Epitaxial Magnetic Oxide Heterostructures for Nano Spin Device

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One of the most exciting aspects of current research on next-generation electronic devices focuses on the manipulation of spin, rather than only electrical charge[1,2]. The advantages of these 'magnetoelectronic' devices include nonvolatility, faster switching in static memory elements, and higher density due to a simpler device structure. The demonstration of spin-injection into semiconductors by a variety of mechanisms[3] raises the possibility of some degree of integration with traditional, charge-based devices. These issues become even more important as technology drives device sizes toward the nanoscale, where new fundamental physical effects emerge that alter spin transport. Quasi-single domain behavior[4], current-induced magnetization rotation in magnetically 'isolated' nano-islands[5], geometry-enhanced magnetic anisotropy and coupling, and superparamagnetic switching effects have all been observed. These nanoscale effects modify not only spin transport, but also high-frequency dynamics that determine magnetic switching.

In the last five years, many important discoveries of basic phenomena have been made in metal-based magnetic nanostructures. The details of these phenomena depend critically on atomic-scale structural and electronic properties of interfacial and barrier layers. But present metallic magnetic heterostructures are imperfect, too complex, and too limited in the range of possible configurations to understand the fundamental origin of phenomena in magnetic nanostructures. The approach proposed here builds on our ability to fabricate epitaxial magnetic oxide nanostructures with atomic-layer control, and whose magnetic and electronic properties can be tuned at will. We will controllably position layers with arbitrary electronic, magnetic, and morphological characteristics in epitaxial systems designed to answer some of the fundamental unanswered questions in magnetic nanostructures.

Several factors are driving structures to the nanoscale – among them the persistent march of technology toward smaller sizes, and also the explosion of new discoveries as defining length-scales are surpassed. In the case of magnetic nanostructures, these two factors are to a large extent intertwined due to technological roadblocks arising from fundamental issues in the nanoscale manipulation of magnetic materials. Two particularly timely examples arise in magnetic sensing and nonvolatile fast magnetic memories. In both these cases, the difficulties are fundamentally related to basic issues at the nanoscale.

In order to attack these fundamental issues in nanoscale spin transport, we have fabricated nanoscale epitaxial magnetic oxide heterostructures with atomic-layer control. These will be patterned with electron-beam lithography and characterized with scanning probe spectroscopies. These structures are near perfect at the atomic scale, and permit the study of intrinsic phenomena. The flexibility of oxide materials allows the epitaxial matching of materials with a wide range of electronic and magnetic properties.

This four-year research program consists **1)** Growth and characterization of **epitaxial magnetic oxide heterostructures with atomic layer control** by pulsed laser deposition with *in-situ* high-pressure RHEED; **2) High-resolution and analytical TEM** to determine atomic structure and electronic properties of the interfaces; **3) Nanoscale patterning** of **novel magnetic heterostructures** at and below 50 nm using electron-beam lithography; **4) Scanning probe** measurements of topography, local electronic properties, and local high-frequency switching response; **5) Theoretical analysis** of spin transport in these systems.

This work will build a fundamental scientific foundation for the understanding of new phenomena in nanoscale spin-controlled devices. Our industrial interactions will be very beneficial in advancing research as well as in educating students, and our outreach will make help to improve the technological outlook of young people. Our research into nanoscale spin transport will also provide fundamental guidelines in the atomic-scale control of nanoscale systems such as ferroelectrics and oxide-semiconductor integration that are important for next-generation technology.

Research, education, and outreach are integrated under the theme of multidisciplinary research in an emerging field. Almost all aspects of modern life are now touched by computers, and almost all computers incorporate magnetic nanotechnology as part of their data storage systems. In spite of this, very few people have but the faintest idea of the technology behind these accomplishments. The educational thrust of this project is to educate 'lay' people, in particular, high school students, on the science and technology of magnetic sensing and storage.

We focus on the introduction of young people to science and technology using our proposed research direction as a vehicle. This involves development of an instructional module on nanostructured magnetic sensors (in collaboration with educational initiatives already in place), as well as a new program involving direct interaction with students and secondary school science teachers.

Secondary school teachers will participate in a summer research experience at U. Wisconsin, U. Michigan, and Northwestern U. This will involve a two-week laboratory experience at the research laboratory in their local area, plus a three-day trip to each of the other two laboratories. Students will visit their local laboratories on field trips during the semester, led by participating teachers. The teachers will also participate in a curriculum-development program hosted by the U. Wisconsin MRSEC outreach program in order to integrate their research experience into the high school curriculum. We are working with the UW-Madison Learning through Evaluation, Adaptation and Dissemination (LEAD) Center on a plan to evaluate the effectiveness of this experience**.** We anticipate that the teachers will be surveyed before and after their visit, and a meeting held at the end of the summer to understand the responses.

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[5] R.P. Cowburn, D.K. Koltsov, A.O. Adeyeye, M.E. Welland, D.M. Tricker, "Single-Domain Circular Nanomagnets", Physical Review Letters **83**, 1042 (1999).