

# Directory of Research Facilities and Laboratories



**MRC**

MATERIALS RESEARCH CENTER

**NORTHWESTERN**  
UNIVERSITY

Materials Research Science & Engineering Center  
NU-MRSEC

## **Central Laboratory for Materials Mechanical Properties (CLaMMP)**

### **Facility Director:**

Prof. David Dunand, Materials Science and Engineering

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### **Facility Manager:**

Mark Seniw

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**Location:** Cook Hall, 1034

<https://www.mccormick.northwestern.edu/materials-science/clammp/>

### **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, 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 -196C to 1100C.

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-strain curve measurements under computer control.

### **Equipment:**

1. Six MTS machines (three servo-hydraulic, one servo-electric, and two screw driven tensile machine) are available to perform static and dynamic mechanical tests and control such parameters as strain rate and rate of loading. Forces can be measured up to 50,000 lb (250kN) and as low as 250 grams (2.5 N).
2. 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
3. Three ATS constant load creep apparatus can be used for creep and stress rupture experiments up to 1100°C.
4. For measuring strain a digital image correlation system (DIC), laser extensometer, several contact extensometers and crack opening displacement gages are available.

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

## **Electron Probe Instrumentation Center (EPIC)**

### **Facility Director:**

Professor **Vinayak P. Dravid**, Materials Science & Engineering Department

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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**

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### **SEM Facility Manager and Scanning Electron Microscopist:**

**Ben Myers**

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<http://www.nuance.northwestern.edu/epic/>

## **Function**

The Electron Probe Instrumentation Center (EPIC) offers a wide range of electron microscopy (scanning (SEM), transmission (TEM) and scanning-transmission (S/TEM) electron microscopy), accessory instrumentation, and expertise to the scientific and engineering community through education, collaboration, consultation, training and service. The laboratory provides facilities for the preparation and examination of many types of bulk and thin specimens (foils/films), and small particles, from traditional engineering alloys, functional nanomaterials to biological materials. Detailed information about surface morphology, size and shape analysis, local chemistry, crystallography, and texture can be obtained with the scanning electron microscopes (SEM) as well as (S)TEM-related techniques.

The SEM facility has six SEMs with digital image acquisition, including four equipped with a field emission gun (FEG) (Hitachi S-4800/SU-8030, JEOL 7900F, Quanta 650F). All SEM's in the EPIC lab have energy dispersive spectroscopy (EDS) systems for compositional analysis. Other advanced SEM techniques include electron backscatter diffraction (EBSD), electron beam lithography (eBL), wavelength dispersive x-ray spectroscopy, Cryo-SEM, and S/TEM imaging. S/TEM allows researchers to probe the crystal structure, defects, local chemistry, electronic structure, and related information spanning from the nanometer to the atomic scale.

The TEM facility currently has six S/TEMs including a state-of-the-art probe-corrected ARM200, and ARM300) two Schottky field emission gun (HD2300, JEM2100F) and two thermionic gun (HT7700, JEM1400). Five TEMs are equipped with Energy Dispersive X-ray Spectroscopy (EDS) system for local chemistry analysis; two are equipped with a Gatan Imaging Filter (GIF) for spectral imaging and energy electron loss spectroscopy (EELS) analysis. Specifically, the ARM200CF has two solid state detectors (SDD), which can be used for atomic resolution elemental analysis. The spatial resolution of the JEOL S/TEMs (ARM200CF, ARM300F, JEM2100F) can be as high as 0.8 Å, 1.5 Å, and 2 Å, respectively. Additionally, the ARM200CF and the ARM300F are each equipped with a direct electron detector (Gatan K2-IS and K3-IS, respectively), which can be used for ultrafast low-dose imaging and EELS acquisition of a multitude of beam-sensitive materials.

The BioCryo facility adds expertise and instrumentation for cryo and conventional electron microscopy (S/TEM, SEM) and microanalysis of biological and soft matter samples. BioCryo houses a comprehensive array for cryogenic and ambient temperature sample preparation including plunge freezing (Vitrobot), high-pressure freezing (HPM100), freeze substitution (AFS2), freeze fracturing (ACE600), cryo/ultramicrotomy (UC7/FC7), automated (ASP1000) and microwave-assisted (BioWave) resin embedding.

The SEM, TEM and BioCryo facilities are equipped with specialized specimen holders for dynamic *in situ* studies involving applied deformation, gas and liquid environments, electrical fields, and temperature variations totaling 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.

## **Jerome B. Cohen X-ray Diffraction Facility**

**Cook Hall, 1016**

**Tel: (847) 491-7810**

**Facility Director: Michael Bedzyk, MSE**

**Facility Manager: Jerry Carsello**

**Visit the J.B. Cohen X-ray Diffraction Facility on the World Wide Web at:**

**<http://xray.facilities.northwestern.edu/>**

### **FUNCTION:**

The primary function is to provide equipment and training to NU and outside users for X-ray scattering and fluorescence studies. The X-ray lab also functions to prepare students and postdocs for beamtime at the Advanced Photon Source (APS).

**EQUIPMENT:** There are thirteen experimental x-ray stations available, of which seven have high flux rotating anode x-ray sources. In addition to the multi-axes diffractometers there are special environmental temperature controlled chambers for vacuum, inert or reactive atmospheres. There are various incident beam and scattered beam optics available along with 0D, 1D and 2D X-ray detector systems. Examples of current measurements are: powder diffraction (PXRd), thin-film reflectivity (XRR), thin-film diffraction, crystal truncation rod scattering (CTR), small angle X-ray scattering (SAXS), ultra-small-angle X-ray scattering (USAXS), Laue diffraction, pole figures, energy dispersive X-ray Fluorescence spectroscopy, single-crystal diffraction, x-ray standing waves, reciprocal-space mapping (RSM), high-resolution x-ray diffraction (HRXRD), and grazing incidence wide-angle X-ray scattering (GIWAXS), and GISAXS.

**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 0D, 1D, or 2D detector systems. The four Rigaku SmartLab stations offer the option of automated or manual control of alignment, data collection, display and analysis. ICDD PDF4+ database, MDI-JADE and CrystalDiffract are available for PXRd analysis. CrystalMaker and SingleCrystal are available for Laue and single crystal diffraction analysis. LINUX based SPEC and NEWPLOT (also used at the APS) are available on four of the stations. A networked printer and wireless network are provided.

The facility uses a university based protect file server for user data storage.

### **AVAILABLE APPARATUS:**

-Rigaku Photon-Max: Fast-sample throughput, high flux 9 kW rotating CuK $\alpha$ , MoK $\alpha$  anodes (no K $\beta$ ). Includes high-flux, focusing and monochromating multilayer optics for both reflection and transmission PXRD studies for either bulk or capillary samples. Other features include: Anton-Paar HTK1200 and Capillary Extension for high temperature XRD ambient-1200C° in bulk or capillary samples, auto-sample changer for transmission and reflection geometry with inert, air or vacuum atmospheres, high-speed linear strip detector and pouch battery cell sample stage to observe charge/discharge state in transmission geometry. Anton-Paar XRK900 reactive gas chamber from ambient to 900°C for gases such as H<sub>2</sub> or NH<sub>3</sub>. The XRK900 is suitable for bulk or film samples.

- Two Rigaku SmartLab Thin-film Diffraction Workstations: A high intensity 9 kW copper rotating anode x-ray source is coupled to a multilayer optic. The system has selectable x-ray optical configurations suitable for: thin-film work with single crystal, amorphous, or poly-crystalline films. Also, high intensity powder diffraction. Additionally, supported are grazing incidence, in-plane diffraction geometries, pole figures and reciprocal space mapping. Other features are: 5-axis goniometer, horizontal sample mounting permitting work with liquid samples , and a high speed high count-rate scintillation detector. Options include: Ge(220) 2-bounce and Ge(220) 4-bounce channel-cut incident beam optics, Ge(220) 2-bounce analyzer crystal on detector arm for USAXS, Anton-Paar DHS1100 ambient to 1100° C hot stage and an Anton-Paar DHC350 cooling and heating sample stage useable from -100 to 350° C.

- Rigaku Smartlab-3kW: Fast sample throughput with high-flux CuK $\alpha$  optics for powder samples in transmission, capillary, or bulk with auto-sample changer. Other features include: grazing incidence, in-plane diffraction geometries, pole figures and reciprocal space mapping, SAXS and USAXS attachment with resolution 1-100 nm, automated 5 x 5 cm XY-translation stage for XRD mapping with a 0.4mm beam size produced by a high-flux poly-capillary bundle, and 0D,1D, and 2D HyPix 55x55mm 300,000 pixel area detector.

- Rigaku ATX-G Thin-film Diffraction Workstation: A high intensity 18 kW copper x-ray rotating anode 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, in-plane diffraction geometries, pole figures, reciprocal space mapping, and large-size wafer sample mounting. Other features are the 5-axis goniometer with several 4-crystal monochromators that couple to the multilayer mirror.

- Rigaku S-MAX 3000 High Brilliance SAXS-WAXS System with a Cu K $\alpha$  MicroMax source, KB multilayer mirror focusing monochromator, automated sample changer for

SAXS-WAXS, and goniometer attachment for GISAXS-GIWAXS. A Bruker Vantec 2000 2-D detector collects the SAXS-GISAXS pattern and a Fuji image plate collects the WAXS-GIWAXS pattern. The Q-range is 0.01 to  $1\text{\AA}^{-1}$ . Capabilities also include a Linkam temperature control stage (-50 to 300°C).

- 18 kW Mo Rigaku: Mo target rotating anode with vertical line source and high-resolution Huber 2-circle diffractometer with Osmic Max-Flux collimating multilayer mirror wide band-pass monochromator, followed by optional (111), (220), or (400) Si 2-bounce channel-cut post-monochromator. Uses Linux PC with SPEC software control, high-count rate scintillation detector, automated beam attenuator and multi-channel analyzer XRF spectroscopy system.

- 12 kW Cu Rigaku: Cu target rotating anode with vertical line source and high-resolution Huber 2-circle diffractometer with Osmic Max-Flux multi-layer mirror wide band-pass monochromator, coupled to a post monochromator stage for a (111), (220), or (400) Si 2-bounce channel-cut or Ge(111) 2-bounce collimator. Uses Linux PC with SPEC software control, high-count rate scintillation detector, automated beam attenuator and multi-channel analyzer fluorescence spectroscopy system.

- 18 kW Cu Rigaku: Medium resolution Huber 4-circle diffractometer with double-focusing Graphite (002) monochromator and SPEC software control and automated beam attenuator.

- Rigaku Ultima IV: Automated powder diffraction stations featuring: high temperature environmental chamber for ambient to 1500°C work, a ten sample multi-sample changer, horizontal sample mounting permitting work with liquid samples and a high speed 1-D detector permitting high volume sample throughput, in addition to a high count-rate scintillation detector.

- Amptek X-ray Fluorescence, Energy Dispersive system with SDD detector, Ag anode x-ray source with analysis software for use with or without standards

- Scintag XDS2000: Automated diffraction system, with four-circle pole-figure and residual stress device, thin film diffraction attachment and solid-state detector.

- Photonic Science Laue diffraction system with CCD camera.



## **Magnet and Low Temperature Facility (MLTOF)**

Facility Director:

Prof. John Ketterson, Physics & Astronomy

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**Facility Technician:**

Byron Watkins

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**Location:** Technological Institute FB24

<https://mrsec.northwestern.edu/facilities/magnetlowtemp/>

## **Function**

This facility maintains various magnet, cryogenic and optical systems operating either separately or together. The systems are designed to be as flexible as possible, and to allow several types of measurements to be performed over a wide range in magnetic field, temperature, and probe frequencies (including both uhf/microwave and optical). The dc and uhf/microwave frequency measurements that are routinely performed include magnetization and magnetic susceptibility, acoustic propagation, microwave absorption, electrical transport (including thermoelectric measurements). Routine optical measurements include optical absorption, photoluminescence, pump-probe studies, and Raman spectroscopy.

## **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: 10 nJ/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.

## **Materials Characterization and Imaging Facility**

### **Facility Director:**

Derk Joester, Materials Science & Engineering

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### **Facility Manager:**

Carla Shute

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**Location:** Cook Hall 2008, 2082, 2084, 2086

<http://matci.facilities.northwestern.edu/>

### **Function**

The Materials Characterization and Imaging Facility offers a broad range of characterization and sample preparation equipment for use by internal as well as external users to Northwestern University. Characterization techniques include optical microscopy, optical coherence tomography, laser 3D surface analysis, thermal imaging, thermal analysis (DSC, TGA), hardness testing (Vicker's, Knoop, Rockwell), electronic characterization (Hall Effect, Impedance Spectroscopy, Kelvin Probe, DLTS), dynamic mechanical testing of softer materials and rheological characterization. Sample and surface preparation capabilities include mounting (castable mounts, hot pressure mounting, vacuum impregnation), cutting, sectioning and wafer dicing, polishing/grinding, electropolishing, ion beam milling and cross-sectional polishing. Tube and box furnaces are available with temperature range up to 1700C for thermal processing.

The Lab Manager is available for consultation and training.

### **Equipment**

Sample preparation:

- Precision and low speed saws for sample sectioning
- Polishing/grinding wheels (3) and semi-automatic polishers (2)
- Triple beam ion miller/slope cutter
- Hot compression mounting and vacuum impregnation systems

Sample observation/structural characterization:

- ThorLabs Ganymede OCT system
- Olympus LEXT OLS5000 3D Laser Scanning Confocal Microscope
- Nikon automated inverted microscope
- Optotherm Micro Thermal Imaging System

#### Thermal Analysis:

- Differential Scanning Calorimetry: TA Instruments DSC250
- Simultaneous Thermal Analysis: Mettler Toledo TGA/DSC3+

#### Polymer and softer materials mechanical testing/viscoelastic properties:

- Rheometer: Anton Paar MCR302
- Dynamic Mechanical Analysis: TA Instruments RSA-G2 solids analyzer

#### Hardness Testing:

- Vickers/Knoop hardness: Struers Duramin 5 hardness tester
- Wilson Rockwell tester

#### Electronic Characterization:

- Impedance Analyzers: Solartron 1260, HP4192A
- Surface Potential: KP Technology Kelvin Probe
- Deep Level Transient Spectroscopy: Semetrol DLTS system

#### Furnaces:

- Box Furnaces – small and large box furnaces are available with temperature range up to 1200°C
- Tube Furnaces – two tube furnaces are available for heating of samples in controlled atmosphere. Up to 1700°C.

## **Materials Processing & Microfabrication Facility – Cleanroom**

### **Facility Director:**

Professor Bruce Wessels, Materials Science & Engineering Department

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### **Facility Manager:**

Dr. Anil Dhote, Materials Science & Engineering Department

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

### **Function**

The Materials Research Center (MRC) cleanroom facility is devoted to materials processing, growth, device fabrication, characterization and electronic & photonic materials. The MRC cleanroom complex in Cook Hall provides microfabrication and thin film processing capabilities. 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 characterization. Training of equipment and assisted use within the facility is available to provide the necessary expertise. This provides a centralized resource for the deposition of metal, semiconductor & dielectric thin films, photolithography, etching, bonding, dicing, characterization and materials processing.

### **EQUIPMENT LIST:**

#### **Photolithography**

1. SUSS MicroTek MABA6 **Mask Aligner**
2. Quintel Q-4000 **Mask Aligner**
3. Quintel Q-2000 **Mask Aligner**
4. Headway PWM32 **Spinners** Programmable
5. Digital Baking Plates
6. Convection Ovens
7. Microscope
8. Photolithography Develop Hood

#### **Deposition**

9. Edwards Auto 500 FL400 **e-beam Evaporator**
10. Edwards Auto 306 **e-beam Evaporator**
11. Nanomaster NPE4000 Plasma Enhanced Chemical Vapor Deposition (**PECVD**)
12. Oxford Instruments  $\mu$ P80 Plasma Enhanced Chemical Vapor Deposition

**(PECVD)**

13. Cambridge NanoTech Savannah S100 Atomic Layer Deposition **(ALD)**

**Etching**

14. Samco RIE-10NR Reactive Ion Etcher **(RIE)**

15. Oxford Instruments  $\mu$ P80 Reactive Ion Etcher **(RIE)**

**Characterization**

16. Filmetrics F-20 **Thin Film Analyzer**

17. Tencore P-10 **Surface Profiler**

18. Metricon 2010 **Prism Coupler**

19. LakeShore HMS8404 **Hall Effect Measurement System**

20. Omano Microscope

**Processing**

21. Chemical Hoods

22. Annealing Tube Furnace

23. Annealsys AS-Micro Rapid Thermal Processor **(RTP)**

24. Ultrasonic Cleaner

**Wire Bonding**

25. West Bond 7374E **Wedge-Wedge Wire Bonder**

22. Kulicke & Soffa 4524D **Ball-Ball Wire Bonder**

**Wafer Dicing**

27. Advance Dicing ADT 7122 **Wafer Dicing System**

28. Advance Dicing WM 966 **Wafer Mounting Station**

List of equipment fees are available online at:

<https://mrsec.northwestern.edu/facilities/cleanroom/>

## **Northwestern University Center for Atom-Probe Tomography (NUCAPT)**

### **Facility Director:**

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### **Facility Manager:**

Research Associate Professor Dieter Isheim, Materials Science & Engineering Department

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**E-mail: isheim@northwestern.edu**

**Location: Cook Hall 1086, Tel (847) 491-7826**

**<http://arc.nucapt.northwestern.edu>**

### **Function**

NUCAPT specializes in high-resolution chemical imaging by three-dimensional **atom-probe tomography (APT)**. APT produces a three-dimensional (3-D) image of a sample volume, resolved atom-by-atom, elementally and isotopically, and with sub-nanometer spatial resolution. A typical APT run typically captures a volume  $100 \times 100 \times 300 \text{ nm}^3$  of a sample by field-evaporating atoms from the specimen surface in a high electric field, atom-by-atom, atomic layer by atomic layer. A high resolution direct-space image is recorded at about one million time magnification, and the chemical and isotopic identity of each atom determined simultaneously by time of flight mass spectrometry. With sub-nanometer spatial resolution and elemental and isotopic sensitivity for all elements across the periodic table, APT is particularly suited to study **nano- or nanostructured materials**. Typical micro- and nanostructural features studied at our research facility include: composition and morphology of second-phase precipitates, segregation and small clusters of solute atoms at grain boundaries and phase boundaries, compositional variations in modulated structures, multi-layer thin-film structures, dopant profiles in semiconductor materials and devices, and analysis of the chemistry and topology of internal (buried) interfaces. Typical materials studied include high-performance metallic alloys (steels, Al-, Mg-, Ni-, Ti-, Co-, Mo-, Nb- and shape memory alloys), semiconductor nanowires and devices, zero-, one, and two-dimensional quantum well structures, thin-film functional materials, nanoparticle growth morphologies and nanomaterials for catalysis and environmental remediation, nanodiamond particles, tooth enamel, bones, biominerals, and hybrid materials, geological materials including meteoritic, lunar, and geological materials, battery and energy materials, including electrode materials for Li-ion batteries and fuel cell barrier layers, and materials from cultural heritage and art such as glass, ceramics and paint pigment. Specimen preparation of almost any material is now possible employing a dual-beam focused-ion beam (FIB) microscope, which also allows



targeted sample preparation of a specific feature, such as a grain boundary or an individual transistor in a semiconductor device.

The experimentally obtained 3D atom-by-atom data from APT permit a direct comparison with atomistic computer simulations and modeling, to understand the investigated microstructures and their dynamics on an atomic scale. Both computer simulations and modeling can be performed at NUCAPT utilizing a suite of software packages and computer clusters.

The instrumentation at NUCAPT serves both educational and research projects for high-school, undergraduate, graduate, and postdoctoral students and professional scientists from academia and industry. NUCAPT is open to any researcher from Northwestern University as well as for external visitors from universities, industry, non-profit, and government laboratories in the United States and internationally, and participates as a member facility of the SHyNE resource in the NSF-supported national NNCI network.

## Equipment

1. A **LEAP5000 XS atom-probe tomograph** manufactured by CAMECA Instruments, Inc. The LEAP5000 XS is a local electrode atom-probe (LEAP) tomograph, has a single-atom sensitive detector with a (78 +/- 2)% detection efficiency (November 2017 upgrade) in a straight-flight path configuration. Atoms are field-evaporated from the sample surface either by voltage or ultraviolet (355 nm wavelength) laser pulses and detected by a position-sensitive time-of-flight microchannel plate and delay-line detector system. The pulse energy of the UV laser is adjustable from 2.5 fJ – 0.75 nJ ( $5 \times 10^5$  dynamic range), allowing optimum evaporation conditions for a wide variety of materials. Field-evaporation can be controlled at pulse repetition frequencies between 10 kHz and 1,000 kHz (voltage pulsing: 500 kHz) and detection speeds of up to 80,000 atoms per second, or about 300 million atoms per hour, enabling high throughput. The system operates at ultra-high vacuum at  $\sim 2 \times 10^{-11}$  Torr and has a dedicated specimen load lock system and ultra-high vacuum specimen storage chamber with a capacity of up to 32 specimen pucks. The cryostage can achieve temperatures from 25–150 K. The local-electrode design of the LEAP5000 XS facilitates the use of microtip array specimens with up to 22 or 36 individual microtips on each carrier coupon. The control software was upgraded in 2019 with the most recent version of CAMECA's AP Suite 6 software that is capable to visualize a live 3D reconstruction with the data from the current APT analysis, with atom-by-atom elemental and isotopic identification by time-of-flight mass spectrometry and subnanoscale spatial resolution, in three dimensions.

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 with a capping layer, 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 and compounds. The raw materials are placed on a water-cooled hearth in a vacuum chamber. After evacuation, the chamber is re-filled with argon as inert working gas. An electric arc heats the raw materials above their melting point, fusing them into an alloy or compound. 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. Since 2016, we also operate a capacious and versatile AM0.5 arc melting system, manufactured by Edmund Bühler GmbH, Germany. This laboratory-size arc melting system is designed for synthesizing alloys and compounds through melting with a maximum 500 g charge, high-purity 99.999 % Ar working gas, and a high-vacuum system with a turbomolecular pump for minimizing oxidation and contamination. The AM0.5 can be configured for suction and tilt casting.

5. NUCAPT computing facility comprising

5.1 A 48 TB data server

5.2 Five high-end PC workstations dedicated to running CAMECA's IVAS code for APT-data reconstruction and data 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 fiberoptical DDR InfiniBand Network for large-scale parallel calculations. This cluster is currently optimized for performing VASP DFT calculations and lattice kinetic Monte Carlo simulations.

### **NU Micro/Nano Fabrication Facility (NUFAB)**

#### **Faculty Director:**

Professor **Vinayak P. Dravid**, Materials Science & Engineering Department

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#### **Director of Operations:**

**Nasir Basit**

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**Location:** FG70-FG99 Technological Institute, 2145 Sheridan Rd, Evanston, IL 60208

<https://nufab.northwestern.edu/>

#### **Function:**

NUFAB is a central micro/nano fabrication facility in Northwestern University. It provides the whole range of nanofabrication equipment and technical expertise to Northwestern as well as external academic and industrial researchers. It supports research in all areas of science, engineering, medicine, and interdisciplinary fields. It is a growing facility with a capability to accommodate research in new directions.

Our state-of-the-art equipment is located in a 6000 square-foot class-100 (ISO 5) clean room with laminar airflow. The attached technical staff offices and a meeting/conference room with windows looking into the clean room provide easy accessibility.

## **Pulsed Laser Deposition Facility**

### **Facility Director:**

Professor **Michael Bedzyk**, Materials Science & Engineering Department

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### **Facility Manager:**

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<https://sites.northwestern.edu/pldcore/equipment/>

**Location:** Technological Institute NG32

### **Function**

The Pulsed Laser Deposition (PLD) Facility provides a means to grow high quality thin films, 1 Å to 1 μm thick, of metals and metal oxides, as well as some nitrides, chalcogenides, and compound materials. PLD provides a convenient way to make thin films of materials heretofore studied in the bulk, by pressing and sintering a PLD target from the bulk material; facilities are available at Northwestern for the pressing and sintering of targets. The PLD Facility is open to all the faculty, staff and students at Northwestern University as well as researchers from other universities, Argonne National Laboratories and industrial companies. The instruments can be used: Independently, after training; Assisted use, where the user gets hands-on experience but with staff present and assisting; Staff-conducted film growth. The staff is highly experienced in Pulsed Laser Deposition and willing to help in the choice of deposition parameters, substrates and targets.

### **Equipment**

The PLD facility has two state of the art deposition chambers: a PVD Products PLD/MBE 2300 and a PVD Products nanoPLD. Both chambers are connected to a Coherent CompEx Pro 102F, 248nm KrF excimer laser. Both chambers can hold multiple targets which allows the deposition of multilayers, superlattices and custom composition films. The PLD/MBE chamber has a linear sweep-shutter that allows the deposition of a linear composition gradient of two materials as well as a step-shutter that allows the deposition of films with stepped thickness-gradients. The PLD/MBE chamber also has differentially-pumped high-pressure RHEED capability. All equipment operation is controlled via a computer interface decreasing the number of operating protocols users need to learn.

### **Deposition Capabilities**

For both the PLD/MBE 2300 and nanoPLD 1000 chambers

- Laser Power: 90 – 300 mJ / pulse at the laser
- Repetition Rate: 1 -20 Hz

## **Surface Science Facility**

### **Facility Director:**

Prof. Yip-Wah Chung, Materials Science & Engineering

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### **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**

**Laser Surface Engineering System:** for generating controlled surface roughness and patterns.

**Optical profilometers:** Two optical interferometers (Zygo and Alicona) are available for surface topographic imaging.

**Three-target magnetron sputter-deposition system (AJA):** Magnetron sputter deposition of samples with up to three source target materials.

### **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.