August 29, 2011 8:30 – 10:00

Oxide Molecular-Beam Epitaxy — An Introduction with Examples

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Molecular-beam epitaxy (MBE) is a technique for creating single crystals whose structure may be customized down to the level of individual atomic layers. This process, which amounts to atomic spray painting in an ultra-empty vacuum environment, provides such structural control at the same time that it achieves superb purity and crystalline perfection. In this talk I will introduce the technique, the underlying technology, and give a practical guide to its use and limitations for tailoring the structure of oxides, including the preparation of new compounds and metastable superlattices. Using thermodynamics, I will describe situations in which film composition is automatically controlled, a regime known as adsorption-controlled growth. We will see how kinetics can provide an idea of what the optimal growth temperature will be for different classes of materials. I will illustrate how the *in situ* combination of a quartz crystal microbalance (QCM) and reflection high-energy electron diffraction (RHEED) have allowed the controlled synthesis of $Sr_{n+1}Ti_nO_{3n+1}$ and $Sr_{n+1}Ru_nO_{3n+1}$ Ruddlesden-Popper phases and metastable $BaTiO_3/SrTiO_3$ superlattices. The controlled synthesis of layered oxide heterostructures offers tremendous opportunities for altering the superconducting, magnetic, ferroelectric, and dielectric properties of oxides.

August 29, 2011 10:30 – 12:00

Pulsed laser deposition of superlattices and nanostructures

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Pulsed laser deposition (PLD) is a thin film fabrication technique.
Photonic energy of usually nanosecond long UV laser pulses is coupled to a bulk target material via elementary electronic excitations. For the laser energy densities employed in PLD, the ultimate result of the laser-matter interaction is most often the formation of a plasma plume containing ionic, atomic and diatomic species of the irradiated target material. The laser ablated material can be condensed on a substrate placed in the plume and thus a stoichiometric thin film, reproducing the composition of the ablated target, can be grown. The fundamentals aspects of PLD, relevant for the growth of high quality thin films, will be presented. PLD application for the growth of superlattices and epitaxial nanostructures of functional (ferromagnetic, ferroelectric, multiferroic) oxides will be eventually outlined.

August 30, 2011 10:30 – 12:00

Polarization dependent XAS and RIXS for the study of the electronic and magnetic structure of oxide thin films and interfaces

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Modern synchrotrons offer brilliant, intense and tunable sources of soft x-rays with a full control of polarization, circular (left or right handed) and linear (vertical or horizontal). In the 450-1000 eV photon energy range we can find all the $L_{2,3}$ absorption edges of 3*d* transition metals, from Ti to Cu, so that the highly resonant $2p \rightarrow 3d$ transition can be exploited to study the 3*d* states in 3dTM oxides, even in very thin films or diluted systems.
XAS (x-ray absorption spectroscopy) is a well established technique at the $L_{2,3}$ edges. In ferromagnetic systems XMCD (x-ray magnetic circular dichroism) is widely used to obtain magnetic (orbital and spin) moments thanks to sum rules. Linear dichroism (LD) can be combined with XMCD to study the orbital anisotropy and the antiferromagnetic component in magnetically complex / orbitally ordered systems. This is particularly interesting for oxide interfaces, thin films and superlattices, where strain and chemical mismatch entrain structural and electronic reconstructions that we want to understand. I will present some recent examples on manganites, cuprates and $SrTiO_3$ where XMCD and LD have been successfully combined.
RIXS (resonant inelastic x-ray scattering) exploits XAS as first step. When measured with high energy resolution, the $2p \rightarrow 3d \rightarrow 3p$ process can provide a wealth of information with chemical and site selectivity. Being an energy loss spectroscopy, RIXS is somehow analogous to optical Raman, electron energy loss spectroscopy, inelastic neutron scattering. Its strength is in the selectivity, where the polarization dependence of the excitation and de-excitation steps adds further information on the symmetry of the excitation left in the sample. I will present very recent examples on cuprates and manganites, where RIXS has been used to study localized *dd* excitations and spin wave dispersion in films and superlattices.

August 30, 2011 13:00 – 14:30

Oxide Interfaces—An Opportunity for Electronics

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Extraordinary electron systems can be generated at well-defined interfaces between complex oxides. In recent years, groundbreaking progress has been achieved in exploring and utilizing the fundamental properties of such interfaces, and it has become clear that these electron systems bear potential for possible future devices. After giving an introduction to oxide electronics, I will present the state of the art of this emerging field of electronics and discuss some of the challenges and pitfalls that may lie ahead [1].

[1] J. Mannhart and D.G. Schlom, Science 327, 1607 (2010)

August 30, 2011 15:00 – 16:30

Thermopower as a probe of interacting condensed matter systems

Josh Folk
Department of Physics and Astronomy
University of British Columbia

This lecture will give an overview of what can be learned from measuring thermopower in condensed matter systems. First, we will derive the Mott relation between thermopower and conductivity, discuss when it is applicable, and discuss what is implied when systems violate this simple relation. Next, we will discuss experimental considerations that must be taken into account when planning and interpreting a thermopower measurement. Several examples will be given in the use of thermopower to decipher bulk quantum materials as well as nanostructured quantum devices. Finally, I will present a recent example from our lab in which thermopower is used to learn about quasi-1D constrictions in two-dimensional electron gas, known as quantum point contacts.

August 31, 2011 8:30 – 10:00

Theory of correlated oxides

D.I. Khomskii
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In my lecture I will shortly present the main notions of the physics of correlated oxides. Approximate plan would be:

1. Correlations
2. Atomic physics
3. Transition metals in crystals
4. Different degrees of freedom: charge, spin, orbitals
5. Types of ordering
6. Doping of correlated oxides
7. Metal-insulator transitions

August 31, 2011 10:30 – 12:00

Aspects of the theory of oxide interfaces

Thilo Kopp
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Metallic conductivity has been realized at the interface between two insulating transition metal oxides, $LaAlO_3$ and $SrTiO_3$. The origin of such an interfacial metallic behavior is assumed to be the electronic reconstruction driven by an electron transfer through the polar $LaAlO_3$ layer. Electronic reconstruction is the key element here to characterize the electronic states at the interface as distinct from those in the adjacent bulk materials. In fact, it is a unique challenge to identify novel electronic interfacial states which are not stabilized in the three-dimensional bulk. This lecture will address the modeling of electronic phases at interfaces of oxide heterotructures. In particular, the focus will be on interface-induced superconductivity, interfacial magnetism and a state of negative compressibility, phases which have been previously identified for $LaAlO_3$ / $SrTiO_3$ interfaces in experiments.

August 31, 2011 13:00 – 14:30

Beta Detected NMR and Low Energy muSR

Rob Kiefl
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University of British Columbia

Nuclear magnetic resonance (NMR) is a well known method which is used extensively to probe electronic and magnetic properties of novel materials. There are many forms of NMR but all have common principles. The first step is to create nuclear spin polarization. One then manipulates the polarization into some non equilibrium state e.g make it perpendicular to a static external magnetic field . The final step is detect the time evolution of the polarization P(t) as it relaxes back to equilibrium. The resulting signal P(t) depends sensitively on local electronic properties of the material. The observables of interest are the Larmor precession frequency in the local environment and the spin relaxation rates 1/T1 and 1/T2 in a longitudinal or transverse magnetic field respectively. beta-detected NMR and low energy muSR are unique in that the highly polarized spin probes (the muon or radioactive nucleus) are implanted in the material on a depth scale of nm. The polarization is detected through the radioactive decay of the muon or nucleus. Consequently these methods are more sensitive than conventional NMR and well suited to studies of thin films and interfaces. In this lecture I will first review the basic principles of beta –NMR and low energy muSR . In the second half of the lecture I will illustrate the use of these methods with a few recent systems that are currently under study. Much of condensed matter physics is focused on the collective behaviour of interacting electrons and the resulting phase transitions that may occur at low temperatures. One of the most fascinating phases of matter is superconductivity in which conduction electrons organize themselves in such a way that currents can flow without any electrical resistance. This field of study has a long history but still has unsolved puzzles as new forms of superconductivity have been discovered in recent years. In the first example I will show how low energy muons can be used to measure directly the London penetration depth in a superconductor one of the most important experimental observables. When a magnetic field is applied to a superconductor the field is expelled from the interior due to the so called Meissner effect. However the field decays exponentially to zero from the surface on a length scale determined by the London penetration depth, which is closely related to the superfluid density and superconducting order parameter. Measurements of lambda can be used to test theories of unconventional superconductors. In the second example I will show how beta NMR provides complementary information. In particular, beta-NMR is sensitive to fluctuations in the superconducting order parameter near the critical temperature.

September 1, 2011 8:30 – 10:00

Polarons in bulk and near surfaces

Mona Berciu
Department of Physics and Astronomy
University of British Columbia

I will first discuss how Green's functions can be used to find the spectrum and local density of states of non-interacting electrons in a crystal with surfaces. I will then use Green's functions to study the physics of a polaron in an infinite crystal. Here I will focus on the Holstein model, since it is the simplest lattice model for electron-phonon interactions; if time permits I will discuss interesting new physics arising in other polaron models. Finally, I will combine the two and discuss what happens to polarons in the vicinity of a surface.

September 1, 2011 10:30 – 12:00

Spectroscopic ellipsometry: application to electrodynamics of correlated electron materials and oxide superlattices.

Alexander Boris
Max Planck Institute for Solid State Research, Stuttgart

When a solid is illuminated with light, most of the light is reflected or absorbed by medium, which is characterized by the complex dielectric function $e(w) = e_1(w) + ie_2(w)$. The analysis of these optical processes yields valuable information about lattice and charge dynamics and electronic excitations. Spectroscopic ellipsometry is an advanced technique, which allows one to measure both $e_1(w)$ and $e_2(w)$ directly, with high accuracy and reproducibility. A novel synchrotron-based approach to a traditional field of spectroscopic ellipsometry has turned it into a powerful technique to study electrodynamics of solids even in the deep infrared spectral range, which is of great importance for correlated electron materials. This lecture will give a tutorial introduction to the basic principles of ellipsometry and its experimental implementation. I will present a few illustrative examples of studies of superconductivity-induced optical anomalies in high temperature cuprate [1] and iron pnictide [2] superconductors and imensionality-controlled collective charge and spin order in nickel-oxide superlattices [3].

[1] A. V. Boris *et al.*, Science **304**, 708 (2004), [2] A. Charnukha *et al.*, Nature Communications **2**, 219 (2011), [3] A. V. Boris *et al.*, Science **332**, 937 (2011).

September 1, 2011 13:00 – 14:30

Introduction to Scanning Tunneling Microscopy:
An atomic perspective on condensed matter physics

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Scanning Tunneling Microscopy (STM) is a technique renowned for its capability of imaging the electron cloud surrounding the atoms in real space. This technique is also capable of many more feats that can be applied to a wide variety of physical systems such as: moving and positioning atoms and molecules individually, performing spectroscopy (including spin polarization) with sub-mV accuracy both in real and in momentum space and creating films with time resolutions ranging from hours down to picoseconds. The inherent versatility of STM has made it one of key experimental probes for modern condensed matter physics.

The lecture will begin with a general introduction where the principle of operation as well the basic theoretical framework of the technique will be presented. The second part of the lecture will deal with the instrumentation. I will present a brief overview of the new Laboratory for Atomic Imaging Research (LAIR) under construction at UBC as well as our state-of-the-art Ultra High Vacuum, High Frequency, High Magnetic Field, milliKelvin STM. The third part of this lecture will present recent examples of STM studies for the investigation of correlated oxides such as Sr2RuO4, BISCO, YBCO and LiFeAs.

September 1, 2011 15:00 – 16:30

Bonding and Structure of Interfaces with Electron Energy Loss Spectroscopy in the TEM

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Electron microscopy is an invaluable tool to study the detailed structure of materials. Many of the analytical methods available in the transmission electron microscope, electron energy loss spectroscopy (EELS) in particular, provide detailed compositional and spectroscopic information with unprecedented spatial resolution. In today's modern instruments, energy resolution down to 0.1eV with an electron beam approaching 0.1nm size is possible.

This presentation will focus on the description of the imaging methods and structure analysis in the TEM, the contrast mechanisms and resolution of the methods. Then an introduction to electron energy loss will be given with the fundamental aspects of inelastic scattering, angular dependence of energy loss spectroscopy, low loss spectroscopy, quantification and the descriptions of electron energy loss near-edge structures for the study of bonding and electronic structure information. The resolution, and sensivitivy of the method will be presented with several examples of recent studies of chemistry and bonding of thin films of oxides. An overview of the basic instrumentation and the state of the art technology will be given.