

## **SELF-ORGANIZATION OF NANOSTRUCTURES IN SEMICONDUCTOR HETEROEPITAXY**

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Exploitation of strain-induced self-organization phenomena during semiconductor heteroepitaxy is an elegant and efficient route towards fabrication of large-scale arrays of uniform nanostructures. This will be demonstrated for the Stranski-Krastanov growth of SiGe films on vicinal Si(001) substrates. In this system, the growth front undergoes a series of strain-relief mechanisms that include the formation of {105}-faceted three-dimensional crystallites and the evolution of a dislocation network. By tuning substrate miscut and film thickness or growing superlattices a variety of patterns with different symmetries can be obtained. Atomic-force microscopy has been applied to obtain quantitative information on nanostructure uniformity and arrangement as a function of growth conditions. The mechanisms of pattern formation will be explained in the framework of continuum elasticity theory. Analogies to pattern formation in heteroepitaxial growth of organic semiconductor films like para-hexaphenyl on a variety of substrates will be discussed.

Since these nanostructure arrays cover the entire wafer on which the films were grown, they can serve as large-area nanopatterned templates. This application will be demonstrated for the fabrication of nanomagnet arrays fabricated by shadow deposition of cobalt onto specially faceted SiGe films. The resulting nanomagnets are single-domain magnets as has been proven by magneto-optic Kerr effect (MOKE) and x-ray circular dichroism photoemission electron microscopy (XMCD-PEEM).

## **ADSORPTION DYNAMICS AND REACTIVITY OF RH/V ALLOYS**

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Bimetallic surfaces have been used in heterogeneous reactions for a long time. The influence of alloy formation is explained in terms of both ligand effects and ensemble effects, which are very difficult to distinguish from each other. Recently two alloy systems (Pd – V and Rh – V) have been found where it may be possible to distinguish between ligand and ensemble effects. Detailed studies of the geometry and electronic structures of a Rh(111) – V subsurface alloy yield the necessary input to understand the reactivity of the alloy surface with respect to ligand and ensemble effects. Molecular beam studies show that the changes in the electrical structure due to alloying lead to significant alterations in the reactivity of the Rh – V subsurface alloy as compared to the V free Rh(111) surface. Experimental results obtained during studies with simple molecules (H<sub>2</sub>, CO and CH<sub>3</sub>OH) are explained with respect to the differences in the electronic structures between Rh(111) and the Rh – V subsurface alloy. A change in the adsorption mechanism of dissociative hydrogen adsorption from dynamical steering to precursor mediated adsorption has been found. CO adsorption dynamics show that the extrinsic precursor is only stable on ordered CO adlayers, which are absent on the alloy surface. The reactivity of the pure and the alloyed surfaces towards the dehydrogenation reaction of methanol shows marked differences. The subsurface alloy has a significantly higher reactivity for methanol dehydrogenation than the V free Rh(111) surface. The latter result is important for the development of methanol powered fuel cells.

**DIFFUSION IN NANOMETER-SCALE**

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Diffusion on nanoscale is a very interesting, new field. For example we have shown recently [1-8] that, if the diffusion distance is comparable to the atomic spacing, the classical Fick I equation is valid only for composition independent diffusion coefficients,  $D$ . For strong composition dependent  $D$  (which is generally the case) surprising results are expected: sharp interface remains sharp and shifts linearly with time even in ideal binary solid solutions (like Cu-Ni). Furthermore, an initially diffuse interface can become sharp, which offers a very useful tool improving the quality of bi or multilayers produced for different applications (X-ray or neutron mirrors, semiconductor electronic devices based on Si/Ge multilayers). In general it is expected that deviations from the classical parabolic law (e.g. in solid state reactions) can be observed on nanoscale even if there is no chemical reaction control at all.

In the lecture results of computer simulations and measurements providing experimental evidences of the above phenomena in different bi- or multilayer systems (Si/Ge, Cu/Ni, Mo/V) will be presented.

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**NEW DEVELOPMENTS IN THE FIELD OF TOF MASS SPECTROMETRY WITH CONTINUOUSLY OPERATING ION SOURCE**

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The operating principle of time of flight (TOF) mass spectrometer is simple. Ions are accelerated by a definite potential and left to run freely in a force free drift region. Having the same kinetic energy, the smaller the mass. the faster the ion. The first ion to hit the detector will be the lightest, and the order of the arrival will be the monotonic function of the mass number.

A new concept for TOF mass spectrometry is presented. Currently, TOF instruments use pulsed ion introduction with a ten or so nanosecond pulse width, followed by a waiting period roughly 100 microseconds. Accordingly, the sample is under excitation in  $10^{-4}$  part of the total measuring time, which limits the sensitivity of the method. Secondly, the ion bunch generated is strongly confined, which gives rise to space charge problems deteriorating the intensity and the mass resolution.

The concept presented uses a continuously operating ion source and a special dual modulation technique [1]. The expected advantages are higher sensitivity and minor space charge limitations.

There are two implementations of the new concept.

In **implementation "A"** two ion beam modulators are used. The first one at the entrance, the second one at the exit of the drift region right before the Secondary Electron Multiplier (SEM). The modulators are

driven with the same sinusoidal driving voltage with increasing frequency in uniform frequency increments. The necessary detection bandwidth of the SEM and the electrometer is as low as some hundred Hz only, which enables to operate the electrometer electronics with unusual high amplification ( $10^{10}$  V/A). There is a shortcoming, however, that the ion beam modulation method is not perfectly linear, thus the higher harmonic peaks inevitably show up in the spectrum. This can be reduced by low level modulation, but there is no way to eradicate it.

In **implementation "B"** there is just one ion beam modulator at the entrance of the drift region. This might still be nonlinear. The second modulation is carried out with an analog multiplier electronics right after the SEM and the electrometer. In here the SEM and the electrometer must have a high enough bandwidth (10 MHz or so) in order to deal with the high frequency modulated ion signal. The advantage in version "B" is, that the appearance of the higher harmonic peaks in the mass spectrum can be avoided, due to the almost perfect sinusoidal modulation of the analog multiplier electronic unit. Mathematical arguments will show, that at least one of the modulations must be perfectly sinusoidal in order to avoid higher harmonic peaks in the mass spectrum.

In both cases, the mass spectrum will be the result of the Fast Fourier Transformation (FFT) on the output signal.

Because of the high signal level, it was possible to omit any electrostatic mirror configuration for bunching the ions. Rather a cylindrical energy filter was installed to remove the ions with undesired energies. The drift tube is roughly two meters long.

[1] International Journal of Mass Spectrometry 225(2003) 101-114

## **Pb/Si(111)-7x7 INTERFACE: TOPOGRAPHY AND ELECTRONIC STRUCTURE**

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Lead on silicon represents a prototype system of metal/semiconductor interface since Pb and Si do not form any compound. The system shows a variety of structures at Pb coverage lower than 1 ML on the Si(111)/(7x7) surface, forming 2D alloys with silicon atoms. The interface is abrupt, making the interpretation of results more straightforward. At a coverage of 1/6 ML, the mosaic- $\sqrt{3}\times\sqrt{3}$  structure forms and consists of alternating rows of Pb and Si atoms. This structure exhibits quantised valence states. At slightly higher coverage of Pb surface the commensurate ( $\sqrt{3}\times\sqrt{3}$ )R30 phase co-exists with the incommensurate 1x1 islands. The interface between these two phases fluctuates substantially at temperatures  $\geq$  RT. Particular phases and corresponding phase transitions were studied using SRPES and VT STM to understand their stability and the driving force behind the transitions. As a main experimental tool the doping of layers with Cs and O atoms was used to identify the charge transfer between Si and Pb and particular states of these atoms.

## **ROLE OF INTERFACES IN THE NANOMETER SCALE PERIOD MULTILAYERS FOR X-RAY OPTICS**

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During the last years, increasing attention has been paid to the interface properties of multilayered structures. It was shown that both the interface roughness resulting from the growth process itself and the interface mixing of constituents affect the quality of a multilayer stack and its applications as an

interference mirror for X-ray optics. In our works the preparation (mostly by electron beam but also by sputtering and MO CVD) of mirrors for standard applications around the wavelength of 13.5 nm and their thermal stability under different types of annealing was studied. The basic bilayers or tetralayers of mirrors were W/Si, Mo/Si,  $W_{1-x}Si_x$ /Si, Co/Si/W/Si. In the paper the interface properties of structures studied by X-ray reflectivity, diffuse scattering and cross-sectional TEM vs. their stability are summarized. The detailed knowledge of the interfaces becomes crucial for nanometer-scale period multilayers with layer thickness below 1 nm. They determine the progress of the soft X-ray examination of biological objects and they are promising for hard X-ray optics. Here Sc/Cr multilayers are reported. Sc/Cr based mirror is one of the best candidates for "water window" range of wavelengths. Attention is paid to the characterization of interfaces of the stack with 250 periods, bilayer thickness of 1.75 nm and interface roughness controlled at the 0.2 – 0.3 nm level.

### NANOSTRUCTURE AS SEEN BY THE SAXS

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Small Angle X-ray scattering (SAXS) has been successfully applied on size and shape investigation of nanometer size features in different fields. With the rise of interest in nanoparticles in material science, the method is fully employed in research of wide variety of materials. Finally, the advance of thin films research with the structural features in nanometer range also shows great need for SAXS, albeit in the grazing incidence set up (GISAXS).

The sensitivity of GISAXS on the surface roughness is employed in the investigation of the quality of the film growth while the thickness and the density of the film are determined precisely. The size and shape of the nanostructures, be it particles or vacancies, precipitations or agglomerations, that are present in the film are easily obtained, as well as the information about their depth distribution. The presence of nanoparticles on the film surface, or on the interface between different films in form of islands is clearly resolved.

A good illustration is the SAXS study of magnetron sputtered tungsten carbide thin films. The surface roughness varies with the carbon concentration, while the films are built solely of nanosized tungsten carbide grains and of these grains surrounded by amorphous carbon matrix, for low and high carbon concentration, respectively. The size and the distribution of these grains has been determined with the combination of both transmission and grazing incidence SAXS.

### QUANTUM OPTICS OF DISPERSIVE DIELECTRIC MEDIA

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We quantize the electromagnetic field in a polar medium starting with the fundamental equations of motion. In our model the medium is described by a Lorenz-type dielectric function  $\epsilon(\mathbf{r},\omega)$ , appropriate e.g. for ionic crystals, metals and inert dielectrics. There are no restrictions on the spatial behavior of the dielectric function, i.e. there can be many different polar media with arbitrary shapes. We assume no losses in our system so the dielectric function for the whole space is assumed as real. The quantization procedure is based on an expansion of the total field (transverse and longitudinal) in terms of the coupled (*polariton*) eigenmodes, and this approach incorporates all previous results derived for similar but restricted systems (e.g. without spatial or frequency dependence of coupled modes). Within the same model, we also quantize the Hamiltonian of a nonretarded electromagnetic field in polar media.

Particular attention is paid to the derivation of the orthogonality and closure relations, which are used in a discussion of the fundamental (equal-time) commutation relations between the conjugate field operators. As an example, we shall apply our theory to the quasi-two-dimensional Wigner crystal, formed by electrons at very low temperature. In particular, we shall discuss the influence of the quantized electromagnetic field on the dynamics of Wigner electrons, i.e., on the dispersion relation of Wigner phonons.

## **INFLUENCE OF DEEP-CRYOGENIC TREATMENT ON WEAR RESISTANCE OF VACUUM HEAT-TREATED HSS**

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In this paper we compare the wear behaviour of a vacuum-heat-treated ESR AISI M2 high-speed steel and the same steel that was vacuum heat treated in conjunction with a deep-cryogenic treatment at  $-196$  °C. Four different tempering temperatures for the specimens austenized at the same austenitizing temperature were carefully selected to obtain various in-advance-determined combinations of the Rockwell-C hardness and the fracture toughness  $K_{Ic}$ . Each of the eight specimens was therefore characterised by these two resulting material properties. The wear behaviours were then compared and discussed in terms of these two properties and the related microstructures. The wear study was performed using a reciprocating sliding device under well-controlled contact conditions. Relatively high loads were used to provide enough wear for a comparison of the selected samples. A much harder and dissimilar model counter-material, i.e. silicon nitride ceramic, was used in order to avoid excessive wear of the counter samples and adhesion, which could occur in contacts with similar materials (metals/steels) under such high loads and in non-lubricated conditions. The wear behaviours were then compared and discussed in terms of these microstructures and the related properties. The differences in the wear resistance obtained in our investigation were as high as an order of magnitude. However, the beneficial effects are not a direct result of the type of the treatment, but relate to a proper combination of the resulting fracture toughness and the hardness. The more uniform and moderate values, which, however, tend to be obtained with a deep-cryogenic treatment, are beneficial to the high wear resistance of the selected high-speed steel.

## **STABLE OPERATION OF FIELD EMITTERS – AN OPEN CHALLENGE FOR THE VACUUM SCIENCE**

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Field emission phenomena attracts theoretical physicists for several decades and the basic mechanism is well understood today. The technology of manufacturing various materials in the form of sharp tips improved greatly in the meantime as well. Namely, a driving force for scientific and technological activities during all decades was the idea to replace power consuming thermionic cathodes by field emitters in various e-beam devices.

The great shortcut towards simple preparation of sharp tips was the discovery of nanotubes, recognized soon afterwards to be field emitters with attractive properties. Several scientific and technical papers manifest their advantage in prototype x-ray tubes, flat panel displays, microwave tubes, etc.

## INVITED SPEAKERS

Unfortunately, great expectations of potential customers were hindered by a simple fact that the degradation of their performance was too fast.

The analysis of a field emitter degradation is thus closely related to general problems studied in vacuum science and technology. The crucial ones are: is it possible to measure the intrinsic performance of a field emitter, what is the influence of the residual atmosphere, can the degradation be predicted from an accelerated test in a specified gas, what determines the residual atmosphere in a sealed device? In the contribution, an overview of present-day instrumentation techniques, which can help to answer the above set questions, is made and supported by some latest and original results.