, Spring 2005, and Fall 2006 is 55 including students from Electrical and Computer Engineering, Chemical Engineering, Mechanical Engineering, and Physics departments.

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