McCormick

Northwestern Engineering

Materials Science and Engineering

The 2012 Jerome B. Cohen Distinguished Lecture Series

Dr. Knut Urban
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Diving into the World of Atoms - Picometer Electron Microscopy

Monday, April 23, 2012 **4 :00 p.m.** **Allen Center, Room 164**

In electron optics, like in any optical system, resolution is limited by lens aberrations. During the nineties, i.e. more than sixty years after the invention of the electron microscope, it became at last possible to realize aberration-corrected electron optics [1,2]. In the past decade this has revolutionized electron microscopy. The Rayleigh resolution increased to about 50 picometers, and it has become possible to measure individual atom displacements in the order of 1 picometer. This means genuine atomic resolution[3,4]. On this basis the electron microscope has become an unsurpassed high-precision measurement tool allowing the direct correlation of macroscopic physical properties with atomic position measurements. The lecture prepared for a general public is embedding electron optics into a general history of optics finishing with examples of picometer electron microscopy in ferroelectrics.

[1] Rose, H. (1990). Outline of a spherically corrected semiaplanatic medium-voltage transmission electron microscope. Optik 85, 19–24.
[2] Haider, M., Uhlemann, S., Schwan, E., Rose, H., Kabius, B. & Urban, K. (1998). Electron microscopy image enhanced. Nature 392, 768–769.
[3] Jia, C. L., Lentzen, M. & Urban, K. (2003). Atomic-resolution imaging of oxygen in perovskite ceramics. Science 299, 870–873.
[4] Urban, K. (2008). Studying Atomic Structures by Aberration-Corrected Transmission Electron Microscopy, Science 321, 506-510.

Pushing the Frontiers - Insight into Transmission Electron Microscopy

Tuesday, April 24, 2012 **4:00 p.m.** **Tech, Lecture Room 211**

The realization of aberration-corrected electron optics provides the instrumental basis for atomic resolution electron microscopy. But, in contrast to common believe, optical resolution is just one of the pre-requisites of atomic resolution work. The world of atoms is that of quantum physics, and there the term 'image' looses its conventional meaning. The electron waves sent through a crystal in order to provide us with information on the object are subject to quantum-mechanical interaction with the atom potential as described by a Schrödinger form of the Dirac equation for relativistic electrons. The resulting complex wave function at the exit plane of the specimen does not lent itself to an intuitive interpretation. And this holds true even more so, when the additional quite complex phase and amplitude shift behavior of an electron lens are taken into account in addition. In order to understand the images and to push the frontiers of electron microscopy to picometer precision it is unavoidable that the highly non-linear quantum-mechanical imaging process is inverted on a computer. This procedure is hampered by the fact that in quantum-physical dimensions such important imaging parameters as sample thickness or sample tilt are unknown (there is no meter rule in atomic dimensions). The key is therefore an iterative matching of the experimental images on the basis that atomic coordinates and imaging parameters are treated as free parameters. This lecture prepared for a non-specialized public will put this basis of atomic resolution electron microscopy into the right perspective and will elaborate on a number of illustrative examples of recent experimental work [2].

[1] Urban, K. (2009). Is science prepared for atomic resolution electron microscopy? Nature Materials 8, 261-262.
[2] Jia, C. L., Urban, K., Alexe, M., Hesse, D. & Vrejoiu, I. (2011). Direct Observation of Continuous Electric Dipole Rotation in Flux-Closure Domains in Ferroelectric $Pb(Zr,Ti)O_3$, Science 331, 1420-1423.

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The White Spot on the Map - Complex Metallic Alloys

Wednesday, April 25, 2012 4:00 p.m. Tech, Lecture Room 211

The year 2012 marks the 30th anniversary of the discovery of quasicrystals. In the past three decades scientists tried to understand why quasicrystals are forming, what is behind their particular structure and how this structure influences the particular physical properties. Searching for answers to these questions it was found that there exists an extended class of metallic alloys whose short-range atomic order is quite similar to that found in quasicrystals but, in contrast to the latter, their structure is nevertheless periodic exhibiting classical point-group symmetry. Their crystal lattice is based on giant unit cells comprising hundreds to thousands of atoms [1, 2]. In contrast to the family of quasicrystals these alloys, termed *Complex Metallic Alloys* (*CMAs*), are quite abundant. Many of their physical properties are similar to those of quasicrystals, others scale with the size of the unit cell. An interesting topic is the study of the plastic deformation behavior. It is based on the propagation of so called metadislocations comprising hundreds of atoms per unit-cell thickness in the dislocation core [3]. The fascinating result of the studies on metadislocations is that the alloys make use of transformations to a number of closely related phases whose particular atomic structure relaxes the elastic energy [4]. This novel mechanism of plasticity indicates that studying the plastic behavior of alloys is still good for surprises. The lecture will give an introduction into the field of *Complex Metallic Alloys* and elaborate on the extraordinary plastic behavior. In order to be able to follow no particular knowledge of quasicrystal or CMA crystallography is required.

[1] Urban, K. & Feuerbacher, M. (2004). Structurally complex alloy phases. J. Non Cryst. Sol. 334, 143 - 153.
[2] Dubois, J.-M., Belin-Ferré, E. & Urban, K. Edts (2010). Complex Metallic Alloys: Fundamentals and Applications, Wiley-VCH (Weinheim).
[3] Heggen, M., Houben, L. & Feuerbacher, M. (2010). Plastic-deformation mechanism in complex solids. Nature Materials 9, 332 - 336.
[4] Heggen, M., Houben, L. & Feuerbacher, M. (2011). Metadislocations in the complex metallic alloys T–Al–Mn– (Pd, Fe). Acta Materialia 59, 4458 – 4466.

Professor Knut Urban studied physics at the Technical University of Stuttgart where he also received his Doctor degree in natural sciences 1972. He was a staff scientist at the Max Planck Institute for Metal Research in Stuttgart from 1972 till 1986 when he became Professor for General Materials Properties at the University of Erlangen-Nuremberg. In 1987 he took over a Chair for Experimental Physics at RWTH Aachen University, and he became Director at the Institute for Solid State Research at the Research Center Juelich. In 2004 he founded the Ernst Ruska Centre for Microscopy and Spectroscopy with Electrons at Juelich as an international user center in the field of advanced electron optics.

He retired from his position at Juelich in August 2010. And took over an appointment as JARA Senior (Distinguished) Professor at RWTH Aachen University. He spent extended times as Guest Professor at Bhabha Research Centre, Mumbai/India, at Saclay Research Centre in Paris/France and at Tohoku University Sendai/Japan. Currently he is also affiliated as a Professor to Tsinghua University, Beijing, and Jiaotong University, Xi’an, China.

His research interests range from ultra-high resolution electron optics to the physics of complex alloys, dielectrics, oxide superconductors and Josephson-effect based Terahertz spectroscopy. Together with Max Haider and Harald Rose he developed during the nineties aberration-corrected electron optics and on this basis atomic-resolution electron microscopy.

From 2004 to 2006 he was President of the German Physical Society. Among his awards are the 2007 Karl-Heinz Beckurts Prize for Innovation, the 2007 Von Hippel Award of MRS and the 2008 Honda Prize for Ecotechnology. In 2011 he was awarded the Wolf Prize in Physics.