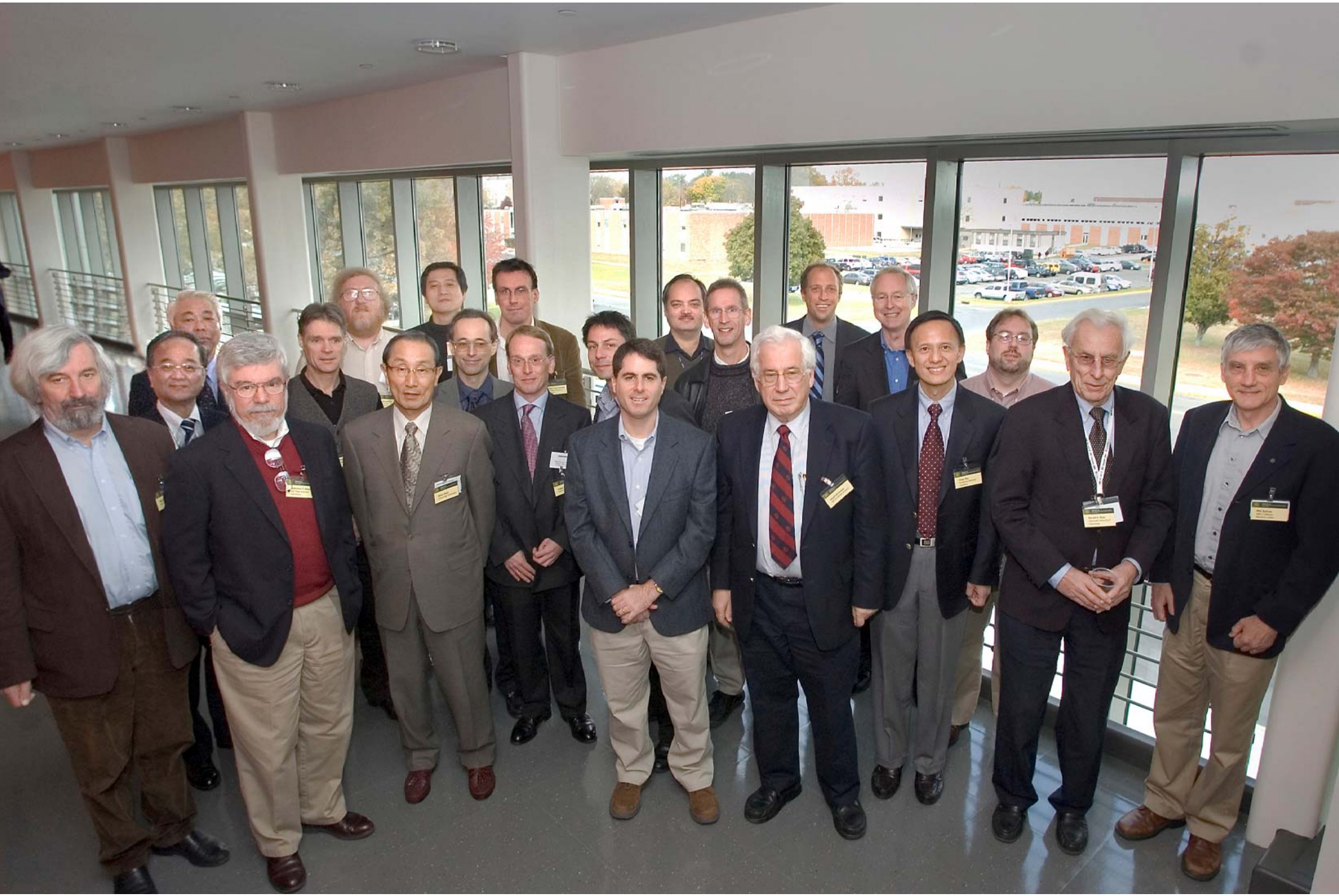
BROOKHAVEN
NATIONAL LABORATORY

WORKSHOP ON
Advanced Electron Microscopy in Materials Physics

Nov. 7-8, 2007
Long Island, New York

Sponsored by the Institute for Advanced Electron Microscopy,
Center for Functional Nanomaterials, and Hitachi High Technologies.


WORKSHOP ON
Advanced Electron Microscopy in Materials Physics
Nov. 7-8, 2007
Sponsored by the Institute for Advanced Electron Microscopy,
Center for Functional Nanomaterials, and Hitachi High Technologies.



ADVANCED ELECTRON MICROSCOPY AND MATERIALS PHYSICS WORKSHOP

November 7-8, 2007
Building 735, CFN Seminar Room
Brookhaven National Laboratory
Long Island, New York

PROGRAM

WEDNESDAY (November 7th)

7:30 – Continental Breakfast
\
8:30 - Welcome from Organizers – Yimei Zhu (BNL) & Konrad Jarausch (Hitachi)
8:40 - Opening Remarks – Emilio Mendez, CFN Director

Instrumentation & Aberration Correction

Rudolf Tromp, Session Chair

8:45 - Harald Rose (TU-Darmstadt) – The History of Aberration Correction
9:15 - Max Haider (CEOS) – New Correctors to Fulfill the Requirements of Future Instruments
9:45 - Bernd Kabius (ANL) - Aberration Correction Concepts Within the TEAM Project

10:15 Coffee Break

10:30 - Phil Batson (IBM) - Unexpected Benefits from Aberration-Corrected Electron Optics
11:00 - Rodney Herring (Victoria) - Coherence Property Measurements of Phonon-, Plasmon-, and Ionization-loss Electrons and Their Contributions to the Stobbs Factor
11:30 - Manfred Ruehle (MPI-Stuttgart) – Challenges of Electron Microscopy in Materials Physics
12:00 -Lunch

Advanced EM in Materials Physics

Manfred Ruehle, Session Chair

1:30 - Steve Pennycook (ORNL) - New Views of Materials with Aberration-Corrected STEM
2:00 - Koji Kimoto (NIMS) - A Few Practical Aspects of Atomic-Column Imaging Using ADF and EELS
2:30 - Nigel Browning (UC-Davis) - Imaging and Spectroscopy of Nanoscale Systems in the STEM

3:00 - Coffee Break

3:30 - Yimei Zhu (BNL) – Structural Analysis of Layered Thermoelectric Oxides Using Aberration Corrected STEM/EELS

4:00 - Ji-Jung Kai (National Tsing Hua University) - The Characterization of Helium Bubbles in SiC/SiC Composite Using EELS and the Current Development on Structure Reversion
4:30 - Rudolf Tromp (IBM) - Cathode Lens Microscopy: The Next Generation
5:00 - Ray Twesten (Gatan) - Advances in Multi-Dimensional Imaging Techniques for STEM

6:00 - Reception, Berkner Hall Lobby
Greetings from Hitachi – I. Muta (General Manager, Sales) and Y. Kawasaki (Executive Vice President)

7:00 - Dinner, Berkner Hall Cafeteria
Talk by Konrad Jarausch (Hitachi) – Novel Approaches for In-Situ and 3D Microscopy

THURSDAY (November 8th)

7:30 – Continental Breakfast

Advanced EM in Materials Physics

Mike O'Keefe, Session Chair

8:00 - Robert Klie (UI-Chicago) - Atomic-Scale Studies of Complex Oxide Interfaces Using Aberration-Corrected Z-contrast Imaging and EELS
8:30 - Angus Kirkland (Oxford) - Imaging and Exit Wave Reconstruction in an Aberration-Free Environment
9:00 - Rafal Dunin-Borkowski (TU Denmark) - Catalyst Nanoparticles Imaged Using Aberration Correction, Focal Series Restoration and Electron Tomography
9:30 - David Muller (Cornell) - Atomic-Scale Chemical Imaging by Aberration-Corrected Microscopy

10:00 – coffee break

10:15 - Mike O'Keefe (LBNL) - Cs Correction and Focal-Series Reconstruction of the Exit-Surface Wave
10:45 - Jim Bentley (ORNL) - Nanoscale Elemental Mapping in TEM and STEM
11:15 - Larry Allard (ORNL) - Catalyst Characterization via Aberration-Corrected STEM in the HTML User Program
11:45 - Doug Blom (U-SC) - Aberration-Corrected STEM of MoVTeNbO Complex Oxide Catalysts.
12:15 - Closing remarks – Yimei Zhu (BNL) + Konrad Jarausch (Hitachi)

12:30 -Lunch

CFN instrumentation, small group discussion and tours (options):

1:30 - Operation and optimization of Cs corrected STEM/EELS (in laboratory) and tour of CFN facilities and instrumentation – break into small groups
(a) Live Cs-corrected STEM/EELS at CFN and discussion (60 minutes)
(b) Tour of the CFN facilities + microscopes and discussion (60 minutes)

ABSTRACTS

DAY ONE

History of Aberration Correction

Harald Rose
University of Darmstadt, Hochschulstr. 6, 64289 Darmstadt, Germany

Aberration correction in electron microscopy dates back to Otto Scherzer who proved in 1936 that chromatic and spherical aberrations of rotationally symmetric electron lenses are unavoidable [1]. His finding was so important that it was named "Scherzer theorem". In 1947, Scherzer found an ingenious way for enabling aberration correction. He demonstrated in a famous article that it is possible to eliminate chromatic and spherical aberrations by lifting any one of the constraints of his theorem, either by abandoning rotational symmetry or by introducing time-varying fields, or space charges [2]. Moreover, he proposed a multipole corrector compensating for the spherical aberration of the objective lens. Subsequently, his student R. Seeliger built and tested this corrector. However, it was G. Moellenstedt who first demonstrated experimentally the correction of spherical aberration by means of this corrector [3]

In 1964, Deltrap built a telescopic quadrupole-octopole corrector to eliminate the spherical aberration of a probe-forming lens. Although he nullified this aberration, he failed, like his predecessors, to improve the actual resolution of the uncorrected system because at that time the resolution was limited by mechanical and electrical instabilities rather than by the defects of the electron lenses. In 1971, H. Rose proved that all known correctors introduce large coma and proposed a novel aplanatic corrector utilizing symmetry properties. This corrector was built and tested successfully in a test microscope within the frame of the so-called Darmstadt project and it demonstrated for the first time the simultaneous correction of chromatic and spherical aberration. The project was abandoned after the death of O. Scherzer, although it was successful as far as it went.

Experimental work on aberration correction was resumed by M. Haider in 1992 within the context of the "Volkswagen Project" aimed to improve the resolution limit of a 200 kV transmission electron microscope (TEM) by eliminating spherical aberration and coma by means of a highly symmetric aplanatic hexapole corrector [4]. Together with S. Uhlemann he developed a fast alignment procedure, which enables a precise and fast elimination of the spherical aberration and all resolution-limiting parasitic aberrations originating from mechanical inaccuracies, magnetic inhomogeneities and misalignment. Employing this computer-assisted alignment, M. Haider improved in 1997 for the first time the performance of a TEM by reducing the resolution limit from 2.1Å to 1.4Å [5]. In the meantime this limit has been lowered further to about 0.8Å

The successful correction of chromatic and spherical aberration of a low-energy electron microscope by means of an electron mirror has been demonstrated recently by T. Schmidt for the SMART microscope by reducing its resolution limit from 15nm to 3nm.

References:

[1] O. Scherzer, Z. Physik **101** (1936) 593.
[2] O.Scherzer, Optik **2** (1947) 114.
[3] G. Moellenstedt, Optik **13** (1956) 209.
[4] H. Rose, Optik **85** (1990) 19.
[5] M. Haider. H. Rose. S. Uhlemann, E. Schwan, H. Kabius, K. Urban, Nature **392** (1998) 768.

New Correctors to Fulfill the Requirements for Future Instruments

M. Haider, H. Mueller, S. Uhlemann, J. Zach and P. Hartel
CEOS GmbH, Englerstr. 28, D-69126 Heidelberg, Germany

The improvement of the resolving power of a TEM and a STEM by means of the correction of the unavoidable spherical aberration was a long ongoing effort. Several attempts to correct these main aberrations have already been made since the first proposal of O. Scherzer in 1947 [1] on how to correct the axial aberrations of an objective lens. However, just with the emergence of the first successfully Cs-corrected TEM [2] the gate for the development of a new generation of high resolution TEMs and STEMs has been opened. Meanwhile Cs-correctors exist for the main class of high resolution TEM and STEM for an accelerating voltage range from 80 kV up to 300 kV. The EM manufacturers are offering these Cs-corrected TEMs and/or STEMs for high resolution and analytical purposes. The resolution of these Cs-corrected lenses is now limited by incoherent aberrations which cannot be compensated by a Cs-correction system. The main incoherent aberration is the chromatic aberration for which the product of $E \cdot Cc$ is the important parameter. This product defines the information limit and, hence, the attainable resolving power of an instrument. Besides this chromatic aberration one also has to consider other disturbing factors such as instabilities of electronics or external sources of noise.

For further improvements of the attainable resolving power one has to investigate the limiting parameters. We are only concentrating on the instrumental parameters which are:

- The wave length (or energy E) of the electrons,
- The energy width E of the electrons one would like to image or to focus into a small probe.
- The chromatic aberration coefficient Cc of the objective lens one uses.
- The higher order aberrations of the objective lens,
- Any incoherent disturbance introduced by the instrument or by the environment.

Current and future developments of aberration correctors are dependent on the system one aims for:

- For UHR-STEM one has to reduce the higher order aberrations, especially the fifth-order aberrations in order to achieve an illumination cone of more than 40 mrads. This has just been currently done for a high resolution STEM [3] for which the goal is to achieve in combination with a monochromator a probe size of d = 0.05 nm (d ~ 20).
- A Cc-correction system for a high resolution TEM for which a resolving power of 0.05 nm and a large field of view should be achieved. This project is in good progress and the first results should be obtained in the first half of 2008.
- The chromatic aberration of a high resolution probe forming system can be compensated by an appropriately designed Cc/Cs-corrector.
- The off-axial coma of a high resolution TEM can also be corrected for and this would lead to a Cs-corrected TEM with a large field of view.

References

[1] O. Scherzer, Optik, 2, (1947) 114.
[2] M. Haider et al., Nature, 392, (1998) 768.
[3] H. Müller, S. Uhlemann, P. Hartel and M. Haider, Micr. & Microanal. 12 (2006) 442-455

Aberration Correction Concepts Within the TEAM Project

B. Kabius
Center for Electron Microscopy, Materials Science Division, Argonne National Laboratory, Argonne, IL 60439

During the last 10 years several aberration-correction concepts for electron microscopes have succeeded in improving spatial resolution and analytical capabilities. Electron optical systems for correction of spherical aberration are now a valuable tool for material science research and several investigations have already exploited some of the benefits of C_s-correction for high-resolution TEM and STEM. The TEAM project is a collaborative DOE project which will extend the present capabilities of aberration correction technology. The goals for aberration correction within the TEAM project are:

- Correction of higher order aberrations such as fifth order spherical aberration is required for improving interpretability at sub-Angstrom resolution (TEM) and higher beam currents in smaller electron probes (STEM).
- Improving the information limit to 0.5Å by correction of chromatic aberration (C_c) and energy monochromation.

The information limit can be improved alternatively by reducing the energy width of the electron emitter using a monochromator. One of the disadvantages of this concept is a strong loss of brightness due to the monochromator. Correction of chromatic aberration improves the damping envelope of temporal coherence without the need for a monochromator thus achieving higher contrast transfer and higher beam currents.

Lens systems for the correction of chromatic aberration for TEM or STEM have not yet been implemented because of the stringent current stability requirements of about 10^{-8} for the multipole elements. Recently, new designs for chromatic aberration correction have been suggested by H. Rose and were analyzed and refined within the TEAM project. At present a corrector is under development which is according to simulations capable of correcting C_c for acceleration voltages up to 300kV. Furthermore spherical aberration as well as axial aberrations and off-axial coma will be corrected up to the fifth order thus enabling aberration free imaging up to a resolution of 0.5Å for a large field of view of 2000*2000 independent image points in TEM mode which is one of the goals of the TEAM project.

Based on this design study and recent progress improving the stability of power supplies C_c correction appears to be feasible with current technology. Further applications of C_c-correction for EFTEM and *in situ* experiments will be discussed.

This work was supported by the US Department of Energy, BES-Materials Sciences, under Contract W-13-109-ENG-38.

Unexpected Benefits from Aberration-Corrected Electron Optics

P.E. Batson
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598

Without a doubt, aberration correction electron optics has vastly changed the quality and accuracy of obtainable imaging data, particularly in the lower voltage microscopes. The ability to image very small crystallites, and to resolve defect structures was expected and welcomed. But with any new tool, we also find that there may also be unexpected benefits. For instance, with a sub-Å probe size, single atom contrast is so high that images can be taken very rapidly, allowing time-dependent inspection of very small objects. Since the electron beam interaction with atoms can give up a fraction of an eV in energy, there is a good chance that single atoms will move under the beam, allowing measurement of an ensemble of atomic positions available to that atom. Thus, some types of dynamic experiments can be done if the probe size, current and dwell time is controlled. In the future, precise control of aberrations implies an ability to control the position and phase of incident and scattered *wavefunctions.* This, in turn implies that we will have much more detailed information about the specimen excitation created by an inelastic scattering event than has been accessible in the past. This should allow, for instance, measurement of structural anisotropy using EXELFS on an atom column by column basis. It also seems possible that very accurate control of the position and propagation direction of the incident and final beam *wavepackets* may allow us to use non-zero impact parameter scattering to probe specific anisotropic specimen properties.

Coherence Property Measurements of Phonon-, Plasmon-, and Ionization-loss Electrons and Their Contributions to the Stobbs Factor

Rodney Herring
University of Victoria Canada

Energy-filtered electron holography of diffracted beams has been used to measure the degree of coherence of energy-loss electrons. Since the fast electrons of the primary beam when passing through the material create phonons, plasmons, magnons, etc., the energy-loss electrons retain the coherence properties of these quasi-particles such as their lateral coherence width, which is required for understanding nanoscience and for our development of nanotechnology. Interestingly, the ability to measure the intensity of ionization-loss electrons will enable the creation of a new magnetic microscopy method, as well as, the coherence properties of the magnon. This work has also led to a better understanding of the Stobbs factor, which is a contrast mismatch between experimental lattice images and simulated lattice images that is required for the development of high-resolution quantitative lattice imaging where the type and number of atoms making up a lattice image can be determined. A mathematical expression is derived that adequately predicts the Stobbs factor.

Challenges of Electron Microscopy in Materials Science

Manfred Ruehle, Christoph Koch, Wilfrid Sigle, Peter van Aken
Max Planck Institute for Metals Research, Stuttgart/Germany

The properties of materials depend on their microstructures. An important task of materials science (materials physics) is to reveal the correlation between microstructure and therelevant property. This, in turn, requires the analysis of defects in the materials or materials systems. Defects can be distinguished according to their dimensionality: 0-dimensional (point defects), 1-dimensional (dislocations), and 2-dimensional (interfaces) defects. It is crucial that the defects are characterized and their critical parameter be determined.

Different TEM techniques allow the determination of the structure, and composition of the defect and its surrounding. Qualitative and semi quantitative results can be obtained rather easy. A quantitative evaluation (Q-TEM) requires the determination of the desired value including error bars (reliabilities). Q-TEM is often very time consuming and is, unfortunately, not pursued in many laboratories. It is however essential that Q-TEM is being done to solve critical problems.

In the talk several examples will be presented, mainly for grain boundaries (in metals and ceramics) and interfaces (between metals and oxides). Most results obtained so far (in our laboratory) do not possess the necessary accuracy so that they can be used to a critical comparison with results obtained by modelling using different approaches.

Advanced instrumentation (aberration corrected instruments with high stabilities) and better TEM specimens will lead to experimental results with better reliability.

New Views of Materials Through Aberration-Corrected STEM

S. J. Pennycook[1,2], M. Varela[1], M. F. Chisholm[1], A. Y. Borisevich[1], A. R. Lupini[1], K. van Benthem[3,1], M. P. Oxley[1], W. Luo[1,2], S-H. Oh[1,4], D. Kumar[4,1], D. L. Sales[5], S. I. Molina[5], A. G. Marinopoulos[2], and S. T. Pantelides[2,1]

[1]Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6030, USA
[2]Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, USA
[3]Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6487, USA
[4]Department of Mechanical Engineering, North Carolina A&T State University, Greensboro, NC 27410, USA
[5]Departamento de Ciencia de los Materiales e I.M. y Q.I., Facultad de Ciencias, Universidad de Cádiz, Cádiz, Spain

The aberration-corrected STEM provides Z-contrast images and electron energy loss spectroscopy with resolution near or below 1 Ångstrom and 0.5 eV, respectively, which represents unprecedented sensitivity for determining atomic arrangements, impurity sites and local electronic structure in materials. For example, charge carriers can be located within the unit cell of the high-temperature superconductor YBCO, and charge transfer across a superconductor/ferromagnet interface can be quantified and linked to the material's properties. Similarly, column-by-column compositional mapping of InAsP quantum wires coupled to elasticity calculations explains their growth morphology and optical properties. The aberration-corrected STEM also has a much decreased depth of field, which can be used to provide structural information in three dimensions by optical sectioning, similar in principle to confocal optical microscopy. Individual Hf atoms have been located within a $Si/SiO_2/HfO_2$ gate dielectric structure to a precision of 0.1 x 0.1 x 1 nm, and the perturbed electronic structure linked by density functional theory to macroscopic device properties. Individual gold atoms have been imaged inside Si nanowires in substitutional and interstitial configurations, with number densities that are in order of calculated formation energies.

This research was sponsored by the Office of Basic Energy Sciences, Division of Materials Sciences and Engineering and by appointment (MPO, KvB) to the ORNL Postdoctoral Research Program administered jointly by ORNL and ORISE.

A Few Practical Aspects of Atomic-Column Imaging Using ADF and EELS

Kimoto[1], T. Asaka[2,1], T. Nagai[3,1], M. Saito[1], K. Ishizuka[4,1], Y. Matsui[1]

[1] National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki, 305-0044, Japan
[2] Institute for Advanced Electron Microscopy, Brookhaven National Laboratory, Upton, NY 11973, USA
[3] ERATO, Japan Science and Technology Agency, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8562, Japan
[4] HREM Research, Inc., 14-48 Matsukazedai, Higashimatsuyama, Saitama, 355-0055 Japan

Atomic-column resolution in STEM and EELS has been recently achieved by a few authors [1]. We have also demonstrated atomic-column imaging of $(La,Sr)_3Mn_2O_7$ and Si_3N_4 [2]. Here, we discuss a few practical aspects of atomic-column imaging; the atomic-site dependence and the energy-loss dependence of the spatial resolution are elucidated on the basis of the experimental results and multislice calculations. We describe two factors for realizing atomic-column imaging in terms of localization in elastic and inelastic scattering. One is the channeling of the incident probe due to dynamical diffraction [3], which has atomic-site dependence. The other is the localization in inelastic scattering [4]; in addition to the energy-loss dependence of delocalization, we point out its dependence on the offset energy from the ionization energy, *i.e.*, an additional localization factor concerning the Bethe surface. The present atomic-column observations indicate that the incoherent EELS imaging, which can be interpreted intuitively, is achievable under appropriate experimental conditions, such as high energy-loss, a small convergence angle and a large collection angle.

[1] M. Varela, *et al.* PRL 92(2004) 095502; M. Bosman, *et al.* PRL 99(2007) 086102; M.P. Oxley, *et al*. PRB 76(2007) 064303.
[2] K. Kimoto, *et al.* Micron (in press); K. Kimoto, *et al.* (accepted).
[3] J. Fertig and H. Rose Optik 59(1981) 407; R.F. Loane, *et al*. Acta Cryst. A 44 (1988) 912.
[4] S. J. Pennycook Contemp. Phys. 23(1982) 371; D. A. Muller and J. Silcox Ultramicrosc. 59(1995) 195; R. F. Egerton Micron 34(2003) 127; M.P. Oxley, *et al.* PRL 94(2005) 203906.

Imaging and Spectroscopy of Nanoscale Systems in the STEM

N. D. Browning[1,2], J. P. Bradley[3], M. Chi[1], R. P. Erni[4], B. C. Gates[1], M. Herrera[1], A. Kulkarni[1], S. Mehraeen[1], N. Okamoto[1], Q. Ramasse[5], B. W. Reed[2]

[1] Department of Chemical Engineering and Materials Science, University of California-Davis, 1 Shields Ave, Davis, CA 95616, USA
[2] Chemistry, Materials and Life Sciences Directorate, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA
[3]Institute for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA
[4] EMAT, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium
[5] Lawrence Berkeley National Laboratory, National Centre for Electron Microscopy, 1 Cyclotron Road, Berkeley, CA 94720, USA

The recent developments of aberration correction and monochromation have given the scanning transmission electron microscope (STEM) unprecedented new capabilities to investigate the atomic and electronic structure of nanoscale materials. In particular, aberration correctors have pushed spatial resolution into the deep sub-angstrom regime while monochromators are pushing spectral resolution rapidly towards the sub-100meV level. However, these capabilities also present challenges for the interpretation and routine quantification of experimental images and spectra. In the case of the aberration correctors, increases in beam current mean that utilizing the same experimental procedures as have been traditionally used for materials science quickly leads to electron beam modification of the sample. In the case of the monochromators, the resolution of the spectrum means that care must now be taken in interpreting fine-structure, especially in the low-loss region of the spectrum. Here, examples of the types of experiments that can readily be performed with aberration correctors and monochromators will be presented. Emphasis will be placed on recent results from UC-Davis, LLNL and LBNL showing the application of these methods to understanding the properties of quantum dots and quantum wells. The potential to extract information from "low-dose" STEM experiments will also be highlighted by the analysis of a series of nanoscale catalysts particularly susceptible to electron beam modification and particle motion.

Structural Analysis of Layered Thermoelectric Oxides Using Aberration Corrected STEM/EELS

Y. Zhu[1], P. Oleynikov[1], V. Volkov[1], L. Wu[1], J.C. Zheng[1], R.F. Klie[2], H. Inada[3], and R.D. Twesten[4]

[1] Brookhaven National Laboratory, Upton, NY 11973
[2] University of Illinois at Chicago, Chicago, IL 60607
[3] Hitachi High Technologies America, Pleasanton, CA 94588
[4] Gatan, Inc. Pleasanton, CA 94588

Cobaltates are of great interest due to its unique thermoelectric and magnetoresistance properties and practical energy-related thermal power applications. In order to understand the origin of these physical properties of layered $Ca_3Co_4O_9$, more precisely, $[Ca_2CoO_3]_{0.62}CoO_2$, cobalt oxides that exhibits high thermoelectric power, a clear understanding of the crystal and electronic structure of the materials is required. $[Ca_2CoO_3]_{0.62}CoO_2$ crystal has a complex misfit lattice structure with rock-salt-type $[Ca_2CoO_3]$ slabs and interpenetrating CdI_2-type $[CoO_2]$ layers stacked along the *c*-axis with an incommensurate modulation along the *b*-axis. The structure can be approximated as a 3D commensurate cell containing 8 $[CoO_2]$ motifs along the *b*-axis that stack along the *c*-axis with 5 $[Ca_2CoO_3]$ blocks.

Single crystal and powder samples were analyzed using electron diffraction including electron diffuse scattering, HRTEM, and synchrotron x-ray. A 4-demensional (4D) structure model was proposed first and then refined by Rietveld algorithm using a 4D super-space approach in order to take the incommensurate modulation into account. To further observe the possible difference in electronic and thermal conductivities of the CoO_2 and the CoO layers (electron crystal and phonon glass) in the $[CoO_2]$ and $[Ca_2CoO_3]$ motifs, respectively, simultaneous acquisitions of column-by-column scanning transmission electron microscopy (STEM) and electron energy-loss spectroscopy (EELS) were carried out using state-of-the-art aberration corrected microscopes, in particular the new Hitachi HD2700. Emphasis was placed on the local lattice order and disorder, variation in oxygen-hole concentration, cation vacancies, bonding states, and valencies across the misfit layers as well as within the layers. Significant in-plan lattice displacement and modulation were observed in atomically resolved STEM-ADF (annular-dark-field) imaging and the results were compared with ADF image simulation. By analyzing the O K-edge prepeak intensity and intensity ratio of the Co-$L_{3,2}$ edges we observed significant charge transfer between the rock-salt CoO layer and CdI_2-like $[CoO_2]$ layer. The EELS data agree well with out DFT based electronic structure calculations.

The authors would like thank J. Qing, and Q. Li for providing samples and J. Hanson for collecting x-ray data at NSLS. The work at BNL was supported by U.S. DOE, BES (DE-AC02-98CH10886).

The Characterization of Helium Bubbles in SiC/SiC Composite Using EELS and the Current Development on Structure Reversion

Ji-Jung Kai and Fu-Rong Chen

Center for Electron Microscopy, Department of Engineering and System Science
National Tsing Hua University, Hsinchu, TAIWAN, 300, R.O.C.

Nuclear reactor core is a very crucial environment for structural materials, not only the high temperature and corrosive atmosphere but also very high flux of fast neutrons which induce severe radiation damage in the materials. For advanced nuclear power reactor, in order to reach higher thermal efficiency, we need to have much higher coolant temperature (1000^{o} C) which is a even great challenge to structural materials. SiC/SiC composites are one of the candidate materials for the fusion reactor first wall and blanket materials because of the very high temperature mechanical strength (above 1000^{o}C) and the low activation nature of them. In order to simulate the D-T fusion reactor environment, triple -ion-beam simultaneous irradiation (Si^{+}, He^{+}, and H^{+}) was performed to simulate high energy neutrons, helium ions, and deuterium and tritium ions, respectively. The major microstructural evolution includes the formation of He bubbles and voids which may affect the mechanical property of the materials. For understanding the fundamentals of the role of He and D and T in the formation of these cavities, it is important to measure the density of He, or D and T in the bubbles and in the matrix. This phenomenon was studied in detail by using high resolution transmission electron microscopy (HRTEM) with electron energy loss spectroscopy (EELS). We did careful measurements on the blue shift of the He K-edge with regard to the diameter of He bubbles which in turn relates to the density of He (also pressure) in the bubbles. Using this method, we can precisely determine the amount of He inside the bubbles and in the matrix of SiC. Similar method was used for hydrogen measurement. Too. Nevertheless, due to it's very high mobility at this temperature range, we did not find H-peak in the EELS spectrum either in the bubbles or in the matrix. However, from the distribution of bubble density and diameter, we concluded that hydrogen played an important role in the nucleation stage to stabilize the bubble which in turn enhanced the number density of bubbles.

We have started to work on structure reversion from the exit wave by using both "Reverse Mutislice Method" and "Reverse Channeling Method". The final goal for this is to achieve atomic resolution tomography. Two cases were studied, namely a simulated $NiSi_2$ example and an experimental $SrTiO_3$ case. From the reverse multislice method, the simulated wedge-shaped $NiSi_2$ can be retrieved completely. From the reverse channelling method, it also shows close results to the actual number of Ni and Si atoms. The results for the experimental $SrTiO_3$ [110], both methods showed a reasonable agreement. The number of atoms in each of the atomic columns is in a difference of one atomic layer. However, without an exit wave from another view direction, it is too soon to conclude the exact result. It is believed that both the reverse multislice method and the reverse channelling method are having the potential to retrieve the structure information.

There are three bottlenecks in bio-imaging using electron microscope. First of all, the bio-sample is usually composed of light elements that interact very weak with electron and such that give rise to weak contrast in the image. Second, the TEM has to be operated in vacuum, therefore, no live sample is allowed and the bio-sample usually is dried out before it is put into TEM system.

Finally, the bio-sample usually suffers from the radiation damage under the high energy electrons during experiment.

In order to overcome the above obstacles for bio-imaging using TEM and its related analytical techniques, The bio-imaging center supported by NSC, IOP, academic Sinica and NSRRC was funded to develop an TEM that allows us to study phase contrast of live bio-samples. In our proposed TEM system, the live bio-sample can be studied in a sealed wet environment with the combined capability of obtaining phase contrast. The preliminary results of the wet cell and electronstatic phase plate will be shown in the presentation. The partial coherent imaging theory of phase contrast from electrostatic phase plate is being developed. An iterative algorithm and fractional Fourier transformation to recover the pure phase image. This method may reduce the number of images needed for reconstructing the “phase” tomography”.

Cathode Lens Microscopy: The Next Generation

Rudolf M Tromp
IBM T.J. Watson Research Center, PO Box 218, Yorktown Heights, NY 10598

Low Energy Electron Microscopy (LEEM) and Photo Electron Emission Microscopy (PEEM) are cathode lens instruments that have become useful research techniques only during the last twenty years.

LEEM is used mostly to study the structure of surfaces and interfaces, relying on contrast mechanisms derived from Low Energy Electron Diffraction. PEEM on the other hand uses the photoelectron emission process to obtain spatially resolved spectroscopic information on the valence band, core levels, or magnetic structure.
Typically, spatial resolution is limited to 5-10 nm in LEEM, and 10-50 nm in PEEM.
While aberration correction is now becoming well-established in transmission electron microscopes, there is still significant room for development of aberration correction in LEEM and PEEM instruments.

Proof of principle of mirror-based correction of Cs and Cc has been established recently.
Additionally, inclusion of an electron energy filter greatly enhances the analytical capability of the instrument, but at the expense of significantly increased instrument complexity.
In this talk I will present results obtained recently with a much simplified imaging electron energy filter which, provides excellent energy and spatial resolution with the simple addition of a strategically placed slit in a standard LEEM instrument. I will also present the design of a new aberration corrected LEEM/PEEM instrument with a compact footprint, straightforward design, and a spatial resolution in the 2-3 nm range. This instrument is presently under construction and is expected to come online in 2008.

Finally, I will discuss the development and installation of new light sources that make lab-based spectroscopic PEEM a reality.

Advances in Multi-Dimensional Imaging Techniques for the Modern Scanning TEM

R.D. Twesten, C.R. Booth, R.T. Harmon, S. Meyer and P.J. Thomas
Gatan Research and Development, Gatan Inc., Pleasanton CA 94588

Computer automation, high-efficiency spectrometers, and high-speed cameras in combination with modern electron microscopes allow the routine acquisition of information rich, multi-dimensional data sets in a simplified, automated manner. These multi-dimension data sets run the gamut from straight forward, line scans of EELS spectra to exotic combinations of spectral, real-space and k-space information. Continuing advances in computing power and processing tools enable rapid identification and extraction of the elemental, chemical and physical information contained within these data sets. Such improvements have made these rich data collection and analysis techniques available to nearly all characterization laboratories.

While software and automation allows routine acquisition of these data sets, obtaining quality data requires the understanding of the limits and trade offs inherent in the experiment. We will reference several case studies that serve to illustrate the strength and potential pit falls of these techniques with particular emphasis on the simultaneous acquisition and analysis of complementary techniques such as EELS and EDS spectrum imaging, spatially resolved diffraction, and electron tomography.

Novel Approaches for In-situ and 3D Microscopy

Konrad Jarausch[1], Xiaofeng Zhang[1], Donovan Leonard[2], Takeo Kamino[3]
[1] Hitachi High Technologies America, Pleasanton CA
[2] North Carolina State University, Raleigh NC
[3] Hitachi High Technologies, Japan

The nanoscale study of complex 3D geometries and in dynamic processes is driving the continuing development of instrumentation and methodology. New tools are required for characterizing nanoparticles with complex three-dimensional (3D) structures and properties. Furthermore the study of nanoparticles in different ambient temperatures and partial pressures is required to understand how structure-property relationships are effected by their environment. Electron microscopy techniques are widely used to characterize morphology, composition and electronic properties of materials at the atomic or near-atomic scale but are not well suited for analyzing complex 3D structures or samples in different ambients. A nanoparticle must be either tilted or rotated with respect to the electron beam to enable 3D analysis but this is often limited by STEM/TEM pole-piece geometry. The high vacuum of a TEM/STEM also precludes the study of living specimens or specimens in a gas or liquid environment. Here we report recent advances in instrumentation and methodology to overcome some of these limitations.

A novel rotation holder has been developed [1] which allows analysis from a full 360 degrees as opposed to traditional tomographic tilt-series based analysis which can suffer from missing wedge artifacts [2]. Focused ion beam (FIB) based techniques can be used for site-specific sample preparation and for attaching samples to such rotation holder stubs. A new protocol for functionalizing these sample holders has been developed to enable 360° TEM/STEM observation of individual nanoparticles and nanostructures [3]. The three step process includes FIB milling to customize sample stub geometry, thin film deposition for substrate selection and subsequent chemical functionalization for nanoparticle adhesion. This protocol was used to determine the morphology and local material properties of individual Au/SiO2 core-shell nanoparticles used in a DNA detection assay.

A new 300kV TEM has been developed for atomic resolution studies of gas-solid reactions at elevated temperatures. This unique design combines a LaB6 source with differential pumping aperture only above the sample to provide a unique combination of imaging performance and in-situ capability. The LaB6 source is much less sensitive to vacuum fluctuations than a field emission source, and allows for interface and boundary imaging with fewer delocalization effects. Gas can be introduced directly into the specimen chamber while samples are heated up to 1500 °C to activate the gas–solid interaction. The stability and gas-injection design of the sample holder allows these interactions be studied at atomic resolution [4]. The microscope is equipped with a high-speed CCD and has been used to capture real-time movies of layer-by-layer growth of nanoparticles. Several examples will be shown of how this low-cost E-TEM is being used to support the development of catalysts and nano-materials.

References:

[1] Koguchi, M., et al., J. Of Electron Microscopy 50(3), 235-241 (2001).
[2] Kawase, N., et al., Ultramicroscopy 107, 8-15 (2007).
[3] Jarausch, K., et. al., Imaging and Microscopy (in press)
[4] T. Kamino, T. Yaguchi, M. Konno, A. Wwatabe, T. Marukawa, T. Mima, K. Kuroda, H. Saka, S. Arai, H. Makino, Y. Suzuki, and K. Kishita, Journal of Electron Microscopy 54 (2005) 497-503.

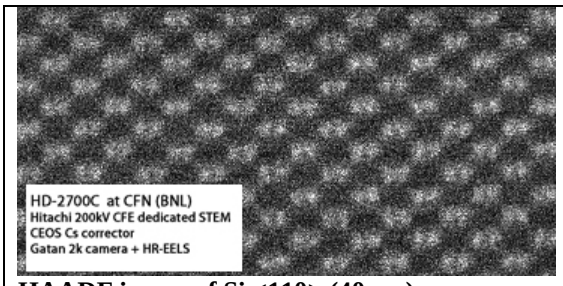
Hitachi HD2700C 200kV CFE Cs corrected STEM

Cold Field Emission electron source (Hitachi patent):
0.35eV energy resolution, in a 2A spot with 200pA of beam current!
Cs corrected STEM (integrated CEOS corrector):
1A HAADF resolution, >40mrad illumination semi-angle
EELS performance (new Gatan HR-Enfina design):
ultra-fast spectrometer with 3rd order correction (300 spectra/sec)
Diffraction analysis (Gatan 2.6k Orius Camera)
nanobeam (NBD) + convergent beam diffraction (CBED)

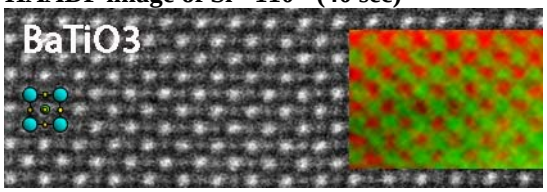
HD-2700C now installed at BNL

HD-2700C at BNL's CFN

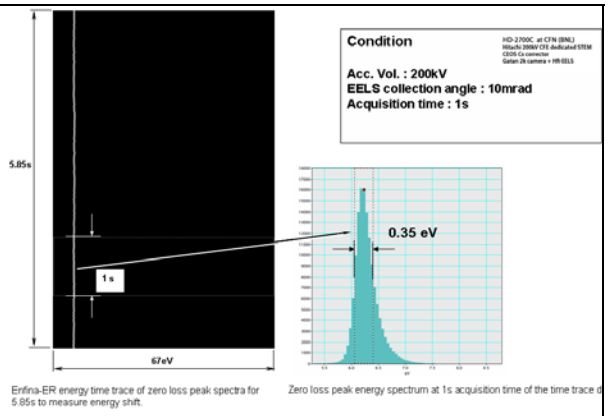
*Remote operation
*Custom sample holders
- specimen heating + cooling (Gatan)
- 360 degree rotation (Hitachi*)
*Two stage projection optics
*Ultra-fast installation time:
(only 2 weeks from uncrate to resolution)



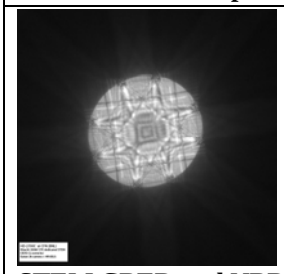
HAADF image of Si <110> (40 sec)



HAADF + EELS Spectrum Image (BaTiO3)

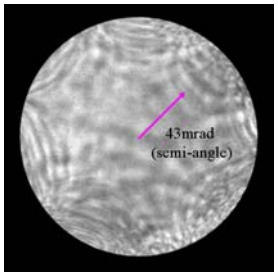


Energy resolution and stability of CFE
(0.35 eV, 1 second acquisition time)
***with* beam-current (200pA / 2A)**



STEM CBED and NBD (Si <100>)

> 40 mrad
(semiangle)



ABSTRACTS

DAY TWO

Atomic-Scale Studies of Complex Oxide Interfaces Using Aberration-Corrected Z-contrast Imaging and EELS

R.F. Klie, Y. Zhao, G. Yang
Department of Physics, University of Illinois at Chicago, 845 W Taylor Street, M/C 273, Chicago, IL 60607

Interfaces in complex oxide materials have been an enduring theme in materials physics, where the interplay of the reduced dimensionality, proximity effects, and surface relaxation and reconstruction creates interfacial states that are distinct from their bulk counterparts. It has been recognized that the perovskite oxides provide a unique opportunity to bring materials with diverse and mutually exclusive properties into intimate contact, and create interfaces with excellent structural and chemical compatibility and potentially novel properties.

In this presentation, aberration-corrected Z-contrast imaging and EELS in combination with in-situ heating/cooling experiments of interfaces in perovskite-type oxides will be shown. More specifically, we utilize the aberration-corrected JEOL2100FS at Brookhaven National Laboratory, the aberration-corrected VG HB-601UX at UIC and the conventional JEOL2010F TEM/STEM for our experiments in the temperature range between 10 K and 700 K. We will discuss our recent results, including the role of oxygen vacancies in the ultrathin $SrTiO_3$/GaAs hetero-interface, the effect of the spin-state transition of the Co^{3+} ions in $LaCoO_3$, and the effects of charge transfer in the $Ca_3Co_4O_9$.

The ultrathin $SrTiO_3$/GaAs interface consists of five monolayers of $SrTiO_3$(001) on GaAs (110), which are shown to be atomically flat without any obvious surface reconstruction and no significant diffusion between the film and the substrate.[1] While the $SrTiO_3$ film is highly oxygen deficient, the Fermi-level remains unpinned at the interface after a Ti-prelayer deposition.[2] Our ab-initio DFT calculation suggest that O-vacancies at the hetero-interface compensate the dangling bonds from the unreconstructed As-terminated GaAs (110) surface, and therefore play an important role in engineering the interfacial properties of this novel high-k dielectric.

Our temperature study of $LaCoO_3$ shows the effect of the Co^{3+}-ion spin-state transition, which occurs at T_s~90K, on the fine-structure of the O K-edge. While the crystal structure of $LaCoO_3$ does not change during the in-situ cooling experiment to 10K, the O K-edge pre-peak intensity decreases for $T>T_s$. A detailed analysis of the O K-edge fine-structure and comparative DFT calculations will be presented.[3]

The misfit-layered structure $Ca_3Co_4O_9$, consists of triple rock salt-type layers Ca_2CoO_3 and single CdI_2-type CoO_2-layers stacked along the *c*-axis.[4] We will present aberration-corrected Z-contrast imaging and atomic-column resolved EELS in conjunction with multiple scattering calculations to elucidate the effects of charge transfer between the different Co-layers and its effect on the thermoelectric properties of $Ca_3Co_4O_9$. Detailed analysis of this structure and the effects of in-situ heating and cooling on the Co-valence and spin-state will be discussed.

References:

[1] R. F. Klie, Y. Zhu, E. I. Altman, et al., Applied Physics Letters **87** (2005).
[2] Y. Liang, J. Curless, and D. McCready, Applied Physics Letters **86** (2005).
[3] R. F. Klie, J. C. Zheng, Y. Zhu, et al., Phys. Rev. Lett. (submitted) (2006).
[4] A. C. Masset, C. Michel, A. Maignan, et al., Physical Review B **62**, 166 (2000).

Imaging and Exit Wave Reconstruction in an Aberration-Free Environment

A. I. Kirkland*, Lan-Yun Chang, S. Haigh and C. J. D. Hetherington
Department of Materials, Parks Road, Oxford, OX1 3PH, UK
*Corresponding Author

Electron-Optical aberration correctors are now firmly established as a key component in many commercial Transmission and Scanning Transmission Electron Microscopes installed around the world. Equally, algorithms that recover the complex specimen exit plane wavefunction from a series of images recorded using one of several possible experimental geometries have also advanced to the point where several commercial software implementations utilizing this approach are readily available.

This paper will discuss the combination of these two complementary approaches with particular reference to exit wave reconstruction from a series of tilted illumination images recorded for several azimuths. This latter geometry benefits substantially from initial electron optical aberration correction which enables larger tilt angles to be used during data acquisition. Direct correction of the spherical aberration also relaxes the otherwise stringent relationship that conditions the defocus and illumination tilt. I will discuss recent calculations that define optimal conditions for tilt azimuth based reconstructions with reference to the effects of higher order aberrations beyond those that can be corrected directly as well as the effects of finite chromatic aberration and sample thickness. It will be shown that overall these effects combine to allow optimal tilt angles of up to ca. 17mrad to be used (at 200kV) compared to ca. 4mrad in uncorrected instruments with a consequent improvement in the resolution of the reconstructed data.

In addition to the above theoretical considerations exit wave reconstruction under aberration corrected conditions also places stringent requirements on instrumental stability. We have recently installed our second generation double corrected 200kV instrument (JEOL JEM 2200MCO) in Oxford. This microscope incorporates both imaging and probe forming aberration correctors in addition to a number of design improvements leading to increased stability. Initial data from this machine will be presented demonstrating axial information transfer at <0.8nm in TEM.

Catalyst Nanoparticles Imaged Using Aberration Correction, Focal Series Restoration and Electron Tomography

Rafal E. Dunin-Borkowski and Lionel Cervera Gontard
Center for Electron Nanoscopy, Technical University of Denmark,
DK-2800 Kongens Lyngby, Denmark

Angus I. Kirkland, Lan-Yun Chang and Crispin Hetherington
Department of Materials, Oxford University, Parks Road, Oxford OX1 3PH, U.K.

Dogan Ozkaya
Johnson Matthey Technology Centre, Blounts Court,
Sonning Common, Reading RG4 9NH, U.K.

Industrial catalysts usually comprise crystalline particles of high atomic number that have sizes of between 1 and 20 nm and are supported or embedded in a lower atomic number matrix. In this talk, I will present a selection of recent results that illustrate how modern transmission electron microscopy techniques can be used to provide quantitative and useful information about 5-10 nm platinum catalyst nanoparticles supported on carbon. I will concentrate on the use of:

1. Spherical aberration correction and focal series restoration to improve image quality, visibility and interpretability;
2. High-angle annular dark-field electron tomography to characterize the three-dimensional morphologies, sizes and positions of the particles and the surrounding carbon support;
3. Low-angle annular dark-field imaging to assess the crystallinity of the particles and its influence on measurements of particle size distributions;

I will conclude by discussing the prospects offered by combining these and other techniques.

References

Aberration-corrected imaging of active sites on industrial catalyst nanoparticles, *L Cervera Gontard, L-Y Chang, C J D Hetherington, A I Kirkland, D Ozkaya and R E Dunin-Borkowski*, Angew. Chemie. **46** (2007), 3683-3685.

Delocalisation in images of Pt nanoparticles, *L Cervera Gontard, R E Dunin-Borkowski, M J Hytch and D Ozkaya*, J. Phys. Conf. Ser. **26** (2006), 292-295.

Electron tomography of Pt nanocatalyst particles and their carbon support, *L Cervera Gontard, R E Dunin-Borkowski, R K K Chong, D Ozkaya and P A Midgley*, J. Phys. Conf. Ser. **26** (2006), 203-206.

Atomic-Scale Chemical Imaging by Aberration-Corrected Microscopy

D. A. Muller,[1]* L. Fitting Kourkoutis,[1] M. Murfitt,[2] J. H. Song,[3,4] H. Y. Hwang,[4,5] J. Silcox,[1] N. Dellby,[2] O. L. Krivanek[2]

[1] Applied and Engineering Physics, Cornell University, Ithaca, NY, 14853, USA
[2] Nion Co., Kirkland, WA 98033, USA
[3] Department of Physics, Chungnam National University, Daejeon 305-764, Korea
[4] Department of Advanced Materials Science, University of Tokyo, Kashiwa, Chiba 277-8561, Japan

Using a fifth-order aberration-corrected scanning transmission electron microscope, which provides a factor of 100x increase in signal over an uncorrected instrument, we demonstrate two-dimensional elemental and valence-sensitive imaging at atomic resolution using electron energy loss spectroscopy, with acquisition times of well under a minute.

Applying this method to the study of a La0.7Sr0.3MnO3/SrTiO3 superlattice, we find an asymmetry between the chemical intermixing on the Mn/Ti and the La/Sr sublattices and corresponding changes in the formal valence. The changes in the Mn and Ti bonding as the local environment changes allow us to distinguish true chemical interdiffusion from imaging artifacts.

Cs Correction and Focal-Series Reconstruction of the Exit-Surface Wave

Michael A. O'Keefe
National Center for Electron Microscopy, Materials Sciences Division, Lawrence Berkeley National Laboratory 2-200, 1 Cyclotron Road, Berkeley, CA 94720, USA

The current revolution in nanoscale science and technology requires instrumentation for observation and metrology of nano-devices operating at the level of a few atoms, calling for microscopes with sufficient resolution for accurate atomic-scale imaging [1]. Sub-Ångström resolution in the high-resolution transmission electron microscope (HRTEM) has been achieved in the last few years by hardware aberration correction [2], software aberration correction [3-4], and electron holography [5].

Focal-series reconstruction (FSR) of the exit-surface electron wave in a non-hardware-corrected FEG-TEM has been used to produce Cs-corrected images with resolution out to the information limit of the microscope [6]. Realization of such resolution requires meticulous attention to experimental conditions, including careful balance of the tradeoff between high-frequency transfer and Cs-induced dispersion leading to large delocalizations that can place significant limits on the reconstructable field of view. In a hardware-corrected microscope, application of FSR is straightforward due to the low delocalization, allowing very accurate reconstruction of the exit-surface electron wave over large fields of view.

[1] *Sub-Ångstrom Electron Microscopy for Sub-Ångström Nano-Metrology*, Michael A. O'Keefe & Lawrence F. Allard, Proceedings of National Nanotechnology Initiative Grand Challenge Workshop on Instrumentation and Metrology for Nanotechnology, National Institute of Standards and Technology, Gaithersburg, MD (2004) 52-53. http://www.osti.gov/dublincore/gpo/servlets/purl/821768-E3YVgN/native/821768.pdf

[2] M Haider et al, *Ultramicroscopy* **75** (1998) 53-60; *NATURE* **392** (23 April 1998) 768-769.

[3] A. Thust, W.M.J. Coene, M. Op de Beeck & D. Van Dyck, *Ultramicroscopy* **64** (1996) 211.

[4] W.M.J. Coene, A. Thust, M. Op de Beeck & D. Van Dyck, *Ultramicroscopy* **64** (1996) 109.

[5] M. Lehmann & H. Lichte, *Crystal Research and Technology* **40** (2005) 149.

[6] M.A. O'Keefe, E.C. Nelson, Y.C. Wang & A. Thust, *Phil. Mag. B* **81** (2001) 11, 1861-1878.

Nanoscale Elemental Mapping in TEM and STEM

J. Bentley
Materials Science and Technology Division, Oak Ridge National Laboratory,
P.O. Box 2008, Oak Ridge, TN 37831-6064

For more than a decade elemental mapping by electron microscopy at resolutions approaching 1nm has been a core capability at the ORNL Shared Research Equipment (SHaRE) User Facility. Quantitative composition mapping has been emphasized and valence or bonding information has been less frequently studied. Two techniques have been used: energy-filtered transmission electron microscopy (EFTEM) and spectrum imaging in the scanning transmission electron microscopy (STEM) mode, often with simultaneous energy-dispersive X-ray spectroscopy (EDS) and electron energy-loss spectroscopy (EELS). Results of applications to materials such as nanostructured ferritic alloys, thin-film magnetic recording media based on Co-Cr and Co-Pt, Y-Ni-O nanocomposites, ceria abrasives, and nanostructured spinel, will be used to illustrate the advantages and limitations of the methods. The impact of recent and expected developments in instrumentation such as aberration correctors will be discussed.

Research supported by the Laboratory Directed Research and Development Program of ORNL, by the Office of Fusion Energy Sciences, by the Office of Nuclear Energy, Science and Technology through I-NERI 2001-007-F and at the ORNL SHaRE User Facility by the Division of Scientific User Facilities, Office of Basic Energy Sciences, U.S. Department of Energy, under Contract DE-AC05-00OR22725 with UT-Battelle, LLC. Collaborations with Drs. J.F. Al-Sharab, C.B. Carter, L. Chaffron, F. Cosandey, N.D. Evans, S.R. Gilliss, D.T. Hoelzer, S. McKernan, J.D. Risner, R. Sinclair, Z.L. Wang and J.E. Wittig are gratefully acknowledged.

Catalyst Characterization via Aberration-Corrected STEM in the HTML User Program

L. F. Allard,* D. A. Blom,*,[1] S. A. Bradley,** M. J. Yacaman*** and P. Ferreira***
*Oak Ridge National Laboratory, Oak Ridge, TN 37831-6064
**UOP LLC, Des Plaines, IL 60017
***University of Texas at Austin, Austin, TX 78712

The High Temperature Materials Laboratory (HTML) at Oak Ridge National Laboratory provides access to advanced instrumental techniques for materials characterization to university and industrial researchers. A capability to characterize materials structures at sub-Ångström resolution levels is provided by the JEOL 2200FS-AC STEM/TEM instrument, which is equipped with a hardware corrector (CEOS GmbH, Heidelberg, Ger.) on the incident probe, to allow high-angle annular dark-field images to be recorded. The instrument is housed in ORNL's new Advanced Microscopy Laboratory (along with 3 other aberration-corrected instruments), which has a controlled environment to allow routine operation of the instrument at its specified resolution. Coupled with the HTML's *ex-situ* catalytic reactor capabilities, the new microscope is particularly useful for imaging metal particles on catalysts, in studies such as the behaviour of Pt atoms and clusters on a variety of oxide supports when reduced, the core-shell structure of Au-Pd bimetallic nanoparticles, Ag on alumina catalysts for advanced lean NOx applications, and ordering effects in bimetallic Pt-Co catalysts for fuel cell applications. Results from these studies will be discussed, and future directions for *in-situ* studies at the atomic level will also be reported.

1 Present address: EM Center, University of South Carolina, Columbia, SC 29208

Aberration-Corrected STEM of MoVTeNbO Complex Oxide Catalysts

D. A. Blom*, W. D. Pyrz**, D. J. Buttrey**, T. Vogt*, V. V. Guliants***, and N. R. Shiju***

*NanoCenter, University of South Carolina, Columbia, SC 29208
**Center for Catalytic Science and Technology, Department of Chemical Engineering, University of Delaware, Newark, DE 19716
***Department of Chemical and Materials Engineering, University of Cincinnati, Cincinnati, OH 45221

Acrylonitrile is an important intermediate in the production of a wide variety of important chemicals [1-3]. The current commercial methods for the production of acrylonitrile use propene over multi-component Bi-Mo-O_x catalysts [1]. Due to the increasing cost of propene, there is significant interest in replacing the more expensive propene with propane as a feedstock. The difficulty in switching to propane is the development of a multifunctional catalyst that is able to activate first a propane C–H bond and subsequently complete the ammoxidation to acrylonitrile without complete combustion to CO_x + H_2O, or other intermediate oxidation products. The dominant candidate for this next-generation process is based on the multiphase MoVTeNbO complex oxide system [1-3].

The best $MoVTeNbO_x$ catalysts with respect to selectivity and activity is a two-phase mixture comprised of an orthorhombic network bronze phase (M1) and a hexagonal tungsten bronze (HTB)-type phase (M2) [2,3]. Transmission electron microscopy was initially used to identify unit cells and symmetry, and to obtain HREM images of the two phases. Starting with preliminary metal coordinates and initial guesses of the oxygen coordination, simultaneous Rietveld refinement of high resolution neutron and X-ray powder diffraction data led to models for both structures in which occupancies and valences were identified [3]. The Rietveld refinement of M1 involves a fit with roughly 200 adjustable parameters; the M2 structure is somewhat less complex, but still required simultaneous refinement of XRD and NPD data sets.

In this work we use Cs-corrected STEM imaging to further probe the structure of the M1 and M2 phases to provide direct evidence confirming the refined model structures. We show that the hexagonal channels in the M1 structure are filled with a high-Z cation in accordance with the refined model which incorporates Te into the hexagonal channels. In addition, some of the heptagonal channels are filled, again in accordance with the refined structure model.

[1]R. K. Grasselli, *Topics in Catal.*, **21** (2002) 79.
[2]R. K. Grasselli, *Catal. Today*, **99** (2005) 23.
[3]P. DeSanto Jr. D. J. Buttrey, R. K. Grasselli, C. G. Lugmair, A. F. Volpe Jr., B. H. Toby, and T. Vogt, *Z. Kristallogr.* **219** (2004) 152.

Participants

	Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
A									
	Lawrence F. Allard	Oak Ridge National Laboratory	1 Bethel Valley Road, P.O. Box 2008	Oak Ridge	TN	37831-6064	USA	865-607-1144	allardLFJR@ornl.gov
	Toshihiro Aoki	JEOL USA, Inc.	11 Dearborn Road	Peabody	MA	01960	USA	978-536-2266	aoki@jeol.com
	Toshihiro Asada	Rutgers University	136 Frelinghuysen Road, Department of Physics & Astronomy	Piscataway	NJ	08854	USA	732-445-3892	asada@physics.rutgers.ed
	Toru Asaka	Brookhaven National Laboratory	Building 480, P.O. Box 5000	Upton	NY	11973	USA	631-344-7899	asaka@bnl.gov
	James R. Attle	Hitachi High Technologies	14 Kevin Drive	Suffern	NY	10901	USA	845-357-1148	roger.attle@hitachi-hta.c
B									
	Timothy J. Bard	OSRAM Sylvania	100 Hawes Street, Bldg. 15A	Towanda	PA	18848	USA	570-268-5521	timothy.bard@sylvania.co
	Phil Batson	IBM T.J. Watson Research Center	1101 Kitchawan Road, Route 134	Yorktown Heights	NY	10598	USA	914-945-2782	'batson@us.ibm.com'
	Marco Beleggia	University of Leeds	Institute for Materials Research, SPEME	Leeds		LS2 9JT	United Kingdom	44-788-1795332	m.beleggia@leeds.ac.uk

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Jim Bentley	Oak Ridge National Laboratory	Materials Science and Technology Division, P.O. Box 2008	Oak Ridge	TN	37831-6064	USA	865-574-5067	bentleyj@ornl.gov
Douglas Blom	University of South Carolina	715 Sumter Street, CLS 001	Columbia	SC	29208	USA	803-777-2886	Doug.Blom@sc.edu
Christine C. Broadbridge	Southern Connecticut State University	501 Crescent Street, Department of Physics, JE-108	New Haven	CT	06515-1355	USA	203-392-6461	broadbridge@southernct.
Nigel D. Browning	University of California-Davis	Department of Chemical Engineering and Materials Science, Shields Avenue	Davis	CA	95616	USA	925-424-5563	nbrowning@ucdavis.edu
John Bruley	IBM	Research Division, 1101 Kitchawan Road, Route 134	Yorktown Heights	NY	10598	USA	914-945-2307	bruley@us.ibm.com
C								
Michael Capers	Hitachi High Technologies Europe	6 Retford Close, Woodley, Reading	Berks		RG5 4TP	United Kingdom	079-009005f70	m.capers@hht-eu.com
Siu-Wai Chan	Columbia University	MC 4701, Applied Physics, 500 W. 120th Street	New York	NY	10027	USA	212-854-8519	sc174@columbia.edu

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Hui Chen	Stony Brook University	Room 311, Old Engineering Building, Dept. of Materials Science and Engineering	Stony Brook	NY	11794-2275	USA	631-632-8501	huichen@ic.sunysb.edu
Martin Couillard	Cornell University	E13 Clark Hall	Ithaca	NY	14853-3501	USA	607-255-5198	mc475@cornell.edu
D								
Michael D. Dixon	Hitachi High Technologies Europe	7 Ivanhoe Road, Hogwood Industrial Estate	Wokingham		RG40 4QQ	United Kingdom	44-7967-692403	michaeld@hitachi-hitec-u
Rafal E. Dunin-Borkowski	Technical University of Denmark	Center for Electron Nanoscopy	Kongens Lyngby		DK-2800	Denmark	45-4525-6465	rafaldb@gmail.com
G								
Yong X. Gan	University of Toledo	MS312, Department of Mechanical, Industrial and Manufacturing Engineering, College of Engineering	Toledo	OH	43606	USA	419-530-6007	yong.gan@utoledo.edu
Lynne M. Gignac	IBM T.J. Watson Research Center	1101 Kitchawan Road 07-029	Yorktown Heights	NY	10598	USA	914-945-3352	gignac@us.ibm.com
Robert J. Gordon	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2817	robert.gordon@hitachi-ht

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Jason Graetz	Brookhaven National Laboratory	Building 815	Upton	NY	11973	USA	631-344-3242	graetz@bnl.gov
Michael Gribelyuk	IBM	2070 Route 52, Mail Stop 40E	Hopewell Junction	NY	12533	USA	845-894-4252	gribelyu@us.ibm.com

H

Maximilian Haider	CEOS GmbH	Englerstr. 28	Heidelberg		D-69126	Germany	49-6221-8946711	haider@ceos-gmbh.de
Weiqiang Han	Brookhaven National Laboratory	Bldg. 735	Upton	NY	11973	USA	631-344-7370	whan@bnl.gov
Naoto Hashikawa	Renesas Technology Corp.	20-1 Josuihon-cho,5chome	Kodaira		187-8588	Japan	81423127415	hashikawa.naoto@renesa
Jiaqing He	Brookhaven National Laboratory	Bldg. 480, P.O. Box 5000	Upton	NY	11973	USA	631-344-3525	jhe@bnl.gov
Rodney A. Herring	University of Victoria Canada	3800 Finnerty Road	Victoria		V8W 3P6	Canada	250-721-8934	rherring@uvic.ca
Yoichi Horibe	Rutgers University	Department of Physics & Astronomy, 136 Frelinghuysen Road	Piscataway	NJ	08854	USA	732-445-2732	horibe@physics.rutgers.e
David Hoyle	Hitachi High Technologies Canada	89 Galaxy Blvd. Unit 14	Etobicoke	Ontario	M9W 6A4	Canada	416-675-5860	david.hoyle@hitachi-hhtc
Lei Huang	Brookhaven National Laboratory	Bldg. 480, P.O. Box 5000	Upton	NY	11973	USA	631-344-3954	lhuang@bnl.gov

I

Hiromi Inada	Hitachi High Technologies	2027 Foxglove Circle	Bellport	NY	11713	USA	81292766147	hiromi.inada@hitachi-hta.

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Thomas C. Isabell	JEOL USA, Inc.	11 Dearborn Road	Peabody	MA	01960	USA	978-536-2467	isabell@jeol.com
Shigeto Isakozawa	Hitachi High Technologies	882 Ichige Hitachinaka-shi	Ibaraki		312-8504	Japan	81-292-75-5364	isakozawa-shigeto@naka.
J								
Konrad F. Jarausch	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2830	konrad.jarausch@hitachi-
K								
Bernd C. Kabius	Argonne National Laboratory	9700 South Cass Avenue	Argonne	IL	60439	USA	630-252-3254	kabius@anl.gov
Ji-Jung Kai	National Tsing Hua University	101, Section 2, Kuang-Fu Road	Hsinchu		30013	Taiwan	88-635-715131	jjkai@ess.nthu.edu.tw
Takashi Katayama	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2818	takashi.katayama@hitach
Masahiro Kawasaki	JEOL USA, Inc.	11 Dearborn Road	Peabody	MA	01960	USA	978-535-5900	kawasaki@jeol.com
Yoshinao Kawasaki	Hitachi High Technologies	882 Ichige, Hitachinaka-shi	Ibaraki-ken		312-8504	Japan	81-29-276-6102	kawasaki-yoshinao@naka
Koji Kimoto	National Institute for Materials Science	1-1 Namiki, Tsukuba	Ibaraki		305-0044	Japan	81-29-860-4402	kimoto.koji@nims.go.jp
Angus I. Kirkland	Oxford University	Department of Materials, Parks Road, Oxford OX1 3PH				UK	441865-273665	angus.kirkland@materials

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Robert F. Klie	University of Illinois at Chicago	Department of Physics, 845 W Taylor Street, M/C 273	Chicago	IL	60607	USA	312-996-6064	rfklie@uic.edu
L								
Edgar Lara-Curzio	Oak Ridge National Laboratory	High Temperature Materials Laboratory	Oak Ridge	TN	37831	USA	865-574-1749	laracurzioe@ornl.gov
Jerry L. Lehman	NXP Semiconductors	2070 Route 52	Hopewell Junction	NY	12533	USA	845-902-1121	jerry.l.lehman@nxp.com
M								
Marek Malac	National Institute for Nanotechnology	Department of Physics, University of Alberta, 11421 Saskatachewan Drive	Edmonton	Alberta	T6G 2M9	Canada	780-641-1662	mmalac@phys.ualberta.c
John F. Mansfield	University of Michigan	North Campus, Electron Microbeam Analysis Laboratory, 417 SRB, 2455 Hayward	Ann Arbor	MI	48109-2143	USA	734-936-3352	jfmjfm@umich.edu
Iliya Mekuz	Hitachi High Technologies Canada	89 Galaxy Blvd., Unit 14	Rexdale	Ontario	M9W 6A4	Canada	416-675-5860	iliya.mekuz@hitachi-hhtc.
Emilio Mendez	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-3322	emendez@bnl.gov

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Mirko Milas	Brookhaven National Laboratory	Building 480, P.O. Box 5000	Upton	NY	11973		631-344-2618	milas@bnl.gov
Kazui Mizuno	Hitachi High Technologies	882 Ichige, Hitachinaka-shi	Ibaraki-Ken		312-8504	Japan	81-29-275-5364	mizuno-kazui@naka.hitac
Karren L. More	Oak Ridge National Laboratory	1 Bethel Valley Road, Building 4515, MS 6064	Oak Ridge	TN	37831-6064	USA	865-574-7788	morekl1@ornl.gov
David A. Muller	Cornell University	School of Applied and Engineering Physics, 274 Clark Hall	Ithaca	NY	14853	USA	607-255-4065	dm24@cornell.edu
Isao Muta	Hitachi High Technologies	24-14, Nishi-Shimbashi 1-chome, Minato-ku	Tokyo		105-8717	Japan	81-3-3504-7480	muta-isao@nst.hitachi-hit
N								
Hideo Naito	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2805	hideo.naito@hitachi-hta.c
Kuniyasu Nakamura	Hitachi High Technologies	882 Ichige Hitachinaka-shi	Ibaraki	312-8504		Japan	81292760796	nakamura-kuniyasu@nak
Samphos M. Ngak	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2831	samphos.ngak@hitachi-ht
O								
Michael A. O'Keefe	Lawrence Berkeley National Laboratory	MSD 2R0200, 1 Cyclotron Road	Berkeley	CA	94720-8197	USA	510-886-5527	sub-Angstrom@comcast.
Peter Oleynikov	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-2414	poleynik@bnl.gov

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Yuji Otsuka	Toray Research Center, Inc.	Sonoyama3-3-7, Otsu-shi	Shiga		520-8567	Japan	81-77-533-8618	yuji_otsuka@trc.toray.co.
P								
Xiaoqing Pan	University of Michigan	2300 Hayward Street	Ann Arbor	MI	48109-2136	USA	734-647-6822	panx@umich.edu
Linda Parise	Suffolk County Crime Laboratory	Bldg. 487, North Country Complex, 725 Vets Highway	Hauppauge	NY	11787	USA	631-853-5585	linda.parise@suffolkcount
Steve Pennycook	Oak Ridge National Laboratory	Materials Science and Technology Division, PO Box 2008	Oak Ridge	TN	37831-6030	USA	(865) 574-5504	pennycooksj@ornl.gov
Q								
Yuhai Qin	New Jersey Institute of Technology	Physics Department, University Heights	Newark	NJ	07102	USA	973-596-3131	yq3@njit.edu
R								
Jan Ringnalda	FEI Company	3075 Asbury Drive	Columbus	OH	43221	USA	614-284-7946	jringnalda@fei.com
Harald H. Rose	Darmstadt University of Technology	TU Darmstadt, Institute for Applied Physics, Hochschulstrasse 6	Darmstadt		64289	Germany	49-6151-41955	harald.rose@physik.tu-da
Manfred Ruehle	MPI for Metals Research	Heisenbergstr. 3	Stuttgart		70569	Germany	011-49-711-689-35	ruehle@mf.mpg.de

	Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
S									
	Marvin Schofield	Brookhaven National Laboratory	Building 480, P.O. Box 5000	Upton	NY	11973	USA	631-344-3507	schofield@bnl.gov
	Marty Schreck	Thermo Fisher Scientific	234 7th Avenue	Saint James	NY	11780	USA	631-686-6376	marty.schreck@thermofis
	Evan Slow	Angstrom Scientific	P.O. Box 663	Ramsey	NJ	07446	USA	201-760-2524	eslow@angstrom.us
	Vlad Stolojan	University of Surrey	Advanced Technology Institute	Guildford		G&2 7XH	United Kingdom	44-12483-689411	V.Stolojan@surrey.ac.uk
	Masaaki Sugiyama	Nippon Steele Corporation	Materials Characterizatio n Lab, Advanced Technology Research Laboratories, 20-1 Shintomi, Futtsu	Chiba		293-1511	Japan	81-439-80-2238	sugiyama.masaaki@nsc.c
	Eli Sutter	Brookhaven National Laboratory	Bldg. 735	Upton	NY	11973	USA	631-344-7179	esutter@bnl.gov
T									
	Hiroki Tanaka	Toshiba Corporation	8, Shinsugita-Cho, Isogo-Ku	Tokohama		235-8522	Japan	80-45-776-5951	hiroki7.tanaka@toshiba.c

	Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
	Yoshifumu Taniguchi	Hitachi High Technologies	Advanced Microscope Systems Design, 2nd Department Naka Division Nanotechnology Products Business Group 882, Ichige, Hitachinaka-shi	Ibaraki-ken		312-8504	Japan	81-29-276-1969	taniguchi-yoshifumi@nak
	Jing Tao	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-7709	jtao@bnl.gov
	Seth Taylor	GE Global Research	One Research Circle, K1-1D47	Niskayuna	NY	12309	USA	518-387-4004	taylor@research.ge.com
	Rudolf M. Tromp	IBM T.J. Watson Research	1101 Kitchawan Road, P.O. Box 218	Yorktown Heights	NY	10598	USA	914-945-1242	rtromp@us.ibm.com
	Ray D. Twesten	Gatan	5933 Coronad Lane	Pleasanton	CA	94588	USA	925-224-7392	rtwesten@gatan.com
V									
	Steve Volkov	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-4071	volkov@bnl.gov
W									
	Haifeng Wang	Western Digital Corp.	44100 Osgood Road	Fremont	CA	94539	USA	510-683-7448	haifeng.wang@wdc.com
	Huiqiong Wang	Yale University	P.O. Box 208284	New Haven	CT	06520	USA	631-805-7948	huiqiong.wang@yale.edu

	Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
	Lumin Wang	University of Michigan	Dept. of Nuclear Engineering & Radiological Sciences, Dept. of Materials Science & Engineering Electron Microbeam Analysis Laboratory (EMAL) 2958 Cooley Bldg. 2355 Bonisteel Blvd	Ann Arbor	MI	48109-2104	USA	734-647-8530	lmwang@umich.edu
	Yun-yu Wang	IBM	Micro-electronics Division, 2070 Route 52, Mail Stop 40E	Hopewell Junction	NY	12533	USA	845-894-1480	wangyy@us.ibm.com
	Grace Webster	Brookhaven National Laboratory	Bldg. 735	Upton	NY	11973	USA	631-344-3227	gwebster@bnl.gov
	Lijun Wu	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-3267	ljwu@bnl.gov

Y

	Nan Yao	Princeton University	Princeton Institute for the Science and Technology of Materials, 120 Bowen Hall	Princeton	NJ	08544	USA	609-258-6394	nyao@princeton.edu

Contact Name	Company	Address	City	State	Zip	Country	Phone	E-mail
Aycan Yurtsever	Cornell University	Applied Physics, Clark Hall E2	Ithaca	NY	14850	USA	607-255-8706	ay45@cornell.edu

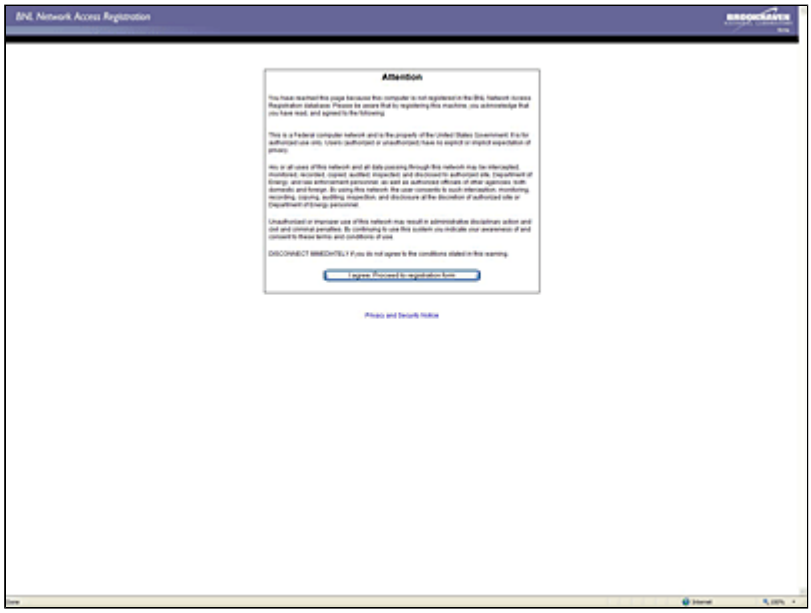
Z

Lihua Zhang	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-3512	lhzhang@bnl.gov
Xiaofeng Zhang	Hitachi High Technologies	5100 Franklin Drive	Pleasanton	CA	94588	USA	925-218-2814	xiao.zhang@hitachi-hta.c
Jincheng Zheng	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-2740	jczheng@bnl.gov
Yimei Zhu	Brookhaven National Laboratory	Bldg. 480	Upton	NY	11973	USA	631-344-3057	zhu@bnl.gov

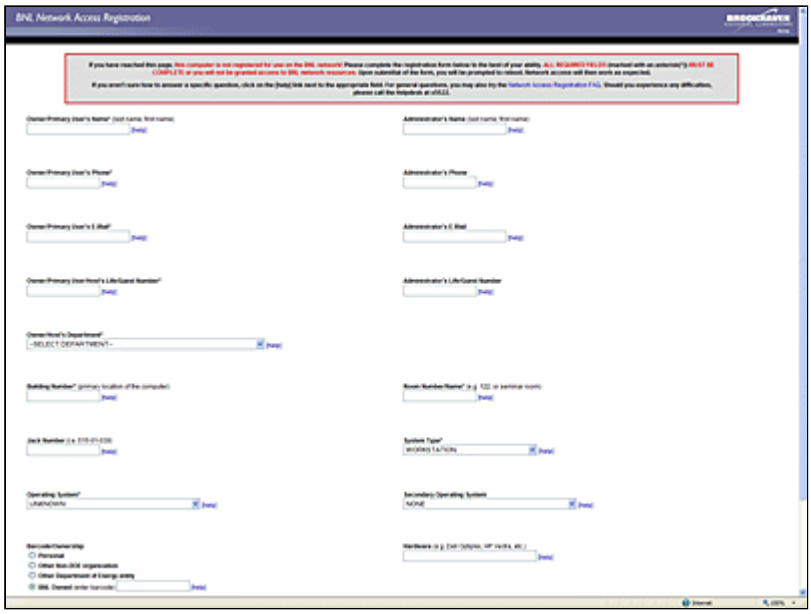
Conference Computer Registration Instructions

Attendee Instructions - BNL policy requires that all computing devices connected to BNL's network be registered in Brookhaven's Network Access Registration system. If you will be using a computer (laptop, PDA, etc.) to access the internet or any of BNL's networked resources while on-site, and that computer has not been previously registered at BNL, your web browser traffic will be redirected to a web page (see below) requesting information about you and your computer. This form **MUST** be completed and submitted **within 30 minutes** of booting their computer, or your network access **will be** terminated. To begin this process, simply open your web browser once you have connected.

User Agreement Screen
Read notice and press the [I agree...] button to continue.



Network Access Registration Screen
Complete all required fields as directed in the accompanying sheet, then press the [Submit] button to finish. Please contact your Event Coordinator, or the on-site Helpdesk (laboratory extension 5522) if you experience problems.



Last Modified: February 21, 2007

BNL Computer Registration Instructions

BNL policy requires that all computing devices connected to BNL's network be registered in our Network Access Registration system. If you will be using a computer (laptop, PDA, etc.) to access the internet or any of BNL's networked resources while on-site, and that computer has not been previously registered at BNL, your web browser traffic will be redirected to a web page requesting information about you and your computer. This form MUST be completed and submitted within 30 minutes of booting your computer, or your network access will be terminated. To begin this process, simply open your web browser once you have connected.

To aid you in the registration process, below is a list of the required fields and the information you will need to enter. Completion of fields **not** listed in these instruction is preferred, but not required.

Owner/Primary User Name:
Enter your name in LastName-comma-FirstName format (e.g. Doe, John).

Owner/Primary User Phone:
Enter: 3227

Owner/Primary User E-mail:
Enter your e-mail address.

Owner/Host Life/Guest Number:
Enter the following conference key: NC-58384

Department:
Select CENTER FOR FUNCTIONAL NANOMATERIALS from the drop down list provided.

Building Number or Name:
Enter: 735

Room Number or Name:
Enter: Seminar Room

System Type:
Select the system type that best fits your device. If you're unsure, leave the default of WORKSTATION.

Operating System:
Select your computer's operating system from the list provided. If you are unsure, you may select UNKNOWN. If your operating system is not listed, select OTHER.

Secondary Operating System:
The default of NONE is acceptable.

Any other fields on the form will be optional, and can be left blank. Should you experience any difficulties during the registration process, please call our Helpdesk at lab extension 5522.

Workshop on Advanced Electron Microscopy in Materials Physics

Date : November 7-8th, 2007

Location: CFN, Brookhaven National Laboratory (NY)

This two day workshop will feature presentations by internationally prominent scientists working at the frontiers of electron microscopy, both on instrumentation development and applications in materials science.

The workshop is structured to stimulate scientific exchanges and explore new capabilities. Join your colleagues at BNL's world class facilities for an exciting two days of invited talks, informal discussions and technical exchanges. While the scientific themes of the workshop are focused on aberration corrected STEM and EELS, other advanced electron microscopy methods for application of materials physics are also incorporated. Invited speakers include P. Batson, R. Borkowski , N. Browning, M. Haider, A. Kirkland, B. Kabius, D. Muller, S. Pennycook, H. Rose, M. Ruehle and R. Trump.

There will be an opportunity check out the newly installed cold field emission, probe-corrected, dedicated-STEM equipped with an ultra-fast high resolution EELS, and tour the new Center for Functional Nanomaterials as well!

TO ATTEND, please REGISTER: http://www.bnl.gov/cfn/seminars/
(1) Registration fee: $100 – Registration deadline: Oct.15, 2007
(60 attendee limit, registration will be first-come first serve)
(2) 30 days lead-time required for visitor access to Brookhaven National Lab!
(if you do not have a US passport, please contact: cfnuser@bnl.gov ASAP)
(3) Conference rate at hotels near BNL, shuttle will be provided from the hotel.
(please contact NSDEvent@hitachi-hta.com for hotel info before Oct. 15th)

A complete schedule of speakers and topics can be viewed on the web at:
www.hitachi-hta.com/emd www.bnl.gov/cfn

MEETING ANNOUNCEMENT
(REGISTER ONLINE)

HITACHI
Inspire the Next

BROOKHAVEN NATIONAL LABORATORY

Center for Functional Nanomaterials

Organizers

Dr. Konrad Jarausch
Electron Microscope Division
Hitachi High Technologies America

Dr. Yimei Zhu
Institute for Advanced Electron Microscopy
& Center for Functional Nanomaterials
Brookhaven National Laboratory

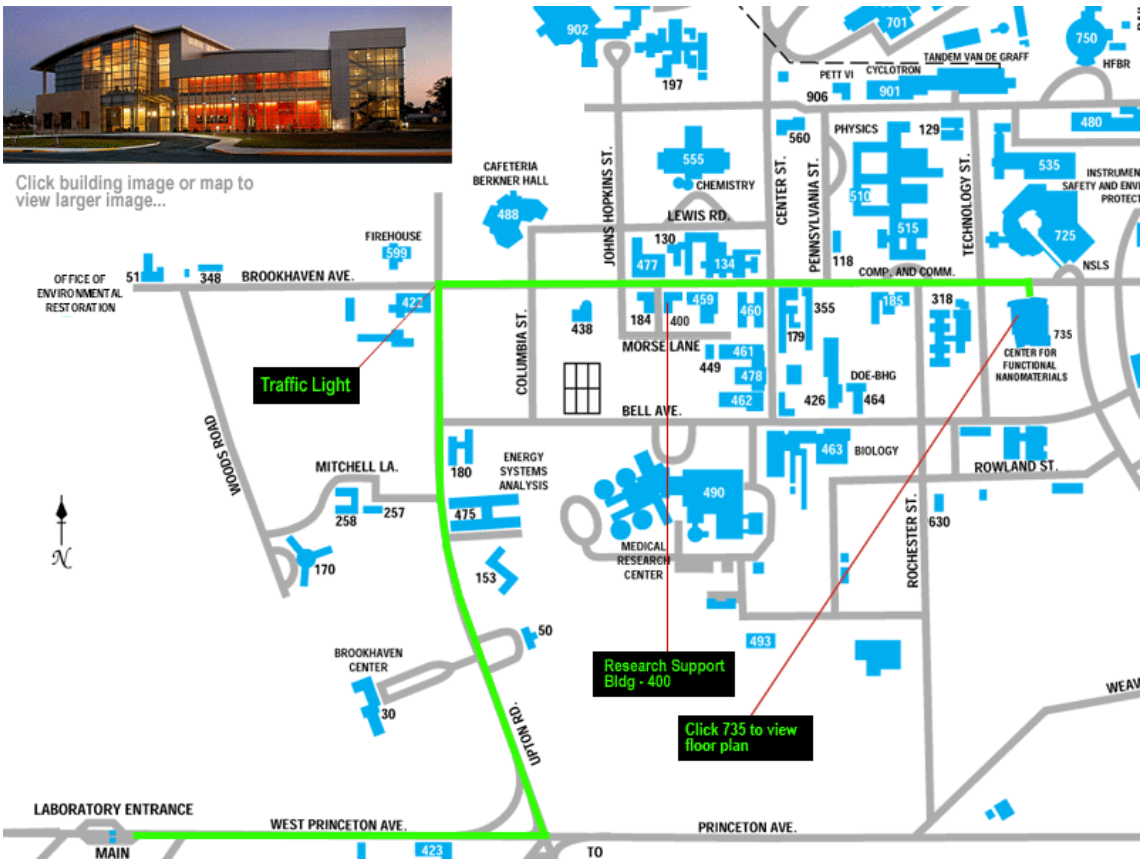
Hitachi High Technologies America
Nanotechnology Systems Division
Pleasanton, CA 94588 / Gaithersburg, MD 20878
Contact: emdwebsite@hitachi-hta.com

Brookhaven National Laboratory
Long Island, New York, 11973
Contact: Grace Webster, Email: cfnuser@bnl.gov

Building 735

Directions to the Center for Functional Nanomaterials (CFN)

Directions Homepage | Other Maps & Directions



The CFN will be located on Brookhaven Avenue across from the NSLS Building. Click the building image or map insert to view a larger scale or these imagers.

- Large Picture of Building 735
- Building 735 - 2nd Floor Plan (Seminar Room)
- Map of BNL Central Campus (pdf)

- Can't read PDF files - Need PDF Plugin

Last Modified: September 18, 2007
Please forward all questions about this site to: Application Services