Imaging Magnetic Surfaces With Atomic Resolution

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Fueled by the ever increasing data density in magnetic storage technology and the need for a better understanding of the physical properties of magnetic nanostructures, there exists a strong demand for high resolution, magnetically sensitive microscopy techniques. The technique with the highest available resolution is spin-polarized scanning tunneling microscopy (SP-STM), which combines the atomic resolution capability of conventional STMs with spin sensitivity by making use of the tunneling magnetoresistance effect between a magnetic tip and a magnetic sample surface. Beyond the investigation of ferromagnetic surfaces, thin films, and epitaxial nanostructures with unforeseen precision, it also allows the achievement of a long-standing dream: the real space imaging of atomic spins in antiferromagnetic surfaces.

The lecture addresses a wide variety of phenomena in surface magnetism which in most cases could not be imaged directly before the advent of SP-STM. After starting with a brief introduction of the basics of the contrast mechanism, recent major achievements will be presented, like the direct observation of the atomic spin structure of domain walls in antiferromagnets and the visualization of thermally driven switching events in superparamagnetic particles consisting of only a few hundred atoms. To conclude the lecture, recently observed complex spin structures containing 15 or more atoms will be presented.

Matthias Bode received the diploma in physics from the Free University of Berlin, Berlin, Germany, in 1993, and the Ph.D. degree in physics from the University of Hamburg, Hamburg, Germany, in 1996. Based on his works on spin-polarized scanning tunneling microscopy he received the habilitation in experimental physics from the University of Hamburg in 2003.

Since 1996, he has been a Research Staff Member at the Institute of Applied Physics at the University of Hamburg. In the past ten years, he developed spin-polarized scanning tunneling microscopy, a magnetic imaging technique with a resolution down to the atomic limit. His research explores correlations between structural, electronic, and magnetic properties of epitaxial nanostructures with a special interest in frustrated antiferromagnetic surfaces, superparamagnetism, and new magnetic phenomena. He has published more than 80 peer-reviewed papers, three review articles, and three book chapters.

Dr. Bode received the Philip-Morris Award for research in 2003.

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Ferrite Nanoparticles, Films, Single Crystals, and Metamaterials: High Frequency Applications

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Ferrite materials have long played an important role in power conditioning, conversion, and generation across a wide spectrum of frequencies (up to ten decades). They remain the preferred magnetic materials, having suitably low losses, for most applications above 1 MHz, and are the only viable materials for nonreciprocal magnetic microwave and millimeter-wave devices (including tunable filters, isolators, phase shifters, and circulators). Recently, novel processing techniques have led to a resurgence of research interest in the design and processing of ferrite materials as nanoparticles, films, single crystals, and metamaterials. These latest developments have set the stage for their use in emerging technologies that include cancer remediation therapies such as magneto-hyperthermia, magnetic targeted drug delivery, and magneto-rheological fluids, as well as enhanced magnetic resonance imaging.

With reduced dimensionality of nanoparticles and films, and the inherent nonequilibrium nature of many processing schemes, changes in local chemistry and structure have profound effects on the functional properties and performance of ferrites. In this lecture, we will explore these effects upon the fundamental magnetic and electronic properties of ferrites. Density functional theory will be applied to predict the properties of these ferrites, with synchrotron radiation techniques used to elucidate the chemical and structural short-range order. This approach will be extended to study the atomic design of ferrites by alternating target laser-ablation deposition. Recently, this approach has been shown to produce ferrites that offer attractive properties not found in conventionally grown ferrites. We will explore the latest research developments involving ferrites as related to microwave and millimeter-wave applications and the attempt to integrate these materials with semiconductor materials platforms.

Vincent G. Harris received the B.Sc., M.Sc., and Ph.D. (1990) degrees in engineering from Northeastern University. He also received the M.Sc. degree in engineering management from the University of Maryland in 1995, and the M.Sc. degree in executive technology management from the Wharton School at the University of Pennsylvania in 2003.

He is presently the William Lincoln Smith Chair Professor in the Electrical and Computer Engineering Department at Northeastern University. He was a member of the technical staff at the Naval Research Laboratory (NRL) from 1990 to 2003. During his time at NRL, he served as the head of the Complex Materials Section and the head of the Materials Physics Branch. In 2001, he established and assumed the position of director of the NRL Synchrotron Radiation Consortium (2001–2003). In 2004, he established the Center for Microwave and Magnetic Materials and Integrated Circuits, and continues to serve as its first director. The mission of this center is to develop high-frequency materials and device solutions for next-generation radar and wireless communication electronics. His research interests include materials design and the study of processing, structure, and magnetism in a wide range of materials. He has pioneered the use of synchrotron radiation techniques to relate the short range chemical and structural properties of materials to magnetism. He has published more than 170 technical articles, including book chapters and review articles on the topical areas of nanotechnology, magnetism, and magnetic materials. In addition, he holds nine patents and patent applications, and has presented more than 150 papers at national and international meetings.

Dr. Harris is a Fellow of the American Physical Society and Senior Member of the IEEE.

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Magnetic Nanoparticles: Self-Assembly and Nanoscale Behavior

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The magnetic behavior of a monodomain nanoparticle was first described by Stoner and Wohlfarth nearly 60 years ago, yet this simple system is frequently invoked in discussions of high-density magnetic recording media, magnetic refrigeration materials, and a host of biomagnetic applications. Here we will examine two cross-cutting themes of current research on magnetic nanoparticles: self-assembly and nanoscale magnetic behavior.

Different types of superstructure can be self-assembled from the same type of particles. In organic solvents, two-dimensional arrays with long-range order can be formed using Langmuir layer techniques. These monolayers are also used as nanomasks for crystallographically oriented thin films, which provide an alternative approach to preparing nanoparticle arrays for data storage media. Faceted three-dimensional single “grain” nanoparticle crystals are formed by colloidal crystallization methods. Magnetic field gradients can also be used to guide self-assembly. For example, gold-coated iron oxide particles can be used to image self assembly dynamics in aqueous media, in response to patterned magnetic elements, using plasmon scattering and dark-field optical microscopy to track single particles.

The ability to make magnetic nanostructures creates a need for new tools that enable us to visualize their magnetization patterns. Small-angle neutron scattering provides average magnetic correlation lengths within three-dimensional assemblies, where correlations of hundreds on nanometers may be present at low temperature. Electron holography shows real-space magnetization patterns of magnetic monolayers, where vortices and transverse domain walls are present as low energy excitations. Scanning probe techniques have the potential for single-particle-per-bit magnetic information storage.

Sara Majetich received the A.B. degree in chemistry from Princeton University, the M.S. degree in physical chemistry from Columbia University, and the Ph.D. degree in solid state physics from the University of Georgia.

She did postdoctoral work at Cornell University. Since 1990 she has been a faculty member, and now full Professor, in the Physics Department at Carnegie Mellon University. She has three patents and over 100 publications. Her research interests focus on magnetic nanoparticles and nanocomposites and their applications.

Dr. Majetich received the Ashkin Award for excellence in teaching, the Carnegie Mellon University Undergraduate Advising Award, and a National Young Investigator Award from the National Science Foundation.

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High Magnetic Anisotropy Materials: From Bulk, Through Multilayers, to Nanoscale Particles

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Magnetic anisotropy is one of the basic properties of magnetic substances. In particular, magneto-crystalline anisotropy is thought to be intrinsic for bulk materials, but the theoretical understanding is not satisfactory, as is often demonstrated. In multilayers and nanoparticles where surface or interfacial magnetic anisotropy plays a key role, magnetic behavior is significantly influenced by extrinsic or induced magnetic anisotropy. Among many alloy systems, ordered alloys are known to exhibit high magnetic anisotropy; in particular the L1₀ ordered phase is of great interest because of applications in bit-patterned magnetic data storage.

Nanocomposite particles with a high magnetic anisotropy phase, together with other magnetic anisotropies, are the subject of intensive research since they offer potential for various applications such as hybrid data storage, sensors, and bio-devices.

This tutorial lecture addresses the magnetism and structure of thin films and nanocomposite particles with a high magnetic anisotropy ordered phase. An in-depth review of magnetic anisotropy in representative materials is given. Recent developments in high magnetic anisotropy of novel materials, multilayers, and nanocomposites will be presented. Emphasis is placed on quasi-L1₂ structured alloy films with very high magnetic anisotropy and on FePt/FeRh nanocomposites of the first-order transition type, in conjunction with possible applications.

Takao Suzuki received the B.S. and M.S. degrees from Waseda University, Tokyo, Japan, in 1962 and 1964, respectively, and the Ph.D. degree from the California Institute of Technology in 1969. He was a postdoctoral fellow at Max-Planck Institute, Stuttgart, from 1969 through 1972, and was an Associate Professor at Tohoku University from 1972 through 1988, where his research interests included magnetic multilayers with high magnetic anisotropy for magneto-optical recording, and magnetic recording applications. From 1988 through 1995, he was a research staff member at IBM Almaden Research Center, San Jose, CA, and was involved with high density magneto-optical and magnetic recording materials developments. In 1995, he joined Toyota Technological Institute, Nagoya, Japan, as a Principal Professor. He is now a Vice President and a Principal Professor of the Institute, and also Director of the Academic Frontier Center sponsored by the Japanese Ministry of Education, Science, Sports and Culture. His current research interests include the magnetic anisotropy and structure of ordered alloy thin films and nanoparticles, and high density perpendicular magnetic recording media applications. He has published more than 260 scientific papers, has written four books, and has 17 patents.

Prof. Suzuki is a Fellow of the IEEE. He has been active in many Intermag and Magnetism and Magnetic Materials conferences, including serving as program co-chair of MMM in 1995, and as treasurer co-chair of Intermag in 2005. He has served as a member of the Administrative Committee of the IEEE Magnetics Society for several terms. He is on the Editorial Board of IEEE TRANSACTIONS ON MAGNETICS and is an advisory editor of the Journal of Magnetism and Magnetic Materials.

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