

FACILITIES, EQUIPMENT, AND OTHER RESOURCES

The PI has access to adequate facilities and equipment, including those from the PI's own lab and shared facilities, for device fabrication and circuits integration, device- and chip-level testing, scientific computing, and physical characterization.

The proposed fabrication will be carried out using the shared facilities on the UMass Amherst campus. Dr. Xia is affiliated with the Institute for Applied Life Science (IALS), established in 2014 based on a total investment of more than \$150 million from the Massachusetts Life Science Center (MLSC) and the University of Massachusetts Amherst. Two 100/1000 clean rooms are administered by IALS, including a 1400 ft² one in the Conte building and a new 1800 ft² clean room in Marcus Hall, both with state-of-the-art fabrication equipment. There is also a teaching clean room in Marcus Hall. In addition, among the 33 core facilities (<https://www.umass.edu/ials/core-facilities>), IALS has an advanced digital design and fabrication facility, a packaging lab, and shared testing facilities that could be used for the proposed research.

Dr. Xia has been assigned about 2700 ft² of lab space for his research group in Marcus Hall. The PI has built a full suite of electrical testing facilities within this space. The main equipment includes four probe stations designated for different functions (with three Keysight B1500 and an Agilent 4156B semiconductor parameter analyzers, several high-performance arbitrary waveform/function generators, and mixed-signal oscilloscopes), an MMR variable temperature microprobe system, a home-made PCB-level circuit test station, two home-made chip-level measurement systems with 128 simultaneous analog inputs and 64 simultaneous analog outputs, and two workstations for IC design and computing, etc.

There are sufficient resources for physical characterization on campus, mostly associated with the IALS core facilities. These analytical tools include electron microscopes, scanning probe microscopes, optical microscopes, spectroscopy tools, x-ray tools, etc. This document is organized according to the functions: fabrication and integration, electrical measurements, scientific computing, physical characterization, etc.

1. Major Fabrication and Integration Facilities and Equipment

1.1. Marcus clean room:

- CHA Mark 50 e-beam evaporator (with rotatable and tiltable substrate fixture, planetary for 4 and 6 in wafers, substrate heating (400 °C) and cooling (liquid nitrogen))
- Multi-chamber Sputterer (AJA Orion-8 Dual) (Two separate chambers that are connected with a load lock; transfer between chambers without breaking vacuum; oxidation capability at 900 °C; substrate up to 100 mm; 4 DC and 2 RF guns for metal and oxide sputtering)
- Reactive Ion Etcher (Oxford PlasmaPro 100 Cobra 300 ICP-RIE, available gases: Ar, O₂, CHF₃, C₄F₈, SF₆, HBr etc.; substrate up to 200 mm; LN₂ cryo cooled and electrically resistance heated for a substrate temperature range of -150°C to +400°C)
- Deep RIE (Oxford PlasmaPro 100 Cobra 300 DRIE; available gases: C₄F₈, SF₆; for wafer size up to 200 mm).
- Wafer Bonder (SUSS MicroTec SB 6 Gen 2 Semi-Automated System; support all known wafer bond processes; suitable for advanced packaging, 2.5D/3D integration, MEMS, LED, etc.; handling wafers up to 150mm; process nitrogen 7-7.5 bar; bond force 300 - 20,000 N; chuck temperature up

to 500 °C; 30 °C/min heating; 12 °C/min cooling; negative 2000 V@ 15 mA for anodic bonding).

- Electroplaters (Technic SEMCON 1000, 2 sets; 'wet bench' type tool, one designed for Cu and the other for Pd; self-contained mono chassis design to meet class 100 clean room specifications; variable substrate sizes from 50 to 200 mm; plating solution temperature up to 70 °C).
- Optical Microscope (Olympus BX53MRF-S; Nomarski prism for differential interference contrast microscopy; 17 MP color CCD camera LED coded illuminator; 10X eyepieces; 2.5X, 5X, 10X, 20X, 50X, and 100X BD objective; stage travel range: 150 mm x 100 mm).

1.2. Conte clean room:

- *Deposition and etching*
 - AJA International Orion 8 Sputtering System
 - CHA Electron Beam Evaporator with Cryopump
 - Cambridge Nanotech Atomic layer deposition (ALD)
 - STS Vision 310 PECVD System
 - STS Vision 320 RIE System
 - March Instruments PM-600 Plasma Treatment System
 - Wafer Etching Hood
- *Lithography*
 - JEOL JSM-7001F E-beam Writer
 - Suss MicroTec MA6 Mask Aligner
 - OAI 1000 Watt DUV Exposure System
 - Brewer Science CEE 100CB Spin Coater
 - Blue M Convection Oven
 - Developer Hood
- *Metrology & Imaging*
 - Gaertner L116C Ellipsometer
 - Dektak 3 Profilometer
 - Olympus BH2 Microscope with Infinity 2 Digital Camera
 - Nikon Optophot Microscope with Infinity 2 Digital Camera
 - JEOL JSM-7001F SEM (same as for EBL)
- *Other Chemical hoods*
 - Laminar Flow Bench
 - Solvent Rinse Hood
 - Wafer Cleaning Hood (RCA cleaning)

1.3. A soft-walled clean room in Conte

- *Nanoimprint Lab*
 - Nanonex Nanoimprinter (NX-2000)
 - Molecular Imprints (IMPRIO 55)

1.4. A teaching clean room in Marcus

- *Thermal processing*
 - 1 Diffusion furnace set (Thermco 4000 4-tube furnace)
 - 1 Alloying furnace
- *Deposition & etching*
 - 1 Sputter
 - 1 Thermal evaporator

- *Lithography*
 - 3 Mask aligners (1 Karl Suss MJB 3 and 2 Cobilt)
 - One home-built imprinter with an alignment function
 - 3 Hot plates
 - 2 spinner coaters
- *Imaging and metrology*
 - 1 Imaging shearing microscope w/video system (Vickers)
 - 1 Inspection microscope
 - 1 Ellipsometer (Gaertner)
 - 1 Surface profilometer (DEKTAK)
- *Miscellaneous*
 - 2 Deionized water production system
 - 4 Wet chemistry stations
 - 4 Laminar flow hoods
 - 1 Sectioner (Philtect)
 - 1 Spin rinser/dryers (Laurell)
 - 1 Portable X-ray diffractometer
 - Wafer storage boxes, chemical safety cabinets, safety shower, etc

2. **Electrical Testing Equipment:**

2.1. **PI's own testing equipment**

- ***Multipurpose Measurement Station (Room 28)***
(Regular IV measurement, fast switching measurement (5 ns), capacitance measurement, retention measurement)
 - Keysight B1500A Semiconductor Device Analyzer
Current versus voltage (IV) measurement, accurate and precise measurement ranges of 0.1 fA - 1 A and 0.5 μ V - 200 V, capacitance measurement, multi-frequency AC impedance measurement supports CV (capacitance versus voltage), C-t (capacitance versus time) and C-f (capacitance versus frequency) measurement, capacitance measurement frequency range of 1 kHz to 5 MHz, arbitrary waveform generation with 10 ns programmable resolution, B1530A Waveform generator/fast measurement unit (WGFMU), B1520A Multi-frequency capacitance measurement unit (MFCMU)
 - Semiprobe Probe Station
Rigid aluminum base with rubber vibration isolation feet, coarse and fine wafer stage adjustment with interchangeable stage options - packaged part or thermal, fine stage movement using precision micrometer control - X (25 mm), Y (25 mm) & Z (>20 mm), coarse (360 degrees) and fine (10 degrees) theta adjustment, 100 mm (4") chuck with isolation adapter and vacuum control system, aluminum with stainless steel plated platen with a removable front wedge, precision micrometer driven platen Z lift (13 mm), two DC MA-8005 manipulators with magnetic bases, face plates and coaxial probe arms (standard), Microscope post with coaxial and linear microscope X, Y movement of 100 mm x 100 mm, 6.7:1 zoom (100x magnification) trinocular stereo zoom microscope with 100 mm working distance
 - Manipulators
Multi-purpose, easily converted to meet a variety of applications, adjustable probe arm faceplate provides additional Z travel of +/- 16 mm, uses all

SemiProbe standard probe arms - DC, HF, Optical, and more, 12 independent manipulators can be placed on the platen, ideal for I/O bond pad and internal probing (<1 μm)

- Probe arms
Specifically designed to be short to minimize mechanical vibrations and electrical losses, one end of the probe arm has a clamping collet. The collet head has three grooved slots that allow the user to insert the probe tip at preset angles of 30, 45, and 180 degrees
- Newport VIS3660-PG4-325A optical station, 36 in. x 60 in., 4 in. thick PG Breadboard, I-325 Isolators. For vibration isolation of the probe station.

- **General Device Measurement Station (Room 28)**

(Regular IV measurement, fast switching measurement (5 ns), endurance measurement, retention measurement)

- Keysight B1500A Semiconductor Device Analyzer
Current versus voltage (IV) measurement, accurate and precise measurement ranges of 0.1 fA - 1 A and 0.5 μV - 200 V, capacitance measurement, multi-frequency AC impedance measurement supports CV (capacitance versus voltage), C-t (capacitance versus time) and C-f (capacitance versus frequency) measurement, capacitance measurement frequency range of 1 kHz to 5 MHz, arbitrary waveform generation with 10 ns programmable resolution, B1530A Waveform generator/fast measurement unit (WGFMU), four high-resolution source monitor units (B1517A)
- Semiprobe Probe Station
High power compound microscope, temperature stage (ambient to 200 $^{\circ}\text{C}$, 0.5 $^{\circ}\text{C}$ accuracy), 4 tri-axial probers and procard adapter
- Manipulators
Multi-purpose, easily converted to meet a variety of applications, adjustable probe arm faceplate provides additional Z travel of ± 16 mm, uses all SemiProbe standard probe arms - DC, HF, Optical, and more, 12 independent manipulators can be placed on the platen, ideal for I/O bond pad and internal probing (<1 μm)
- Light source
- Probe arms
Specifically designed to be short to minimize mechanical vibrations and electrical losses, one end of the probe arm has a clamping collet. The collet head has three grooved slots that allow the user to insert the probe tip at preset angles of 30, 45, and 180 degrees
- Keysight E3630A Triple output DC power supply
35 W Triple Output, 6 V, 2.5 A and ± 20 V, 0.5 A
- Keysight B2901A Precision source/measure unit
Source/Measure Unit, 1 ch, 100 fA, 210 V, 3 A DC/10.5 A Pulse
- Keysight InfiniVision MSOX3104T mixed-signal oscilloscope
1 GHz, 4 analog plus 16 digital channels, 4 Mpts memory, 1,000,000 waveforms/sec update rate, and standard touch zone trigger with an 8.5-in capacitive touch screen
- Keysight 33600A Waveform generator
1 GSa/s sampling rate and up to 120 MHz bandwidth, Arb with sequencing and up to 64 MSa memory, 1 ps jitter
- Newport VIS3660-PG4-325A optical station, 36 in. x 60 in., 4 in. thick PG Breadboard, I-325 Isolators. For vibration isolation of the probe station.

- **Reliability Measurement Station (Room 20)**
(Regular IV measurement, fast switching measurement (5 ns), endurance measurement (high temperature), retention measurement)
 - Keysight B1500A Semiconductor Device Analyzer
Current versus voltage (IV) measurement, accurate and precise measurement ranges of 0.1 fA - 1 A and 0.5 μ V - 200 V, capacitance measurement, multi-frequency AC impedance measurement supports CV (capacitance versus voltage), C-t (capacitance versus time) and C-f (capacitance versus frequency) measurement, capacitance measurement frequency range of 1 kHz to 5 MHz, arbitrary waveform generation with 10 ns programmable resolution, B1530A Waveform generator/fast measurement unit (WGFMU), four Mid Power Source Monitor Units (B1511B)
 - Semiprobe Probe Station
High power compound microscope, temperature stage (ambient to 200 °C, 0.5 °C accuracy), 4 tri-axial probes and procard adapter
 - Manipulators
Multi-purpose, easily converted to meet a variety of applications, adjustable probe arm faceplate provides additional Z travel of +/- 16 mm, uses all SemiProbe standard probe arms - DC, HF, Optical, and more, 12 independent manipulators can be placed on the platen, ideal for I/O bond pad and internal probing (<1 μ m)
 - Intralux 4000-1 light source
 - Probe arms
Specifically designed to be short to minimize mechanical vibrations and electrical losses, one end of the probe arm has a clamping collet. The collet head has three grooved slots that allow the user to insert the probe tip at preset angles of 30, 45, and 180 degrees
 - Newport VIS3660-PG4-325A optical station, 36 in. x 60 in., 4 in. thick PG Breadboard, I-325 Isolators. For vibration isolation of the probe station.
- **MMR Station (Room 28)**
(Test device with 4 probes under a temperature range of 70-730K, vacuum or different gas environments)
 - MMR Variable Temperature Microprobe System
 - Four probes
 - Shared B1500A with the general device measurement station
- **Training Measurement Station (Room 28)**
(Training for new group members in semiconductor testing)
 - Agilent 4156B Precision Semiconductor Parameter Analyzer
 - 4 high-resolution SMUs, 2 VMUs, and 2 VSUs.
 - Wentworth probe station
 - Manipulators
 - Probe arms
- **PCB-level Circuit Test Station (Room 16)**
(Discrete IC component test, PCB-level circuit test)
 - Teledyne T3DMM4-5 Digital multimeter

- Real 4½ digit (60,000 counts) readings resolution up to 150 rdgs/s measurement speed, True-RMS AC Voltage, and AC Current measuring, 1 Gb NAND flash size, Mass storage configuration files, and data files
- Keysight E3630A Triple output DC power supply
35 W Triple Output, 6 V, 2.5 A and ±20 V, 0.5 A
- Precision 4065 Dual arbitrary waveform/function generator
160 MHz Arbitrary, Sweep Function Generator, DDS 2 Channel Sine, Square, Triangle, Pulse Display Type LCD
- Keysight E36312A Triple output programmable DC power supply
6 V, 5 A and 2 x 25 V, 1 A, 80 W, VAC +/- 11V operation, 47 to 63 Hz
- Precision 9129B Triple output programmable DC power supply
0 ~ 30VDC, 0 ~ 30VDC, 0 ~ 5VDC Output Bench (AC to DC) Power Supply
VFD 0 ~ 3A, 0 ~ 3A, 0 ~ 3A Output 195W Features Memory, Programmable, Tracking
- Agilent 34972A Lxi data acquisition/ switch unit
3-slot mainframe with built-in 6 1/2 digit Digital Multimeter and 8 optional switch and control plug-in modules
- Keysight N9320B spectrum analyzer
Fast spectrum analysis covering frequency 9 kHz to 3 GHz, 0.5 dB overall amplitude accuracy, Efficient AM/FM, ASK/FSK
- Keysight InfiniVision MSOX3104T mixed-signal oscilloscope
1 GHz, 4 analog plus 16 digital channels, 4 Mpts memory, 1,000,000 waveforms/sec update rate, and standard touch zone trigger with an 8.5-in capacitive touch screen
- **Two Chip-Level Measurement Stations (Room 18)**
(Large array-level (up to 128x64) programming, large array-level (up to 128x64) crossbar array computing demonstration, 128 synchronized input, and 64 synchronized output channels)
 - Voltage-based measurement system
Eight sets of column boards, eight sets of row boards, and one motherboard
 - Time-based measurement system
Four sets of column boards, four sets of row boards, and one motherboard
 - Semiprobe Probe Station
High power compound microscope, temperature stage (ambient to 200 oC, 0.5 oC accuracy), 4 tri-axial probers and procard adapter
 - Keysight E3633A DC power supply (2)
Single output, dual range: 0-8V, 20A; 0-20V, 10A 160/200W. GPIB
 - Agilent E3630A DC power supply
35 W Triple Output, 6V, 2.5A & ±20V, 0.5A
 - Motic-MLC150C light source
 - ZC702 FPGA evaluation board
1GB DDR3 Component Memory, USB OTG, UART, IIC, CAN Bus, Dual ARM Cortex-A9 core processors, 10-100-1000 Mbps Ethernet (GMII, RGMII and SGMII), HDMI out, FPGA Mezzanine Card (FMC) interface
 - ZCU102 FPGA evaluation board
DDR4 SODIMM, 4GB 64-bit w/ ECC attached to PS, DDR4 Component, 512MB 16-bit attached to PL, PCIe® Root Port Gen2 x4, USB3, Display Port, and SATA, 4x SFP+ interfaces for Ethernet, 2x FPGA Mezzanine Card (FMC) interfaces for I/O expansion, including 16 16.3Gb/s GTH transceivers and 64 user-defined differential I/O signals

- ThinkPad laptop P1 Gen4
Intel® Core™ i9-11950H (2.60GHz), 64GB, 1TB SSD, NVIDIA RTX 3080 Max-Q 16GB
- Optical table for better isolation.

2.2. Shared Testing and Packaging Equipment in IALS (Sensor Development & Sensor Integration Labs):

- *Keysight/Cascade Probe Station for Network Analysis to 1.1THz*
For use in characterizing devices and integrated circuits operating up to Terahertz frequencies
 - Microwave network analyzer, Keysight N5247A PNA-X, 0.01-67 GHz (options 080, 400, 419, H01)
 - VNA frequency extenders, 70-1100 GHz (VDI, WR10, WR6.5, WR4.3, WR3.4, WR2.2, WR1.5, WR1.0)
 - Probe station, Summit 12000B-M 200 semi-auto microchamber. Large area manipulators and E-Vue microscope
 - Dominion wafer probes for WR4.3, WR3.4, WR2.2, WR1.5, WR1.0 bands
 - VDI calibration kits (WR10, WR6.5, WR4.3, WR3.4, WR2.2, WR1.5, WR1.0)
- *Bruker Vertex 80 Fourier Transform Spectrometer*
For use in characterizing materials such as polymers, pharmaceuticals, semiconductors
 - Spectral range from very far IR (THz) to near IR, visible, and UV
 - Standard resolution better than 0.2 cm⁻¹
 - PC-based data system controls optics and signal processing
 - Sources
 - MIR standard internal, Globar
 - NIR/UV internal, tungsten lamp (Q428/7)
 - FIR external, Hg arc (Q201), to 4cm⁻¹
 - Detectors
 - MIR KBr/DLaTGs D301, room temp
 - NIR/MIR MCT D316, LN temp
 - VIS/NIR Si D510, room temp
 - FIR(to 150 GHz), IRLab bolometer, 4.2°K
 - Beam splitters for the entire range in steps
 - Temporal resolution to 6μS
 - Reflection accessories: Bruker, 13°-83° computer-controlled angle adjustment, Pike 30° angle, horizontal sample position
- *Firefly Pulsed THz Laser*
A compact tunable THz source useful for spectroscopy, non-destructive testing, biomedical diagnostics, and THz detector testing
 - Output Pulse Energy > 9 nJ at 50 Hz
 - Tuning Range 0.8 to > 2.5 THz
 - Repetition Rate 50 Hz (fixed, nominal)
 - Pulse Duration < 25 ns (FWHM)
- *High-Frequency Measurements*

- Signal Analyzer 50 GHz Agilent (N9030A, options B1X, BBA, CR3, EXM, P50, RT2, 1FP, 2FP, 9068A, 9069A, 1FP, 2FP)
- Noise source 26GHz, Agilent N4002A
- Signal generator 50 GHz Agilent, E8257D (options 1E1, 550, UNW, UNX)
- Multipliers, VDI 650 and 850 GHz
- E-calibration module, Agilent N4694A
- Power meter Erickson PM4, with waveguide flange adapter kit
- Power meter, Agilent E4416A (2)
- Power sensors, Agilent (N8485A, E4413, N8488A, 8487D, W8486A)
- Supporting waveguide equipment (2x horns and 2x 1" waveguide for WR10, WR6.5, WR4.3, WR3.4, WR2.2, WR1.5, WR1.0 and variable attenuators for WR10, WR6.5, WR4.3, WR3.4, WR2.2 and WR1.5).
- THz to MIR Golay cell detector, Tydex
- FIR bolometer (to 150 GHz), IRLab, 4.2°K
- *Scientific Instrumentation*
 - SRS Small Instrument Modules: SIM910 JFET preamplifier, SIM918 Precision current preamplifier, SIM954 Dual-channel 300 MHz inverting amplifier, SIM965 Bessel and Butterworth filter, SIM923 Platinum RTD monitor, SIM928 Rechargeable isolated voltage source, SR540 Optical chopper (with 5/6 and 25/30 slot blades), SR250 Gated integrator
 - Lock-in Amplifier, Zurich Instruments HF2LI
- *Basic Equipment*
 - DC Source meters (5) Agilent B2901A
 - Triple DC sources (5) Agilent E3631A
 - Oscilloscope, Agilent MOSX3104A 1 GHz
 - Arbitrary waveform generator, Agilent 33250A
 - Microscope, Nikon SMZ 745
 - Assorted tools and cables
 - Infrared Laboratories 4.2K bolometer system 15-2000 microns
- *Summit 11000 Probe Station with Laser Cutter*
For measuring and modifying prototype integrated circuits
 - EZLaze3 laser cutter:
 - for cutting metal traces (532 nm)
 - for removing passivation (355 nm)
- *Advanced Dicing Technology 7122*
For precision dicing of hard material components such as silicon wafers
 - Work piece size: up to 200mm x 200mm
 - Indexing: resolution/accuracy is 0.2 μ m/1.5 μ m
 - Cut Depth: resolution/accuracy is 0.2 μ m/2.0 μ m
- *LPKF Protolaser U3*
For prototyping of printed circuit boards
 - Diameter of UV laser beam 20 μ m
 - Resolution of scan field 2 μ m
 - Repeatability +/- 2 μ m

- Surface structures down to 75µm
- Max material size 9" x 12" x 0.27"
- *FineTech FINEPLACER pico ma*
For flip chip bonding and die attach
 - Placement accuracy 5 µm
 - Components from 0.125 mm x 0.125 mm to 100 mm x 100 mm
 - Working area up to 450 mm x 234 mm
 - Supports wafer/substrate sizes up to 200 mm
- *LPKF Minicotac RS*
For plating via holes in prototype printed circuit boards
 - Maximum size board 9" x 12"
 - Minimum via size 0.4 mm
- *LPKF Multi-press S*
For laminating multiple layers of printed circuit boards
 - Laminating area 9" x 12"
 - Up to 8 layers
- *Other equipment*
 - Vector Network Analyzer: Keysight E5071c 8.5 GHz with Ecal kit
 - Solder Rework Station: Weller wha3000
 - Wire Bonders (2): TPT HB16(link is external) (stud bump and bump/wedge)
 - DC triple power supplies (4): Keysight E3631a
 - Logic Analyzer: Keysight 16806
 - DC source meters (2): Keysight B2901
 - Oscilloscope 1GHz: Keysight MSOX3104a
 - Oscilloscope handheld: Keysight U1620a

2.3. Shared Measurement Equipment in Conte:

- Wentworth MP-2300 Probe Station
- Keithley 4200 SCS Parametric Analyzer

3. Computing facilities

3.1. PI's own servers

- *Two Dell Precision Workstations (Room 216)*
 - Cadence Virtuoso VLSI design
 - High-performance simulations based on Linux system

3.2. Shared computing resource

The Massachusetts Green High-Performance Computing Center (MGHPCC), located in Holyoke, MA, provides state-of-the-art high-performance computing resources for UMass Amherst faculty and researchers pursuing a diverse body of research. With high-end computing equipment and storage, including thousands of CPU cores and GPU cards, UMass Amherst operates one of the biggest GPU clusters in the nation in the MGHPCC. This includes the UMass System Shared Cluster, available for general use to UMass Amherst researchers and researchers from other UMass campuses.

4. Physical Characterization Facilities and Equipment

- *Magnetic property Measurement Systems (MPMS XL7)*
 - Support of all measurements: AC, DC, Reciprocating sample;
 - Minimum continuous operating temperature: 1.9 K;
 - Maximum magnetic field: 7 Tesla.
- *Electron Microscopy*
 - JEOL- JEM-2200FS Energy Filtered Transmission Electron Microscope
 - JEOL JEM-2000FX Transmission Electron Microscope
 - FEI Magellan 400 XHR-SEM
 - FEI Tecnai-T12 TEM
 - Asylum MFP-3D Scanning Probe Microscope
 - Bruker (Digital Instruments) Dimensions 3100
 - Bruker (Digital Instruments) MultiMode
 - Leica Ultracut UCT EM FCS
 - Leica (Reichert & Jung) Ultramicrotome
 - FEI Vitrobot MKI
 - Balzers Critical Point Dryer
 - Cressington 108 Sputter Coater
 - Cressington 208 Sputter Coater
- *Atomic Force Microscopy (AFM)*
 - Bruker MultiMode AFM for high resolution
 - Bruker Dimensions AFM for large-scale samples
 - Oxford Asylum MFP-3D for specialized experiments
- *X-Ray Scattering Facility*
 - SAXSLAB Ganesha with WAXS and GIXRD
 - Panalytical XRD with Reflectivity option
- *Device Characterization Laboratory*
 - 3D Systems Capture
 - KLA Tencor Alpha D-500
 - Nikon Altera 7.5.5 Coordinate Measuring Machine
 - Edibon EBVR
 - Stress Photonics GFP 1500 Full Field Strain Measurement System
 - Instron ElectroPuls 10000
- *Light Microscopy Facility*
 - A1R25: Nikon Ti2 stand with A1HD(1024) Resonant Scanning Confocal
 - A1R-SIMe: Nikon TiE stand with A1 Resonant Scanning Confocal and N-SIM Structured Illumination Super-Resolution
 - A1SP-FLIM: Nikon TiE stand with A1 Spectral Detector Confocal and FLIM/FCS Module
 - A1R-TIRF: Nikon TiE stand with A1HD(1024) Resonant Scanning Confocal and TIRF Module
 - A1RMP: Nikon FN1 stand with A1HD(1024) Resonant Scanning Multi-Photon Confocal
 - CrestV2 with 2xTIRF: Nikon Ti2 stand with spinning disk confocal and 2 camera TIRF system
 - Spinning disk (SD): Nikon TiE stand with Yokogawa Spinning Disk Confocal and FRAP/PA unit for perturbations
 - SMZ-18: Nikon stereoscope
 - HCA: Nikon TiE with High Content software and robotic hardware
 - N-STORM: Nikon TiE stand with N-STORM/TIRF
 - LCMD: Nikon TiE stand with Arcturus Laser Capture Micro-Dissection

- Keyence BZ-X800
- Ephys: Nikon TiE with patch clamp electrophysiology rig including Axopatch 200B and micromanipulators
- Raman, IR, and XRF Spectroscopy
 - DXRxi Raman Imaging Microscope
 - DXR Raman Microscope
 - EZ Portable Raman Spectrometer
 - Handheld Raman Spectrometer
 - FTIR Spectrometer
 - FTIR Microscope
 - X-Ray Fluorescence Spectrometer Epsilon 4
 - X-Ray Fluorescence Spectrometer Epsilon 1
- Biophysical Characterization
 - Li-Cor Odyssey CLx Imaging System
 - GE Typhoon FLA 9500 Phosphorimager
 - Rock Imager 2
 - Analytical Ultracentrifuge Fluorescence Detection System (AU-FDS)
 - Beckman ProteomeLab XL-I Analytical Ultracentrifuge with Fluorescence Detection System
 - BioTek Plate Reader with Fluorescence Anisotropy Capability
 - Formulatrix Robotics System for Crystallization
 - Jasco J-1500 Circular Dichroism Spectrophotometer
 - Malvern Auto-iTC200
 - Malvern Zetasizer ZSP - Dynamic Light Scattering (DLS) System
 - Nanotemper Monolith Thermophoresis Instruments
 - Wyatt Technology/Agilent SEC-MALS

5. **Other accessible resources:**

- National Labs: The PI can submit proposals to gain access to the e-beam writer with stitching function at the Molecular Foundry at Lawrence Berkeley National Laboratory or to Brookhaven National Laboratory. The PI is a current user of both the fabrication and TEM facilities in the Center for Functional Nanomaterials at Brookhaven National Lab.
- Computers: The Department of Electrical & Computer Engineering runs a professionally staffed Engineering Computer Services facility, with over a hundred computer systems installed in the College of Engineering. Computer systems, including Windows, Linux, and SUNs are readily available in the department.
- Software: The ECE department has licensed the most common software packages, including MATLAB, Cadence tools, Altium for PCB design, and ANSYS tools for verification, to name a few.
- Machine shops: There are three machine shops at the UMass Amherst campus (one in Electrical Engineering, one in Mechanical Engineering, and one in Physics). PI has access to all of them to machine homemade parts or systems.
- Offices: The PI has a faculty office of ~180 sq. ft. (Marcus Hall), and ~700 sq. ft. office area (also Marcus Hall) for students. Both are equipped with printers, telephones, and computers with Internet access.
- Staff service: The ECE Department has assigned a bookkeeper for the PI. The department also has administrative assistants for secretarial work and technicians for lab maintenance.