ABSTRACTS

POSTER SESSION 2

TUESDAY 9TH, 17:30

ADVANCES IN LEEM-PEEM INSTRUMENTATION
MAGNETISM
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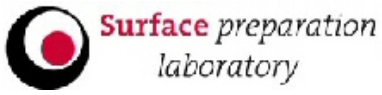	**Surface Preparation Laboratory** Penningweg 69 F 1507 DE Zaandam The Netherlands **Phone:** +31-75-6120501 **Fax:** +31-75-6120491 **Email:** koper@surface-prep-lab.com **Web:** http://www.surface-prep-lab.com/
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Construction of Display-type Ellipsoidal Mesh Analyzer for Simple PEEM with an Energy Filter

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We have constructed a new 1 π sr Display-type Ellipsoidal Mesh Analyzer (DELMA) [1] which works as a photo emission electron microscope (PEEM) and a high sensitive display-type electron energy and two-dimensional angular distribution analyzer. Its acceptance angle is $\pm 60°$, which is much larger than the largest so far commercialized and comparable to the display-type spherical mirror analyzer developed by Daimon [2].

Fig. 1 shows a schematic drawing of DELMA. DELMA consists of a Wide Acceptance Angle Electrostatic Lens (WAAEL) [3], following cylindrical lenses, deflectors (not shown), aperture and a screen with MCP. The vertical long and short lines (except for EA) show the positions of image planes and diffraction planes, respectively. Contrast apertures are placed at one of the diffraction planes, such as shown by CA, to select angular regions to be collected. This aperture can control the energy resolution and the spatial resolution of the image. Field apertures are placed at one of the image planes, such as shown by FA, to select sample regions to be imaged. Angular distribution of the emitted electron from the selected area can be measured when one of the diffraction planes is shifted to next image plane, which is displayed on the screen. In this way DELMA has a capability of 1 π sr display-type electron analyzer, which works as a PEEM and a high sensitive display-type electron energy and two-dimensional angular distribution analyzer from selected area.

We are constructing a new excitation light source of Orbital Angular Momentum Light (OAML) [4]. OAML is considered to create strong dichroic effects in photoelectron angular distribution, which may be used for stereophotograph of atomic arrangement [5]. The present statuses of DELMA and OAML system are presented.

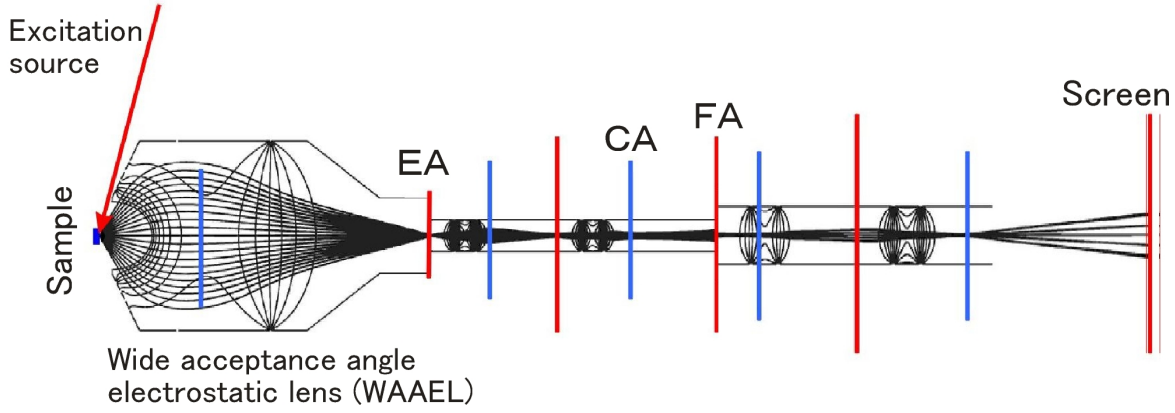

Figure 1: schematic drawing of Display-type Ellipsoidal Mesh Analyzer (DELMA)

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Momentum microscope for angular and time resolved imaging of valence band electron states

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The first application of a novel design of a photoelectron microscope with an imaging energy filter for momentum resolved photoelectron detection is presented [1]. The basic concept of the microscope is to project the momentum image from the back focal plane of the objective lens of a Photoelectron Emission Microscope (PEEM) through an energy filter onto an image detector. Our design is based on a PEEM with an imaging energy filter. The spherical (α^2) aberrations of the imaging energy filter are strongly reduced by a novel analyzer design [2]. Fast imaging of complete momentum distributions in an energy plane through the Brillouin zone is feasible with a laboratory UV-source and acquisition times of few minutes.
Together with a time resolved imaging detector it is possible to combine spatial, momentum, energy and time resolved acquisition of photoelectrons within the same instrument. The time resolution of this type of energy analyzer can be better than 100 ps what enables the imaging of correlated electrons [3]. First results of such experiments are shown.
The ARUPS pattern of a Cu(111) sample excited with a He I VUV and a Hg UV light source (21.2eV and 4.9 eV, see figure) is imaged in parallel and energy resolved up to the photoelectron emission horizon (at ±90°, see figure). At hν = 4.9 eV the Shockley surface state is imaged clearly in k-space.
The results are compared to k-space images of a Ag(100) surface obtained with a simple high-pass energy filter [4].
With the high transmission and time resolution of this instrument, possible new measurements are discussed: Time and polarization resolved ARUPS measurements, probing changes of bandstructure due to chemical reactions, in-situ thin film growth and investigation of phase transitions e.g. melting or martensitic transformations.

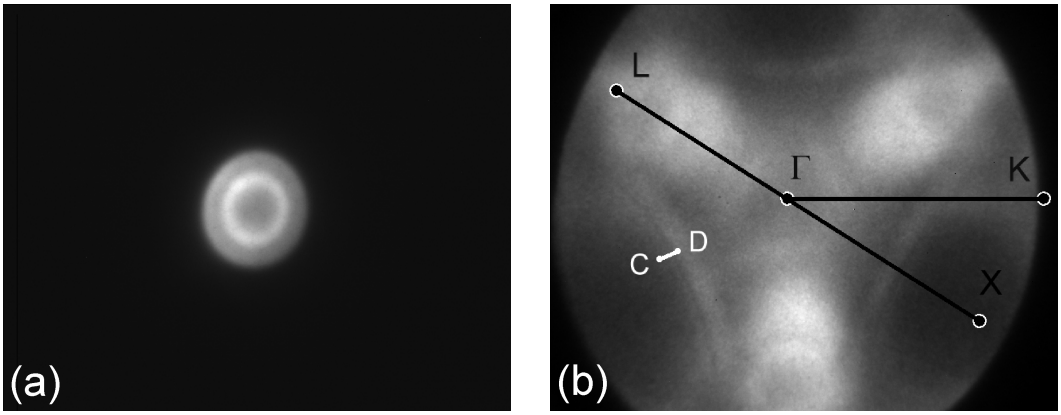

Figure: k-space image of Cu(111). Left: Shockley state exited with hν = 4.9eV (Mercury UV-source). Right: 3d-electrons at 3eV binding energy excited with 21.2eV (HeI gas discharge). The marked feature CD shows a k-space-resolution of 0.0034 $Å^{-1}$.

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X-PEEM end station at the Siam Photon Laboratory

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An X-PEEM end station has been designed to utilize synchrotron light from a planar undulator. The end station employs an Elmitec PEEM III with an imaging energy analyzer. The standard main chamber of Elmitec PEEM III provides ports for synchrotron light, a UV lamp, an evaporator and spares for future uses. A new load-lock system is designed to be able to connect with a preparation/deposition chamber, as well as to allow sample loading without breaking UHV condition in the PEEM main chamber. The load-lock chamber is also equipped with an ion sputter gun for surface cleaning. A UHV deposition system using an e-beam evaporator is also being built. The system can be connected to the load-lock system to provide possibilities to prepare thin metal films for X-PEEM investigations.

The end station will be connected to one of the branchlines of the first undulator beamline, BL3, of the Siam Photon Laboratory [1]. The beamline will deliver photons with energy between 40-160 eV and 220-1040 eV. The beamline is under construction, and will be ready for commissioning in March 2009.

Reference

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A dedicated photoemission electron microscopy beamline with high flux-density, spectral resolution and mechanical stability

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The aberration corrected photoemission electron microscope SMART [1], with unprecedented spatial and spectral resolution, is installed at a new beamline at BESSY. The optical layout and design are optimized for spectro-microscopy experiments with lateral resolution down to few nanometers. The requirements are stringent: high flux density with high spectral resolution and variable linear and circular polarization in a photon energy range between 100 and 1500 eV. Dedicated beamline strategies combined with the high brilliance of a third generation light source fulfill such prerequisites. The improvements in the production of optical components, such as elliptical mirrors, result in the collimation of the source into a spot down of few µm. Therefore, issues such as the mechanical stability requirements of the microscope with respect to the refocusing optics and beamline become a priority. At the UE49-PGM-2-SMART beamline [2], the spot size achieved has a *quasi*-Gaussian profile of 11 x 7 µm^2 (figure 1). The mechanical instability due to vibrations is compensated by active vibration damping of *both,* microscope and refocusing optics mounted together on the same frame. Additional to the nearly negligible short term mechanical vibrations, the long term effects consistent with thermal drifts and mechanical strains are also presented. Moreover, the systematic alignment of a single refocusing optical element of ellipsoidal shape is presented together with the possibility of illuminating larger regions by, e.g., methodical defocusing.

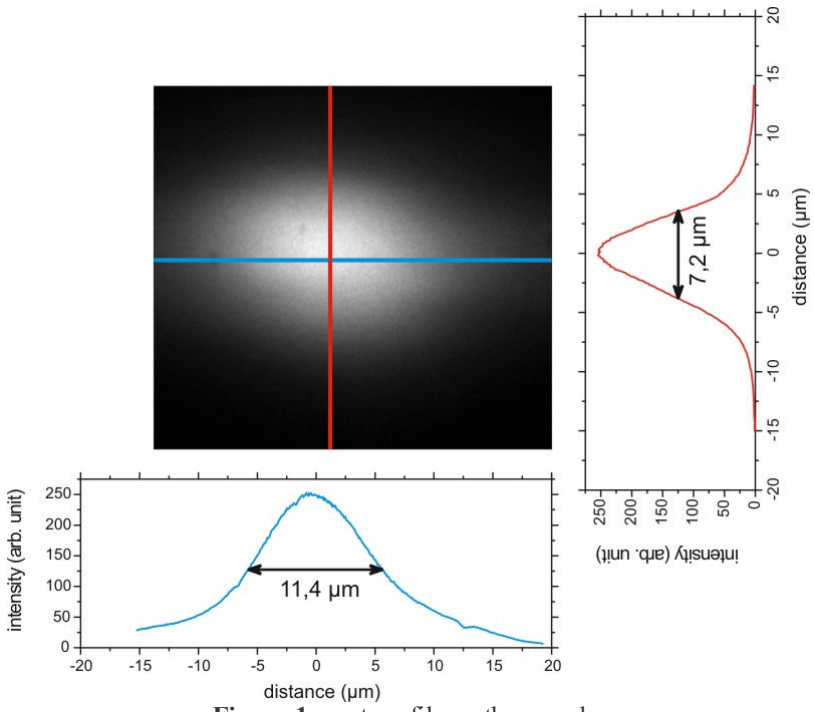

Figure 1: spot profile on the sample.

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Lateral resolution and spatial sensitivity of an XPEEM instrument measured with cross-sectional epitaxial multilayer samples

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Measuring in a reliable and reproducible way the performances of x-ray photoelectron emission microscopes (XPEEM) regarding lateral resolution becomes crucial if the imaging of nano-objects with intrinsic dimensions below 100 nm is addressed. However, the number of experimental parameters influencing directly the result of the measurement drastically complicates this task if the optimal resolution of the instrument needs to be reached. Some parameters are intrinsic to the sample used, while others are related to the imaging conditions (excitation source, microscope settings determining the instrumental response function). The XPEEM image is a convolution of the instrumental response function with the intensity distribution photoemitted from the surface. For optimized measurements the nature and properties of the sample surface is the most critical. For a good reliability, on the one hand the chemical interfaces considered must be made from patterns of known and controlled shape and be atomically sharp and flat; on the other hand, these patterns must also ideally be organized within the field of view to allow measurements of (i) the lateral resolution (related to the imaging of a *dense distribution* of nano-objects) following several criteria (including the Rayleigh one) [1], and (ii) the spatial sensitivity which is relevant to the analysis of *isolated* nano-objects. In this contribution, we will show how *ex situ* prepared, cross-sectioned samples of epitaxially-grown semiconducting multilayers can be used to improve the reliability of the measurements of lateral resolution and spatial sensitivity in XPEEM. We worked with an XPEEM instrument equipped with aberration-corrected energy filtering (NanoESCA) operated with different excitation sources [2, 3]. Two kind of samples were used : (i) a certified (BAM institute, Germany), embedded cross-section of $Al_{0.7}Ga_{0.3}As/GaAs$ layers on a GaAs substrate (Figure) [4], and (ii) a customized cross-section of $Si/Si_{0.5}Ge_{0.5}$ layers. The measurements are obtained from the experimental intensity profile modelled from the ideal intensity profile and complementary error functions. With the imaging conditions used for the first sample, a reliable value of the lateral resolution is 110 nm, whereas spatial sensitivities at near vanishing contrast are less than 50 nm and 10 nm for core-level and secondary electrons respectively. The advantages and drawbacks of this approach in comparison with others will be discussed.

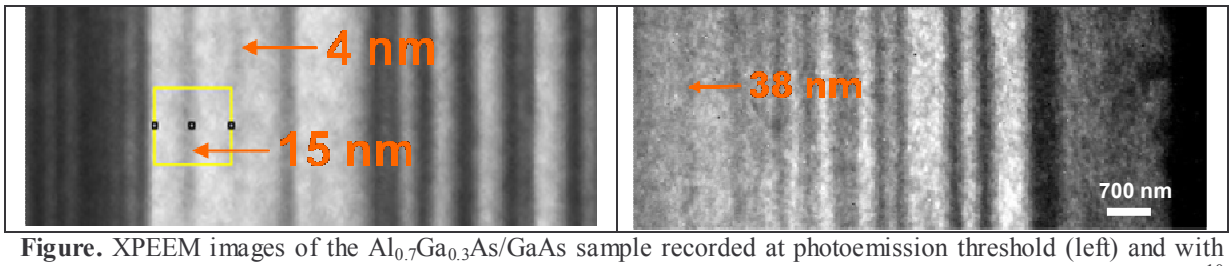

Figure. XPEEM images of the $Al_{0.7}Ga_{0.3}As/GaAs$ sample recorded at photoemission threshold (left) and with Ga3*d* electrons (right); excitation : hν=700eV (ESRF ID08), flux density into 25 μm field of view : 1.4×10^{10} $ph.s^{-1}$. 0.1% BW^{-1}. Arrows indicate the real thickness of the layers.

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Time-Resolved and Non-Linear Photoemission Microscopy

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We use spectroscopic photoemission electron microscopy (ELMITEC PEEM III) in combination with a 80 MHz Ti:Sapphire oscillator for generation of the photoelectrons. The 20 fs short pulses with a wavelength of 800 nm are frequency doubled in a beta barium borate (BBO) crystal. After dispersion correction of the frequency doubled 400nm pulses, an actively stabilized Mach-Zehnder-Inteferometer is used to generate two collinear pulses that are delayed with respect to each other with an accuracy of less than 20as. The application of this illumination source to the PEEM allows us to study various electronic excitations in metals, and to follow the decay of the excitations in time and space.

Usage of just one wavelength for illumination, however, is not in all cases sufficient to obtain the desired information: each single laser pulse is the source of a two photon photoemission signal in the PEEM that is superimposed to the desired pump-probe signal. The obvious solution to suppress the background signal is to use pulses with different photon energies for the pump- and probe pulses. Ideally, a low-photon-energy pump-pulse would excite the electronic system while a high-photon-energy probe-pulse could cause threshold photoemission from the excited states. The necessary UV laser pulses can be created by amplification of the Ti:Sapphire seed pulses and by frequency quadrupling of the amplified 800nm fundamental in a series of BBO crystals.

We will present first results from our home-built regenerative amplifier system which delivers ultrashort laser pulses with a photon energy of 6.2 eV at a repetition rate of 250kHz. The high repetition rate is necessary to avoid space charge effects in the PEEM - commonly observed with high photon density illumination sources – while keeping the exposure times manageable.

We applied the new light source to study the non-linear field enhancement at defects on Ag islands (see left panel of the figure). Using the 800nm fundamental of the amplified laser pulses leads to a localized three-photon photoemission yield that completely dominates the PEEM contrast (see right panel of the figure). As the emission is limited to small areas on the surface (the left and the right panel of the figure show the same area on the surface) this phenomenon is usually referred to as a “hot-spot”. The emitted electrons from the hot-spots can reach energies of up to 20 eV.

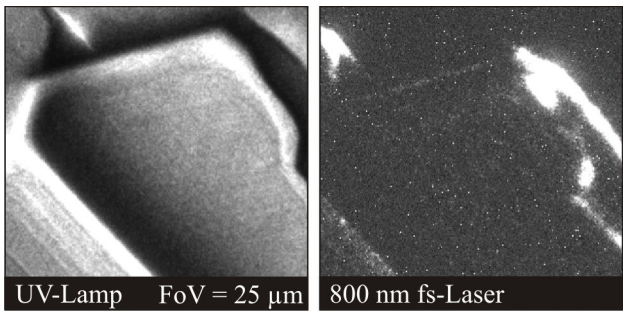

Figure. Two images of the same self assembled Ag-island recorded with a UV-lamp as illumination source (left) and 100 kHz regenerative amplified system (right) with a wave length of 800 nm.

Energy and time resolved microscopy with PEEM: Comparison of two approaches

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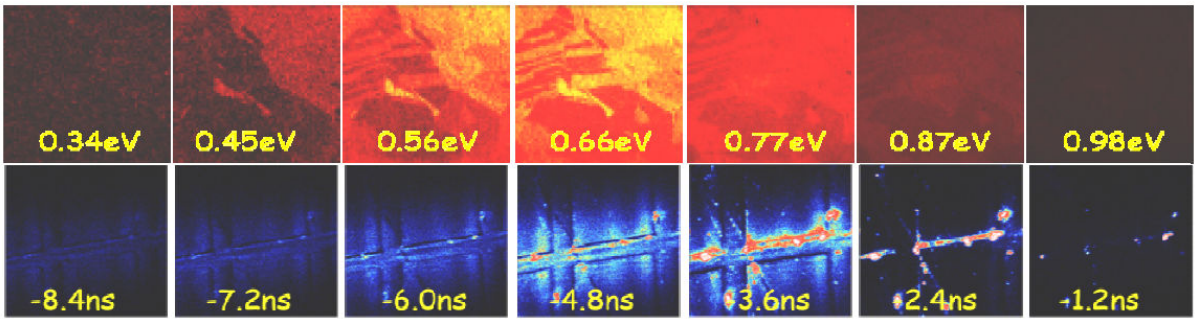
Energy filtered photoemission electron microscopy (PEEM) is realized using different more or less complex methods. Techniques in use are retarding field analyzers, time of flight spectrometers and energy dispersive band pass analyzers. The common approach for energy resolved imaging with PEEM is band-pass imaging as realised in several instruments [1,2]. This contribution compares two other versatile approaches that are high pass energy filtering [3] and time of flight imaging [4], [5]. We show recent results with a state of the art high pass imaging energy filter (IEF). With this technique we achieved an energy resolution of about 75 meV and a lateral resolution of better than 30nm.



Figure, 1st row: IEF PEEM Image Stack; Sample: Polycrystalline Copper; Excitation: 4.9eV(Hg arc lamp)
2nd row: TOF PEEM Image Stack ; Sample: Ag on structured Si; Excitation: 400nm pulsed diode laser

With a delay line detector (DLD) we realized time of flight PEEM with a time resolution of 300 psec (2 σ). With this technique the energy and time dispersion of "hot spots" excited by two photon photo emission (2PPE) is imaged. We acquired a series of time slice images of a micro structured Ag:Si sample excited by a 400nm pulsed diode laser. The "hot spots" show a lower cut off energy compared to all other sample regions. We derived TOF spectra integrated over $3x10^9$ laser pulses. Each spectrum corresponds to a certain area at the sample. Huge intensity differences between the "hot spots" and background areas demonstrate the good dynamics range of the DLD. The Fermi cut off of a copper sample did verify an energy resolution of approx. 100meV using the detector as TOF energy analyzer at a drift energy of 10eV. The in situ combination of the IEF and the DLD techniques opens up possibilities for experiments, where both low and high intensity measurements are needed. We will show PEEM measurements on the same sample to compare the two filtering techniques.

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Three-dimensional characterization of EUVL mask blank defects by interference contrast PEEM

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Photoemission electron microscopy based on an interference contrast mechanism in the extreme UV range is applied to characterize EUV lithography mask blank defects. The position of constructive or destructive interference fringes (anti-nodes or nodes of the standing wave field, respectively) on the surface of a multilayer in the local region of a phase defect is a powerful tool to determine local phase defects [1]. In this contribution we demonstrate that the same approach can be exploited for 3D tomographic imaging. This EUV interference contrast turned out to be superior over topographic contrast in standard UV-PEEM in detecting mask blank defects.

At a fixed inspection wavelength the standing wave field can be employed to disclose height variations of a defect by counting the interference fringes generated by anti-node and node interaction in the vicinity of the edge. The EUV-PEEM image in Fig.1 is an example for this operational mode to gain 3D information [2]. This image was obtained for a 3D defect structure of Si on a Mo-Si multilayer mask blank at the EUVL inspection wavelength of 13.5nm. A nodal plane of the standing wave field was intentionally positioned at the defect-free multilayer surface (bottom-left part of the PEEM image) by choosing the proper wavelength. A series of interference fringes is observed propagating towards the top-right direction.

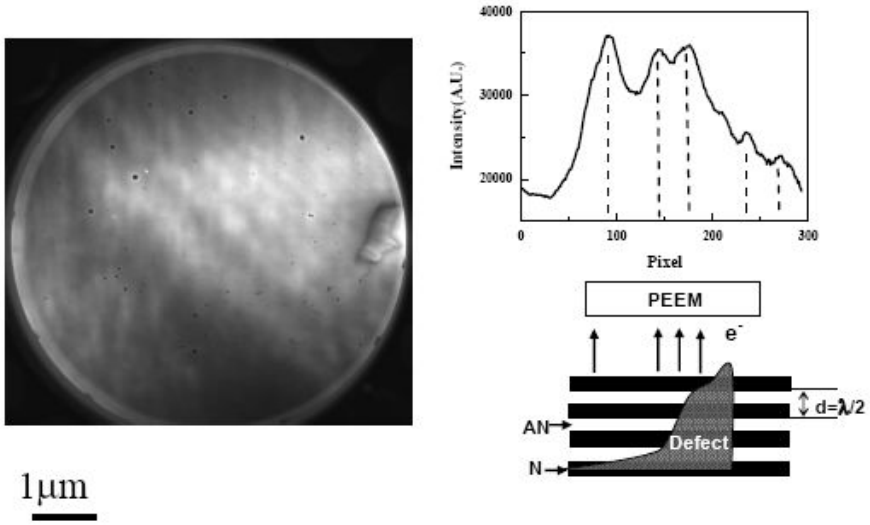

Figure 1. 3D interference contrast observed in EUV-PEEM at 13.5nm wavelength. A linescan is performed perpendicularly across the fringes. The fringes in the linescan are caused by the standing wave pattern of the EUV field above the surface as illustrated in the sketch (AN: anti-node, N: node).

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Attosecond technology towards combining ultrahigh spatial and temporal resolution - Nanoplasmonic optical field microscopy by ToF-PEEM

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There has been recently significant attention attracted by attosecond science that aims at pulse generation, system excitation, detection, spectroscopy, and electron motion control on the attosecond time scale. In nanoscience, one of important problems is the study and utilization of phenomena that are localized on the nanoscale and ultrafast. The localization length of surface plasmons can be on order of several nanometers. The relaxation rate of the surface plasmons is in the 10-100 fs range, allowing coherent control of nanoscale localization with femtosecond laser light. Importantly, collective motion in plasmonic nanosystems unfolds on much shorter, attosecond time scales. Here we propose a principally new approach that will allow one to *directly* measure the spatiotemporal dynamics of the nanolocalized optical fields with ~100 as temporal resolution and nanometer spatial resolution. Measurement of nanolocalized optical fields is interesting from both the fundamental positions and in view of the multiple applications of nanoplasmonics.

Future steps towards the experimental realization of an *attosecond nanoplasmonic field microscope*, which measures the time-evolution of excited optical fields on plasmonic nanostructures with nanometer spatial and attosecond time resolution, would be based on probing the response of photoelectrons excited by an attosecond XUV pulse (photon energy ~ 90 eV, pulse duration ~ 100 as) and emitted from the outer surface regions of the nanoplasmonic structures to the locally enhanced plasmonic fields excited by a few-cycle infrared (800 nm, < 4 fs) and carrier envelope phase stabilized laser pulse. We report on the design, setup and first characterization experiments of a new type of Time-of-Flight PEEM combining laser excitation of surface plasmons by few-cycle femtosecond laser pulses with core level photoemission excited by sub-femtosecond XUV pulses.

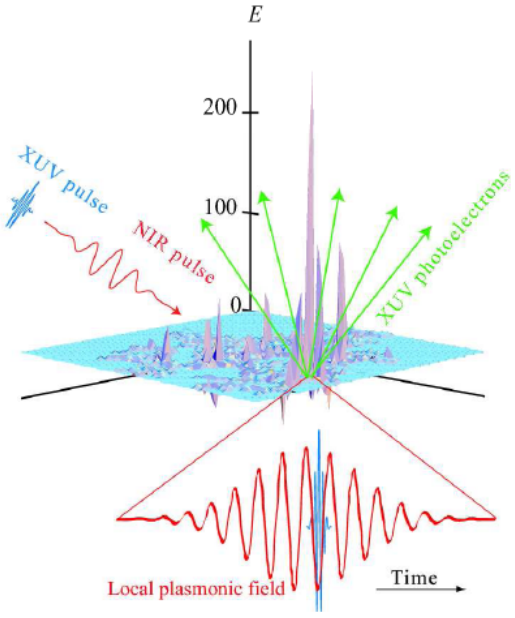

Figure. Schematic diagram of a vis-pump/XUV probe experiment on nanoplasmonic dynamics [1]

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Interaction of domain walls and spin-polarized currents studied with X-PEEM

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Domain walls in nanoscale ferromagnetic elements are in the focus of interest because of their potential for applications in a variety of fields like magnetic logic as well as data storage and due to their associated fundamental physical effects.
In a magnetic wire, two head-to-head domain wall configurations prevail: the vortex wall (VW) and the transverse wall (TW). The TW is similar to a Néel wall, where the magnetization rotates in-plane by 180°. In a VW the magnetization curls around a vortex core, where the magnetization points out-of-plane to reduce the exchange energy.

By using high resolution X-PEEM, we study in detail the domain wall spin structure. A phase diagram between TW and VW for varying thickness and width of the wire is presented and compared with theoretical calculations and the results of micromagnetic simulations [1].
The phenomenon of current-induced domain wall motion is studied, where due to a spin torque effect electrons transfer angular momentum and thereby push a domain wall. We have comprehensively investigated this effect and observed that this interaction is strongly dependant on the wall spin structure [1,2]. In addition to wall motion we observe periodic domain wall transformations in line with theoretical predictions [3] as shown in Fig. 1:

The initial transverse wall (TW) at the kink (a) is transformed by a 25 µs long pulse to a clockwise vortex wall (VW). (c) Further injection results in a TW with the opposite transverse component of the wall spin structure compared to the first. The marked dark spot originates from a channel plate defect in the imaging unit. (d) The next injection yields an off-center VW. (e) Subsequent injection results again in a VW with the same sense of rotation as in (b) and (d). These results yield valuable information concerning the basics of the spin-torque effect.

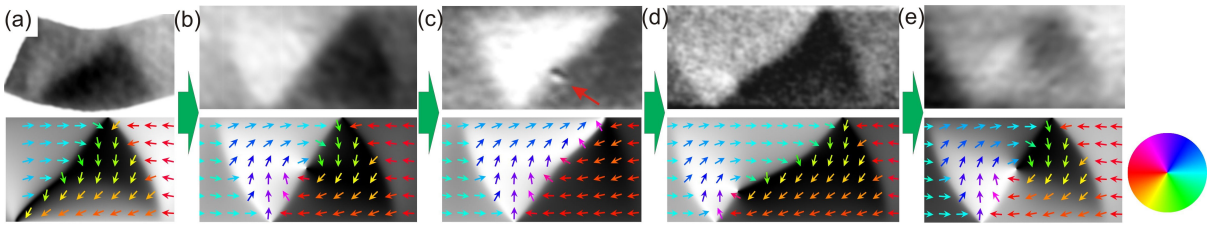

Figure 1. XMCD images of current-induced DW transformations (top row). The bottom row shows results from a corresponding simulation.

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Threshold MCD in 1PPE and 2PPE: promising magnetic contrast mechanism for PEEM

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Magnetization dynamics in PEEM commonly exploits stroboscopic illumination with circularly polarised Synchrotron radiation providing pulse lengths of typically 50ps (for a review, see [1]). On the quest for higher time resolution, fs-laser based magnetic contrast would be highly desirable. Marx et al. [2] detected linear magnetic dichroism in threshold PEEM. However, this phenomenon does not allow an asymmetry reversal for the elimination of non-magnetic contrast contributions. We report the observation of magnetic circular dichroism (MCD) in one- and two-photon photoemission (1PPE, 2PPE) at 3.1eV and 4.6eV photon energy for magnetite and Heusler compounds [3],[4].

Threshold photoemission was excited by perpendicular incident polarization-modulated light, while the magnetization was orientated parallel or antiparallel to the laser beam by an external magnetic field. Asymmetries were measured by phase-sensitive detection of the total electron yield (TEY). Measurement sequences are defined by alternating magnetic field reversals together with helicity changes of the photon beam to assure pure magnetic asymmetries, see Fig.1a. MCD is primarily confirmed by two criteria: (1) periodic changes in the TEY following periodic changes in the magnetization orientation M^+ and M^- parallel or antiparallel to the laser beam, and (2) constancy in the TEY during simultaneous change of both the magnetic field orientation and the helicity of the circular polarization (arrows). A theoretical explanation is provided based on local spin-density calculations; the computed 2PPE MCD for Ni_2MnGa [4] agrees well with the experiment. Our results are compared with recent work of Nakagawa et al. [5], including contrast in PEEM imaging.

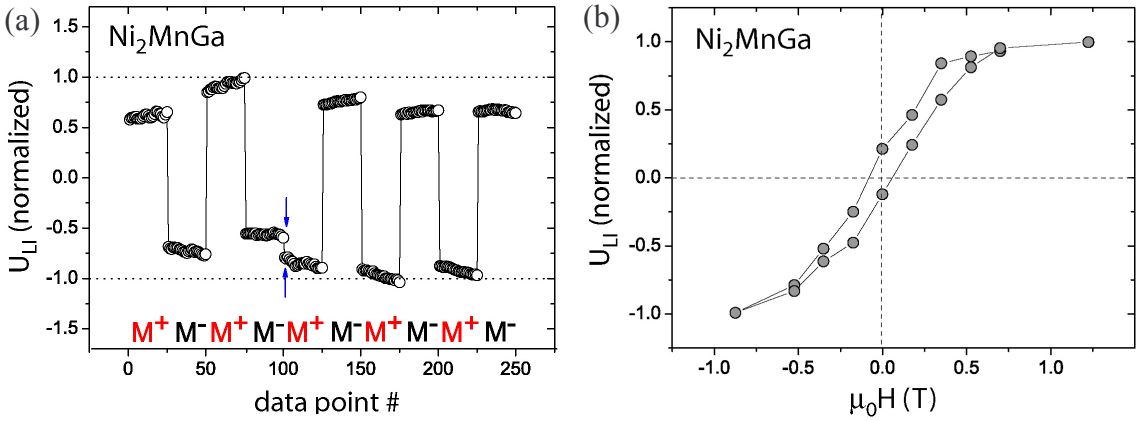

Figure. (a) Normalized MCD measurement sequence for the Heusler alloy Ni_2MnGa obtained from 2PPE. (b) 2 PPE- MCD hysteresis loop for Ni_2MnGa revealing non-vanishing coercive field

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Magnetic structure and antiferromagnetic domain-walls of epitaxial NiO layers coupled to Fe_3O_4 -- A study by X-PEEM

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Thin antiferromagnetic (AF) layers have a large potential for application in spintronics and data storage devices. Due to the vanishing net moment in antiferromagnets, however, their magnetic structure is difficult to determine. As a result, only few techniques can provide access, most of which are based on the interaction of spin-carrying particles or polarized x-rays with the material on atomic length scales. Besides x-ray and neutron scattering, PEEM using polarized soft x-rays is one of the most powerful techniques for a microscopic investigation of the AF magnetic structure. The magnetic moment orientation in ferro- or ferrimagnetic substances can be obtained by evaluation of the X-ray Magnetic Circular Dichroism (XMCD) in essentially the same way for both crystalline and disordered samples. However, exploiting X-ray Magnetic Linear Dichroism (XMLD) for single crystalline or oriented samples, the anisotropic nature of the effect has to be considered for the local determination of the spin-axis alignment [1-3]. Only then, the magnetic structure of AF domains and domain walls can be extracted reliably.

In this study we make use of the recent advances in the theoretical treatment of XMLD, for the case of highly-ordered NiO/Fe_3O_4 samples. Our results reveal a strong influence of the system crystallinity on the magnetic coupling properties. The crystalline interface orientation crucially determines the type of magnetic structure both at the interface and in the AF adlayer via electronic and magnetoelastic effects. Finally, magnetic coupling of the thin AF layer leads to a non-natural domain pattern comprising new types of AF domain walls not present in the bulk. The structure of these walls has been resolved by PEEM.

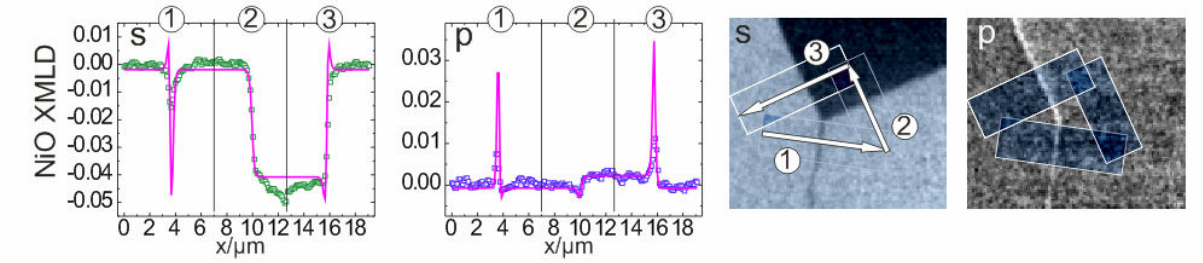

Figure 1. Constrained antiferromagnetic domain walls in a thin NiO layer coupled to a single-crystalline Fe_3O_4(110)-substrate.

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Magnetic property of meteoritic $L1_0$-type FeNi phase studied by PEEM, XRD and XMCD

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Iron meteorite shows an extraterrestrial pattern termed as the Widmanstätten structure (Fig. 1(a)). Its metallographic feature has been of great benefit to planetary scientists for studying the history of the solar system. The scientists have believed that the Widmanstätten structure was formed by the long-range thermal diffusion of Fe and Ni in asteroid's core over a period of 4.6 billion years. Meanwhile, the iron meteorite is also characterized by remarkable magnetic properties, namely large magnetic anisotropy and strong coercivity, differing from those of synthetic Fe-Ni alloys. However, there is no explanation how the magnetic properties are associated with the Widmanstätten structure. From the viewpoint of materials science, the Widmanstätten structure is regarded as Fe-Ni alloy segregated α (bcc-FeNi, kamacite) and γ (fcc-FeNi, taenite) lamellae on the micrometer scale (Fig. 1(b)). The Ni concentration in the γ lamella rapidly increases toward the interface, resulting in several laminated Fe-Ni alloys, namely invar alloy ($Fe_{65}Ni_{35}$), tetrataenite ($Fe_{50}Ni_{50}$) and permalloy ($Fe_{25}Ni_{75}$). Such a heterogeneous structure near the boundary can be considered a sort magnetic multilayer system. In this study, we investigate the magnetic properties of iron meteorite resulting from the Widmanstätten structure for the first time. Among the Fe-Ni alloys, we pay particular attention to the tetrataenite phase, which is described as a chemically ordered FeNi alloy with on $L1_0$–type superstructure.

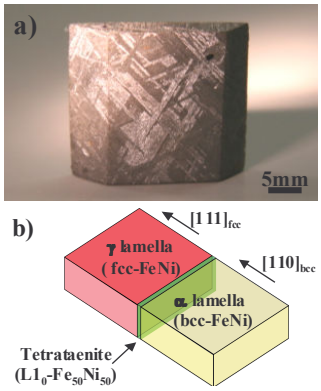

Fig.1 a) Widmanstätten structure in iron meteorite, b) schematic view of boundary region

To elucidate the relationship between the Widmanstätten structure and the magnetic property, we used a photoelectron emission microscopy (PEEM) installed in SPring-8. The metallographic structure is investigated in the connection with a hard x-ray beamline of BL39XU, and magnetic domain structure is studied at a soft x-ray beamline BL25SU (Fig.2a). The observed domain structure shows unique shape resulting from extremely large magnetic anisotropy of tetrataenite phase segregated at the interface. To study the origin of magnetic property in tetrataenite phase, its solid-state properties (composition, crystallographic structure, magnetism and electronic structure) are evaluated quantitatively. Powder XRD measurement is performed by the large Debye-Scherrer camera installed at BL19B2. Weak diffraction peaks due to the $L1_0$ superstructure were successfully observed. The tetragonality of $L1_0$ structure and the degree of order is evaluated. The XMCD measurement is performed using K edges of Fe and Ni at BL39XU. Tetrataenite shows larger amplitude in MCD spectra compare to disordered FeNi. It suggests that the magnetic property in tetrataenite has strong relevance with its super structure.

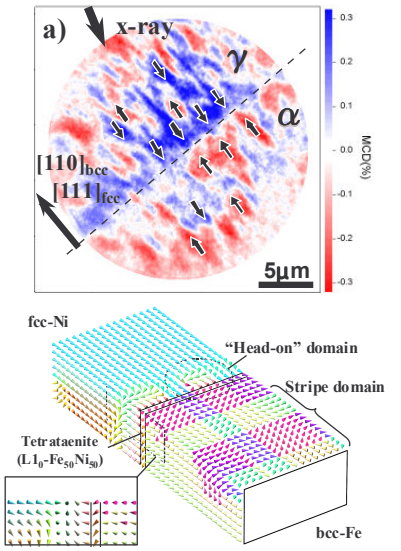

Fig.2 a) magnetic domain structure at the boundary region, b) micromagnetics simulation

Exchange coupling at the Fe/NiO(100) interface

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The magnetic domain structures in exchange coupled systems, a ferromagnetic (FM) Fe thin film on an antifferomagnetic (AFM) NiO(100) surface, has been investigated. Although the FM film on the NiO(100) is one of the widely investigated exchange coupled systems, FM domains coupled with the 12 kinds of AFM domains in NiO is not well understood. We observed the AFM domain structures at a NiO(100) surface by photoemission electron microscopy combined with x-ray magnetic and non-magnetic linear dichroism at the Ni-L_2 and at the O-K absorption edges, respectively [1,2]. The FM domain structures in Fe ultrathin film and at the interface were observed by x-ray magnetic circular dichroism at the Fe-L_3 and the Ni-L_2 edges, respectively [3].

The experimental results show that magnetic easy axes in the Fe ultrathin film exist not only along the <011> as reported in Ref. [1], but also along the <001> directions and that collinear exchange coupling between Fe and Ni spins arises at the interface. The 12 kinds of AFM spin axes in NiO are distinguished to two types with respect to the angle to (100) surface. One has the smaller angle (24 deg.), and the other the larger (55 deg.). This difference of the angles would cause a difference of the Fe easy axes. We also performed a numerical calculation based on Ref. [4] in order to understand the phenomena described above. According to the calculation, domains with Fe spins along the <011> directions are located on the domains with the AFM spins having the smaller angle to the surface plane. On the other hand, domains with Fe spin along the <001> directions are located on the AFM domains having the larger angle.

In addition to these results, we present the assignment of spin axes in the bare NiO(100) by x-ray absorption intensities in the Ni-L_2 edge and the O-K edge as a function of azimuthal angle and by a comparison with theoretical calculations.

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Magnetic domain structure of a patterned $La_{0.6}Sr_{0.4}MnO_3$ thin film

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$La_{1-x}Sr_xMnO_3$ (LSMO) is a ferromagnet that possesses almost full spin polarization of its conduction carriers and has a high Curie temperature of 350~K for x=0.40. It is expected that LSMO thin films with an atomically flat surface is useful for a possible application in tunnel magnetoresistance (TMR) [1]. Because a Mn ion shows Jahn-Teller effect, magnetic properties are strongly influenced by a lattice distortion. Therefore, an induced strain through step-and-terrace structure in a manganese oxide thin film can play an important role on a magnetic domain structure [2]. Besides, in a technically patterned LSMO thin film, we can control over the ratio of a shape anisotropy to a step-induced uniaxial anisotropy in magnitude. Recently, we have observed magnetic domain formation in an LSMO thin film [3]. However, there have been few works on features of magnetic domains in the LSMO thin film with a practical size of several microns, so far.

In this letter, we observed magnetic domains in patterned La1-xSrxMnO3 thin films on the micron scale through photoelectron emission microscopy (PEEM) [4]. The PEEM measurements were done at the soft-x-ray undulator beamline BL25SU at SPring-8. The PEEM used in this study consists of an Elmitec PEEMSPECTOR with deflectors and stigmators. We have found that the cooperative effect between the step-induced uniaxial anisotropy and shape anisotropy generates a single magnetic domain in the patterned La1-xSrxMnO3 thin films on the micron scale, while the competitive effect produces a multi-magnetic domain. The magnetic domain formation depends on a subtle balance between the uniaxial anisotropy and the shape anisotropy. For further practically realizing the TMR devices from the manganese oxide thin film, we should consider the deterioration of the ferromagnetism occurring locally near the insulator/ferromagnet interface, as well as the magnetic domain formation.

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XMCD-PEEM on nanomagnets arrays on self-organized semiconductor templates

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An alternative approach to the fabrication of high-density patterned magnetic media by nanolithography is the formation of nanostructures by self-organization, where atoms spontaneously arrange into aggregates forming spontaneously ordered, large-area patterns of nanometric objects. This fabrication method potentially represents a new parallel patterning technology, much advantageous regarding speed and efficiency with respect to serial procedures.

Here we describe the obtention of large-area arrays of magnetically independent nanoparticles with remanence at room temperature. This is achieved by grazing-incidence deposition of the magnetic material onto self-organized SiGe substrates [1,2] consisting of an arrangement of truncated pyramids with approximately square base and lateral faces forming an angle of ~25° with respect to the base plane. When the magnetic material is obliquely deposited onto this template, facets oriented towards the incoming beam receive the highest flux, while those in the back of the pyramids remain shadowed and unexposed.

Using (Pt/Co/Pt) trilayers with high magnetic anisotropy we have been able to obtain self-organized arrays of magnetically independent nanoparticles of dimensions as small as ca. 200 × 25 nm^2. The morphology and magnetic status of these nanomagnet ensembles have been studied by means of Photoelectron Emission Microscopy experiments with Magnetic Circular Dichroism (XMCD-PEEM) performed at the Nanospectroscopy beamline of synchrotron Elettra. With Co thicknesses below ~6 monolayers, strong dichroic contrast is obtained at room temperature revealing nanoparticles with inplane magnetization separated by perpendicularly magnetized areas. The magnetic orientation of the nanoparticles is uncorrelated with those of their neighbors. For higher Co thicknesses, the nanomagnets become coupled and the magnetizations of neighboring particles appear aligned parallel. The basic experimental features have been successfully reproduced by numerical modelling.

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Magnetic domain imaging of antidot arrays by photoelectron emission microscopy

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The magnetic behavior of magnetic thin films can be controlled by the introduction of geometrical "defects", e.g. arrays of holes (antidots). These magnetic nanostructures are promising candidates for a new generation of ultra-high-density magnetic storage media mainly due to the absence of the superparamagnetic limit, once there are no isolated small magnetic entities. The introduction of antidots into a continuous magnetic thin film results in novel domain configurations as well as shape anisotropies that allow to control properties such as magnetoresistance, coercivity, permeability and magnetization reversal [1-3]. An alternative method to the lithography process that is being increasingly employed to produce antidot arrays makes use of nanoporous alumina membranes as templates [1, 3]. Moreover, X-ray photoemission microscopy seems to be a powerful imaging technique to perform element selective magnetic domain imaging of this kind of nanostructures [2]. In this work we report on the magnetic domains configuration of highly ordered arrays of magnetic antidots (i.e. Ni and $Fe_{20}Ni_{80}$) obtained by depositing the corresponding magnetic thin film, by ion beam sputtering (ex-situ) or evaporation (in-situ), on different nanoporous alumina membranes (NAM) used as templates [3]. The antidots grown ex-situ by sputtering were capped with 2 nm Cu layer to prevent oxidation. The NAMs used in this work showed pores self-assembled into close packed domains of $\approx 2x2\mu m^2$ with high hexagonal order. The characteristic diameter of the nanoholes was 35, 55, 70 and 85nm whereas the distance between the centres of two adjacent pores was 105 nm. We have observed a clear dependence of the magnetic domain configuration on the antidot diameter for both "ex situ" and "in situ" grown antidots. In the case of $Fe_{20}Ni_{80}$ antidot arrays (grown ex-situ) with an antidot diameter d_1~50nm and an interantidot distance d_2~55nm, i.e. d_1/d_2~0.9, we have observed mainly domain chains whose width corresponds to the antidot period (Fig.1a). On the contrary, when the diameter of the antidots decreased up to 20nm, i.e. d_1/d_2~0.2 we observed large magnetic domains, i.e. in the micrometer range (Fig. 1b), since the demagnetized field associated with the antidots is not enough to induce the formation of small domains. In fact d_1/d_2 value controls the domain configuration on the antidot nanostructures as it has also been observed on in-situ grown antidots. For completeness, in fig.1c it is show the magnetic image of $Fe_{20}Ni_{80}$ antidot array (grown in-situ") with d_1/d_2~1.3.

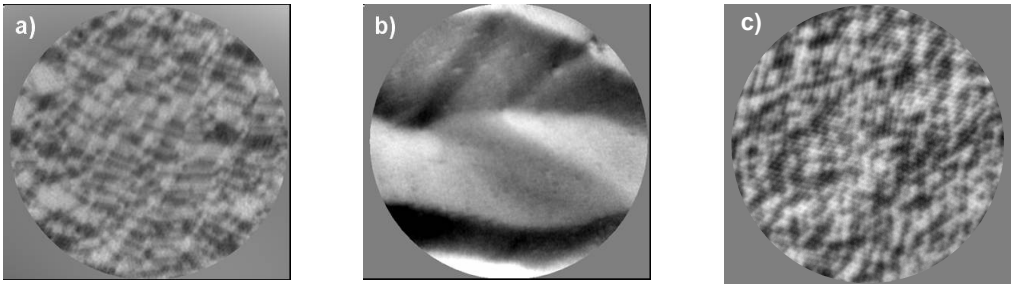

Figure 1. XMCD-XPEEM images taken at the Fe edge (field of view = 5 microns) of $Fe_{20}Ni_{80}$ antidots with diameters of 50 nm (a) and 20nm (b) grown "ex situ" and with diameters of 60nm grown "in situ

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Magnetic frustration in "Spin-Ice" nanostructured networks

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The recent progress made in lithography technologies allows the preparation of well-controlled artificial magnetic structures on the nanometer scale. The comprehension of magnetic interactions on such length scales is important both for the realization of magnetic logic devices and for fundamental studies. Prototypical "frustrated" system can be artificially created realizing networks of nanomagnets that cannot minimize their individual exchange interaction, due to the particular geometry. The physics of frustration[1] and the nature of the disordered ground states, like the "spin-ice"[2] phase observed in different physical systems (frozen water, pyrochlore antiferromagnets), can be studied on different length scales and tailoring the interaction energies between the nanomagnets.

We realized with lithographic techniques honeycomb arrays of nanomagnets[3], whose size and shape are chosen to allow only a single-domain configuration, with a strong uniaxial shape anisotropy. The networks can thus be treated within the Ising model approximation, as a Kagomé network of localized spins interacting spins.

We present the results of a first study on hexagonal magnetically-frustrated network using the combination of high-resolution X-PEEM microscopy and Magnetic Force microscopy. The goal of this work is to highlight the importance and the influence of short-range interactions and the demagnetization process[4] on the magnetic frustration phenomena.

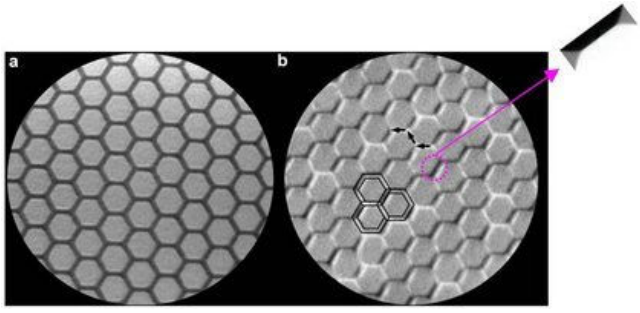

Figure 1 'Spin-Ice' Kagomé Network: periode 700nm. Nanostructure individual size: 100x400nm. a) LEEM microscopy image b) Magnetic domains images obtained using X-PEEM microscopy highlighting the magnetic frustration.

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Scanning low energy electron microscopy of doped silicon at units of eV

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Very low energy electron microscopy with the primary beam of hundreds of eV has proven very useful when imaging doped areas in semiconductors at high lateral resolution and high sensitivity to the dopant concentration. We employed the scanning low energy electron microscope equipped with the cathode lens in imaging of doped silicon samples at the landing energy of few eV.

Dynamic effects owing to the charge injected in small p-type patterns (10^{17} to 10^{19} cm^{-3}) were observed (see Figure). Negatively charged areas decrease kinetic energy of incident electrons down to nearly total reflection of the beam toward or off the detector, causing a strong contrast between doped areas even at light doping that exhibits only poor contrast at 1keV. Resulting high contrast imaging of the doped structures is free of radiation damage and enables one to study charging effects at high lateral resolution [1].

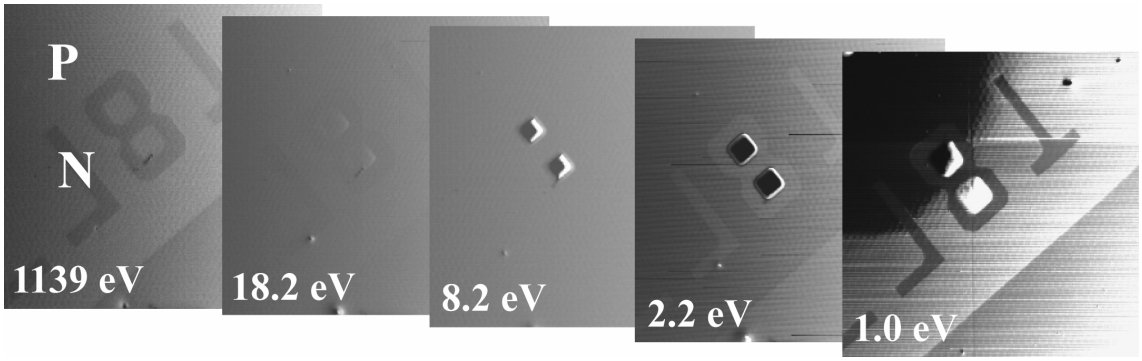

Figure: Contrast evolution between p- and n-type areas when decreasing the landing energy of the primary beam. Notice the charging of small p-type islands and inversion of the contrast at 2.2 and 1.0 eV.

Below 20 eV strong elastic backscattering of electrons takes place and variations in the local density of states induced by doping demonstrate themselves as electron energy variations in the reflectivity [2]. Large p-type areas on a lightly doped n-type substrate exhibit a contrast at 1 keV, which gradually decreases to zero when lowering the landing energy. At few eV a strong contrast, attributed to the modulated reflectivity, reappears of the opposite sign (see Figure for 2.2 eV). When the sample surface is covered with hydrocarbons, the primary beam decomposes them forming a metal-semiconductor junction [3]. Approaching the total reflection conditions at few eV, we encountered dynamical behavior probably connected with the graphitic contamination layer. Contrast of the doped areas, now obviously uncharged ones, inverts its sign once more and becomes very strongly pronounced (see Figure for 1.0 eV).

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From nanoislands to nanowires - Growth of Ge on Ga terminated Si(112) surfaces

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The growth of nanoscale three-dimensional (3D) Ge islands on Si has become a major field of today's research because of many possible technological applications, e.g., in opto-electronic devices. In contrast to intensely investigated surface orientations like (001) and (111), low-symmetry vicinal substrate orientations like (112) should allow for the growth of highly anisotropic Ge structures such as Ge quantum wires.

In this study, the impact of Ga pre-adsorption on the subsequent Ge growth on Si(112) is investigated, with an emphasis on density, size and shape of the resulting nanostructures. In similar previous investigations, nanoscale surface self-patterning effects [1-3] have been shown to drastically change the Ge growth after Ga adsorption on Si(111) and Si(113).
We performed experiments at the LEEM/PEEM endstation of the beamline U5UA at the National Synchrotron Light Source at Brookhaven National Laboratory. Ga and Ge were evaporated onto Si surfaces under UHV conditions using an e-beam evaporator. The changes of the surface morphology were observed in-situ via LEED or LEEM.

After Ga adsorption, the unstable and faceted bare Si(112) surface is smoothened, as observed, e.g., by the vanishing of the facet spots in the LEED pattern (not shown here): A (6x1) reconstruction is formed, saturating at a Ga coverage of about 0.84 monolayers. Subsequent Ge growth results in a smooth wetting layer with (5x1) reconstruction, cf. Fig. (a). Upon further Ge growth, 3D Ge islands nucleate on top of the Ge wetting layer, see Figs. (b) and (c). The size and shape of these islands can be tuned from small, rather round islands with a diameter below 100 nm towards highly anisotropic and monodisperse islands with a length of up to 3 µm, just by varying the growth temperature, as demonstrated in Figs. (b) and (c). In contrast, Ge growth on bare Si(112) always results in almost isotropic 3D islands (not shown here).

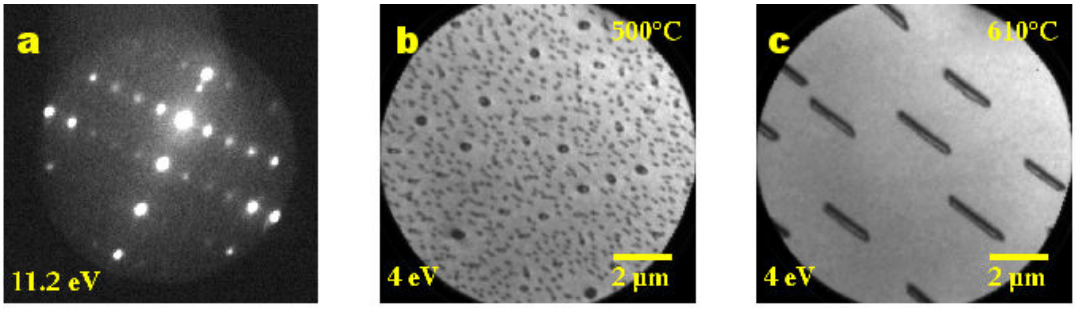

Figure. (a) LEED pattern of Ge/Ga:Si(112) with (5x1) reconstruction; (b,c) bright-field LEEM images of Ge islands on Ga terminated Si(112) at different growth temperatures.

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Reaction Process of Sb on In/Si(111) Observed with SR-XPEEM

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We have already shown the growth process of Sb on In/Si(111) $\sqrt{3}\times\sqrt{3}$ and $\sqrt{31}\times\sqrt{31}$ co-existing surface observed with LEEM, local-area LEED and XPS, and XPEEM [1]. Because of the relatively large lattice mismatch between InSb and Si, the satisfactory hetero-epitaxial growth of InSb has not proceeded. The In/Si(111) surface shows the other surface reconstructions such as the 4×1 structure. Therefore it is quite interesting to observe the growth of Sb on the different In/Si(111) surfaces to compare with the previous results and to see the details of the reaction process between In and Sb as a first step of the formation of InSb. In the present talk, we will show the growth process of Sb on the several In/Si(111) surfaces observed with SR-XPEEM, which was carried out at the soft X-ray beamline BL27SU of SPring-8.

The In/Si(111) $\sqrt{31}\times\sqrt{31}$ and 4×1 co-existing surface was prepared and Sb was evaporated on it at about 300 ^{o}C. In the LEEM images, a clear evidence of the nucleation or reaction induced by Sb deposition has not been observed in the initial process and the two-dimensional layer started to form after some amount of Sb was deposited. The LEED spots due to the $\sqrt{31}\times\sqrt{31}$ and 4×1 structure gradually weakened by the Sb deposition and the 2×2 pattern appeared simultaneously with the appearance of the two-dimensional layer in LEEM. Furthermore three-dimensional In islands form on the surface. Figure 1 shows the change of the In 3d and Sb 3d XPS signal intensities and the core level shift as a function of the deposition time of Sb. Up to about 200 s, In 3d intensity stays constant and suddenly drops. The Sb 3d intensity increased with the deposition time almost linearly. No distinct chemical shift can not be observed for the In 3d level, while the shift of about 0.35 eV takes place for the Sb 3d level at around 200 s.

From the above experimental results, the chemical shift of the Sb 3d level can be explained by the reaction of Sb atoms, which were weakly bounded to the surface in the initial stage, and the formation of the 2×2 structure. The sudden drop of the In 3d signal is explained by the formation of the three-dimensional islands. In the conference, the details of the growth process will be shown.

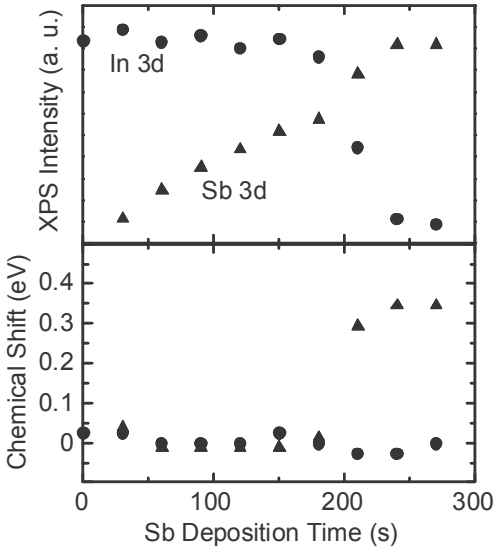

Fig. 1 Upper: The change of In 3d (circles) and Sb 3d (triangles) XPS intensities as a function of the deposition time of Sb. Lower: The core level shift of In 3d (circles) and Sb 3d (triangles)

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Ga droplet mediated surface ordering of GaP (111) – Structure and dynamics

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Understanding the dynamics and ordering of (111) semiconductor surfaces is of fundamental importance for 1D nanowire growth because they constitute the growth planes of many of these structures. GaP(111)B is for example the basis of GaP nanowire trees and can be used as substrate for nitride nanowires. The growth of nanowires from these surfaces are governed by the dynamics and structures found on length scales from sub-micrometer to microns. The complex growth mechanism is far from understood, partly due to the lack of surface microscopy studies. We have investigated the ordering of the GaP(111)B surface from the micron to the atomic scale using Synchrotron based Spectroscopic Photo Emission and Low Energy Electron Microscopy (SPELEEM) and Scanning Tunneling Microscopy (STM). We find that upon initial removal of the native oxide small faceted islands and a structure with tiny six-fold domains, tens of nano meters across, appear. Further annealing leads to the formation of Ga rich droplets which move across the surface perpendicular and up hill to the steps of the wafer. We directly follow the dynamics of the Ga droplets as they form and move across the surface and we image the resulting structures down to the atomic scale. In the trace of the droplets a significant ordering of the surface occurs, creating huge, micrometer sized, domains of the six-fold structure. This structure is similar on the atomic scale to the structure found prior to the ordering by the Ga droplets. We finally show that the movement and domain formation of the Ga droplets can be qualitatively altered by adsorbing Au aerosol nanoparticles on the surface.

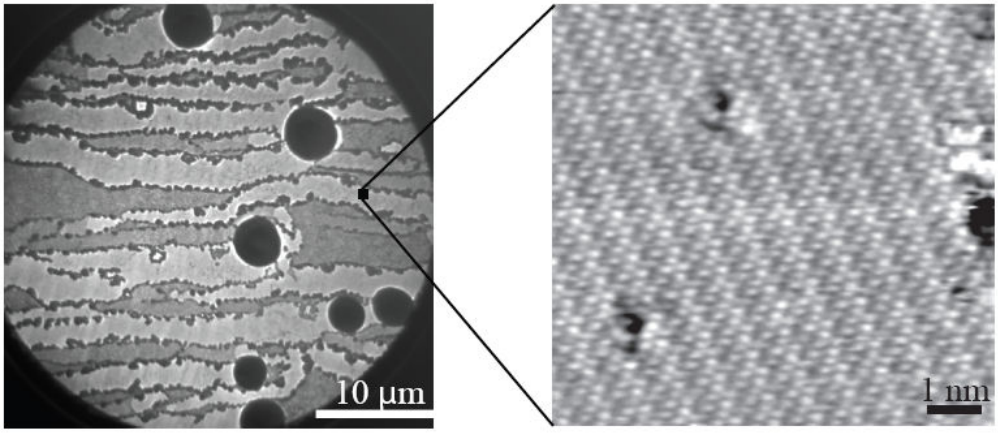

Figure. Left: Bright field LEEM image of GaP(111) after prolonged annealing at 670C. Large Ga droplets and the traces they have formed on the surface can be observed. Right: High resolution STM image of the structure found in the traces.

The Interplay of Anisotropic Diffusion Fields and Ag Nanowire Formation on vicinal Si(001)

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Photoemission Electron Microscopy (PEEM), Low Energy Electron Microscopy (LEEM) and Scanning Electron Microscopy (SEM) are used to study the interplay between surface vicinality of Si(001) substrates and the formation of Ag nanowires. During island formation, Ag nanowires are formed along 3D single crystalline islands on flat and vicinal Si(001) substrates. In our study of Ag nanowire growth, we observe that these nanowires are forming exclusively in the two distinct directions given by the orientations of the (2x1) reconstructions on neighboring terraces of the Si(001) substrate. Furthermore, the wire growth behavior shows a dependence on the surface vicinality. First, the fraction of wires forming on a 4° vicinal Si(001) surface, inclined in the [110] direction, is much higher than on a flat Si(001) surface. Second, on a flat surface, we find wires in both of the possible directions, while on 4° vicinal surfaces, the majority of wires forms oriented along the step edges. Wire formation at a variety of temperatures reveals an Arrhenius type behavior of the ratio wires/islands, indicating that an energy barrier has to be overcome in order to form the nanowires. The findings are explained in terms of the anisotropic diffusion of Ag atoms with respect to the step edges of the vicinal Si(001) surface [1].

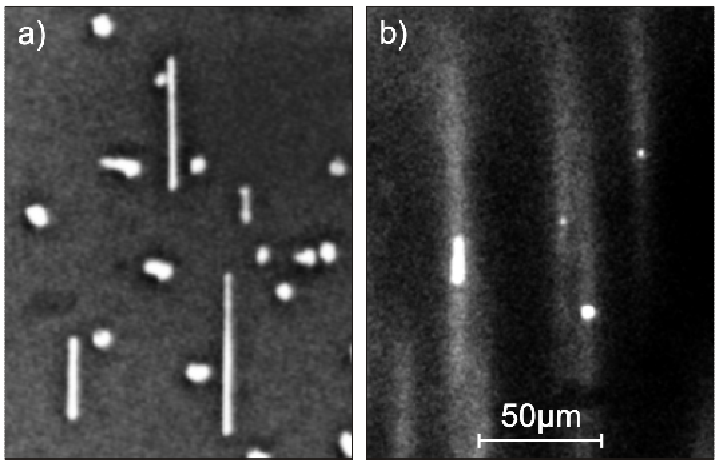

Figure 1: PEEM images of Ag islands and wires on 4° vicinal Si(001) are shown. Panel a) shows a typical Ag nanowire distribution, panel b) shows the strongly anisotropic Ag diffusion fields around decaying islands and wires.

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