Directory of Research Facilities and Laboratories

NORTHWESTERN UNIVERSITY

Materials Research Science & Engineering Center
NU-MRSEC

INTRODUCTION

The Materials Research Science & Engineering Center (MRSEC) at Northwestern University is pleased to provide this print directory of its research facilities and laboratories. A complete list of facilities is also available on our web site at http://www.mrsec.northwestern.edu/

NU-MRSEC is at the forefront of materials innovation, playing a leadership role in interdisciplinary research, the development of new technologies, and the commercial application of advanced materials. The activities and programs of NU-MRSEC are primarily supported by the National Science Foundation (DMR #0520513).

Facilities and Laboratories described herein are available for use by members of the Northwestern University research community and other academic institutions. Qualified research personnel from profit and nonprofit organizations may also use these resources, provided that comparable services are not available on a commercial basis in the private sector and such use will not interfere with the progress of internal research projects.

In most cases, users are given the necessary instructions to operate the instrumentation independently; however, ongoing assistance is available when needed. Modest fees are charged for facility use to help defray operational expenses. Charges may vary and are subject to change without notice.

If you would like additional information about the NU-MRSEC, use of facilities, or research activities, please feel free to contact us.

August 2008
Materials Research Science & Engineering Center, Northwestern University
2145 Sheridan Road, K111
Evanston, IL 60208
TEL. 847-491-3606 FAX 847-467-6727 E-MAIL mrc@northwestern.edu

TABLE OF CONTENTS

Facilities

Advanced Optical Facility……………………………………………………………4
Center for Atom Probe Tomography (NUCAPT)………………………………6
Electron Probe Instrumentation Center (EPIC)…………………………………8
Surface Science Facility………………………………………………….……... 10
Jerome B. Cohen X-ray Diffraction Facility…………….…………………… 11
Materials Processing & Microfabrication Facility – Cleanroom……….……..... 13
Central Laboratory for Materials Mechanical Properties (CLaMMP)………….. 15
Magnet and Low Temperature Facility………………………….................... 17
High Resolution Electron Microscopy and Surface Structure Facility…….…… 19
Optical Microscopy & Metallography Facility…………………….…………… 21

Laboratories

Impedance Spectroscopy Laboratory.…………………………………..…… 23
Advanced Thin Film and Laser Laboratory.……………………………………. 24
Integrated Molecular Structure Education and Research Center (IMSERC).…... 25
Ceramics Laboratory.…………………………………………………………… 28
Polymer Characterization Laboratory.…………….…………………………. 29
Charge Transport Laboratory…………………………………………………… 30
Synchrotron Research Facility………………………………………………….. 31

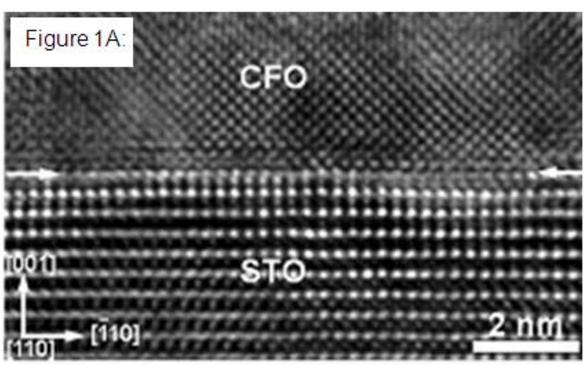
FACILITIES

<u>*This research highlight impacted by use of NU facilities is the courtesy of:*</u>
Northwestern University Materials Research Science & Engineering Center
DMR-0520513

Molecular Beam Epitaxy of Ferroic and Multiferroic Thin Films

Ji Cheng, G. Sterbinsky, B. W. Wessels, Sujing Xie and Vinayak P. Dravid

Epitaxial ferroic oxide thin films and multilayers have been synthesized by oxide molecular beam epitaxy (MBE), for combining materials with different properties such as ferromagnetism and ferroelectricity in a single structure. Fe_3O_4, $CoFe_2O_4$ and $MgFe_2O_4$ were deposited, which exhibit sharp interfaces with excellent cube-on-cube orientation. Magneto-optic Kerr effect (MOKE) and SQUID magnetometry measurements indicate that bulk-like magnetic properties can be obtained in the thin films.



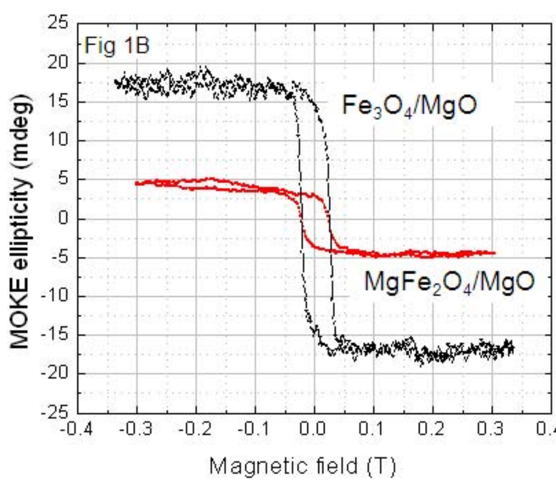


Fig. 1A: Cross-section HRTEM of epitaxial $CoFe_2O_4$ film on $SrTiO_3$ substrate, showing sharp interfaces with cube-on-cube orientation; Fig. 1B: In-plane MOKE hysteresis loops of Fe_3O_4 and $MgFe_2O_4$ films.

Advanced Optical Facility

Facility Director:
Professor **John B. Ketterson**, Physics and Astronomy Department
Tel: (847) 491-5468
E-mail: j-ketterson@northwestern.edu

Facility Technician:
Oleksandr Chernyashevskyy, PhD.
E-mail: o-chernyashevskyy@northwestern.edu

Location: Technological Institute FB36

Function

The facility provides instrumentation for the optical and spectroscopic characterization of materials with special emphasis on the non-linear optical response.

Equipment

1. Quantronix 416 Nd: YLF laser CW modelocked, 1.053 microns, < 100 ps, 100 Hz
2. Optical CSK Superdoubler for frequency doubled output
3. Optical Parametric Oscillator (OPO) LBO crystal based, tunable from 0.65 to 2.2 microns -Driven by the Quantronix YLF laser
4. ESKPLA Nd:YAG laser Cavity dumped active/passive mode-locked 35 ps pulses at 10 Hz Doubled and tripled frequency outputs Optical Parametric Amplifier BBO crystal based, tunable from 400 nm - 2.2 microns Driven by the Continuum YAG laser
5. Quanta Ray Nd: YAG laser, model DCR-1
6. Spectra Physics 164 argon ion laser
7. Model 375B dye laser (driven by the argon laser)
8. Spectra Physics 164 krypton ion laser
9. Spectra Physics argon ion laser, model 2025-05
10. Spectra Physics krypton ion laser, model 2025-05
11. Two temperature controlled optical dewars (LN2, L4He, and L3He)
12. Jarrell Ash half-meter grating monochromator, model 82-415
13. Stanford-Computer-Optics Image-intensified ICCD, model 4picos
14. SPEX 500M grating spectrometer
15. SPEX 1401 double-grating spectrometer
16. SPEX Spectrum-One LN-cooled CCD detector
17. InGaAs LN-cooled IR detector
18. Numerous prism spectrometers;
19. Two general purpose SHG arms at 1.053 microns and 527nm (Quantronix YLF). Poling SHG arm (Quanta Ray). Angular dependent SHG arm (Quanta Ray). Time resolved SHG

arm (Quanta Ray). Variable wavelength SHG arm (OPA). Electro-optic coefficient characterization, @He-Ne wavelength 632.8 microns. Variable temperature optical capability.

20. Photochemical Research Associates Nitrogen LN1000 laser
21. Mellinea 532nm 5w YAG laser
22. Pulsed Ti Sapphiere laser
23. Magneto-optical set up
24. Displex refrigerated optical cryostat

Northwestern University Center for Atom-Probe Tomography (NUCAPT)
Facility Director:
Professor **David N. Seidman**, Materials Science & Engineering Department
Tel: (847) 491-4391
E-mail: d-seidman@northwestern.edu

Facility Manager:
Research Assistant Professor **Dieter Isheim,** Materials Science & Engineering Department
Tel**:** (847) 491-3575
E-mail: isheim@northwestern.edu

Location: Cook Hall 1086, Tel (847) 491-7826
http://arc.nucapt.northwestern.edu

Function

Atom-probe tomography (APT) is a microanalytical instrument producing an atom-by-atom three-dimensional reconstruction of a sample, with sub-nanometer resolution with a typical analyzed volume of about 150 x 150 x 500 nm^3. APT is particularly suitable to investigate nano-structured materials. Typical micro- and nanostructural features studied are: composition and morphology of second-phase precipitates or small clusters of solute atoms, compositional variation in modulated structures, multi-layer thin-film structures, dopant profiles of semiconductor structures (transistors), and analysis of the chemistry and topology of internal interfaces. Specimen preparation of almost any material is now possible employing a dual-beam focused-ion beam (FIB) microscope, which allows targeted sample preparation of a specific feature, such as a grain boundary or an individual transistor in a semiconductor device.

Equipment

1. **LEAP 4000XSI manufactured by Imago Scientific Instruments, Madison, Wisconsin:** This instrument, a local electrode atom-probe (LEAP) tomograph, has an ultrafast detector capable of collecting up to 360 million ions per hour. Ions are evaporated from a sample's surface either by voltage or ultraviolet (UV) laser pulses, which allows for the analysis of a broad spectrum of materials: metals, semiconductors, ceramics, biominerals, organic and biological samples, albeit with different degrees of success. A computer reconstructs a three-dimensional image of a sample with both the chemical identities and positions of individual atoms, with a depth resolution equal to the interplanar spacing, which can be as small as 0.1 nm: the lateral resolution in an atomic plane is between 0.3 to 0.5 nm. The microelectrode in the LEAP tomograph allows the analysis of microtips, prepared by FIB (ion-milling and/or the lift-out technique to target specific features), or wire microtips prepared by conventional electropolishing. Additionally, digital field-ion microscopy can be performed with this instrument.

2. A **specimen preparation laboratory** for preparing needle-shaped specimens for atom-probe tomography. Our lab features a high-speed precision saw to cut specimen blanks, an electropolishing station with a high-resolution stereo-microscope, and a commercial Simplex Electropointer automated electropolisher.
3. An **Ion-beam sputter system (IBS/e) manufactured by South Bay Technologies**. This system is utilized for depositing high-quality thin films for: (1) generating multi-layer structures; and (2) to assist with LEAP-tip preparation by FIB milling where the thin-film deposit marks and protects a sample's surface when milling with gallium ions. The ion-beam sputter system does not use magnetron-based sputter guns and therefore is suitable for the deposition of magnetic materials, such as iron, nickel, and cobalt.
4. **Arc Melter**: Arc-melting is a fast and clean way of producing alloys of electrically conductive materials. The raw materials are placed on a water-cooled hearth in a vacuum chamber. After evacuation, the chamber is re-filled with Argon to be employed as an inert working gas. An electric arc is produced with a pointed electrode which heats the raw materials above their melting point, fusing them into an alloy droplet. The facility operates a MAM-1 arc melter manufactured by Edmund Bühler GmbH, Germany. The arc melter can process about 10-15 grams of material in one melting charge. A specially designed hearth allows for suction casting into a 3 mm diameter mold.
5. **NUCAPT computing facility** comprising
   - 5.1 An 8 TB data server
   - 5.2 Five individual high-end PC workstations for running IVAS for LEAP-data reconstruction and analysis
   - 5.3 One workstation for Thermocalc, DICTra and MedeA simulations
   - 5.4 Microway AMD Quad-core Opteron cluster with 31 nodes and 62 quad-core processors, with a total of 248 CPUs, 372 GB shared-memory and high-quality fiber-optical DDR InfiniBand Network for large-scale parallel calculations. This cluster is currently optimized for performing VASP DFT calculations and lattice kinetic Monte Carlo simulations.

Electron Probe Instrumentation Center (EPIC)

Facility Director:
Professor **Vinayak P. Dravid,** Materials Science & Engineering Department
Tel: (847) 467-1363
E-mail: v-dravid@northwestern.edu

Facility Managers:

TEM/JEOL-JEM 2100F:
Jinsong Wu, Ph.D.
Tel: (847) 491-7807

TEM Electron Microscopist and Specimen Preparation Facility Manager:
Shu-You Li
Tel: (847) 491-6723
E-mail: syli@northwestern.edu

SEM Facility Manager and Scanning Electron Microscopist:
Ben Myers
Tel: (847) 491-3439
E-mail: b-myers3@northwestern.edu

Location: EPICTEM Cook Hall 1154 / EPICSEM Cook Hall 1114
http://www.nuance.northwestern.edu/epic/

Function

The Electron Probe Instrumentation Center (EPIC) EPIC facility offers a wide range of electron microscopy (both transmission and scanning), accessory instrumentation, and expertise to the scientific and engineering community through education, collaboration, and service. The laboratory provides facilities for the preparation and examination of many types of bulk and thin specimens (foils/films), fine particles, and replicas, including biological materials, by transmission and scanning electron microscopy.

Collectively, the Electron Probe Instrumentation Center (EPIC) offers instrumentation, techniques, and expertise for all aspects of microstructure materials. Detailed information about surface morphology, size and shape analysis, local chemistry, crystallography, and texture can be obtained with the scanning electron microscopes (SEM). The SEM facility has four SEMs with digital image acquisition, including three equipped with field emission gun (FEG), and several have EDS systems. The transmission electron microscopes (TEM) allow researchers to probe the crystal structure, defects, local chemistry, electronic structure, and related information at the nanometer or less length scale. The TEM facility currently has three TEMs, one cold field emission gun (cFEG) (HF2000), one Schottky field emission gun

(JEM2100F), and one thermal emission gun (H8100). All three microscopes are equipped with Energy Dispersive X-ray Spectroscopy (EDS) system for local chemistry analysis; two are equipped with Gatan Imaging Filter (GIF) for spectral imaging and EELS analysis. Both FEG microscopes are equipped with STEM detectors. The JEOL JEM2100F FEG TEM/STEM has sub 0.2nm probe capability, equipped with high-angle annular dark field (HAADF) detector, which gives atomic resolution of Z-contrast imaging of STEM.

Both SEM and TEM facilities are equipped with specialized specimen stages for dynamic studies involving deformation, fracture, current transport, applied electrical and magnetic fields, and temperature variation from -184°C to 1000°C. The diversity and quality of SEM and TEM instrumentation, along with the numerous analytical accessories, makes EPIC one of the most advanced laboratories in the country.

Please visit the EPIC web site (http://www.nuance.northwestern.edu/epic/) for more detailed information about the capabilities and contact information.

Surface Science Facility

Facility Director:
Professor **Yip-Wah Chung**, Materials Science & Engineering Department
Tel: (847) 491-3112
E-mail: ywchung@northwestern.edu

Function

The Surface Science Facility provides multiple-technique characterization of a variety of surfaces with regard to atomic structure, surface chemical composition, and chemical bonding characteristics.

Equipment

1. **PHI 590A Scanning Auger Microprobe:** This scanning Auger microprobe is capable of standard Auger analysis with 200 nm lateral resolution and provides composition information in the top few atomic layers with about 1% monolayer sensitivity. It is equipped with in situ fracture and argon ion sputter for depth profiling. A fast entry system allows rapid specimen turnaround.
2. **VG ESCA/SIMS system:** This is a fully computer-controlled instrument from Vacuum Generators that combines two analytical instruments into a single workstation, viz., x-ray photoelectron spectroscopy (XPS) and secondary ion mass spectrometry (SIMS). The XPS subsystem can be run with a normal Al/Mg anode or a monochromatized Al anode for higher energy resolution. A small spot mode allows analysis down to 150 microns. The SIMS subsystem works with a quadrupole mass spectrometer with unit mass resolution up to m/e = 800 and single ion detection capability. A fast entry system permits rapid sample introduction and interchange. A high-pressure cell is also incorporated for simulation of processes occurring at pressures up to 30 atmospheres.
3. **Nanoindentors:** Two nanoindentation instruments (**Hysitron** and **UMIS)** are available to determine surface mechanical properties and tribological behavior. An additional nanoindentor is being installed that allows nanoindentation and friction measurements at up to 500 C.

Training Seminars/Workshops

Provisions have been made to accommodate routine short-term measurements by user groups as well as more extended studies. User and research groups are encouraged to work with the facility staff to tailor the facility resources to the research project.

Jerome B. Cohen X-Ray Diffraction Facility

Facility Director:
Professor **Michael Bedzyk** , Materials Science & Engineering Department
Tel: (847) 491-3570
E-mail: bedzyk@northwestern.edu

Facility Manager:
Jerry Carsello
Tel: (847) 491-7810
E-mail: j-carsello@northwestern.edu

Location: Cook Hall 1016
http://www.research.northwestern.edu/xray/

Function

The primary function of the Jerome B. Cohen X-Ray Diffraction Facility is to provide general-purpose x-ray equipment for diffraction and fluorescence studies. The facility can also make accommodations for non-routine experiments such as, special attachments for high and low temperatures, vacuum or protective atmospheres, monochromators, special detectors, etc. Examples of current measurements are: powder diffraction, single-crystal diffraction, thin-film reflectivity, thin-film diffraction, crystal truncation rod scattering, small angle scattering, Laue diffraction, wave-length dispersive x-ray fluorescence, x-ray standing waves and high-resolution x-ray diffraction.

Equipment

There are presently thirteen experimental x-ray stations available, four of which have rotating anode sources.

Computers and Software

All of the x-ray stations operate via networked PC's with software that allows for control via stepping motors and data collection via counters. A networked printer is available. ICDD database, JADE diffraction analysis, CaRine crystal builder simulation and Laue diffraction software packages are available. SPEC and CPLOT are available on four of the stations.

Available apparatus

1. Rigaku ATX-G Thin-film Diffraction Workstation: A high intensity 18kW copper x-ray source is coupled to a multilayer mirror. The system has selectable x-ray optical configurations suitable for work with single crystal, thin-film or poly-crystalline film

samples. Also supported are grazing incidence and in-plane diffraction geometries. Other features are the 5-axis goniometer with several 4-crystal monochrometers that couple to the multilayer mirror.

2. Rigaku S-MAX 3000 High Brilliance SAXS System Rotating anode with multilayer mirror, Bruker Hi-Star 2-D wire detector, SAXS-GISAXS, WAXS capabilities including high temperature. q(min) = 0.04 $Å^{-1}$.
3. 18kW Rigaku: High-resolution 4-circle diffractometer with Osmic Max-Flux multi-layer mirror, coupled to Si or Ge monochromator, SPEC software control, high-count rate scintillation detector, automated beam attenuator and multi-channel analyzer fluorescence spectroscopy system.
4. 18kW Rigaku: Medium resolution 4-circle diffractometer with SPEC software control and automated beam attenuator.
5. 12kW Rigaku: 2-circle diffractometer with Osmic Max-Flux multi-layer mirror, high-count rate scintillation detector and multi-channel analyzer fluorescence system.
6. Bruker S4 Explorer: Automated wavelength dispersive x-ray fluorescence (WD-XRF) system.
7. Scintag XDS2000: Automated diffraction system, with four-circle pole-figure and residual stress device, thin film diffraction attachment and solid-state detector.
8. Rigaku Dmax: Automated powder diffraction stations featuring Jade Analysis software.
9. PC data analysis workstation: JADE 9.0 powder diffraction analysis software, CaRine diffraction simulation software, ICDD powder diffraction database and Laue analysis with digital scanner and Orient Express analysis software.
10. Blake High Resolution tangential goniometer: 5-Bounce high-resolution rocking curve-scan system. Sealed tube x-ray source.

Other available equipment

1. A variety of x-ray anode targets and source sizes to accommodate the four high intensity rotating anode generators and the nine sealed- tube x-ray generators.
2. Various Si, Ge, Graphite and LiF crystals and multi-layer mirrors are available for incident or diffracted beam monochromators.
3. Environmental chambers for vacuum, atmosphere, low temperature (>2 K) or high temperature (<2300 K) operation.
4. Seven solid-state detectors including a Vortex high count rate detector with associated electronics, SCA's and MCA's.
5. Three gas-filled 1-dimesion linear position sensitive detectors.
6. Variety of film cameras: Debye-Scherrer, Laue, rotating crystal, cylindrical, topographic, Buerger precession, Guinier, high pressure and darkroom facilities.

Materials Processing & Microfabrication Facility – Cleanroom

Facility Director:
Professor **Bruce Wessels,** Materials Science & Engineering Department
Tel: (847) 491-3219
E-mail: b-wessels@northwestern.edu

Facility Manager:
Dr. **Anil Dhote**, Materials Science & Engineering Department
Tel: (847) 491-5959
E-mail: a-dhote@northwestern.edu

Location: Cook Hall 4026, (847) 491-5959

Function

The Materials Research Center (MRC) cleanroom facility is devoted to materials processing, growth, device fabrication, and electronic & photonic materials. The MRC cleanroom complex in Cook Hall provides ***microfabrication and thin film processing*** capabilities. The facility includes class 100 and 1000 cleanrooms. The facility provides microfabrication tools for general use by the Northwestern community, government and industrial researchers. Various techniques are available for the growth, preparation, and processing of a wide range of thin film materials including in-process characterization. Training on equipment and assisted use within the MPCGF is available to provide the necessary expertise.

This facility provides a centralized resource for the deposition of metal, semiconductor & dielectric thin films, photolithography, and processing. Standard microfabrication processes have been established. Available techniques include plasma enhanced chemical vapor deposition, e-beam evaporation, reactive ion etching, photolithography and some characterization instrumentation.

Equipment

1. Quintel Q-2000 Mask Aligner
2. Quintel Q-4000 Mask Aligner (0.5 µ m)
3. Headway Spinners-Programmable
4. Baking Furnace
5. Oxford Instruments µ P 80 Plasma Enhanced Chemical Vapor Deposition (PECVD)
6. Edwards Auto 306 e-beam Evaporator
7. Edwards Auto 500 FL400 e-beam Evaporator
8. Oxford Instruments µ P 80 Reactive Ion Etching (RIE)
9. Kulicke & Soffa 4524D Ball-Ball Wire Bonder
10. West Bond 7374E Wedge-Wedge Wire Bonder
11. Filmetrics F-20 Thin Film Analyzer

12. Metricon 2010 Prism Coupler
13. Hall Effect Measurements
14. Tencore P-10 Surface Profiler
15. Omano Microscope
16. Photolithography Wet Bench
17. Digital Hotplates
18. Chemical Hoods
19. SUSS MicroTek MA6/BA6 Mask Aligner

List of equipment fees are available online at:
http://www.mrsec.northwestern.edu/content/facilities/cleanroom.htm

Central Laboratory for Materials Mechanical Properties (CLaMMP)

Facility Directors:
Professor **David Dunand** , Department of Materials Science & Engineering
Tel: (847) 491-5370
E-mail: dunand@northwestern.edu
Professor **Katherine Faber** , Department of Materials Science & Engineering
Tel: (847) 491-2444
E-mail: k-faber@northwestern.edu

Facility Manager:
Mark E. Seniw
Tel: (847) 491-7780
E-mail: m-seniw@northwestern.edu

Location: Cook Hall 1034
http://www.matsci.northwestern.edu/clammp/index.html

Function

This NU-MRSEC funded facility provides testing equipment for studying the mechanical behavior of materials. We have the capability of conducting tension, compression, fatigue, creep, stress rupture, impact, and 3 or 4-point bend tests. Additional equipment is also available to perform tests in controlled atmospheres, vacuum, and cover the temperature range of 77.2°K to 1773°K.

The computer-interfaced MTS machines can perform static and dynamic mechanical tests that relate an applied force to the elastic, anelastic, and/or plastic deformation of solid materials. The facility also makes available investigation of strain or stress controlled fatigue experiments, fatigue crack initiation studies, fatigue crack propagation studies, cyclic hardening, cyclic softening and cyclic stress-stain curve measurements under computer control.

Equipment

1. Five MTS machines (three servo-hydraulic, one servo-electric, and one screw driven tensile machine) are available to perform static and dynamic mechanical tests and control such parameters as strain rate and rate of loading. Tests can be performed up to 50,000 lb (250kN) and as low as 250 grams.
2. Three ATS constant load creep apparatus can be used for creep and stress rupture experiments up to 1100°C.
3. Charpy tests can be conducted in the ranges of 0 - 357 J and 0 - 22.5 J. Izod tests can be conducted in the range of 0 - 22.5 J
4. A laser extensometer, several contact extensometers and crack opening displacement gages are available for both static and dynamic tensile or compression tests. These include extensometers that can be used at temperatures up to 1100º C.

5. One of the fatigue machines is equipped with a Centorr high temperature (1100 °C) environmental chamber. Test environments including vacuum, inert gas, liquids, or a controlled atmosphere can also be carried out.
6. A metallurgical microscope can be attached to the testing frames enabling observation of real-time fatigue crack growth and examination of specimen surfaces during test cycling.

Please visit the CLaMMP web site (http://www.matsci.northwestern.edu/clammp) for more detailed information about our capabilities and contact information.

Magnet and Low Temperature Facility

Facility Director:
Professor **John B. Ketterson,** Physics & Astronomy Department
Tel: (847) 491-5468
E-mail: j-ketterson@northwestern.edu

Facility Technician:
Oleksandr Chernyashevskyy
Tel: (847) 491-4212
E-mail: o-chernyashevskyy@northwestern.edu

Location: Technological Institute FB24

Equipment

Our equipment includes cryostats, magnets, magnetometers, a nanovoltmeter, constant-current sources, and constant-voltage sources. The magnetometers include a computer-controlled Quantum Design (http://www.qdusa.com) Magnetometer (MPMS5) that permits SQUID magnetic-moment sensitivity (and a user probe for transport measurements), a LAKESHORE AC susceptometer for measuring both real and imaginary components of susceptibility, and a quick-turnaround AC bridge susceptometer.The MPMS provides the exceptional sensitivity of a SQUID-based magnetometer in a fully automated, analytical instrument. It provides a much needed solution for a unique class of magnetic measurements, meeting the needs of research in key areas such as high-temperature superconductivity, biochemistry, and magnetic recording media. This system was upgraded in 2004 by the addition of a horizontal rotator option and an "oven" insert for high-temperature measurements. This instrument can measure DC magnetic susceptibility and magnetic moments on samples as small as a few mg.

Field range: -5.0 T to 5.0 T
Temperature range: 1.8 to 700 K
Measurement range: 10-7 to 100 emu
Absolute sensitivity: 10-7 emu

Additional cryostats include a computer-controlled Quantum Design Physical Properties Measurement System (PPMS) and a SHE VTS 50 SQUID susceptometer outfitted for low-noise transport measurements. The PPMS was designed to measure heat capacity, thermal transport, and thermoelectric effects. Key optional features of the MPMS have been greatly expanded and improved in the PPMS. The PPMS brings a new level of measurement automation to researchers in rapidly expanding fields such as materials science, condensed matter physics, biology and analytical chemistry. The tremendous flexibility of the PPMS - open architecture - lets you create your own experiments and easily interface your own third-party instruments to the PPMS hardware. For example, we can connect a user's equipment to

PPMS analog outputs with signals proportional to magnetic field, system temperature, bridge resistance, bridge excitation, etc.

Field range: -9.0 T to 9.0 T
Temperature range: 1.9 to 390 K
Thermal conductance accuracy: 5%
Heat capacity sample size: 1 to 200 mg
Heat capacity resolution: 10nj/K at 2 K

Ease Of Use

The hallmarks of our instruments are automation and ease of use. We can quickly and easily configure them to perform different types of measurements. In a matter of minutes we can install a measurement application, set up an automated sequence, and start collecting meaningful data. And, our equipment is designed to run 24 hours a day, 7 days a week. We know your time is valuable, so we have laboratory automation on a new level. While the PPMS or MPMS runs your measurements, you can be analyzing data from previous measurements, planning your next experiment, and creating new materials. The MPMS and PPMS work like dedicated systems, but their tremendous flexibility lets you perform different types of measurements. Plus, we can easily integrate a user's unique experiment with our measurement systems. Samples can be easily prepared from a variety of materials. The exceptional dynamic range of our devices allows us to accommodate samples in many forms, from single crystals to bulk solids, films and powders.

High Resolution Electron Microscopy & Surface Structure Facility

Facility Director:
Professor **Laurence D. Marks**, Materials Science & Engineering Department
Tel: (847) 491-3996
E-mail: L-marks@northwestern.edu

Location: Catalysis Center, B12
http://www.numis.northwestern.edu/

Function

This facility provides unique equipment to investigate the atomic scale structure of both the surface and subsurface region of a sample combined with in-situ growth and chemical characterization. Please visit the High Resolution Electron Microscopy and Surface Structure Facility web site for more information about instrumentation capabilities and contact information: http://www.numis.northwestern.edu/

Equipment

1. **SPEAR:** The Specimen Preparation Evaluation Analysis and Reaction System is a system of interconnected Ultrahigh Vacuum (UHV) chambers for the preparation and study of surfaces and interfaces. The Analytical Chamber is equipped with a PHI Electronics Duoplasmatron Ion Gun, a PHI Electronics Dual-Anode X-ray Source, a FEI Thermally Assisted Schottky Field Emission Electron Gun, and the PHI Electronics Spherical Electron Energy Analyzer. The ion gun can produce oxygen, argon, or xenon ions which, when coupled with a secondary electron detector, generate useful Secondary Electron Microscopy (SEM) images during sputtering. The electron energy analyzer can acquire XPS data from either Al K-alpha or Mg K-alpha x-rays from the X-ray source, as well as highly spatially resolved Auger electron data generated by the electron gun. The electron gun can also be used for the direct heating of samples. The Transfer Chamber allows samples to be moved between the Load-Lock, the Analytical chamber, and various other connected systems (UHV-HREM, MIBE, SINBAD) while at all times remaining in a UHV environment.
2. **UHV-HREM:** The Hitachi UHV-H9000 High Resolution Electron Microscope is the first conventional transmission instrument to achieve routine mid 10E-11 torr operation. It is equipped with a Gatan Parallel EELS and CCD Camera, both interfaced to computers. Routinely the instrument will resolve at about 0.18nm for bulk spacings and atomic structure of surfaces at about the 0.25nm level.
3. **MIBE:** The main goal of the Magnetron and Ion Beam Epitaxy System is to combine deposition processes with the analytical capabilities of SPEAR and an UHV TEM. Samples can be grown in MIBE and then transferred to SPEAR where analytical techniques can be performed. It has two metal ion sources currently fitted with boron and

carbon targets, two d.c. magnetron sputtering sources used to form ZrN and CNx multilayer materials, and one gas ion source.

4. **SINBAD:** The Stabilizing Ion and Neutral Beam Assisted Deposition system is a specially designed system for the in-situ investigation of thin solid films. It is designed to handle the deposition of thin films onto thin 3mm TEM ready samples and investigate the effect of energetic particles on materials. The sample manipulation stage can be used for d.c. biasing of the sample as well as resistive heating during deposition and the unit is equipped with a single position electron-beam evaporator, a 4 keV ion-gun, and a compact electron cyclotron resonance (ECR) plasma source. It is also connected to the SPEAR system.
5. **Computers:** Two Linux clusters, JosephSmith and HyrumSmith, are used for running DFT calculations and compiling code. Additionally, computers are used for image simulation and diffraction calculations. The primary software is NUMIS, a combination of Semper 6 and multislice/imaging programs. Originally these calculations were run on UNIX machines, but are gradually being moved to PC's running an X-windows environment. Additionally, the EDM software package, which is continually being updated, is used to combine various aspects of image processing and manipulation of high resolution images and diffraction patterns as well as direct methods.

Optical Microscopy & Metallography Facility

Facility Director:
Professor **Kenneth Shull**, Materials Science & Engineering Department
Tel: (847) 467-1752
E-mail: k-shull@northwestern.edu

Facility Manager:
Carla Shute
Tel: (847) 467-1671, 847 491 7794
E-mail : c-shute@northwestern.edu

Location: Cook Hall 2008

Function

This facility is equipped for the metallographic preparation of specimens by producing strain-free surfaces usually examined by optical microscopy. Other applications of mechanically polished specimens involve producing strain-fee (surface) tensile specimens, optically flat electrodes, and flat substrates for subsequent thin-film depositions. Both transmitted light and reflected light metallographs are available for photomicrography and microstructural characterizations. The Lab Manager is available for consultation and training.

Equipment

Fourteen microscopes ranging from 6X to 1600X are in the facility. Selected microscopes have brightfield and darkfield modes, and polarized light. 4" X 5" or 35mm camera formats are available for taking photomicrograph as well as digital image capture. A micro hardness tester (loads from 10 grams to 1000 grams with either Knoop or Vickers indentors), and interference microscope, and a hot state (300EC maximum) for viewing optically clear specimens are available. In addition, a "digital" darkroom is available with AV Macintosh, scanner, and dye-sublimation printer capable of photographic quality prints.

Metallographic specimens can be cut with diamond-tipped blades on either a slicer/dicer, low-speed, or high-speed cut-off saw. Samples can be encapsulated in either cold-mount acrylics or phenolic resins. Manual abrading with silicon carbide paper or with variable speed 12" diameter SiC platens can be done in the facility.

Various 8" diameter platens for polishing are available with diamond paste sizes ranging from 30 to 0.1 micrometer. Alumina slurry polishing is also available with sizes from1.0 to 0.05 micrometer. A semi-automatic Buehler Ecomet IV Abrasive and Polishing System is capable of preparing up to eight specimens simultaneously with reproducible parameters of platen speed, pressure, and diamond concentrations. The system is very useful in preparing ceramic specimens due to the higher pressures that can be produced.

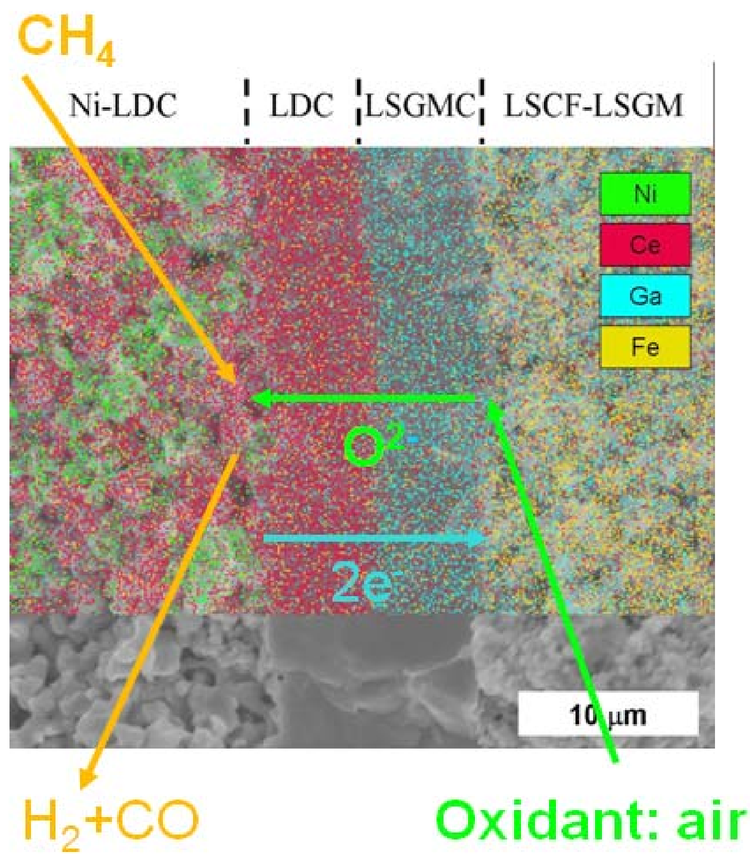
LABORATORIES

<u>*This research highlight impacted by use of a NU laboratory is the courtesy of:*</u>
Northwestern University Materials Research Science & Engineering Center
DMR-0520513

Mixed-Conducting Oxygen Membrane

Manoj Pillai, David Bierschenk, Blake Stevens, and Scott Barnett

Researchers at NU-MRSEC demonstrated a new mixed-conducting oxide membrane material: (La,Sr)(Ga,Mg,Co)O_3 (LSGMC). The material produces pure oxygen (on the left side of the figure) from air (supplied on the right side of the figure). Potential applications of this new material incude the production of hydrogen and liquid fuels from natural gas, as shown in the figure; and the production of pure oxygen for efficient, clean coal power plants with CO_2 sequestration.



Impedance Spectroscopy Laboratory

Laboratory Director:
Professor **Thomas Mason**, Materials Science & Engineering Department
Tel: (847) 491-3198
E-mail: t-mason@northwestern.edu

Location: Cook Hall 3072

Equipment

This laboratory houses Agilent Technologies 4192A and Solartron 1260 impedance analyzers, fully computer-controlled, for performing frequency-dependent impedance/dielectric spectroscopy studies of materials. Recent materials and topics under investigation include fiber-reinforced composites, the aging of polymer wiring insulation in aerospace applications, interface/electrolyte characterization of solid oxide fuel cells and materials, the characterization of thin film electroceramics for grain vs. grain boundary effects, and the measurement of powder conductivities via the novel "power-solution-composite" method. The potential also exists for the characterization of soft materials, including biological and biomaterials.

Advanced Thin Film & Laser Processing Laboratory
Laboratory Director:
Professor **R.P.H. Chang**, Materials Science & Engineering Department
Tel: (847) 491-3598
E-mail: r-chang@northwestern.edu
Location: Cook Hall 1062

Function

This laboratory has equipment which supports the synthesis and processing of thin film systems ranging from ultra thin films to multi-layers and superlattices. Both physical deposition systems, such as sputtering and electron beam equipment, as well as chemical vapor deposition systems, such as metalorganic chemical vapor deposition equipment, are available. The laboratory also provides a means of forming metastable materials with a laser, and is equipped with a scanning ellipsometer which can be used from IR through the visible range. Software is available to perform simulation on multi-layer structures.

Equipment

1. **Thermal Vacuum Evaporator:** Diffusion pumped (base pressure 5 x 10^{-7}) Glass Bell Jar and guard
2. **Two Pulsed Organometallic Chemical Vapor Deposition Systems:** Each system can handle up to eight solid or liquid sources for deposition. All the source materials are fed into the main chamber via computer controlled valves. Microwave power is available to sustain a gas discharge at 10^{-3} torr. Thus complex oxides and nitrides can be made by this machine with precise stoichiometry. In addition, superlattice film of oxides can be synthesized. These systems are the only ones of its kind in the world.
3. **SOPRA Scanning Ellipsometry System:** This spectroscopic ellipsometer with an automated computer control allows samples of thin film to be measured and mapped with high precision for the dielectric function as well as the layer thickness. The ellipsometer covers an optical range from near IR to visible. Computer software is available for simulating film composition, multilayered structures, as well as surface roughness.
4. **Laser ablation:** This system is used for thin film processing.

Integrated Molecular Structure Education and Research Center (IMSERC)

Laboratory Director:
Dr. **Andrew Ott**, Department of Chemistry
Tel: (847) 467-1622
E-mail: northrup@chem.northwestern.edu
Laboratory Staff:
Saman Shafaie, Mass Spectrometry, optical spectroscopy, ICP atomic emission, ICP/MS
Tel: (847) 491-5514
E-mail: sepehr@northwestern.edu
Charlotte Stern, X-ray crystallography, differential scanning calorimetry
Tel: (847) 491-2950
E-mail: c-stern@northwestern.edu

Dr. **Yuyang Wu**, NMR
Tel: (847) 491-7080
E-mail: wu@chem.northwestern.edu
Location: Technological Institute K Wing Ground Level
http://pyrite.chem.northwestern.edu/analyticalserviceslab/asl.htm

---

Function

The Analytical Services Laboratory, operated by the Department of Chemistry, is a shared facility for performing a full range of chemical analyses. Such analyses include qualitative composition determination, quantitative analysis, and molecular structure determination. Instrumentation housed in this facility includes NMR spectrometers, mass spectrometers, X-ray crystallography equipment, optical spectrometers, elemental analysis equipment, and chromatography equipment. Users may be trained to use most of these instruments independently or samples may be submitted to the ASL staff for analysis.

Equipment

Nuclear Magnetic Resonance (NMR) Spectrometry
Varian Gemini 2000
Varian 400 (Solid State)
Varian INOVA 400
Varian Mercury 400 (with Varian SMS autosampler)
Varian INOVA 500
Varian INOVA 600
Probes for most instruments for a full range of NMR active nuclei, VT operation, a full range of multidimensional NMR experiments

Mass Spectometry
Agilent 1100 MSD with HPLC interface

Applied Biosystems 2000 (ESI/APCI) electrospray triple quadrupole mass spectrometer with HPLC interface
Applied Biosystems 3000 (ESI/APCI) electrospray triple quadrupole mass spectrometer
Applied Biosystems Voyager DE Pro MALDI (matrix assisted laser desorption ionization) - TOF (time of flight) mass spectrometer
Hewlett Packard 6890 GC/MS
Waters Q-TOF2 (ESI) electrospray quadrupole / Time of Flight high resolution mass spectrometer
VG Isotech isotope stabilized mass spectrometer
Thermo Finnigan MAT 900 high resolution mass spectrometer
Thermo Finnigan LCQ Advantage ion trap mass spectrometer

X-Ray Crystallography
Bruker SMART1000 single crystal X-ray diffractometer with CCD detector
Bruker KAPPA APEXII single crystal X-ray diffractometer with CCD detector (July 2007)
workstations for X-ray crystallography data analysis

Atomic Analysis
Varian VISTA-MPX Inductively Coupled Plasma (ICP) spectrometer
VG PQ ExCell ICP/MS

Optical Spectroscopy
Infrared and Raman:
Mattson Polaris FTIR spectrometer
BioRad FTIR spectrometer (near, mid and far IR) with microscope
BioRad FT-Raman II spectrometer
Ultraviolet/Visible:
Cary 1 UV/visible spectrometer
PTI QM-2 fluorescence/phosphorescence spectrometer

Chromatography
Gas Chromatography:
Hewlett Packard 5890 with capillary column for chiral separation
Varian 3700 HPLC: HP 1090 with reverse phase and gel permeation columns and UV and refractive index detectors
HP 1100 (used as an attachment for the electrospray mass spectrometer) with UV detector
GC/MS: Hewlett Packard 6890
Waters Alliance GPCV 2000 high T gel permeation chromatograph with viscosity, refractive index and light scattering detectors
Waters room temperature GPC system with refractive index and UV/Vis detectors.

Thermal Analysis
Instrument Specialists differential scanning calorimeters (DSC) miscellaneous: calorimeters, viscometers

Polarimeter
Optical Activity AA-100 automatic digital polarimeter

Ceramics Laboratory

Laboratory Director:
Professor **Scott Barnett**,
Tel: (847) 491-2447
E-mail: s-barnett@northwestern.edu

Location: Cook Hall 3006

Function

This laboratory houses equipment used to process and characterize ceramic materials. Equipment is available for the preparation, milling and characterization of ceramic powders and subsequent fabrication by pressing, tape casting, slip casting, extrusion, and sinter forging. The laboratory is also equipped with a an ultrasonic machine tool for drilling, planning, and milling ceramic particles.

Equipment

1. **Powder processing:** Ball mill, Vibratory mill, Sonic sifter, Mettler balance (0.1 mg resolution), Porsimeter, centrifuge, Sedigraph, Freeze-dryer
2. **Forming Equipment:** Uniaxial platen press, Hot isostatic press, Extruder, Tape caster
3. **Furnaces:** 1000C box furnace, 1200C box furnace, Tungsten furnace, 1600C CM rapid temperature box furnace, 1500C Lindberg box furnace, Carbon furnace 1700C, CM tube furnace, 1500C tube furnace, 1200C vertical tube furnace
4. **Additional Instruments:** Branson ultrasonic machine tool, diamond saw, low speed Isomet saw

Polymer Characterization Laboratory
Laboratory Director:
Professor **John Torkelson**, Chemical & Biological Engineering Department
Tel: (847) 491-7449
E-mail: j-torkelson@northwestern.edu
Location: Cook Hall 2022

Function

This laboratory is oriented toward the polymer community, providing the researchers with space and specialized instrumentation for the physical characterization of polymeric materials. Determination of molecular weight, mechanical properties, and thermal behavior of polymer solids are routinely performed in this lab.

Equipment

1. The **chromatic Low-Angle Laser Light Scattering photometer** and modified **Brice-Phoenix refractive index increment apparatus** are used for molecular weight characterization. Moreover, dilute solution viscometers are available for obtaining the absolute molecular weight and are thermostated for work up to 180ºC.
2. For Thermodynamic Characterization, the **Perkin-Elmer DSC-7 differential scanning calorimeter** is capable of automatic data acquisition and analysis of transition temperatures and heats of melting, crystallization, and reaction. The calorimeter is interfaced with a thermogravimetric analyzer (TGA), an automatic balance with microgram sensitivity, and the same data station for data acquisition and analysis of weight loss measurements. Density gradient columns are available for determining density of polymer solids.
3. **Mechanical Characterization Bohlin VOR Mechanical Spectrometer** is equipped for the measurement of viscoelastic properties of polymer solutions, melts, and solids at various sheer rates and temperatures.
4. The **Precision Profilometer**, the **Tencor Model P10 surface Profiler** and the **Spin Coater** are used for producing thin polymer films.

Charge Transport Laboratory
Laboratory Director:
Professor **Mark Hersam**, Materials Science & Engineering Department
Tel: (847) 491-2696
E-mail: m-hersam@northwestern.edu
Location: Cook Hall 4082

Function

The Charge Transport Laboratory includes equipment to perform variable temperature DC electrical conductivity and Hall measurements (mobility and carrier concentration), from 4.2 K to 340 K using a computer automated four- and five-probe technique, respectively.

Typical samples can range from thin films to single crystals, with specimens mounted on interchangeable sample holders. Hall measurements are made with a magnetic flux density of 0.74 Tesla. The measurements of the sample cross-sectional area and voltage probe separations (Hall and conductivity) are made with a calibrated Bausch & Lomb binocular microscope.

Equipment

DC electrical conductivity and Hall measurements: Liquid helium/liquid nitrogen cryostat and associated equipment (such as vacuum pumps), and lab-made dipsticks for sample mounting. Keithley and Lake Shore rack-mounted source-measure and switching equipment are all GPIB controlled by a computer running control software written using LabView. A Lake Shore electromagnet and power supply are used for the Hall measurements. Sample preparation includes various fine tweezers and wire, conductive dags, colloids, pastes, etc.. A calibrated Bausch & Lomb binocular microscope is used to mount and physically characterize the specimens under test.

Northwestern Synchrotron Research Center

APS/ANL, Building 432A
9700 S. Cass Ave.
Argonne, IL
Tel: (630) 252-0222

Center Co-Director (DND-CAT):
Michael J. Bedzyk, PhD
Tel: (847) 491-3570
E-mail: bedzyk@northwestern.edu

DND-CAT Director:
Denis T. Keane, PhD
Tel: (630) 252-0224
E-mail: dtkeane@northwestern.edu

APS Research Scientists:
Steven Weigand, PhD
Tel: (630) 252-0623
E-mail: weigansj@northwestern.edu

Qing Ma, PhD
Tel: (630) 252-0229
E-mail: q-ma@northwestern.edu

APS Beamline Technical Sys. Engineer:
Benjamin Stillwell
Tel: (630) 252-0234
E-mail: benstillwell@northwestern.edu

Administration:
Diane Sandberg
Tel: (630) 252-0222
E-mail: d-sandberg@northwestern.edu

http://www.dndcat.com

Center Co-Director (LS-CAT):
Wayne F. Anderson, PhD
Tel: (312) 503-1697
E-mail: wf-anderson@northwestern.edu

LS-CAT Operations Manager:
Keith Brister, PhD
Tel: (630) 252-0626
E-mail: k-brister@northwestern.edu

APS Research Scientists:
Spencer Anderson, PhD
Tel: (630) 252-0628
E-mail spencer-anderson@northwestern.edu

Joseph Brunzelle, PhD
Tel: (630) 252-0629
E-mail: j-brunzelle@northwestern.edu

Zdzislaw Wawrzak, PhD
Tel: (630) 252-0223
E-mail: z-wawrzak@northwestern.edu

APS Research Scientist:
Elena Kondrashkina, PhD
Tel: (630) 252-5554
E-mail: e-kondrashkina@northwestern.edu

APS Beamline Technical Systems Engineer:
Joseph (Jay) VonOsinski
Tel: (630) 252-0620
E-mail: j-vonosinski@northwestern.edu

Electromechanical Technicians:
Jason Ackley
Tel: (630) 252-0622
E-mail: j-ackley@northwestern.edu

Michael Bolbat
Tel: (630) 252-0621
E-mail: m-bolbat@northwestern.edu

Administration:
Nancy Brennan
Tel: (630) 252-0627
E-mail: n-brennan@northwestern.edu

http://www.ls-cat.org

DND-CAT

The Synchrotron Research Center manages the operations of the DuPont-Northwestern-Dow Collaborative Access Team (DND-CAT) instrumentation at the Advanced Photon Source at Argonne National Laboratory. Funds for construction, management, and operations to date have been obtained from E.I. DuPont de Nemours & Co. , the Dow Chemical Company, the National Science Foundation through the Academic Research Infrastructure program and the Materials Research Center , the State of Illinois through the Department of Commerce and Community Affairs and the Higher Education Cooperation Act, and the US Department of Energy. University sources of funds include the McCormick School of Engineering and Applied Science , the office of the Vice President, and the Office of Research. The facility supports state of the art x-ray research in the fields of biology, physics, chemistry, chemical engineering, environmental science, and materials science and engineering.

DND-CAT Equipment

DND-CAT operates five experimental stations. Three of these utilize undulator radiation and two utilize a part of the dipole radiation fan. DND-CAT currently supports several interdisciplinary X-ray techniques including x-ray spectroscopy, macromolecular and inorganic crystallography, small angle x-ray scattering, x-ray tomography and powder diffraction.

LS-CAT

The Life Sciences Collaborative Access Team (LS-CAT) provides macromolecular cystallography resources for those with a need to determine the structure of proteins. Mainly LS-CAT provides access to state of the art x-ray diffraction facilities at Argonne National Laboratory's Advanced Photon Source where extremely intense beams of x-rays are focused using both mirrors and beryllium lenses onto tiny protein crystals. The x-rays diffracted by these crystals are collected with giant CCD detectors that produce the images needed to calculate where the atoms in the protein crystal are.

LS-CAT was formalized in 2003 with seed money from the State of Michigan through the Michigan Core Technology Alliance. Northwestern University was selected as the managing partner and personnel from the du Pont-Northwestern-Dow Collaborative Access Team (DND-CAT) started work on the design of the facilities.

Construction of the LS-CAT facilities started in January 2006. By December, 2006 the construction of the x-ray enclosures had been completed and the instrumentation of the main station, 21-ID-D, was far enough along to accommodate an aggressive experimental schedule.

Sadly, one of the driving forces behind the formation of LS-CAT, Martha Ludwig, passed away in late November, 2006, just days before the first x-rays were delivered at LS-CAT for its members. The experimental facilities at 21-ID are dedicated in her honor.

Current LS-CAT members are Michigan State University, University of Michigan, Wayne State University, Van Andel Research Institute, Northwestern University, University Wisconsin-Madison, Vanderbilt University, and University of Illinois at Urbana-Champaign.

LS-CAT Equipment

The LS-CAT facilities include four experimental stations using 2 insertion devices. The main beamline (21-ID-D) uses a shortend "Undulator" A and a Kohzu monochromator in a layout very similar to XOR Sector 4 and Northeastern Collaborative Access Team (NE-CAT), APS Sector 24.

In addition to the main beamline there are three experimental stations that share a single 3.0 CM undulator. The first two of these stations use diamond laue monochromators supplied by JJ X-Ray along with beryllium lenses to focus a beam monochromatic x-rays onto the sample. This allows SAD experiments to be done at the selenium edge (12.668 KeV). This arrangement is very similar to the ID14 beamline at the ESRF.