

## I. FACILITIES AND EQUIPMENT AVAILABLE

### Equipment in PI's Laboratory:

The laboratory of Prof. Kumta is equipped with state-of-the-art facilities for low temperature chemical processing of ceramics. Following is a brief description of the major equipment that is currently available in the laboratory of the Principal Investigator.

#### 1. Glove Boxes:

Complete inert gas system, including modular glove-box, external gas purification system, PLC control with touch-screen, large standard antechamber and mini antechamber.



## 2. Parr Hydrothermal:

High temperature, high pressure reactor with 500 mL moveable vessel assembly. Temperature up to 500 degrees C. Pressure up to 5000psi.



## 3. Arbin Rechargeable Battery Testing System:

General-purpose testing equipment for battery testing, life cycling, and material research. Each channel is a fully functional potentiostat/galvanostat and covers very wide current, voltage and power ranges. Also a useful tool for studying battery packs and chargers. BT2000 Arbin 32 Channels and 20 channels systems with a operating voltage range of 0 – 10V and current ranges of 5 $\mu$ A – 1A.



#### 4. Spex Mixer/Mill:

Includes a variable-range electronic timer, safety interlock system, and shock-mounted electric motor for tabletop operation. A P5 unit is also available for milling materials in larger quantities.



5. Misonix Ultrasonic Liquid Processor:

Includes digital processing and touch screen control. Output amplitude is controlled from 0-100%. Includes standard horn and sound enclosure.



6. Fisher Scientific Isotemp Vacuum Oven:

Operates with reduced pressures and/or inert atmospheres. Oven is equipped with separate vacuum and gas ports, each with its own control valve.



7. Thermcraft Standard "S Line" High Temperature Hinged Tube Furnace:

The tube furnace has a maximum temperature of 1200°C (2192°F) and accepts tubes with OD of 1 inch. The three zone includes a heating zone length of 24 inches. The single zone has a heating zone of 12 inches. This unit is modified for use in liquid injection chemical vapor deposition.



8. Lindberg/Blue M Tube Furnace:

1200°C Split-Hinge Tube Furnaces, Single zone; 240V, 60Hz; Process tube: 2"; heated length 12"



### 9. Fully Automatic Gas Cabinets:

Fully automatic gas cabinets for ultra high purity gases provide safe, clean delivery of toxic, corrosive and/or flammable gases.



### 10. Micromeritics ASAP 2020:

Characterizes the active and support surfaces of catalysts, to determine the high surface areas of adsorbents, and to determine the microporosity and hydrogen storage capacity of various nano materials.



11. Netzsch STA 409PC Luxx:

Offers simultaneous thermogravimetric and calorimetric analyses from room temperature into the high temperature range of 1650°C. Vacuum-tight construction also provides for pure atmospheres during analysis.



12. ACE-Burlitch Inert Atmosphere System:

The Burlitch inert atmosphere or no-air system was developed for air sensitive compounds and can be used for no-air protocols or for inert gas atmospheres.



13. Ametek-Princeton Applied Research VersaSTAT3:

High speed DC measurement and experiment sequencing (e.g. for step/pulse analysis). High current and power booster options for electrodeposition, pulse-plating and energy storage. Versatile, easy to use V3 Studio software. Optional built-in frequency response analyzer providing fully integrated DC and EIS analysis.



14. Denver Instruments Summit Series SI-403 Electronic Top-loading Balance (x3):

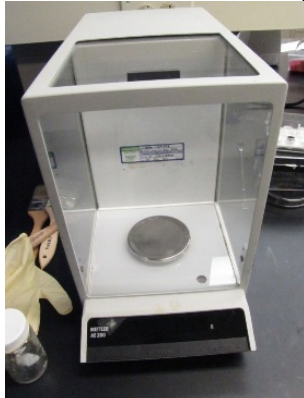


Incorporates single-block weighing technology for quicker response times and accurate, repeatable results. Latest microprocessor technology makes these balances super fast.



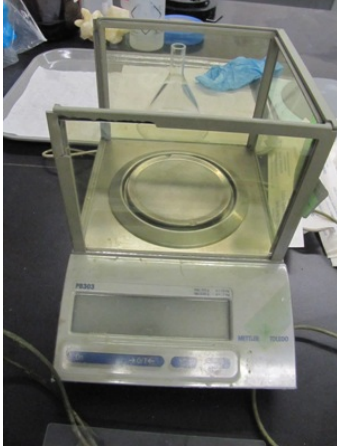
15. Mettler Toledo AE200 Analytical Balance:

Analytic grade balance incorporating internal calibration, quick response time, and rugged construction for use in pressurized environments.



16. Mettler Toledo PB 303 Precision Balance:

Generously proportioned draft shield aids precise weighing-in.



17. Ohaus Adventurer AR1530 Top-loading Precision Balance



18. Ohaus Adventurer Pro AV53 Milligram Precision Balance:

Offers unsurpassed access to the weighing platform to clean up spills or to place or retrieve materials to be weighed, greatly reducing spillage and virtually eliminating waste.



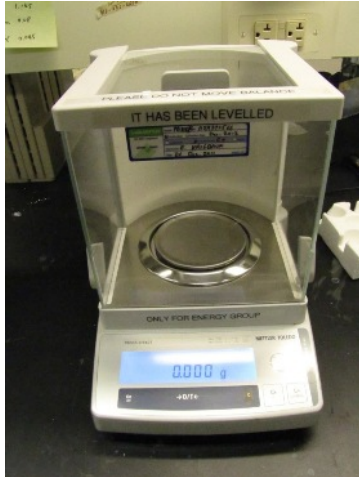
19. Mettler Toledo AB135-S/FACT Dual Range Analytical Balance



20. Mettler Toledo XP105 DR Dual Range Analytical Balance



21. Mettler Toledo PB 303-S/FACT Precision Balance



22. Mettler Toledo PB4002-S/FACT Precision Balance



23. Mettler Toledo PB8001-S/FACT Precision Balance



24. Thermo-Scientific Lindberg/Blue M model HTF55322C 1200°C tube furnace (with model CC58114PBC-1 controller):

With maximum temperature ranges from 100°C to 1200°C, applications include ashing, sintering, crystallizing, annealing, fusion, tempering and hardening, atmosphere processing and more.



25. Lab Research Products LRP-26 4°C Refrigerator:

Provides precise temperature settings and maintenance with the security of alarms.



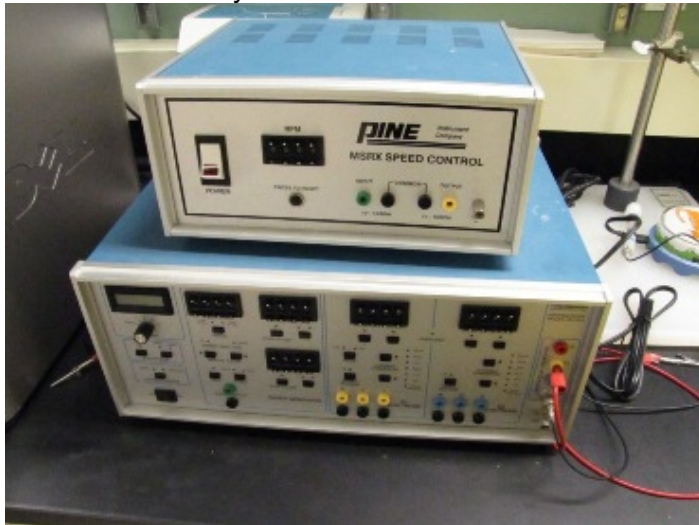
26. Portable precision Spin Coater:

Top precision spin coating systems, designed for low volume production coating applications and to apply a variety of liquid materials to planer substrate.



### 27. Rotating Ring Disc Electrode:

Can be operated as either a three or four electrode potentiostat for use in many kinds of electrochemical experiments, including cyclic voltammetry, anodic stripping voltammetry, rotated disk voltammetry, rotated ring-disk voltammetry, and inter digitized array experiments. It can also be operated as a two-electrode device for tracing the current-voltage characteristics of electrochemical systems..



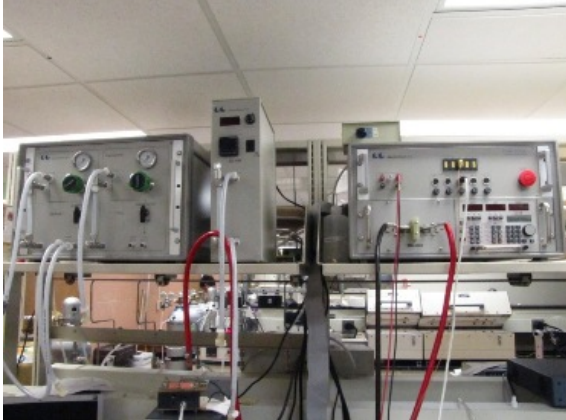
### 28. Multichannel battery testing system:

Advanced testing equipment for research and development of energy storage or electrochemical devices, such as battery, supercapacitor, and fuel cell. Besides functions commonly used in energy storage device testing; such as charge discharge, constant current, constant voltage, constant load and constant power;

Same as #3

### 29. Fuel Cell Station:

PC controlled, electronic load bank and fuel cell system controller, operating on ElectroChem's proprietary Windows-based software system. The user can program the flow rate, temperature, and humidification of the reactant gases and the load to the fuel cell.



30. 1200C tube Furnaces:

Five 1200C split hinge single zone tube furnaces with a heated length of 12 inches.

**SAME As #24**

31. 1700C box Furnaces:

Digital, multiple segment, programmable controller with over temperature control and communication port.



32. Spex Mill:



Two mills capable of pulverizing samples in the 10-gram range. Reduces hard, brittle samples to analytical fineness, blending powders, making emulsions, and performing mechanical alloying.



33. Mercury Porosimeter:

Determines pore size distribution, pore volume, and apparent density of solid/powder samples. Pore diameter range: 360 mm-5 nm.



34. Gas Pycnometer:

Fully automatic. Determines the true density and volume by measuring pressure change of helium within a calibrated volume. Measures samples having volumes above 1 cc maximum up to 30cc



35. Spin coater:

Used for uniform coating of liquids, gels, and sol suspensions on different substrates. Speed: 100-8000 RPM, Acceleration: 1-30 sec, Spin time: up to 999 sec. Interchangeable vacuum chucks.



36. 1500°C tube furnace:

Used for high temperature synthesis and sintering of electro-ceramics, bio-ceramics and metals. Maximum temperature: 1500 °C.



37. 1200°C Box Furnace (integrated controller):

Used for high temperature synthesis and sintering of electro-ceramics, bio-ceramics and metals. Maximum temperature: 1200 °C.



38. Cold room:

Used for handling and storage of temperature and moisture sensitive biological samples. Temperature range: 2-10 °C, Operating at 4 °C, Humidity range: 75-90% of R. H. at 4 °C, operating at 75% of R. H.



39. Sonicator:

Power output: 200W, 10-100% amplitude control, Horn frequency: 19.850-20.050 kHz.



40. Desiccators:

Auto-Desiccators for storage of hygroscopic chemicals. Maintains low (30 to 40%) relative humidity inside the cabinet.



41. Water Bath:

Used for heating liquid samples. Temperature range: ambient to 90 °C ( $\pm 0.5$  °C).

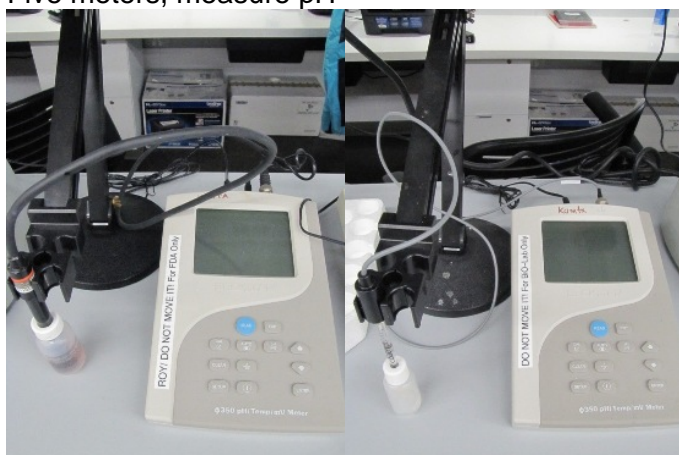


42. Ice machine:

Ice production: up to 395 lb in 24 hrs; 60lb storage capacity.



43. pH meter:  
Five meters, measure pH



44. Refrigerator:  
Temperature maintained at 4 °C



45. Freezer:

Temperature maintained at -20 °C, auto defrost unit



46. Ultralow Freezer:

Temperature maintained at -80 °C, can go down to - 86 °C



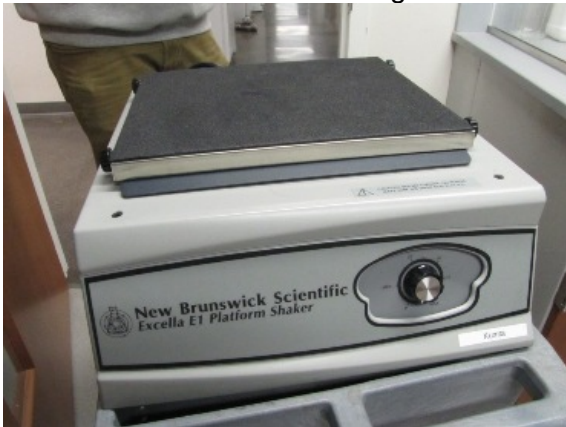
47. Biosafety Cabinets:

Sterile environment for tissue culture related work



48. Benchtop Shakers:

Uniform distribution and mixing of solutions or suspensions



49. Plate Reader:

Measurement of absorbance, fluorescence, and luminescence



50. Autoclave (sterilization):

Sterilization of tissue culture supplies and tools



51. Incubator (ventilated):

Non-sterile incubator with temperature maintained at 37 °C



52. Lyophilizer:



Freeze-drying and lyophilization of samples



53. Microscope (optical):

Observation of cell culture using white light



54. X-Ray diffraction analyzer:

A Philips PANalytical self-enclosed analytical powder diffractometer for crystal structure analysis equipped with a goniometer and X'Celerator



55. XRK X-ray Reactor Chamber:

Studies solid state and solid state-gas reactions under *in-situ* conditions.

56. X'Celerator:

The implementation of the latest RTMS (Real Time Multiple Strip) X-ray detection technology into a compact, yet powerful PreFIX module has changed the world of powder diffractometry.

57. Diamond Saw/ ISOMET 1000 Precision Saw:

Automatic cut-off switch, counterbalanced sliding load weight system, 0-500g, built-in inch or metric digital micrometer cross-feed for sample location, removable coolant tray with built-in dressing device, 1/8 HP (90W) DC motor with variable arbor speed 0-975 rpm.



58. Nicolet 6700 FTIR Spectrometer:

Equipped with a diamond ATR a KBr beamsplitter (7800 - 350 cm<sup>-1</sup>), a solid substrate far-IR beamsplitter (700-50 cm<sup>-1</sup>) X700, and a gold monoflect dual detector optical system. It is connected to the TGA unit for the gas phase analysis.



59. Smart Orbit:

Offers additional sampling flexibility by offering optional germanium and silicon crystal plates and a 45 degree specular reflectance option.

**Same as above**

60. Milli-Q Academic System:

Utilizes the standard three-step purification process - pretreatment, application specific polishing and final filtration - to produce Type 1, reagent-grade water suitable for all general laboratory applications.



61. Milli-Q Advantage A10 Water System:

The Milli-Q Advantage system has been designed to deliver high quality ultrapure water adapted to every user's needs in today's laboratory environment. The system features two separate and distinct components: the production unit and the delivery point-of-use unit. It produces Type 1, reagent-grade water suitable for all general laboratory applications: Resistivity 18.2 MΩ·cm at 25 °C, TOC ≤ 5 ppb, Particulates\* (> 0.22 μm/ml) < 1 particulate/ml, Bacteria\* < 1 cfu/ml, Pyrogens (endotoxins)\* < 0.001 EU/ml, RNases\* < 0.01 ng/ml, DNases\* < 4 pg/μl, and it's flow rate goes up to 2 l/min



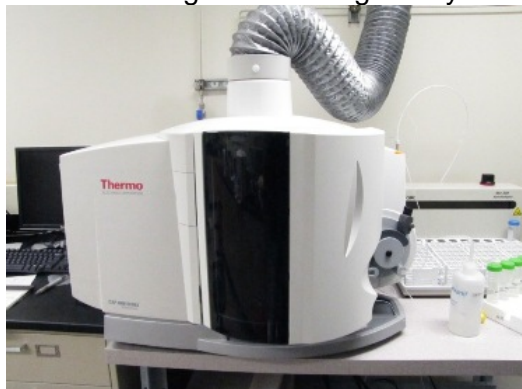
62. Titration:

Fully automated and capable of: Liquid handling with the Dosino® intelligent dosing unit, Potentiometric, Karl Fischer and STAT titration, monitored dosing for synthesis, uninterrupted dosing in tandem operation, and sample processor control.



63. ICP:

Compact bench-mounted simultaneous ICP spectrometer unit, based on a RF induced plasma emission source, a purged Echelle polychromator and Charge Injection Device (CID) array detector and includes as standard: - A 4 channel, 12 roller peristaltic pump under full computer control feeding a standard glass cyclonic spray chamber via a glass concentric nebuliser.



63. Centrifuges in the Bio-Lab:

Refrigerated micro centrifuge with Max. capacity 24 x 1.5/2.0 ml, Max. RPM (speed) 14,000 min<sup>-1</sup>, Max. RCF 18,626, Temperature control, infinitely variable - from -10 to +40 °C, Precooling time (Fast Cool) - in 10 – 15 min. to +4 °C.



64. ROTINA 38R, 110-127V 60Hz:

Regular bench-top refrigerated centrifuge with Max. capacity 4 x 250 ml, Speed (RPM) 15000, Force (RCF) 24400, and temperature controllable from -20 OC to +40°C.



65. ROTANTA 460R:

High capacity bench-top centrifuge with 4 x 750 ml, swing - out rotor, speed of 15,000 min<sup>-1</sup> / RCF 24,400, and controllable temperature from - 20 °C to + 40 °C.



66. MIKRO 120:

Micro centrifuge with Max. capacity 24 x 1.5 / 2.0 ml, Max. RPM (speed) 14,000  $\text{min}^{-1}$ , Max. RCF 17,530.



67. ROTINA 38:

Regular bench-top centrifuge with Max. capacity 4 x 250 ml, Speed (RPM) 15000, and Force (RCF) 24400.



68. Savant DNA SpeedVac Concentrator:



Rapid and efficient concentration and drying of DNA/RNA samples, nucleic acids, PCR preps and synthetic oligos.



69. CO<sub>2</sub> Incubator:



70. Aktaprime Plus for Ion Exchange Chromatography:

Compact chromatography system designed for one-step purification of proteins at laboratory scale.



71. Liquid Nitrogen Cell Storage Tank:

Liquid nitrogen cell storage system with 165 L LN2 Capacity, 0.84 liters/day Normal Evaporation Rate, 194 days of Static Holding Time.



72. Deltek Furnace:

A 1200°C bottom loading inert atmosphere hydraulic furnace for melting ceramics and metals.



73. 3-D Ink-Jet Printers (Z-Corp, Z-310 and Z-510):

Three 3-D Z-corp inkjet printers for printing ceramic and metallic particles.



74. 3-D Ink-Jet Printers for metals (ExOne, X1-Lab):



75. Ocean Optics- USB 2000-FLG gated spectrofluorometer:

Portable fluorimeter along with fiber optic cables, filters, cuvette holders, reflection/backscattering probes



76. Ocean Optics – MONOSCAN 2000:

Fiber optic scanning monochromator, 300-700 nm



77. Ocean Optics – Px2 light source:

Pulsed Xenon Lamp, 220 Hz, 220-750 nm, ~5500 hrs at 50 Hz



78. Gas Pycnometer:

Fully automatic. Determines the true density and volume by measuring pressure change of helium within a calibrated volume. Measures samples having volumes below 1.0 cc down to 0.1cc.



79. GeoPyc 1360 Automatic Envelope Density Analyzer:

Rapidly measures the envelope density of porous objects of irregular size and shape. The method uses a unique displacement measurement technique that uses a quasi-fluid called *DryFlo™*.



80. Desk-Top Vacuum Induction Heater EQ-SP-16BVM:

20-100 KHz 7KW with Complete Accessories. Maximum temperature: 1500°C. Can be operated under inert and vacuum.



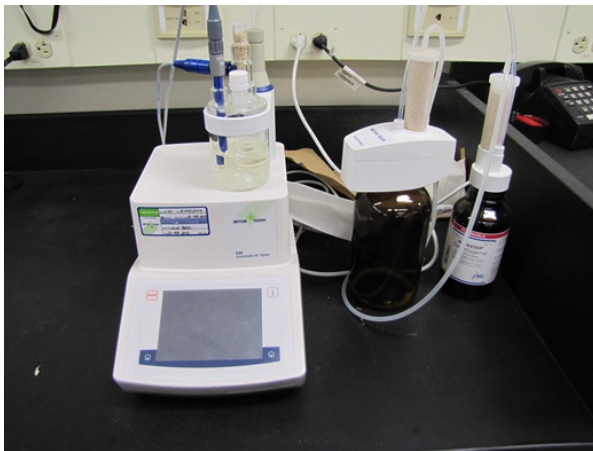
81. Desktop Dip Coater- EQ-HWTL-01-A:  
With Digital Controlled Temperature Chamber, maximum temperature 200°C. Pulling rate 01 mm/sec. to 2.33 mm/ sec. (1- 140 mm/minute).



82 MTI Battery Cycler



83 Coulometric KF Titrator



84 Sputtering machine

Anatech USA brand sputtering machine

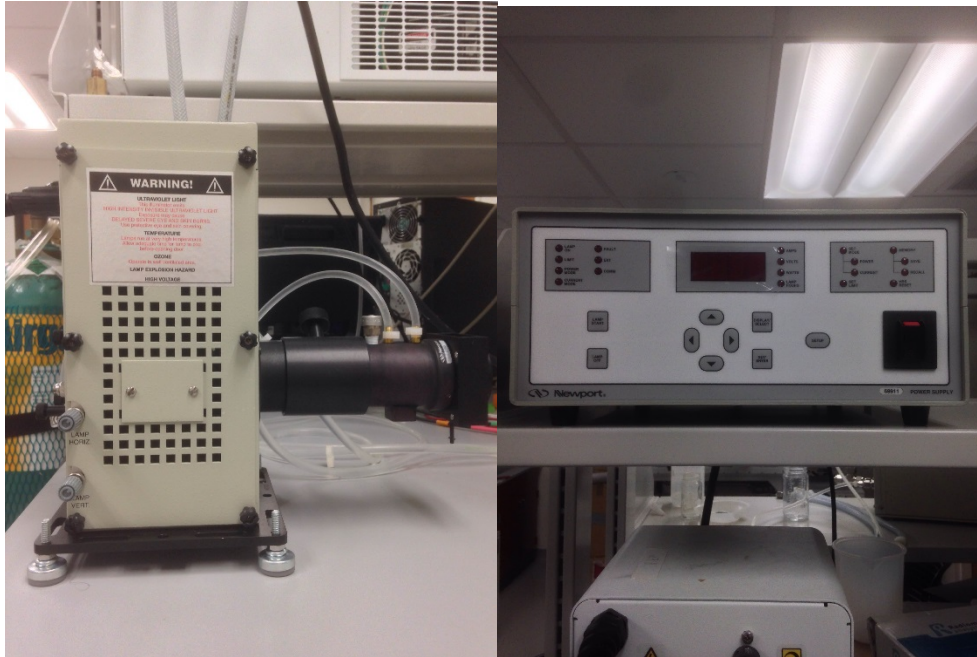


85 Viscometer  
Brookfield brand, model DV-II+ Pro



86. UV-Vis light source for photoelectrochemical cell





### 87. Cryomill: Retsch solution in milling and sieving

The CryoMill is tailored for **cryogenic grinding**. The grinding jar is continually cooled with liquid nitrogen from the **integrated cooling system** before and during the grinding process. Thus the sample is embrittled and volatile components are preserved. The liquid nitrogen circulates through the system and is continually replenished from an **Autofill system** in the exact amount which is required to **keep the temperature at -196 °C**. Powerful impact ball milling results in a **perfect grinding efficiency**.

Applications	size reduction, mixing, homogenization, cell disruption
Field of application	agriculture, biology, chemistry / plastics, construction materials, engineering / electronics, environment / recycling, food, geology / metallurgy, glass / ceramics, medicine / pharmaceuticals



#### 88. CH instruments 604A:

The Model 604A series is designed for general purpose electrochemical measurements. The system contains a fast digital function generator, a high speed data acquisition circuitry, a potentiostat, and a galvanostat. The potential control range is  $\pm 10$  V and the current range is  $\pm 250$  mA. The instrument is very fast. Two high speed and high resolution data acquisition channels allow both current and potential (or an external voltage signal) to be sampled simultaneously at a rate of 1 MHz, with 16-bit resolution. The instrument offers a very wide dynamic range of experimental time scales.



#### 89. Gamry PCI4/G300

The Series G 300™ Potentiostat/Galvanostat/ZRA is a researchgrade electrochemical instrument with specifications suitable for a wide range of applications. The Series G 300 Potentiostat can be used with desktop and notebook computers (with the eStation Portable Electrochemistry System). It supports Gamry's electrochemical software packages such as the DC105™ DC Corrosion Techniques, PHE200™ Physical Electrochemistry, PV220™ Pulse

Voltammetry, EIS300™ Electrochemical Impedance Spectroscopy, and the ESA400™ Electrochemical Signal Analyzer.

90. Asylum MFP-3D w/ Olympus IX71 Inverted Microscope:



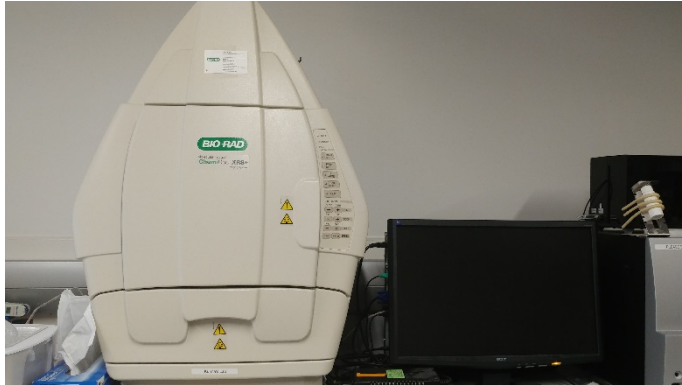
91. Microtome (for Histology: Leica RM 2255) -Room 423A

It is a tool used to [cut](#) extremely thin slices of material, known as sections. Important in science, microtomes are used in [microscopy](#), allowing for the [preparation of samples](#) for observation under transmitted [light](#) or [electron](#) radiation.



#### 92. ChemiDoc XRS+ - Room 423A

The system is able to image chemiluminescent, fluorescent and colorimetric samples and comes complete with a compact darkroom, transilluminator and supercooled high resolution 1.44 megapixel CCD camera.



#### 93. Cryomicrotome – Room 410

For the cutting of frozen samples, many rotary microtomes can be adapted to cut in a liquid-nitrogen chamber, in a so-called cryomicrotome setup. The reduced temperature allows the hardness of the sample to be increased, such as by undergoing a glass transition, which allows the preparation of semi-thin samples.



#### 94. Direct-Q® 3, 5, 8 system

Direct-Q® systems deliver both RO (Type 3) and ultrapure (Type 1) water directly from tap.

With the Direct-Q® range of water purification systems, you benefit from a choice of ultrapure water configurations. All systems produce Type 1 water (18.2 MΩ•cm at 25 °C ultrapure water) on demand from the RO stage, the first step in the purification chain. The system delivers RO production flow rates of 3 L/h with Type 3 water is easily available from the 6L built-in storage tank.

The Direct-Q® system has a Certificate of Conformity ensuring that it has been built and tested fully assembled following internal Standard Operating Procedures. All Direct-Q® consumables are delivered with their Certificate of Quality as per ISO 9001 v.2000 and ISO 140001 standards.



**95. COMPex Pro lasers**  
Coherent Laser Systems GmbH & Co.KG

COMPex lasers are highly efficient light sources, featuring a compact design and easy installation and operation. They deliver superior results in demanding applications, such as solid sampling systems (LA-ICPMS), material research (PLD), and precise material processing. The COMPex laser provides multi-hundred millijoules output, plus unmatched pulse-to-pulse stability. It also comes with an improved gas processor that extends both gas and optics lifetimes.



**96. Anton Paar GmbH - Synthos 3000 (Microwave synthesis platform)**

Synthos 3000 is a high-performance microwave reactor for chemical synthesis. It enables direct scale-up of reactions from small batch sizes (in  $\mu\text{L}$  to mL range) up to liter volumes. Therefore optimized protocols can be directly scaled up using the same reactor without changing the reaction parameters.

Vessels and rotors can be easily exchanged, which allows you to set up the best possible configuration for any chemical application. Either up to 1 L reaction volume or up to 192 different reactions on the smallest scale can be processed in one single run. This proves particularly useful for work in R&D laboratories in the pharmaceutical industry and for suppliers of chemical building blocks.



**Peterson Institute of NanoScience and Engineering (PINSE) Nanofabrication and Characterization Facility (NFCF)**

**Characterization Equipment**

**JEOL JEM2100F:** a 200KeV field-emission gun TEM/STEM, with Oxford EDS system and Gatan Tridium system and was installed in May 2006. This instrument is equipped with an analytical pole piece with  $\pm 40^\circ$  tilt, offers in TEM mode 0.23nm point resolution at Scherzer defocus and 1nm diameter point probes for diffraction and spectroscopic (EELS, XEDS) analyses. In STEM mode (incoherent imaging) a minimum probe diameter of 0.18nm can be accomplished for Z-contrast HAADF imaging and spectroscopic analyses (EDS, EELS). The post-column Gatan Tridiem GIF energy filter enables energy-filtered TEM and offers energy

resolution of 1.2eV at 194 $\mu$ A emission current. This instrument offers atomic resolution imaging and analytical studies of most metals.

**HORIBAJOBINYVON UVISEL Spectroscopic Phase Modulated Ellipsometer (SPME)** is a unique instrument that incorporates photoelastic device to modulate the polarization without any mechanical movement. The phase modulation technology provides significant advantages in terms of performance and experimental versatility. When compared to conventional ellipsometers the UVISEL spectroscopic ellipsometer features high accuracy determination of the ellipsometric angles (Y, D) across their full range allowing superior precision and sensitivity for the characterization of transparent substrates, ultra-thin films and films with low index contrast. Owing to the phase modulation technology the UVISEL spectroscopic ellipsometer performs advanced measurements of the degree of polarization, anisotropy and Mueller Matrix elements. The fastest acquisition speed at up to 1ms / point is guaranteed making the instrument the ideal solution for dynamic studies and liquid-surface measurements. The UVISEL is a versatile spectroscopic ellipsometer. It covers a wide spectral range from 190 to 2100 nm and offers a large range of automation features and accessories to best match the system capabilities to your experiment's demand. Its modular design allows the UVISEL to be used ex-situ, in-situ or to be integrated into a cabinet to provide a smaller footprint and clean-room compatibility.

**Bruker Vertex-70LS FTIR** is a versatile research-grade step-scan spectrometer operating in the mid- and far-IR spectral regions. The main optical bench is equipped with both extended range KBr and multilayer beamsplitters (10,000-400 and 680-30  $\text{cm}^{-1}$ , respectively) as well as liquid nitrogen cooled MCT A (12,000-600  $\text{cm}^{-1}$ ) and FIR DLATGS (700-10  $\text{cm}^{-1}$ ) detectors. Spectral resolution is adjustable with a maximum resolution of 0.4 $\text{cm}^{-1}$ . Standard IR sampling accessories are available including a pellet press and wig-I-bug for KBr pellets as well as transmission cells for mulls and neat liquids. The Vertex-70 is equipped with a step-scan interferometer and internal digital signal processing which can be used for time-resolved FTIR spectroscopy with a resolution of 5 msec, with either an internal or external trigger, and with phase or amplitude modulation.

**QDI 2010 Micro-spectrophotometer** allows the user to measure UV-visible-NIR range transmission, absorbance, reflectance, emission and fluorescence spectra of samples ranging from the sub-micron to well over 100 microns across. And while microspectra are being acquired, the sample may be simultaneously viewed with a high-resolution digital imaging system or through eyepieces with the DirecVu package and research grade microscope optics. Deep UV and NIR digital imaging are new capabilities for this instrument.

**Renishaw in Via Raman microscope** is a high-sensitivity system with integrated research grade microscopes, enabling high-resolution confocal measurements. This Raman microscope supports multiple lasers, with automatic software switching of excitation wavelength.

**Multimode V SPM and the Dimension V SPM** combination offers AFM (Atomic Force Microscopy) and LFM (Lateral Force Microscopy) both in ambient and liquid conditions, MFM (Magnetic Force Microscopy), EFM (Electrostatic Force Microscopy), SCM (Scanning Capacitance Microscopy), TUNA (Tunneling AFM), and SSRM (Scanning Spreading Resistance Microscopy) in ambient condition. The SPM Combination, controlled by Veeco's most advanced controller--Nanoscope V, can generate up to 5120x5120 pixel density and acquire and display

up to 8 images simultaneously. The Nanoscope V controller supports standard and advanced SPM scanning modes including contact mode, tapping mode, force modulation mode, tensional resonance mode, and etc. The Multimode V SPM routinely achieves atomic resolution both in air and liquid while the Dimension V SPM is able to characterize sample in wafer size with sub-nm resolution.

**Bruker D8 DISCOVER X-ray Diffractometer** includes a whole set of unique advantages:

- Third generation Göbel Mirrors providing the highest x-ray flux density – essential for all thin film applications.
- The entire system is designed for easy and failsafe operation. Tools like the motorized absorber allow fully automatic operation without user intervention.
- High performance optics are selected and exchanged to provide the optimum resolution for each application and sample.
- Optimal sample handling takes advantage of the new UMC stages as well as different types of Eulerian cradles for e.g. residual stress, texture, micro-diffraction investigations. For x-ray reflectometry on coatings or semiconductors dedicated stages allow even temperature studies.
- Shortest measurement times are achieved using Ultra GID for nanometer layers and the VANTEC-1 detector for reciprocal space maps.

### **Nanofabrication Equipment**

**Seiko Instruments ‘SMI3050SE FIB-SEM’ Dual Beam System with Oxford Instruments ‘Inca XEDS’** combines a Ga<sup>+</sup> focused ion beam column for nanoscale fabrication and a field emission SEM for observation during FIB processing. The specified image resolution is 4nm. The common applications of this instrument are for nanoscale patterning/fabrication or TEM sample preparation. The ion beam can be used to remove regions of a sample or to deposit W metal in specified locations and patterns. The material removal process can also be enhanced by the injection of XeF<sub>2</sub> or H<sub>2</sub>O gases. Bitmap files or vector scan can be used to create complex patterns and shapes. For TEM sample preparation, an attached microprobe is used to “pick-up” cross-sectional samples in-situ and transfer them to grids. The instrument is also equipped with an Oxford Instruments XEDS system for elemental identification and quantification.

**Raith ‘E-Line’ Ultra high resolution electron beam Lithography and Nano Engineering workstation e\_LiNE** is the most versatile e-beam system for uncompromised nano structuring, pattern inspection, dimensional metrology and nano engineering. The state-of-the-art e\_LiNE electron column matches perfectly with a number of key applications in CNT research, thin film engineering, photonic crystals and EBID.

**South Bay Technology ‘PC 2000’ Plasma Cleaner** is a compact, easy to use, parallel plate plasma cleaning system designed specifically for the removal of hydrocarbon contamination from a specimen and specimen stage. The specimen and stage are subjected to reactive gas plasma that efficiently removes a wide range of contaminants. The specimen can be placed on the 8” diameter stage or mounted in a TEM holder. Our unit has both an Argon and Oxygen supply. Samples, including TEM samples, can be cleaned with an Ar, O<sub>2</sub> or mixed gas plasma.

**Trion Technology Orion 111 Plasma Enhanced Chemical Vapor Deposition (PECVD)** is a plasma deposition system designed to supply research laboratories with state-of-the-art plasma



etch capability for single wafers and small samples. Our PECVD system has four process gases for deposition of films such as silicon dioxide, silicon nitride and polysilicon.

**Laurell Technologies 'WS-400B-6NPP-LITE' Single Wafer Spin Processor** is a single wafer, manual dispense spin processor with a nitrogen purged process chamber and is controlled by a digital controller. The wafer is held in place during process by means of a vacuum chuck. The digital controller has twenty programs each with fifty-one steps stored in non-volatile memory. The program sizes and steps/program can be changed.

**Q4000 Mask Alignment System** is an integrated optical-mechanical, pneumatic-electrical system which allows accurate alignment of sensitized semiconductor wafers or substrates with a mask and exposes them to ultraviolet radiation to transfer the pattern of the mask to the substrate for further processing on the way to producing a semiconductor or other microelectronic device. The Mask Aligner consists of several coordinated, inter-related systems. These include the substrate loading, holding and unloading system; the mask supporting system; the substrate/mask / scan/align/ lock system; the viewing system (microscope and illuminators); and the exposing system.

**KLA Tencor 'Alpha-Step IQ' Surface Profiler** is a computerized, highly sensitive surface profiler that measures roughness, waviness and step height in a variety of applications. It features the ability to measure micro-roughness, with up to 0.1-nm or less resolution, over short distances as well as waviness in a scan over a full surface length of 10-mm.

**Zeiss 'Axio Imager' Motorized Optical Microscope** is an optical microscope equipped with next generation optics which have superb contrast and excellent resolution. The microscope design is optimized for maximum stability and vibration-free work. Many functions including objective lens selection are touch screen controlled for easy to obtained, repeatable results. The microscope is also equipped with a digital camera and image recording system. Image recording and analysis is accomplished through multidimensional acquisition methods and comprehensive measurement and analysis functions.

**Reynoldstech Fabricators 'Lithography Hood'** is equipped with a sink and DI water faucet. It is also equipped dry nitrogen and DI water sprayers and vacuum connections. The DI water supply is distilled water that is then filtered and supplied at 18 Meg ohm or better. There is an ultrasonic shaker and digital and stirring hot plates available for the hood. The wafer spinner is located in this hood. In addition to solvents a variety of photoresists are stocked for use in this hood.

## **Mechanical Engineering and Materials Science Department**

### **Materials Micro-Characterization Center**

Standard TEM preparation equipment, such as wire saws and diamond-embedded saws, polishing and grinding equipment, Gatan dimplers, Gatan PIPS and Fischione ion mills, electropolishing equipment, exist here.

Other current TEM instrumentation at includes a TEM (JEOL 200CX) with a W-filament and a TEM/STEM (JEOL 2000FX) with a LaB<sub>6</sub>-filament. Both instruments are over 20 years old, the

best attainable spatial point-resolution is limited to  $>0.24\text{nm}$  and analytical data (EDS) cannot be obtained from areas with diameters  $<15\text{nm}$  and only for elements with  $Z\geq 11$ .

A HB501 VG-STEM with a nano-probe size of  $\sim 5\text{\AA}$  and  $\sim 0.8\text{ eV}$  energy resolution with Oxford EDS detector equipped with cold field emission gun.

### **John A. Swanson Facility Micro and Nanotechnology (JASMiN) Laboratory**

**Se-Oe-Pvd-3000 Dc and Rf Magnetron Sputtering System** is used for deposition of metal, oxide and nitride thin film materials.

**Pascal Dual E-gun UHV Evaporator System** is used for deposition of metal and metal alloys. It is an UHV system with load-lock, two e-guns with four-pockets each and 3 QCMs for deposition of metal layers or co-deposition.

**Cressington 108 Auto Sputter-Coater** is used for routine sample preparation for scanning electron microscopy.

**Karl Suss Rc8 Spinner** is used for spin-on coating of photoresist materials and polymeric materials. Distributes materials evenly across the surface of a substrate by spinning the substrate. Wafer size: Up to 6 inches

**Karl Suss Ma 6 Double-Side Mask Aligner** is a UV Mask aligner with double-sided capability used for photolithographically defining photoresist patterns onto substrates.

**Chemical Wet Bench** used for general chemical processing, such as wet chemical etching

**Veeco Dektak3 St Surface Profile Measurement System** is used to measure surface profile (sub micron) and film thickness (up to  $262\mu\text{m}$ ) after microfabrication steps. Permits scans as long as 50mm with a maximum of 8,000 data points to determine accurate step heights and surface roughness.

**Hybond Model 572a-40 Wedge Bonder** is used for making wire connections onto finished devices.

**Nikon Eclipse L150 Microscope** is used for optical characterization or observation of samples. Capabilities: 5x, 20x, 50x, 100x extra long working distance Plan objectives; 6x6" XY stage; Brightfield, darkfield, differential interference, polarization illumination; Spot Insight color camera (1600x1200) image capture, feature measurement, documentation.

**Micro Automation 1100 Wafer Dicing Saw** is a Microprocessor-controlled, programmable, automatic saw for cutting semiconductor wafers and other hard materials. A closed circuit TV system with split image optics is used to align the wafers before cutting.

**Agilent 4284 A Precision LCR Meter** is used for measurement of electrical properties. Range: 20 Hz to 1 MHz with over with 8610 selectable test frequencies.

**Karl Suss PM5 Analytical Probe System** allows electrical probing of device under test. Capabilities: Applying signals to individual die or wafers up to 8" diameter. Currently used in conjunction with ETEC MMA.

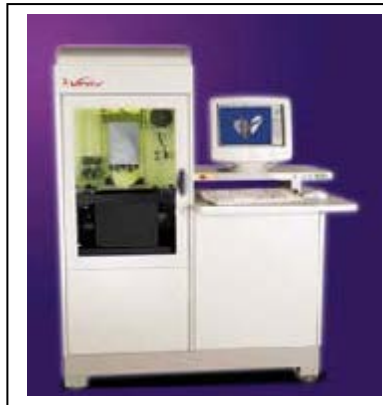
### **Facilities in the Swanson Center for Product Innovation (SCPI)**

The John A. Swanson Center for Product Innovation is a joint initiative of the Departments of Bioengineering, Industrial Engineering, and Mechanical Engineering and Materials Science. The center was dedicated on April 18, 2001. It is a state-of-the-art network comprising three laboratories that serve as a focal point for product development education within the school and the University, while working as a one-step shop for manufacturing and bioengineering companies. The center ties together three otherwise distinct laboratories that parallel the new product's developmental life cycle of design, prototyping, and manufacturing: (1) the Design and Multimedia Laboratory; (2) the W.M. Keck Rapid Prototyping and Reverse Engineering Laboratory; and (3) the Kresge Rapid Manufacturing Laboratory. These laboratories contain design workstations, reverse engineering equipment, and rapid prototyping equipment (that allow the manufacturing of polymer-based prototypes), and rapid manufacturing equipment (that will produce fully functional prototypes and soft tooling). These facilities allow users to move from concept to real parts in a matter of days. A collaborative effort with faculty in the Joseph M. Katz Graduate School of Business allows the center to offer a comprehensive and integrated package of engineering research, business, and applied project capabilities in new product development. The Swanson center for product innovation (SCPI) has several state-of-the-art equipment for obtaining 3D computer aided design data (3D CAD) data necessary for duplicating designs.

The Center boasts of two machines – the the Cyclone and the Gauge 2000—use touch probes that define the surface geometry of the object being measured with extreme accuracy. The third machine, the Digibot laser scanner, is a three-dimensional digitizer. The Digibot directs a laser at the product being examined and slowly, methodically turns the item so that the laser touches every nook and cranny of the surface.

The center also possesses the following instrumentation:

#### **Rapid prototyping:**



- Stereolithography: System shown below that creates physical prototypes by curing thin layers of a liquid epoxy photopolymer with an ultraviolet laser beam. Provides high accuracy, excellent surface finish, can be used for multiple materials to build volume in the range of 10"x10"x10". The prototypes generated are good for form, fit and functionality testing as well as masters for secondary tooling.

- Ex One 3D printing that allows printing of metals utilizing aqueous binders. The printers are amenable for generating 3D parts of metal components but will not work for reactive metals and are subject to warping and dimensional limitations similar to

conventional techniques.

#### **Rapid Manufacturing:**

- CNC machine tools
- Injection molding
- vacuum casting

#### **Virtual Prototyping:**

- Solid modeling software (Pro/E, Solid Works Geomagic)
- FEA (ANSYS, ABAQUS)
- CAM software and simulators
- FARO Laser Scanning Systems that involves a manual contact/non-contact system utilizing an adaptive laser scanning and probing process
- Renishaw Contact Scanning: This involves a semi-automated contact system that utilizes a touch probe to continuously acquire data along a scanning path.

**Equipment available in the Dietrich School of Arts & Science Materials Characterization lab:**

The University of Pittsburgh is very well equipped to carry out state-of-the-art materials related work. Some of the research facilities relevant to the proposed research are highlighted below:

**(i) Electron Microscopy Facility**

The Materials Science and Engineering department maintains a state-of-the-art facility in electron microscopy, that is operated for the benefit of the university community at large. This facility houses four transmission electron microscopes (TEM), a scanning transmission electron microscope (STEM), two scanning electron microscopes (SEM) and extensive specimen preparation tools. The facility provides equipment and services to faculty, staff and graduate students engaged in a wide variety of research programs.

The Electron Microscopy facility contains three transmission electron microscopes (JEOL JEM 120CX TEMSCAN, Phillips 420 TEM/STEM and JEOL 4000 EX), three scanning electron microscopes (CamScan Series 4, JEOL JSM 35 and a Philips XL-30 FEG with EDS and WDS), and peripheral supporting equipment.

The JEOL 120CX and Philips EM420T transmission electron microscopes (TEM) are equipped for scanning transmission electron microscopy (STEM) and also have microdiffraction capabilities, while the JEOL 4000 EX can be used for high resolution transmission electron microscopy. The JEOL 4000 EX is also now equipped with a Gatan Energy Filter (GIF) which will allow for chemical identification of features at high spatial resolution with digitized images. Hence, Electron Energy Loss Spectroscopy (EELS) can be used to detect a number of light elements including lithium. For energy dispersive analysis, both instruments have fully quantitative PGT System IV series energy dispersive analyzer systems which provide local chemical analysis capabilities of regions as small as 25 nm. The Philips EM420T TEM is also equipped with EDS and EELS capabilities. The MSE department has also recently procured a state-of-the-art field emission gun analytical transmission electron microscope from Philips (CM 200FEGTEM). This instrument is capable of 2nm resolution and has the capabilities for microdiffraction, EELS, EDS and GIF. In the Spring of 2000 this was replaced with Tecnai F20. The department also owns a VG HB501 STEM with SEMPA capabilities. The electron optical instruments are part of the Digital Microscopy Lab, which also houses a DEC Alpha workstation cluster (13 machines) for modeling and image simulations.

Both scanning electron microscopes (SEM) are also equipped with energy dispersive x-ray analyzers to conduct quantitative elemental chemical analysis. The CamScan Series 4 has a PGT System IV analyzer with a distortion free full TV rate scan generation system. A motor-driven eucentric stage provides working distances from 10 to 100 mm. Capabilities include advanced video and scan processing for secondary electron imaging, back scattered electron

imaging, and absorbed current imaging. The recently procured Philips XL-30 FEGSEM is also equipped with EDS and WDS capabilities.

Supporting equipment includes several wafering machines, thin-foil preparation equipment, two ion milling machines, two vacuum evaporators, an RF sputterer for specimen preparation, and darkroom facilities for photographic processing. A full-time engineer/microscopist is assigned to the facility for training, routine maintenance, and general supervision.

### **(ii) X-ray Analysis Facility**

The X-ray analysis facility, has nine x-ray generators (three Siemens Kristalloflex 4, two Siemens Kristalloflex 2, two Rigaku, one Philips, and one Elliot Rotating anode), three horizontal diffractometers (two Siemens and one Rigaku) employing Bragg-Brentano geometry, a vertical diffractometer (Philips) employing the same type of geometry, a Guinier Thin Film Glancing-Angle goniometer (Huber) employing Seemann-Bohlin geometry, a pole figure goniometer (Siemens), a pole figure attachment to the Rigaku diffractometer, and a fluorescence spectrometer (Siemens). The facility has a number of Debye-Scherrer, Laue back-reflection, Precession, and various other x-ray cameras. Peripheral supporting equipment includes incident and diffracted beam monochromators, low and high temperature attachments to the Rigaku diffractometer, densitometers, view boxes, and the powder diffraction files.

Two of the three horizontal diffractometers are interfaced to minicomputers giving them fully automated dedicated microprocessor. While this is a less sophisticated arrangement than the fully automated systems, it does provide real-time control and data acquisition capabilities. Various software packages are available for data analysis and display (computer graphics), including automated plotting of data acquired with the pole figure attachment to the Rigaku diffractometer.

Using an attachment acquired for the Guinier Thin Film Glancing-Angle Goniometer, intensity measurements with the instrument have been converted from photographic means to a counter tube. This conversion has also made it possible to interface the goniometer to a microcomputer (IBM PC) for real-time control and data acquisition.

The recent purchase of a high-power, high resolution x-ray system has considerably enhanced the capabilities of the X-ray Analysis facility. The system consists of a high-power rotating anode x-ray generator (Elliot/GEC Avionics model GX21), and a high-resolution four circle goniometer (Huber) capable of holding sample conditioning devices such as cryostats and hot stages, and various accessories. In addition to usage for preliminary work to assure sample quality and to outline phenomena of interest for experiments which may subsequently be performed at the national synchrotron sources, the system is designed to meet the broad research needs of the entire materials community at the University. These include detailed studies of line shapes and widths; line shape analysis in quenched and finite size systems and in systems with thermally induced short range order; glancing incidence scattering studies on surface and large unit cell systems; structure determinations in weakly scattering systems such as surface adsorbed layers; diffraction analysis of newly formed bulk phases of low total volume such as at an interface; and studies on defects in nearly perfect crystals (Lang topography).

### **(iii) Surface & Micro Analysis Facility**

The Surface and Micro Analysis facility provides capabilities for Auger electron spectroscopy (AES), x-ray photoelectron spectroscopy (XPS), and low energy electron diffraction (LEED).

In one instrument, the Multi-Purpose Surface Analyzer (an AES, XPS, and LEED system), a coaxially mounted electron gun serves as the source for Auger studies and a double pass cylindrical mirror analyzer provides the necessary high-resolution capabilities. For XPS studies, a dual-anode x-ray source capable of providing both Mg K-alpha and Al K-alpha soft x-rays is available. An ion sputtering system, which has an ion gun capable for high sputtering rates and ion beam rastering, enable simultaneous depth profiling of several elements. A quadrupole mass spectrophotometer (UTI Model 100C) enables gas constituents to be measured and monitored in this system.

Another instrument, a Scanning Auger Microprobe (Physical Electronics Model 600), provides the most sophisticated Auger instrumentation available. This completely automated instrument has a nominal resolution of 35 nm. Auger spectra can be acquired in a number of different modes including point analysis, depth profiling of several elements simultaneously, and mapping of microstructures. The instrument is managed by the Materials Science and Engineering department.

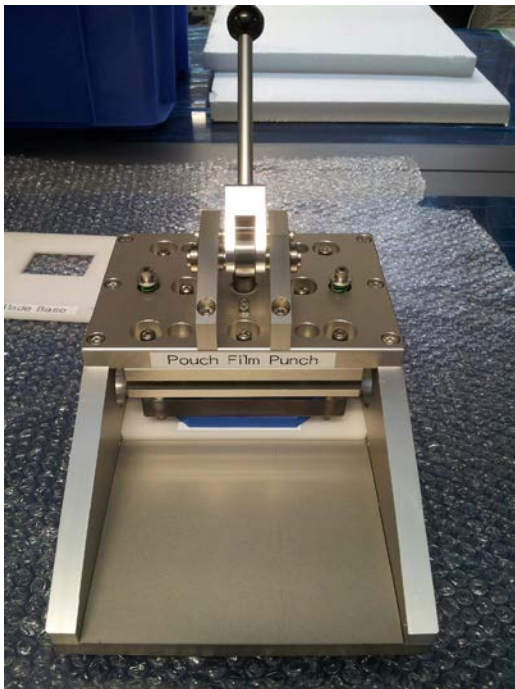
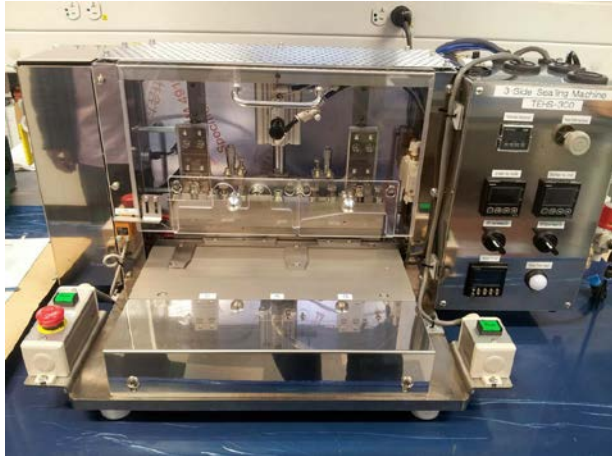
Auger electron spectroscopy capabilities are also available in a system being used primarily for the study of catalytic materials and surface reactions on solids. This system also has a quadrupole mass spectrometer and a sample carousel with heating and cooling capabilities. The system design allows for the addition of LEED, sputtering and other options.

The Electrical and Computer Engineering department has excellent Class 10 and Class 100 clean room facilities equipped with several state-of-the-art sputtering and electron beam evaporation deposition equipment that can be easily accessed.

**Equipment procured at the Pittsburgh Energy Innovation Center (EIC):**

Empyrean X-ray diffraction system equipped with Co, Mo tubes; Parallel plate collimators; Programmable XYZ stage; Galipix detector; coin cell and pouch cell holder; Electrochemical Test Cell ECC-Opto-Std: The ECC-Opto-Std test cell serves to monitor the optical properties of an electrode material in the course of electrochemical charging. For this purpose, the working electrode (WE) material, which is supported on a meshed or holed current collector, is placed right below the optical window. This WE is sandwiched from below with a glass fiber separator and an appropriate counter electrode, (CE). This way, the optical instrument “looks” from the top through the optical window onto the backside of the electrode material. Typical instrumentations include optical and confocal Raman microscopy in the reflection mode. A re-fitting kit for X-ray is available as an option. The maximum diameter of the working electrode WE is 10 mm, while that of the inspection hole is 1 mm (optional up to 10 mm). The cell is equipped with a reference electrode pin for 3-electrode operation.

Pouch cell capabilities are available for fabrication and testing of prototype pouch cells. The following units are available.



Pouch cell capabilities including: pouch film punch, three side sealer, electrolyte filler/sealing, and electrode stacking, Kurabo mixer/deaerator, doctor blade thin film applicator .

MAZERUSTAR Planetary Mixer / Deaerator: Enables simultaneous mixing / deaerating within a short time without using mixing rods and blades. This system is used for a wide variety of materials such as highly viscous materials and materials having different specific gravities, without contamination by foreign matter.

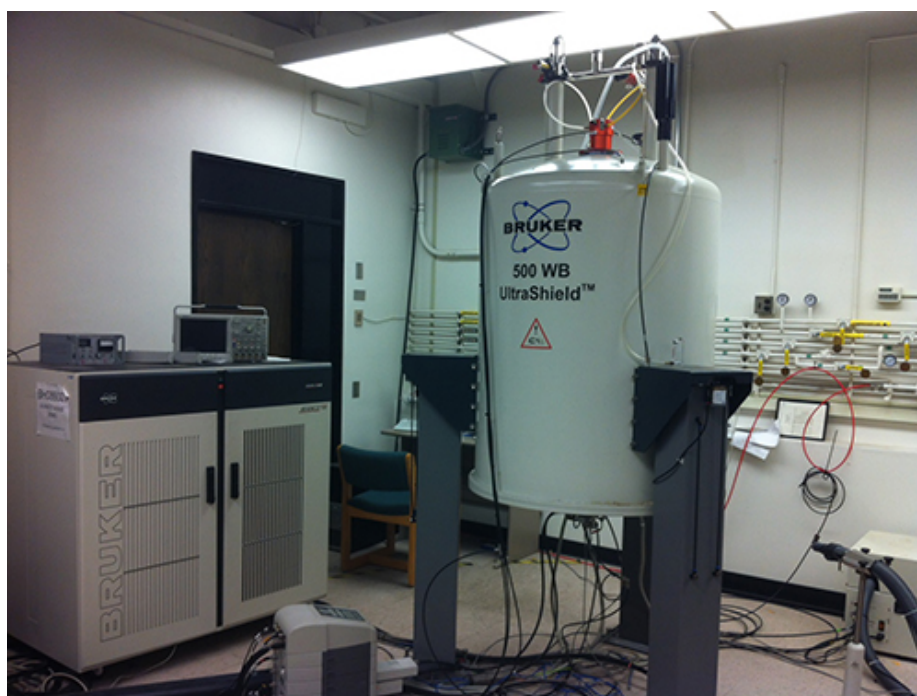
Three side Pouch sealing machine: Heat sealing machine to seal pouch cells for Lithium ion battery. Tab side and flat side are sealed controlling temperature, pressure, and time as parameters.

Electrolyte Filling / Sealing machine: Ideal vacuum sealing machine for Lithium ion battery, to seal pouch cells under vacuum with Electrolyte filling option installed inside inert atmosphere glove box.

Electrode Punching Tool: The tool is used for punching anode, cathode and separator sheets for pouch cell. The dimensions of the existing anode/separator die is 44mm x 55mm and that of cathode is 40mm x 50mm. The dimensions can be altered and will need a RFQ. It is a necessary tool in the production line of pouch cell to produce specific shapes of cathodes and anodes with current collector tabs.

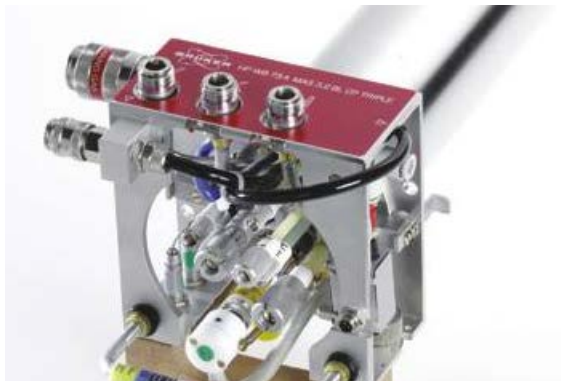
### NMR Facility

The NMR Facility at the University of Pittsburgh Chemistry Department has eight high field instruments dedicated solely to research. These include two 300 MHz, two 400 MHz, 500MHz, 600 MHz 700 MHz solution NMR spectrometers. Also a 500 wide bore solid state NMR spectrometer is available for materials science research.





This solid state NMR spectrometer is equipped with three probes. (1) 4mm HR-MAS (High Resolution Magic Angle Spinning) probe, (2) 4mm CP-MAS (Cross-Polarization) probe and (3) 3.2 mm CP-MAS probe capable of spinning sample up to 24 kHz. These broadband probes offer a highly versatile solution for NMR studies of a wide range of samples from material science to polymers and biological applications.



Atomic Probe Tomography (APT) user facility at EMSL (Environmental Molecular Sciences Laboratory), Pacific Northwest National Laboratories (PNNL)

The LEAP® 4000 XHR local electrode atom probe tomography instrument enabled the first-ever comprehensive and accurate 3-D chemical imaging studies of low electrical conductivity materials, such as ceramics, semiconductors and oxides. The atom probe is assisting EMSL's efforts to further scientific advancements in interface analysis and microstructural characterization, providing a new tool for understanding the relationship between the nanoscale structure of materials and their macroscopic properties. It's also being used to advance aerosol research.

#### **EMSL's Atom Probe Offers:**

**Unique capability** – images low electrical conductivity materials, such as ceramics, semiconductors and oxides

**True 3-D imaging** – ~0.5 nm spatial resolution and ppm elemental sensitivity with an unprecedented field-of-view

**Very high mass resolution** – large area detector with a reflectron lens achieves excellent mass resolution and eliminates chromatic aberration

**Sample optimization** – tips can be mounted on convenient multiple, presharp microtip array

**Accurate spatial reconstruction** – conducted with Imago Visualization and Analysis Software (IVAS)

**Diverse impact** – supports studies in materials science, ceramics, metallurgy, geochemistry and biomineralization.

#### **Instrument ID:**

34110

**Availability:** 10 hours a day, 5 days a week

**BIO X (CELLINK, USA, [www.cellink.com](http://www.cellink.com)):** BIO X is the most user-friendly and flexible 3D bio-printer in the world, providing the user to print 3D constructs with high speed and precision. The built-in features



along with the new BIO X software managed through the large touchscreen display minimize the learning curve and ensure easy users friendly printing. It's a complete standalone system that gives users unrivaled flexibility with exchangeable print-heads and features like: Heated print-heads, print-heads, Heated print bed, Cooled print bed, Clean Chamber Technology, Piston-driven syringe head, Pneumatic print-heads, Multi well-plate printing and Touchscreen control. This printer can be used for bio-printing of various tissues as well as gels, polymers and metal/ceramic-polymer composites. The print-bed temperature can be controlled between 4-60 °C. Heated Pneumatic print-heads can be heated up to 130 °C and cooled Pneumatic print-head can be used at 4 °C. The thermoplastic print-head can be used up to 250 °C. The

syringe pump print-head enables to have a better control of the ink extrusion process by controlling the flow rate and deposited volume, no matter the viscosity. The other printing features of the BIO X printer are:

Build volume: 130x90x70 mm  
 Layer resolution: 1 µm  
 Positioning resolution: 1 µm  
 Calibration: Automatic  
 Materials per scaffold: 3 (using 3 print-heads)  
 Photo curing LED Default: UV 365 nm, 405 nm and other wavelengths.

### **1200°C Max. PECVD Split Tube Furnace ( 2" - 3.14" OD) w/ 4 Channels Gas Delivery & Vacuum Pump - OTF-1200X-PEC4LV**

OTF-1200X-PEC4LV is a **CE certified** compact **PE-CVD (Plasma Enhanced Chemical Vapor Deposition)** tube furnace system, which consists of 300W RF plasma source, 2" or 3.14" O.D optional split tube furnace, 4 channels precision mass flow meter with gas mixing tank, and high-quality mechanical pump. The PE-CVD furnace is an ideal and affordable tool to deposit thin films or grow nanowire from a gas state (vapor) to a solid state, and benefits:

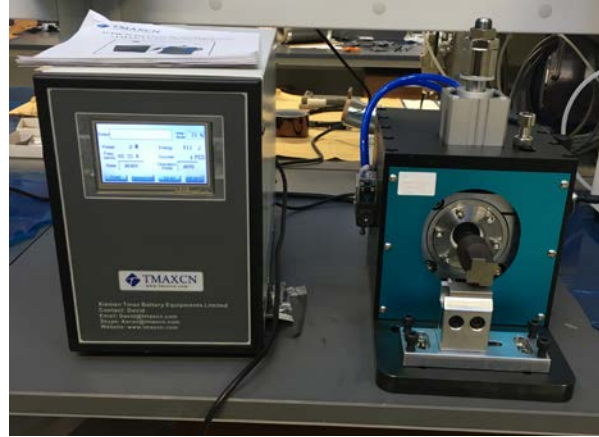
- Lower temperature processing compared to conventional CVD.
- Film stress can be controlled by high/low frequency mixing techniques.

- Control over stoichiometry via process conditions.
- Offers a wide range of material deposition, including SiO<sub>x</sub>, SiN<sub>x</sub>, SiO<sub>x</sub>N<sub>y</sub> and Amorphous silicon (a-Si:H) deposition.



**Al Tab Ni Tag Ultrasonic Welding Machine  
(TMAX-VS-39B,20KHz,2000W)**

Ultrasonic spot welding machine is advanced high-tech equipment that converts high-frequency electric energy into mechanical vibration energy through a transducer and acts on the bases material, to generate high-frequency friction between the surfaces of the two work-pieces until the surfaces of the two bases material are heated and welded together. It can perform spot-like and strip-shaped soldering on thin materials such as copper, silver, chrome, nickel and other conductive metals. It can be widely used in lead wire of silicon controlled chip leads, fast-fuse holders, electrical lead terminals, lithium ion, nickel point-like, strip-shaped soldering of poles such as hydrogen and nickel-cadmium batteries. The welding process of an ultrasonic spot welder is a mechanical process in which no current flows through the material and no melting occurs. Moreover, the same or the different alloy materials can achieve the ideal welding; the electrical and the thermal properties are not achieved by other processes. Compared with fusion welding, ultrasonic welding has low electrical consumption, long life and low labor intensity.



**FPP 5000 Four Point Probe**

The **VEECO FPP-5000** 4-point probe simplifies the measurement of resistive properties of semiconductor wafers and resistive films. The microprocessor based electronics permits direct computation of  $V/I$ , sheet or slice resistivity, and metallization thickness and P-N type testing. Unlike most four point probes and probing stations, which move the probe head into the wafer, the FPP-5000 is designed so that the wafer is moved into the probe head. This insures constant probe force independent of operator force and wafer thickness.

