

BINGHAMTON UNIVERSITY'S INNOVATION TECHNOLOGY CENTER: FACILITIES, EQUIPMENT & OTHER RESOURCES

Binghamton University's Innovative Technologies Complex (ITC) provides modern, collaborative facilities for research, education, and administrative in the physical sciences and engineering. The ITC comprises 445,000 ft² of space as result of a \$181M capital investment over the last decade. The complex features the New York Center of Excellence for Small Scale Systems Integration and Packaging (S3IP) and is home to the Thomas J. Watson School of Engineering, including electrical and computer, mechanical, and biomedical engineering. The Smart Energy R&D building will be ready for occupancy in April of 2017, and will host the chemistry and physics departments.



Figure 1: Shows a birds-eye view of the ITC complex, with the Engineering & Science Building on the left, the Biotechnology Building in upper right corner, and the Center of Excellence building in the lower right corner. Each of these buildings are connected. To the left of this picture, is the new Smart Energy building, which is to be connected to the Center of Excellence Building, and open in 2017.

The Center of Excellence in Small Scale Systems Integration and Packaging (S3IP) is the nexus for research efforts of the following campus centers: **The NorthEast Center for Chemical Energy Storage (NECCES), the Energy-Smart Electronic Systems Center (ES2), the Center for Advanced Microelectronic Manufacturing (CAMM),** the Integrated Electronics Engineering Center (IEEC), and the Center for Autonomous Solar Power (CASP). By co-locating faculty in engineering and the physical sciences and affiliated with these centers, collaboration and cross-fertilization between the colleagues in the multiple disciplines is naturally promoted and enabled. This is consonant with the university strategic plan emphasizing transdisciplinary research in topics such as Smart Energy, Health Sciences, Sustainable Communities and Materials and the Visual World.



Figure 2: Center of Excellence Building, Binghamton University, which will serve as the NRT Hub.

S3IP also provides central coordination for core lab facilities serving multiple research centers and industrial partners. Key among these are the Analytical and Diagnostics Lab (ADL), an 8,000ft² laboratory providing \$25M in research instrumentation for the characterization and analysis of materials, surfaces, and interfaces in physical materials, especially those relevant to electronics manufacturing. It has growing instrumentation capabilities for biomedical engineering, as well. The ADL is staffed by PhD-level materials scientists and engineers with extensive industrial experience. The ADL instrumentation supports faculty research in engineering and the physical and life sciences and industrial analyses and problem-solving relating to materials, diagnostics, analysis, characterization, and device fabrication processing, electronic systems integration and packaging development for conventional flexible electronics, industrial and consumer electronics. The ADL contains a host of measurement and characterization tools. Most relevant to this project include: spectroscopic ellipsometer; atomic force microscope; ion milling; dimple grinder; SEM; TEM; JEOL2100 (scanning) transmission electron microscope, the capabilities of this TEM/STEM include Z-contrast imaging, high resolution electron microscopy, XEDS, EELS, elemental mapping, field-free Lorentz imaging, and tomography. This microscope will be utilized for in situ study of oxide reduction using a heating/environmental TEM holder; TEM sample preparation equipment; Dual-beam focused-ion-beam (FEI Nova 600 Nanolab); High resolution field emission scanning electron microscope (Zeiss Supra 55 SEM); Environmental LaB6 SEM (Zeiss EVO50XVP); Atomic force microscope (AFM): Veeco Dimension 3100; X-ray imaging and analysis; and a Hall Effect (Van der Pauw): Ecopia HMS 3000.

Additional core laboratories include the Integrated Electronics Engineering Center (IEEC) Failure Diagnostics and Reliability Laboratory, which provides environmental test chambers and instrumentation for diagnosis of faults in electronics, as well as supporting research on thermal management for electronics, solder mechanics, high temperature solders, 2.5D/3D chip stacking technology, and growth into power electronics packaging and packaging-related technology for secure electronics. The Center for Autonomous Solar Power (CASP) Laboratory includes capabilities for constructing thin-film photovoltaic, supercapacitor, and thermoelectric devices, with particular emphasis on earth-abundant, low toxicity materials. The Nanofabrication Facility features a class-1000 clean room for construction of nano-engineered devices and materials, fabrication and coating. Its microfabrication tool set includes: Electron beam evaporation; Sputter deposition; Plasma enhanced chemical vapor deposition; Reactive ion etch; Rapid thermal

processing; Contact alignment; Thermal evaporation; Reflectometer; Wet benches; and a Critical point dryer. In addition, faculty have access to the Cornell Nanofabrication Facility, about 50 miles away, which has an extensive collection of microfabrication tools.

The Southern Tier Regional Economic Development Council is recipient of a 5-year, \$500M commitment for investments in economic infrastructure by New York state's Upstate Revitalization Initiative (URI). The university has a major role in expending URI funds working in partnership with industry to extend the R&D infrastructure accessible to academia and industry. Included in this award is \$600K funding to establish a battery dry room for NECCES at the ITC to further advance battery research and prototyping capabilities, and \$3M in funding for an electronics cybersecurity lab that address cybersecurity from a hardware architecture perspective. The hardware cybersecurity lab will complement a \$5M software cybersecurity lab focused on the security of devices, such as advanced wearable electronics, participating in the Internet of Things. These investments at the ITC are in addition to URI funding for \$5M expansion of the CAMM at its current location on the Huron Campus Building 258 in Endicott, NY, and establishment of a \$10M industrial 3D printing development center in laboratory space immediately adjacent to the CAMM in Building 258. Under the URI a \$3M advanced materials applications and technology transfer center is planned in nearby Elmira, NY, leveraging materials science and electronics manufacturing capabilities resident at the ITC.

Other areas of capability growth in process or in planning for the ITC include materials and sample preparation lab for the CAMM, a pharmacy research lab, a health sciences core lab, and a power electronics lab. A telemedicine research and prototyping center is also available.

As such, the ITC has established itself as a key research hub for the university and industrial / academic collaborations. The S3IP and its constituent research centers such as CAMM, IEEC, ES2, CASP, and NECCES, supported by the ADL, have distinguished itself by the over \$1.2 B of economic impact and 2050 jobs created or retained in New York state over the last 20 years. This impact is attributed and audited by New York state's Empire State Development (ESD) agency, which funds operations of the S3IP and IEEC, and is reaffirmed by ESD's 10-year \$9.2M funding commitment to the IEEC for a third decade of operations in service of the electronics manufacturing industry.

The following national research and other centers are integral to the project's research and educational agenda and their facilities, located at Binghamton University, will be available to the program:

- A. **NorthEast Center for Chemical Energy Storage (NECCES)**, DOE Energy Frontier Research Center: The NECCES labs and offices, a combined 4000 ft², are located in the newly constructed Center of Excellence Building at Binghamton University. NECCES has a new (2015) Bruker D8 powder x-ray diffractometer, Scintag XDS-2000 X-Ray Diffractometer, Superconducting Quantum Interface Device (SQUID) Design MPMS and Physical Property Measurement System (PPMS), 4 glove boxes, over 120 channels of coin-cell battery cyclers, thermal analysis and data analysis computers with software, including the Thermogravimetric Analyzer. NECCES also has access to Argonne National Laboratory-

APS, Brookhaven National Laboratory-NSLSII, and Lawrence Berkeley National Laboratory—Advance Light Source. Additionally, NECCES started-up a lithium battery-grade Dry Room, in January of 2017. By the Fall of 2017 it will be fully equipped with materials and electrode fabrication machines, as well as cell fabrication. This will be available for fundamental materials studies through prototyping.

- B. **The Center for Energy-Smart Electronic Systems (ES2)**, built through an NSF MRI award is a National Science Foundation Industry/University Cooperative Research Center: ES2's new, is fully instrumented 4500 square foot data center laboratory. This data center laboratory has the scale of a mid-range data center but unlike a real data center, it permits disruptive experiments to be carried out. There are 3 cold aisles - 2 of which are fully contained. The laboratory incorporates different types of cooling facilities (traditional chilled air-cooling, rear door heat exchangers using chilled water and warm water cooling) to permit experiments involving different cooling technologies that are seen in legacy as well as state-of-the-art data centers. This facility currently has over 20 racks of storage servers, 2U and blade compute servers and another 30 racks, which are now being populated. The networking infrastructures within this data center laboratory consists of 10 Gbits/sec. Ethernet, and extensive switched optical fiber-based connections for the large storage arrays and load balancing switches. A DC power distribution unit was recently added for research exploring the benefits of hybrid AC/DC power distribution in data centers. A separate 1200 feet staging laboratory and a separate laboratory space for a full-sized container based data center are also available to ES2 researchers. The laboratory has extensive instrumentation and controls in hardware and software to permit a wide variety of experiments to be carried out. On the IT side, these include the ability to measure power consumption of individual servers, server load statistics, network traffic in real time and the ability to generate realistic loads on individual servers and the data center as a whole. The instrumentation and controls on the cooling systems and thermal side include the ability to measure temperatures in various zones of the servers, air velocities and water flow rates in real time and the ability to control CRAC fan speeds, inlet temperatures and adjust the mix of chilled and warm water. The facility was developed in part using a NSF MRI award and in part using donations from several ES2 member companies.



Figure 3: Energy-Smart Electronic Systems Data Center, housed in the Center of Excellence Building.

- C. **The Center for Advanced MicroElectronics Manufacturing (CAMM)** serves as the New York Node of the Innovation Institute for Flexible Hybrid Electronics Manufacturing (FHE-MII). The CAMM facilities feature a 10,000 sq ft. (10K) cleanroom area located at the University's facility on the Huron Campus, in Endicott, NY (a former IBM site). The

CAMM tools consist of a panel line for process/product research and development for flexible or rigid substrates ranging from 4" wafers up to 20"x20". Primary equipment includes: Tamarack large-area aligner/scanning broad band exposure tool for features down to 4 μ m; KDF sputter down physical vapor deposition system for metals and insulators; spin coater and spin wet process tool for substrates up to 7"; optical microscope with measurement system; vacuum laminator; Unijet double headed inkjet printer with a 200mm square stage equipped with vacuum chuck for printing up to 1200 dpi; recently upgraded Optomec AJ 300 aerosol inkjet high resolution printer with a UA MAX enhanced ultrasonic atomizer for increased material output and more consistent printing, wide feature print head, to allow for one pass printing of millimeter sized features, and updated KEWA interface, allowing compatibility with AutoCAD15 greatly enhancing design and toolpath data creation, other capabilities include +/- 1 μ m stage resolution, the ability to use materials with viscosity from 1-1000cP and, printing over non-uniform substrates with features as small as 10 μ m; Xennia 3000 printer with range of travel: 600 mm x 600 mm, for up to 300 mm substrates, CCD camera for alignment, measuring system accuracy \pm 3 μ m, repetition accuracy <1 μ m, and typically three Xaar 760 GS8 print heads.

The CAMM also has a unique integrated roll-to-roll (R2R) research line for process/product research and development with rolled based substrates ranging from 6" to 24" wide webs with thicknesses from 5 to 150 microns. Roll-to-roll tooling includes: Azores high precision large-area photolithography to image and stitch single micron features with better than 1 μ m registration capability; CHA Industries high vacuum physical vapor deposition coater for metals; Bobst Optilab high vacuum physical vapor deposition coater for insulators and semiconductor coatings; "Etched-In-Time" linear plasma reactive ion dry etch source in zone 2 of the Bobst Optilab system; Energy Conversion Devices Integral Vision (ECD-IV) in line roll-to-roll defect optical inspection system; Northfield Automation roll-to-roll handling systems; vacuum lamination; Kraemer Koating cleaning and wet process system; Hollmuller-Sigmund (ME Baker) wet process systems for cleaning, develop, etch and strip operations. Large wet process tools are plumbed directly in to the Huron campus industrial scale waste water treatment facilities.

The CAMM lab has additional infrastructure for materials analysis including: a) Dektak XT Profilometer capable of measurements down to tens of nanometer scale, with accuracy +/- 30A with a manual 300 mm round stage, low-force options down to 0.03 g for soft and flexible substrates, analysis capabilities include examining surface roughness, film stress and substrate deformation; b) Filmetrics F20-UV: for optical transmission spectra measurement between 190 to 1100nm for substrates up to 40 μ m thick; c) JANDEL RM3-AR 4 point probe system with auto-detection and manual input of currents from 10nA up to 1A and compliance voltage up to 40V; d) SemiProbe PS4L M12 probe station equipped for 300mm substrates, a compound microscope for high resolution inspection, four multipurpose manipulators for needle probing at frequencies up to 500MHz with 5 μ m resolution, a computer interfaced Keithley 2636B two channel source measurement unit for high precision electrical measurements, down to 0.1fA for I-V characterization; e) various optical microscopes equipped with digital cameras.



Figure 4: Selected CAMM equipment: Optomec, Azores, Bobst GVE and Northfield Automation