SYMPOSIUM GG

GG: Advanced Characterization Techniques for Data Storage Materials

December 2 - 3, 2003

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*Invited paper
9:00 AM *GG1.1
Spin-Polarized Scanning Tunneling Microscopy as an Ultimate Tool for Magnetic Data Storage Technology, Roland Martin Wiesendanger, Institute of Applied Physics, University of Hamburg, Hamburg, Germany.

In order to probe and tailor magnetic properties at the spatial limit we have combined the scanning tunneling microscope (STM) with spin-sensitivity. This is achieved by the use of ferromagnetic and antiferromagnetically coupled probe tips offering a high degree of spin-polarization of the electronic states in the tunneling process. Magnetic-domain imaging with subnanometer-scale spatial resolution has been demonstrated for magnetic transition metal as well as rare earth metal films. Ultrasharp domain walls were discovered in ultra-thin iron films while for antiferromagnetic samples, the different orientation of magnetic moments could directly be made visible at the atomic level. The phenomenon of magnetic hysteresis was observed for the first time at the single-magnon length scale and has directly been correlated with microscopic processes of domain nucleation and domain wall motion. We also studied magnetic vortex structures in mesoscopic-scale ferromagnetic systems which are of relevance for current developments in MRAM technology. Magnetic switching phenomena of magnetic nanostructures was studied by time-dependent spin-sensitive STM imaging. It will be shown that granular thin films exhibit a complex magnetic switching behavior due to the statistical distribution of grain sizes, grain orientation, and interaction between them. Finally, I will discuss the application of spin-sensitive STM measurements to individual atoms and molecules on magnetic substrates.

9:30 AM *GG1.2
Bias-Voltage-Dependent Magnetic and Non-magnetic Correlation in Atomic-Scale Spin-Polarized Scanning Tunneling Microscopy, Arthur Reed Smith,1 Rong Yang,2 Haigeng Yang1, and Werner H. L. Hubener1 for Physics and Astronomy, Ohio University, Athens, Ohio. 1Physics, Case Western Reserve University, Cleveland, Ohio.

Spin-polarized scanning tunneling microscopy (SP-STM) is a very promising technique for the study of surface magnetism since detailed magnetic contrast can be obtained down to the atomic scale. Recently, we have investigated the surface magnetic structure of $\text{Mn}_2\text{Ni}_3\text{Ge}_4$ (001) - a model row-wise antiferromagnetic surface. This surface is prepared by molecular beam epitaxy with Mn diffusion cell and radio frequency N plasm-source. Normal insitu STM images reveal a row structure with row spacing 8.06 Å. Using magnetic- and nonmagnetic tapers, we have modulated the height of the rows by a few to a few times 12 Å, indicating the surface magnetic ordering. The spatially correlated magnetic and nonmagnetic components are separated using a procedure developed. The magnetic and electronic components are modeled by calculation of the local density of states at the Fermi level. We have measured the anisotropy of the magnetic moment in these systems. The results will be discussed, including a reversal of the polarization at positive sample voltage. In addition, the good agreement of these results with the polarization calculated from the energy-dependent local density of states from first-principles will be discussed.

10:15 AM *GG1.3
The Magnetism of Cement from Adatoms to 2D Nanostructures, Harold Brent, Physics, EPFL, Lausanne, VD, Switzerland.

The magnetic anisotropy energy $K$ is closely related to the anisotropy of the orbital magnetic moment $\text{g}{\text{S}}\cdot\text{m}_{\text{orb}}$. Both quantities can be measured with X-ray magnetic circular dichroism (XMCD). In the gas phase transition metal atoms have large orbital moments given by Hund's rules ($m_{\text{orb}} = 3 \mu_B$ for Co), whereas in the bulk $m_{\text{orb}}$ is almost entirely quenched because of the crystal field and electron delocalization ($m_{\text{orb}} = 0.15 \mu_B$ in hcp Co), and therefore $K$ is small (40 meV/atom for hcp Co). This comparison suggests spectacular magnetic properties for low coordinated atoms at surfaces. We report on the evolution of $K$ and $m_{\text{orb}}$ as a function of size starting from single atoms and going up in size almost atom by atom for Co on Pt (111) using XMCD measurements carried out in-situ to self-organized growth. Monomers have giant values of $K = 9.3 \pm 1.6$ meV and $m_{\text{orb}} = 1.1 \pm 0.1 \mu_B$ (Gruner and Münzel, 2001). These values strongly decrease as coordination goes up in dimers and trimers etc. The XMCD results are complemented by Magneto-optical Kerr effect (MOKE) measurements for larger 2D nanostructures confirming a strong correlation effect on the anisotropy energy. For Co/Pt (111) and for Co/Au (78 Å) we find $K \approx 1$ meV for the low-coordinated edge atoms forming out-of-plane magnetization, whereas due to the shape anisotropy the atoms in the interior weakly favor in-plane magnetization with $K \approx 30 \mu_B$ (Rusponi et al., Nature Materials 2003). The temperature dependence of the susceptibility shows that mutual interactions between the monomolecular layers are absent up to densities of at least 26 trees particles/Å$^2$.

10:45 AM *GG1.4

Ballistic electron magnetic microscopy (BEMM) is a scanning-tunneling-microscope-based technique for imaging the magnetic structure of ferromagnetic thin films and nanostructures. This technique utilizes the spin-dependent differences in the quasi-ballistic transmission $T$ of a hot ($\sim 1$ eV) electron beam propagating through ferromagnetic nanostructures. This technique allows the local magnetic orientation of a thin film sample relative to that of a “spin analyzer” layer that is separated from the sample by a thin metallic layer. Since the resolution is determined by the width of the STM injected ballistic electron beam, BEMM is capable of clearly imaging magnetic changes that occur over a rather short length scale, $\sim 1$ nm. BEMM is distinguished by the fact that the technique does not require an external magnetic field to be applied to the sample during the measurement, and is also compatible with imaging a sample in the presence of a strong applied field. BEMM can also be employed to examine the magnetic structure of ferromagnetic layers buried as much as 20 nm beneath the surface of a thin film multilayer system. This BEMM is effective for studying low coercivity materials and the magnetic behavior of thin film multilayers and nanostructures of the type that may be employed, for example, in spin-valve sensors and in thin-film magnetic information storage devices. BEMM is also a powerful tool for measuring spin-dependent hot-electron transport through magnetic thin film systems of potential importance to future spintronics applications. I will cover the capabilities and limitations of BEMM and discuss some examples of its application to imaging magnetic changes in thin-film nanostructures with dimensions $\lesssim 100$ nm that are in some cases approaching the pernigran limit, and to studies of spin-dependent transport.

SESSION GG2: MPM and Optics-Based Magnetic Probes
Tuesday Afternoon, December 2, 2003
Berkeley (Sheraton)

2:00 PM *GG2.1
Precessional Magnetization Reversal in Hard-magnetic, High-Density Perpendicular Media, Hans-C. Siegmann, Stanford Linear Accelerator Center, Stanford University, Stanford, California.

The very short and intense Gaussian magnetic field pulses that can be generated in solids by passing through heavily bunched pulses of electrons induce precessional switching of the magnetization $M$ in granular perpendicular magnetic media. The experiments show that the switching is stochastic, independently of specific properties of the Co/pure iron layers and also independent of the presence of an additional soft magnetic under-layer. This demonstrates that the precession of the spins becomes homogeneous, and that the Landau-Lifshitz equation can only describe the average motion of $M$ under these conditions. The experiments indicate that there is an upper limit to the speed of magnetic switching useable in magnetic recording at the $\sim 10^{12}$ sec level. It also shows that these pulses provide a new, conceptually simple technique, besides electron/field pulse excitation with pulsed lasers and spin injection, to evaluate the dynamics of ferromagnetic spins underlying all fast magnetization dynamics. This work is done in collaboration with I. Todaon, C. Stamm, A. B. Kardax, P. King, J. K. and G. J. and B. Lu, D. Weller.

2:30 PM *GG2.2
High Resolution and Quantitative Magnetic Force Microscopy, Hess J. Hag, P. Keppeneberger and S. Martin, Institute of Physics, NCIC/NCN, N genocide, Basel, Switzerland.
In the past decade magnetic force microscopy (MFM) has been an important tool to characterize magnetic media for magnetic data storage and magnetic data-applications. MFM has been especially successful in the exploration of storage media. An unexpected increase in storage density has led to a reduction of the dimensions of the magnetization transitions that are close or already beyond the present resolution limit of conventional MFM. Using optimized tip and operating methods we routinely obtain a lateral resolution around 10nm. MFM methods with 1nm resolution that can routinely be used are vital for the further development of magnetic data storage media. In addition to the high lateral resolution, methods for the calibration of magnetic force microscopy tips [1] were developed. Such calibration methods were used to determine the uncompensated spin density at the interfaces of exchange coupled Co/Cu/CoPt multilayers [2]. [1] P. J. A. van Schendel, S. M. Groenewegen, J. W. M. Kuipers, St. Martin, and H. J. Giltiethoff, J. Appl. Phys. 88, 435445 (2000) [2] P. Kajanderpen, H.J. Hug, J.B. Kortright, O. Hollweg and E. E. Fullerton, submitted.

3:30 PM *GG2.3
Phase separation in 30%La58/S38/38/MnO3 + 70% LaMnO3 bulk sample studied by scanning microwave microscopy.

Jino Lee, Jewook Park, Aihua Kim, Kookmin Char, Sooyeong Park, Namjung Hur and Sung-Wook Cheong, Dept. of Physics, Seoul National University, Seoul, South Korea, Dept. of Physics & Astronomy, Rutgers University, Piscataway, New Jersey.

Using our scanning microwave microscopy (SMM), we have investigated the phase separation phenomenon in 30%La58/S38/38/MnO3 (LSMO) + 70% LaMnO3 (LMO) polycrystalline pressed powder sample, in which the LSMO phase is a perovskite ferromagnetic metal while the LMO phase is a hexagonal ferroelectric insulator. Using a polarized light, a high microwavex sample exhibits clear grain boundaries among the grains in size of several microns. When the electrical properties of the sample were imaged using our SMM, the sample showed a significant contrast between the metal LSMO and the insulating LMO grains. The boundaries observed by SMM agreed with those observed under the optical microscope. When we further investigated the metallic phase using scanning magnetic force microscopy (SMM), the metallic phase, identified by the SMM clearly showed ferromagnetic signal, providing solid evidence that the metallic phase is indeed the ferromagnetic LSMO. However, we have noticed a slight difference between the images generated by SMM and MFM. While the images by the MFM looked almost identical, the images measured by the SMM displayed a noticeable distinction. We believe the difference comes from the fact that the density scales the different microwave techniques probe are different. In other words, the SMM signals are only sensitive to the surface layer of a few tens of nm thickness, while the SMM probes a deeper region, a few microns. We infer that the contrast among the metallic LSMO grains measured by the SMM is due to the different thickness of the grains.

3:45 PM *GG2.4
Spin wave propagation effects in thin NiFe films. Hans Neubacher, Michael M. Kohler, Jurgen Prange, Heiko Hilberlands, Fachbereich Physik, University of Kaiserslautern, Kaiserslautern, Germany.

For a deeper understanding of the magnetization dynamics and damping mechanisms in thin magnetic films spin wave propagation effects are important. These manifest themselves in a reduction of the magnetization vector magnitude within a finite sample area. In order to determine and control vector components in thin magnetic films a special calibration and measurement procedure has been performed. The measurement principle is an extension of a standard method used for the separation of the in-plane components of the magnetization vector [1,2]. It additionally leads to the polar magnetization vector component, which cannot be neglected in magnetization precession experiments. The magnetization dynamics of polycrystalline NiFe films has been investigated by means of time-resolved magneto-optic Kerr effect measurements and compared to commercial spin wave simulations based on the Landau Lifshitz Gilbert equation. The observed reduction of $M_2$ during application of a short magnetic field pulse indicates the generation of propagating spin waves. Even though $M_2$ is not zero in a magnetic film it is very low compared to the microwavex simulations [1] H. F. Ding, S. Potter, H. P. Oepen, J. Kirschner, J. Magn. Magn. Mater. 212, L5 (2000). [2] R. Lopasnik, PhD thesis, University of Kaiserslautern (2001).

SESSION GG3 Electron Surface and Imaging Probes I

Wednesday Morning, December 3, 2003

Berkeley (Sheraton)

9:00 AM *GG3.1
Scanning Probe Energy Loss Spectroscopy (SPELS).

R. E. Palmer, Nanoscope Physics Research Laboratory, University of Birmingham, Edgbaston, United Kingdom.

Nanometer-scale science has the potential to contribute to a range of different application areas, including data storage, chip fabrication, cancer diagnosis and biosensors. The rapid increase in storage density has led to a reduction in the dimensions of the magnetization transitions that are close or already beyond the present resolution limit of conventional MFM. Using optimized tips and operating methods we routinely obtain a lateral resolution around 10nm. MFM methods with 1nm resolution that can routinely be used are vital for the further development of magnetic data storage media. In addition to the high lateral resolution, methods for the calibration of magnetic force microscopy tips were developed. Such calibration methods were used to determine the uncompensated spin density at the interfaces of exchange coupled Co/Cu/CoPt multilayers [2]. [1] P. J. A. van Schendel, S. M. Groenewegen, J. W. M. Kuipers, St. Martin, and H. J. Giltiethoff, J. Appl. Phys. 88, 435-445 (2000) [2] P. Kajanderpen, H.J. Hug, J.B. Kortright, O. Hollweg and E. E. Fullerton, submitted.

9:30 AM *GG3.2

Scanning tunneling microscopy (STM) provides us information on atomic structure of material surface with high spatial resolution. But it is not easy to obtain chemical or elemental information except for a few special cases using inelastic tunneling. The reason is simply because STM probes tunneling current which basically reflects valence electronic states. In order to access elemental information, one needs to probe core-level electrons like the cases of Auger electron spectroscopy and X-ray photoelectron emission spectroscopy. In this paper, we present our recent effort for picking up core-level electrons with STM by exciting them with UV light source. We have developed a ultrahigh vacuum (UHV) STM system which can be operated with the tip and sample illuminated with synchrotron radiation (SR) light (SR-STM). Using SR light source, we can tune the energy of light to excite core electrons of the particular element and detect photoemitted electrons, which give element identification. We first tested a performance of the system by using a standard sample of the Si(111) -7x7 surface. All experiments were made at BL-19A, Photon Factory, KEK, Japan. In spite of mechanically noisy environment, we successfully took monochromated images of the surface, implying a suitability of our system as a UHV-STM. We then checked a detection of photoemitted electrons under the SR illumination. To test this, we measured the photoemitted electrons as a function of photon energy from 96eV to 106eV, which crosses the Si 2p adsorption edge (90eV). We found a sharp increase in the amount of the photoemitted at the energy, demonstrating a capability of detecting excited core electron and thus possibility of elemental identification using this technique.

10:15 AM *GG3.3
Imaging, Manipulation, and Analyzing with Nanometer Precision: Application of the Nanoworkbench. Oliver Giese, Hubertus Marbach, Jeremy Levy, John T. Yates, and Joachim Ahnert; Department of Chemistry, University of Pittsburgh, Pittsburgh, Pennsylvania; Department of Physics, University of Pittsburgh, Pittsburgh, Pennsylvania; Seagate Technology, Pittsburgh, Pennsylvania.

It is well appreciated, that in the size of material objects approaches nanometer dimensions, the materials structural and electronic properties change. The investigation of these effects forms a broad active area of current research aimed at the optimization of nanometer sized materials properties for use in a large field of technologies including electronic devices and high density data storage. We report the development of novel nanomanipulators, manipulative and analytical devices for imaging, chemically analyzing and manipulation of nanometer scaled material. Two different versions of the nanoworkbench are operating currently at the Surface Science Center of the University of Pittsburgh and at the Seagate Research Center in Pittsburgh. The instrument at Seagate consists of a modified commercially available high resolution scanning electron microscope (HRSEM) lateral resolution down to 1 nm, equipped with an STM tip in a combination with a set of four unique nano-manipulators, which can...
be equipped with different kinds of probes for nano-scale materials characterization in pressure ranges from 10^-8 to 10^-3 mbar. At the University of Illinois, the complete set of the nancoworkbench is in operation. Several interconnected UHV chambers allow the in situ deposition of thin films and conventional surface analysis. The resolution of the SEM of the UHV system is limited to about 20 nm. We report results obtained using both versions of the nancoworkbench, where we succeeded in writing patterns of ultrasmall carbon-containing dots (8nm in diameter) with high position accuracy (~2nm) by electron-beam-induced dissociation of carbonyl-based monolayer graphene in a planar arrangement. Electron stimulated carbon film creation on Si (100) using various purile hydrogen compounds was studied in UHV by AES, TD and XPS. The thermal stability of the Carbon film has been studied and confirmed over the temperature range from 500K - 1400K, where the carbon converts to SiC, giving high thermal stability. We are planning to use these carbon templates for the growth of Germanium quantum dots, important for the development of novel quantum electronic devices.

This work was conducted by DARPA QSEST through ARO contract number DAAD17-01-1-0650.

10:30 AM GG3.3 Characterization of Magnetic Recording Media Using Analytical Electron Microscopy, James Wittig, 1 James Bentley 2 and Neal Evans 2; 1 Electrical Engineering and Computer Science, Vanderbilt University, Nashville, Tennessee; 2 Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Composition inhomogeneities in magnetic recording media strongly influence magnetic properties such as intrinsic coercivity and magnetic anisotropy. In nanometer dimensions, inhomogeneities that produce a paramagnetic grain boundary layer between the grains also affect the signal-to-noise ratio of the recording process. Whereas exchange decoupling decreases transition noise, non-magnetic material increases the integral of the resistance in the radial direction. Since the material dimensions of modern magnetic recording media are on the nanometer scale, characterization of the composition variations in the grain interiors and grain boundaries requires analytical methods with nanometer spatial resolution. These experimental data are critical for accurate micromagnetic modeling of the recording process. Over the last seven years we have optimized experimental methods specifically for elemental mapping of Co based alloy thin films using energy filtered transmission electron microscopy (EFTEM) and spectrum imaging with a field emission gun scanning transmission electron microscope (FEG-STEM). Extensive work has been done to understand the grain boundary segregation phenomenon in sputtered Co/CrPt alloys. Addition of Ti to CoCr results in greater Cr grain boundary segregation with fewer intragrain defects and higher coercivity compared to a binary alloy or an alloy of Co/CrPs. Analysis of EFTEM elemental maps and high-resolution TEM images from identical areas suggests that a layered-layer growth mode for the Co/CrTs thin films versus an island-like nucleation and growth mode for CoCrPs is responsible. The EFTEM elemental maps provide quantitative data for the dimensions of the paramagnetic grain boundary layer as well as the changes in the magneto-crystalline anisotropy of the grain interiors from Co depletion. Recently, these experimental methods have been adapted to address the more challenging characterization problem of boron segregation in Co/CrPtB sputtered films using electron energy-loss spectroscopy (EELS) and spectrum imaging using electron energy-loss spectroscopy (EELS) has proven to be superior to EFTEM for boron analysis owing to significantly greater statistics that improve the signal to noise of the background subtraction. This paper will draw from these examples to describe the capabilities and limitations of analytical electron microscopy for characterization of nanostructured magnetic materials.

10:45 AM GG3.5 Structural Evolution of Epitaxial Magnetic Thin Films: a UV/TEM Study, J. Yu 2, Y. Xue 1, K. Yen 1, W. Tian 1, H. Sun 1, X. Q. Pan 1, C.B. Boothroyd 2, R.A. Lukasiewicz 1 and R. Clarke 2; 1Materials Science and Engineering, National University of Singapore, Singapore, Singapore; 2IME, Singapore; 3Dept of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; 4Dept of Physics, University of Toledo, Toledo, Ohio; 5Dept of Physics, University of Michigan, Ann Arbor, Michigan.

Understanding structure/property relationships in metal/oxide systems is of substantial importance in applications ranging from magnetic recording to high-power electronic devices. The Epitaxial growth can be achieved in certain metal/oxide systems and the properties of the films may strongly depend on the interfacial structure as well as growth mode. Using a modified ultrahigh vacuum transmission electron microscope (the MERLIN system), we have investigated the nucleation and growth of Ni thin films on electron transparent metal oxide substrates. The system is equipped with solid source electron beam evaporators together with gas injection capability, all within the polepiece of the electron microscope which has a base pressure of 1 x 10^-10 Torr. The paper will focus on structural evolution in the early stages of nucleation and growth, through to the formation of the UHV source. The basic mechanisms and limiting factors of such transport is one of the major challenges. This, the use of probes directly sensitive to the magnetic anisotropy of the thin film bulk and its interfaces (typically a few nm wide) are of great interest. So far, intense research activities to probe the magnetic anisotropy have been centered on polarized synchrotron x-ray spectroscopy techniques. However, the spatial resolution of these techniques is currently limited to tens of nanometers. Therefore, there is a compelling need for new techniques capable of probing the magnetic anisotropy on the few-nanometer scale or less.

Momemtum-Resolved Electron Energy-Loss Spectroscopy as a Magnetic Anisotropy Probe, Y. Xue 1,2, Michel van Veens 1,2, Brandon D Armstrong 1, Russell E. Cook 2, Dean J Miller 1 and Nand M Menon 1; 1 Physics, Northern Illinois University, DeKalb, Illinois; 2 Materials Division, Argonne National Laboratory, Argonne, Illinois.

Spin polarized transport across interfaces is one of the critical issues for the spin-based electronics, and understanding the basic mechanisms and limiting factors of such transport is one of the major challenges. Thus, the use of probes directly sensitive to the magnetic anisotropy of the thin film bulk and its interfaces (typically a few nm wide) are of great interest. So far, intense research activities to probe the magnetic anisotropy have been centered on polarized synchrotron x-ray spectroscopy techniques. However, the spatial resolution of these techniques is currently limited to tens of nanometers. Therefore, there is a compelling need for new techniques capable of probing the magnetic anisotropy on the few-nanometer scale or less.

Momentum-Resolved Electron Energy-Loss Spectroscopy (MREELS) has been applied as a probe for nanometer-scale magnetic anisotropy. For testing the technique, α-Fe₂O₃ (hematite) was analyzed as a model sample, which has an antiferromagnetic ground state with spins on specific neighboring planes oriented in opposite directions at room temperature. MREELS is an Electron Energy-Loss Spectroscopy (EELS) technique utilizing a Transmission Electron Microscope (STEM). It senses the orientation dependence of element-specific electronic structure of nanometric materials. When making use of the polarization dependence of EELS on the 2D transition metal magnetic anisotropy is evaluated in the form of a magnetic line dichroic (MLD) spectrum [1]. The Fe L₂₃ difference spectrum was successfully extracted from a pair of spectra acquired from a (001) oriented α-Fe₂O₃ microcrystalline using an electron probe (less than 1 nm diameter) with different convergence angles, i.e., different scattering angles perpendicular to perpendicular components of the scattering vector. For validation, a theoretical MLD spectrum was also calculated using the Ab-initio multipole theory for the octahedrally coordinated Fe³⁺ ion. The experimental result agrees with the simulated MLD spectrum indicating that the spin orientation is parallel to the basal plane of the unit cell. This is also consistent with a published x-ray MLD result.[2] The STEM MREELS will provide new element-specific anisotropic magnetic structure information with the highest spatial resolution (less than a few nm) among available bulk-sensitive magnetic anisotropy probes. [1] J. Y. Yuan, N.R. Menon, J. Appl. Phys., 81, 5087 (1997); [2] P. Kuiper et al., Phys. Rev. Lett., 78, 1549 (1997). [3] This work is supported by the State of Illinois under HECA, NIU URA program, and work at Argonne, carried out in the Electron Microscopy Center, is supported by the U.S. Department of Energy, Office of Basic Sciences-Materials Sciences, under Contract #W-31-109-ENG-38.

11:15 AM GG3.7 Nano-scale Compositional Characterization of ONO Stacks for Charge-Storage Structures, Igor Levin 1, Mark Kozier 2, Richard Leinman 3 and Yakov Rozin 2; 1NST, Gaithersburg, Maryland; 2Tower Semiconductor Ltd, Migdal Haemek, Isreal; 3National Institutes of Health, Bethesda, Maryland.

Silicon oxide-nitride-oxide multilayers (ONO stacks) attract considerable interest for the charge storage structures in non-volatile memory devices. The critical structural and compositional parameters that affect electrical performance of ONO based devices include the physical density of the amorphous oxide/nitride layers and depth distributions of both oxygen and nitrogen atoms. In this study we applied (i) spatially-resolved electron-energy loss spectroscopy (EELS) in a transmission electron microscope and (ii) secondary ion mass spectrometry (SIMS) to analyze elemental distributions in the differently processed ONO stacks deposited on Si. EELS measurements were made using (i) energy-filtered TEM and EELS spatially-resolved acquisition in a high-resolution STEM equipped with a thermionic electron source, and a post-column energy filter, and (ii) EELS spectrum imaging in a dedicated scanning transmission electron microscope (STEM) equipped with a cold field-emission source and an EELS spectrometer. Our results revealed radiation-induced nitrogen segregation to silicon oxide interfaces; the extent of nitrogen segregation increased visibly with increasing the radiation dose. The EELS measurements cannot gain artifact-free data. The results of combined EELS and SIMS chemical analyses were correlated with electrical performance of ONO-based flash memories.
11:30 AM GG3.8
Direct Observation of Charge Transfer at MgO(111) Surface.
Arun K. Sridhar1, Richard F. H. Bailey2, Laurence D. Marks3, Oliver Wronski4, and Donald E. Ellis2. 1Materials Science and Engineering, Northwestern University, Evanston, Illinois; 2Physics, Northwestern University, Evanston, Illinois.

MgO is typically rock salt oxide that is commonly used as a model system for testing calculations on ionic oxides. Though most studies thus far on MgO have focused on its non-polar (100) surface, the polar (111) surface attracts much attention in recent years. Experimental studies on this surface have identified various reconstructions that are remarkably stable. Critical to understanding the properties of the surface and knowledge of the electronic charge distribution. We have employed Transmission Electron Diffraction (TED) combined with Direct Methods to study the structural and electronic properties of MgO. The valence charge distribution of the various surface species was directly refined from the experimental TED data. This is the first direct observation of the charge transfer phenomenon in a surface structure.

11:45 AM GG3.9
Imaging Titanium Structures at Buried Interfaces in PEEM.
Karen M. Siggia1, V. Ballrott2, M. Breban3, R. Youngsbaum2, and F. D. Williams3. 1Optical Technology, National Institute of Standards and Technology, Boulder, Colorado; 2Laboratory for Physical Sciences, College Park, Maryland; 3Physics, University of Maryland, College Park, Maryland.

Despite the limited (~2 nm) escape depth of photoelectrons used for imaging in photoelectron emission microscopy, PEEM has a powerful capability for imaging fine-structured surface and subsurface features. Present results demonstrate imaging of titanium lines buried under at least 0.5 nm of PECVD oxide. Physically, this result arises due to photo-stimulated charge injection from the buried substrate into the covering oxide layer, from which surface photoemission then occurs. Differences in the photoemission rate from the surface of the Ti lines and the underlying Si substrate yield a primary contrast mechanism. Charge injection from the buried interface also results in charge trapping and generation of electric fields around the buried structures. These fields result in pronounced edge effects which clearly delineate the buried structures in images formed by photoemission from the oxide surface.

The lateral surface fields generated can be greater than the longitudinal, non-local field of the microscope, over short distances, while it was found in previous work that lateral fields as small as 5% of the total field produce strong contrast effects. PEEM is therefore a sensitive detector of potential gradients at the sample surface, but also as buried structures. Because field-induced effects are non-local, the field-induced effects on intensity are clearly visible in showing the buried titanium lines with an applied bias. The field-generated effects on intensity are similar in magnitude and spatial extent for both the bare surface of biased titanium lines and the same surface buried under 0.5 nm of oxide. Although this non-intrusive surface-sensitive technique has primarily been used to investigate nanometer scale surface chemistry and morphology, these results demonstrate that PEEM is a potentially powerful technique for real-time imaging of electronic devices including buried structures. Supported by the Laboratory for Physical Sciences and University of Maryland MRSEC.

SESSION GG4: Electron Surface and Imaging Probes II
Wednesday Afternoon, December 3, 2008
Berkeley (Sheraton)

2:00 PM *GG4.1
Coincidence Spectroscopy of Correlated Electron Pairs.
Jens Buehler1, Maximilian Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany.

We observe electron-electron scattering events in which a primary electron (with some tens of eV kinetic energy) scatters from a valence band electron. If both electrons escape from the solid, they may be detected in coincidence, while both kinetic energies are determined by a time-of-flight technique. Though the time resolution of the apparatus is only of the order of half a meV, the intrinsic interaction time is much shorter, presumably of the order of fs. This is assured by selecting only one eV-time, suppressing non-coincidences. The experiment is extremely surface sensitive since the mean free path for low energy electron is short and both electrons must escape without energy loss. We essentially probe the electronic structures of the first two monolayers, on the time-scale of the interaction time. We studied W, Cu, and LiF. The experiments were extended by developing a pulsed spin-polarized electron source and using ferromagnetic Fe single crystals. The electron-spin-pair intensity distribution curves are obtained on the relative orientation of the primary electron spin and the sample magnetization. The dominant scattering channel produces two spin-polarized electrons in a single event. These results are interpreted in term of the spin-resolved surface density of states of Fe(110). This work was done in collaboration with S. Samarin, A. Morozov, and J. Berakdar.

2:30 PM GG4.2
Detection of electronics and holes localized in the gap thin film of Metal-Oxide-Nitride-Oxide-Semiconductor type flash memory using the Scanning Non Dielectric Microscopy.
Koichi Hanada1, and Yasuo Cho1. 1Nano-electric Materials Lab., Fujitsu Laboratories Ltd., Atsugi, Kanagawa Prefecture, Japan; 2Research Institute of Electrical Communication, Tohoku University, Sendai, Japan.

By applying Scanning Non Dielectric Microscopy (SNDM), we succeeded in clarifying the position where electrons/holes existed in the gate SiO2-SiN4-SiO2 (ONO) film of the Metal-Oxide-Nitride-Oxide-Semiconductor (MONOS) type flash memory. SNDM is an atomic force microscopy measurement technique where a ring electrode is used in conjugating with the cantilever. Alternating electric field is biased between this electrode and the sample, and the capacitance variation of the surface under the ring of the sample is detected. The charge injected in the ONO film induces a permittivity change of the ONO. The charge accumulated in the film can be detected by SNDM as a change in capacity by scanning the surface of the ONO film. Thus the visualization of the charge distribution becomes possible. In the SNDM image, a bright contrast existed in the neighborhood of the source in the channel area, when the electron was injected. On the other hand, a black contrast existed in the substrate neighborhood in the channel area, when the hole was injected. These images can be interpreted as the visualization of the polarization of the electron-hole pair. When the positive charge exists in the insulating film, the minus charge is introduced from the drain area in neighborhood in the channel area. The visualization of the charge distribution becomes possible. Therefore, the contrast becomes weak. On the other hand, when the minus charge exists in the ONO film, the positive charge is generated from the Si substrate of p type. In this case, when the electric field is impressed from the substrate side, the capacity grows, and the contrast becomes strong. Therefore, the SNDM signal will be reversed by the polarity and the charge of the channel area. It was also clarified that the electron is localized in the SiN4 part in the ONO film. On the other hand, the results showed that the hole not only existed in SiN4 but also extended to the Bottom SiO2.

2:45 PM GG4.3
Temperature Controlled Scanning Nonlinear Dielectric Microscopy.
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Recently, ferroelectric DRAM storage system (ferroelectric random access memory [FeRAM] or high-density ferroelectric recording system [1]) has been studied by various researchers. And investigating the characteristics on surface of ferroelectric materials is becoming important in order to achieve high-density recording. On the other hand, Scanning Nonlinear Dielectric Microscopy (SNDM) has been developed and developed by Cho et al. [2] This method is the linear and nonlinear dielectric constant distribution (Especially the sign of the odd rank nonlinear dielectric constant tensor is correspond to the polarization direction) of dielectric and ferroelectric materials. [3] Moreover, the formation of ferroelectric surface layer on ferroelectric materials can be observed by varying the power order of nonlinearity and it is very useful for observing the state of polarization on surface of ferroelectric materials. [4] In this time, we present the new type of SNDM which can control the sample temperature in vacuo (less than 5x10-7 Torr). This temperature-controlled SNDM can cover the temperature range between 80K and 700K. The linear and nonlinear dielectric constant distribution on ferroelectric materials caused by temperature change, especially neighborhood of the phase transition point or boiling point of water which absorbs on surface. Using this SNDM, we have succeeded in measuring the linear and nonlinear dielectric constant distribution on BaTiO3 single crystal at the temperature change from 300K (room temperature) to 420K (above the Curie
temperature. Moreover, using higher order nonlinear dielectric microscopy, we also succeed in measuring the surface non-ferroelectric layer variation on LiNbO3 and LiTaO3 by temperature change.


3:30 PM GG4.4
Neutron Studies of Magnetic Recording Media, Stephen Lee,
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There exists an enormous amount of research in the literature on both
the bulk magnetic properties and the local dynamic response of
magnetic recording media. In addition the physical grain structure
and composition are also well-characterized by techniques such as
TEM and XRD. There has, however, been relatively little work on the
microscopic magnetic structure, especially regarding the
magnetisation at a granular level. Small-angle neutron scattering
(SANS) is an ideal tool for probing magnetic structure at a nanometre
length scale; yet it is extremely difficult to perform experiments due
to the tiny volume of material in the active magnetic layer.
Furthermore, since the magnetic properties of thin film recording
media depend critically on the sputtered multilayer structure and
post-deposition processing, samples prepared especially for neutron
studies may have properties which differ significantly from commercial
materials. To overcome these drawbacks we have used some innovative
approaches to SANS measurements to study the magnetic structure of
materials intended for commercial application. Despite the inherent
difficulties of the measurements it is nonetheless possible to extract a
surprisingly large amount of information concerning the magnetic
structure, including the size, shape and separation of the magnetic
grains. One interesting result is that the extent of the magnetic core is
significantly smaller than the physical grain in which it resides. We
have also followed the evolution of the magnetic structure some way
below saturation, which allows one to extract information on the
orientation and anisotropic shape of the magnetic grains relative to
the applied field.

3:45 PM GG4.5
Heteroepitaxy of InSe/GaSe on Si(111) Substrates,
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Due to its favorable structural and electrical properties, InSe is a
candidate for application in a novel high-density storage medium [1].
In this paper we report on a structural study of InSe/GaSe
heterostructures grown by molecular beam epitaxy on Si(111)
substrates. Transmission electron microscopy indicates that these
layers have good structural quality. Two-dimensional growth mode
was achieved and layers have uniform thickness and flat surfaces. Two
types of structural defects are present in these layers: stacking faults
and dislocations. Selected area electron diffraction (SAED) shows that
InSe preserves the orientation of the GaSe layer. A good quality of
InSe/GaSe/Si(111) heterostructures seem to be consistent with the
work of Budiman et al. [2] which shows that direct growth of InSe on
GaAs(100) is very difficult, whereas an insertion of a GaSe layer leads
to much better quality of InSe film. The GaSe intermediate layer
seems to play a similar role in the case of Si(111) substrates, e.g.
passivates the substrate dangling bonds [3]. Energy dispersive X-ray
spectroscopy indicates a strong interdiffusion between Ga and In at
the InSe/GaSe interface. SAED results suggest formation of the
InGaSe phase. Similar interdiffusion has already been reported in