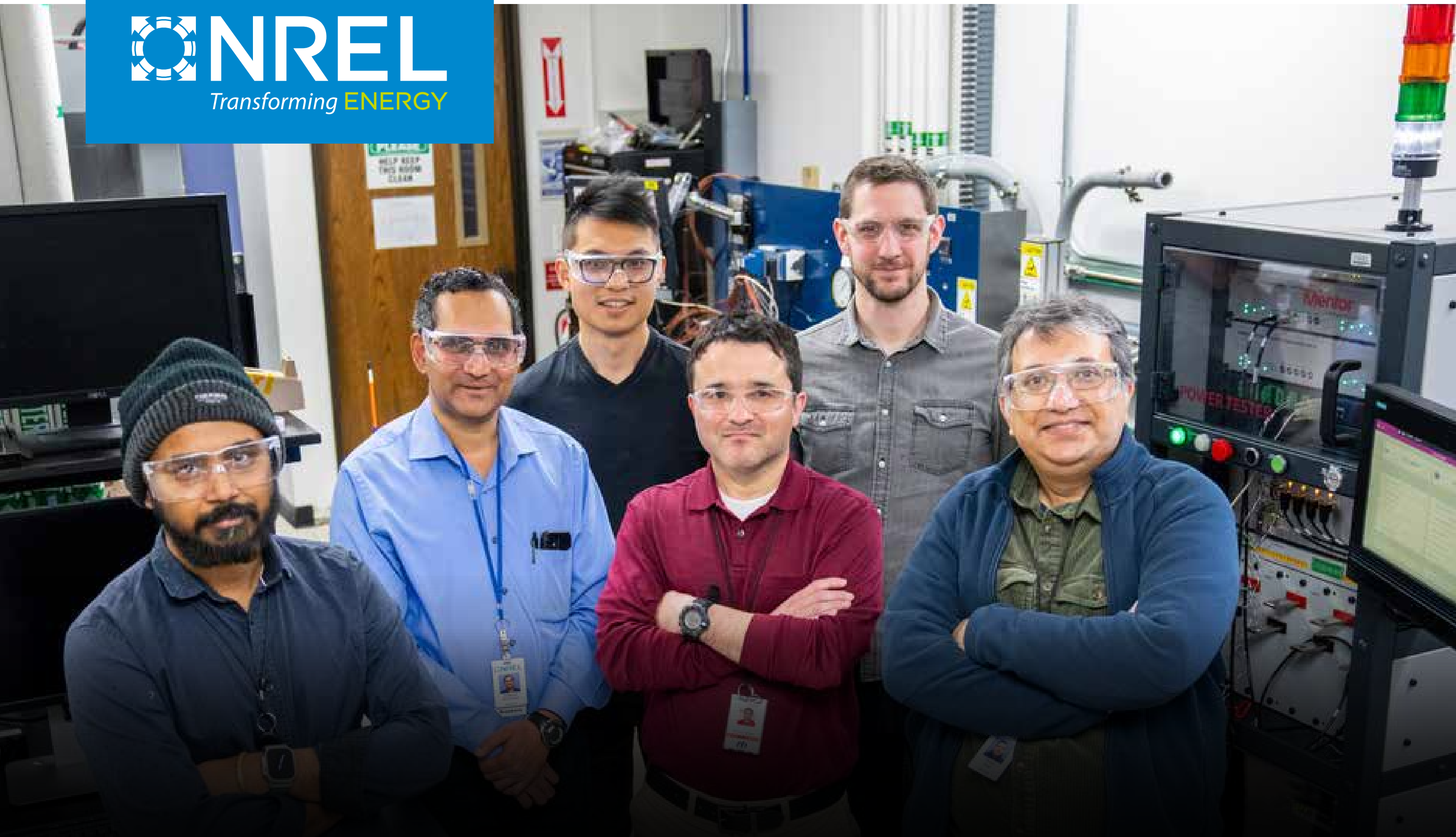
NREL
Transforming ENERGY



Advanced Power Electronics and Electric Machines

The advanced power electronics and electric machines (APEEM) research group at the National Renewable Energy Laboratory (NREL) has developed world-class experimental and modeling capabilities for designing and evaluating efficient and reliable power electronics and electric machines thermal management systems. They also design, fabricate and characterize advanced power electronics packaging, and are developing state of-health monitoring techniques.

Our researchers deliver safe, reliable, high performing, power dense components that allow seamless integration between renewable energy sources, electric transportation, and the grid, helping to make widespread electric vehicle (EV) adoption and greenhouse gas emissions reduction more feasible.

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Research Capabilities

Power Electronics

Wide-scale decarbonization—of our transportation systems, our electrical utilities, and other critical sectors—will rely on better power electronics, electric machines, and electric-drive systems, all of which help control and convert electricity into usable forms. NREL's research works to improve power electronics and electric machine component and system performance, reliability, and efficiency. These advancements make decarbonized technologies possible.

Our scientists and engineers work closely with vehicle manufacturers, suppliers, universities, and other research organizations to develop solutions that overcome the most challenging technical barriers to renewably powered technologies, including EVs and other applications. They are devoted to designing, building, and characterizing power converters, control systems, traction drivers, advanced gate drivers, state of health estimation of converters, electric machines, and batteries, all in addition to performing degradation analysis for individual components and modules.

Most importantly, NREL's world-class research and characterization facilities form an end-to-end pipeline. Our researchers can design, build, characterize, and validate prototypes spanning from proof-of-concept to high-performance systems all in one laboratory setting.

Module development and characterization

NREL researchers push the boundaries of power electronics by improving the performance, reliability, durability, and power density of power electronics modules and packaging.

The laboratory has established a one-stop solution for fabricating and characterizing ultra-wide bandgap (UWBG) power semiconductor devices, building modules to accommodate those devices, and creating systems to characterize these high-performance power modules and meet decarbonization goals of the future. The wide-bandgap (WBG) and UWBG semiconductor devices evaluated at NREL offer improved performance, reliability, and cost.

Module development research at NREL also aims to design, fabricate, and characterize a universal architecture for medium-voltage power modules that could be used with both silicon carbide (SiC) and gallium nitride (GaN) devices for current and future high-voltage applications. This research includes wide-band-communication enabled smart modules which exploit wireless power transfer to eliminate gate driver ancillary power supply issues at extremely high voltage levels, isolating the power module to provide onboard state-of-health information.

Finally, because high-temperature bonded interface materials are essential to enable compact, lightweight, low-cost, reliable power electronics packaging that fully utilizes the capabilities of both WBG and UWBG devices, NREL researchers apply the laboratory's world-class thermal modeling and management capabilities to each package.

Thermal modeling and management

Advanced thermal management systems are critical to the performance and safety of all electrified traction drive components, including semiconductor power devices, power modules, inverters, and electric motors.

NREL researchers are experts in system-level thermal management designs that incorporate advanced heat transfer to regulate temperatures throughout the complete power electronics and electric machine system.

NREL researchers rely on cutting-edge modeling capabilities to develop predictive and remaining lifetime models to evaluate and improve the reliability of new high-temperature technologies. NREL's electric machine thermal management research generates experimental data and simulation processes for the modeling, analysis, design, and construction of new electric machines for vehicles and other applications.

NREL research helps to better understand and evaluate the material and interface properties of electric machines as a function of temperature. Researchers also develop and evaluate advanced fluid-based electric machine cooling strategies for improved performance and reliability of electric vehicles.

Modeling the thermal (steady-state and transient) performance of power modules enables researchers to evaluate the effects of coolant temperature and convective cooling performance. They also leverage thermal analysis tools like computational fluid dynamics (CFD) simulations to evaluate thermal performance, predict the thermal resistance versus flow rate characteristics, and gain insight into critical thermal contact resistances within the module assembly.

Thermomechanical reliability analysis of devices, modules, inverter/converter, and electric machines

Modeling stress, strain, and strain energy density within the packaging stack-up helps researchers to understand the impact of these factors on package and module reliability. NREL helps to design, develop, fabricate, and validate wide-bandgap power electronics systems for all-electric vehicles and other applications.

NREL's role encompasses the thermal design optimization and thermo-mechanical modeling and analysis of critical components. The thermo-mechanical analysis includes:

- Cooling design and thermal performance impacts of alternative manufacturing processes
- Die, package, and interface material analysis for power module reliability
- Manufacturing process impacts versus thermal cycling impacts on power module reliability
- Power module stress and deflection for safety and coolant system sealing
- Inverter enclosure stress and deflection based on operating and safety requirements.

Physics-offailure-based reliability analysis

NREL researchers rely on leading-edge modeling and characterization to perform reliability evaluation and failure analysis of new power electronics designs. Advanced modeling capabilities allow researchers to identify thermal bottlenecks and optimize the performance of power electronics packaging. In addition, researchers leverage extensive characterization through thermal, humidity, and vibration testing to better understand how stressors affect emerging technologies. As a result, NREL-designed systems prioritize safety, reliability, and efficiency for peak operating performance.

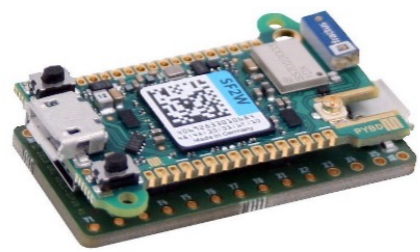
Microelectronics

MEMS-based systems

NREL can provide microelectromechanical systems (MEMS) based designs such as resonator-based circuits. MEMS devices such as piezoelectric resonators are widely used in low-power circuits for frequency generation. However, MEMS devices could be used in power conversion and voltage regulator circuits.

Microcontroller-based systems

The team can design and fabricate microcontroller (MC)-based systems that can utilize sensors to implement a feedback control system. These types of systems have applications in both low- and high-power electronics. An MC-based system involving sensors and communication stack acts as the key component to realize internet of things (IOT). This combination can be used to design smart power converters for both transportation and utility applications.



Equipment List

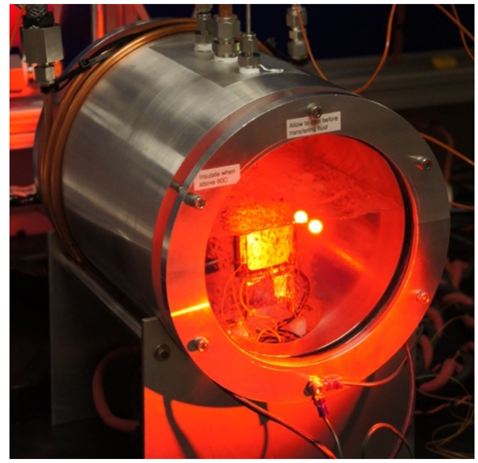
Fluid-based Thermal Management

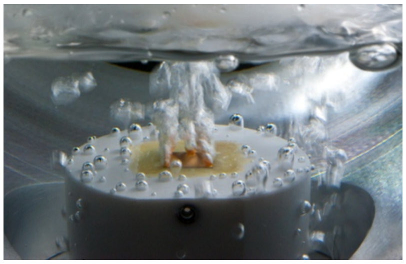
Single-Phase Liquid Cooling Test Bench

A water-ethylene glycol (50/50% mixture by volume) flow loop is used to develop and evaluate heat exchangers, liquid jets, and spray technologies for cooling electrical system components such as electric motors and inverters. The loop can deliver flow rates up to 36 liters per minute at temperatures up to 100°C. Experimental studies include heat-transfer performance of multiple flow configurations such as jet impingement cooling, and surface enhancement techniques. The flow loop can be used with the ABC-1000 power supply or the transient thermal tester.

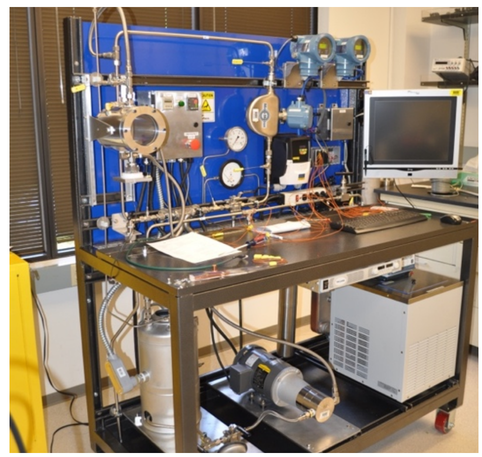
Two-Phase Liquid Cooling Test Benches

An immersion boiling vessel, low-pressure flow loop, and a high-pressure flow loop are used for cooling research. All are compatible with a wide range of refrigerants/dielectric coolants and are instrumented to precisely measure and control temperature, pressure, and flow rate. The loops are used for fundamental and system-level jet impingement, spray cooling, flow boiling, and pool boiling experiments to evaluate two-phase heat transfer for power electronics cooling applications.





Oil Cooling Test Bench



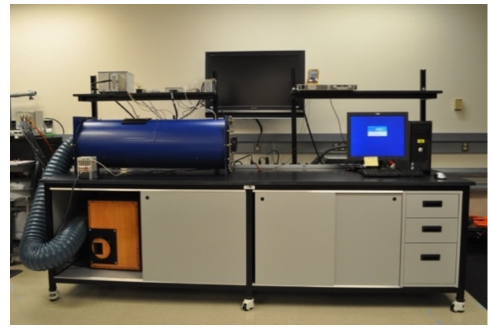
The flow loop is used to characterize the heat transfer performance of automotive automatic transmission fluid. A variety of test configurations including channel flow, jet impingement, and larger-scale (i.e., electric motor cooling) experiments can be evaluated using this loop. The flow loop is instrumented to accurately measure flow rates, temperatures, and pressures and can provide flow rates of up to 20 liters per minute and operating fluid temperatures of up to 120°C. This system is used to conduct research into cooling electric motors and power electronic components.

Fundamental Air-Cooling Heat Transfer Test Bench

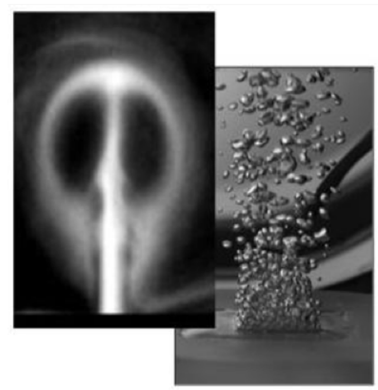
This test bench provides air at controlled flow rates and temperatures and includes an insulated test fixture for evaluating heat transfer and parasitic power losses in air cooled heat exchangers. The bench is instrumented to measure air flow rate, pressure drop, input power and temperature. Additionally, hotwire anemometry and flow visualization, combined with CFD capabilites, are used to measure and understand velocity fields and flow behavior. Novel cooling technologies being evaluated include steady and synthetic air jets and heat pipes.

Air-Cooled System Test Bench

This air flow bench measures performance characteristics of fans and ducting system impedances and is designed in accordance with AMCA standard 210-99. The test bench is capable of measuring air flow rates of 3.5 to 500 CFM, made possible by exploiting multiple nozzles of different diameters. It provides an experimental basis for determining proper selection of balance-of-system components (fans and ducting) to meet the flow specifications for heat exchanger design. The bench yields highly accurate results with an average relative error in flow measurement of 1.2% and an average relative error in pressure of 0.94%.



Thermal Measurement & Characterization

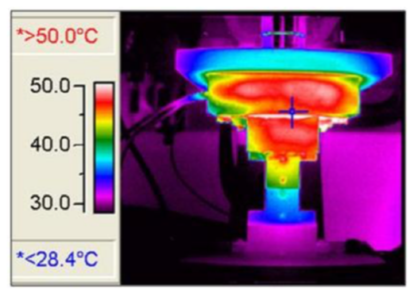


High-Speed Digital Video

A Photron Fastcam high speed video camera is used for flow visualization. It provides full resolution (1,024 × 1,024) up to 2,000 frames per second (fps). Higher frame rates (up to 120,000 fps) are possible at lower resolutions. The equipment can be used in conjunction with a Schlieren Shadowgraph system and/or stroboscope for additional visualization capability. The camera is used for flow visualization of self-oscillating jets, flow within heat exchangers, synthetic jets, other flow configurations, and two-phase heat transfer experiments.

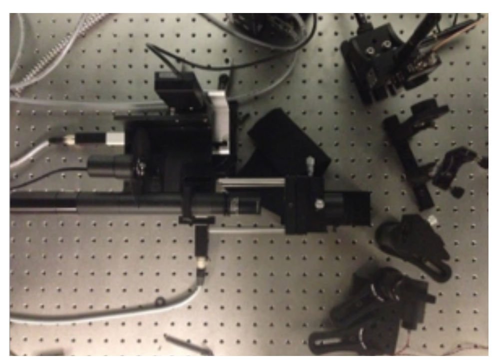
Infrared (IR) Imaging

The infrared camera is used to understand the temperature distribution in devices and equipment for a variety of applications. Examples include imaging of the TIM test apparatus, inverters, and energy storage devices. IR imaging of hot spots and temperature gradients in power electronic devices is an essential tool, owing to the importance of temperature uniformity to power electronics performance and reliability.



Transient Thermoreflectance Technique

The transient thermoreflectance technique employs two localized fast lasers to help determine critical thermal properties of materials and interfaces, such as thermal conductivity and thermal resistance. A modulated pump laser is irradiated on the sample surface to induce temperature rise and consequent thermal wave travels through the sample, while the modulated temperature change on the other surface is detected by a probe laser. By extracting inherent phase information, thermal properties are derived, and it is efficient for evaluating thermal performance of thermal interface materials and multilayer packaging structures.



Differential Scanning Calorimeter

The differential scanning calorimeter (DSC) measures the heat flow of a test sample relative to a reference standard. Several properties can be measured with the DSC, including heat capacity, glass transition point, phase transitions, polymer degradation, and oxidative stability.

Transient Thermal Tester

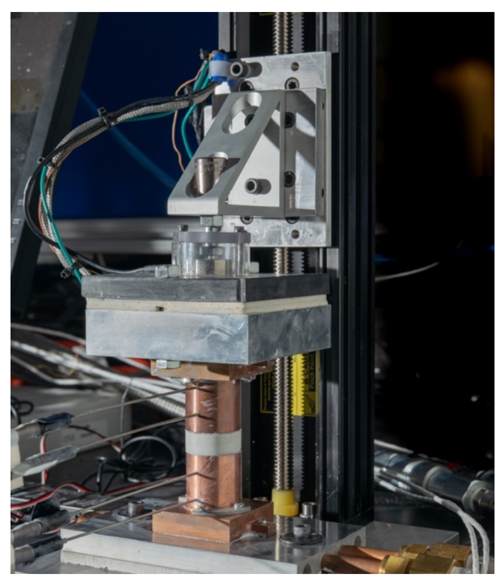
The Mentor Simcenter POWERTESTER 2400A 16C 12V has four heating channels each with a maximum output of 600 A, 12 V for a total maximum current of 2,400 A and 16 (4 × 4) measurement channels. A POWERTESTER allows in-situ measurement of the thermal resistance of a power electronics package (based on insulated gate bipolar transistor (IGBT), or metal oxide semiconductor field effect transistor (MOSFET). Transient conduction analysis can be used to compute the resistance-capacitance network for the package and identify the resistance of select package materials and layers. The system can power cycle devices per the AQG 324 standard and evaluate for thermal degradation via thermal resistance measurements.

Large Calorimeter

This calorimeter can measure the heat generation and efficiency of electronic components within a test cavity measuring 60 × 40 × 40 cm at heating rates up to 1 kW under thermal isolation conditions, from -40 to 100 °C. There are dual power ports for power electronics testing. It can be powered by any of the laboratory battery cyclers with a capability of 0 to 440 VDC and current of 0 to 530 A.

ASTM D-5470 Thermal Interface Material (TIM) Tester

The ASTM D-5470 “TIM Stand” is an ASTM standard that is designed to measure the thermal resistance of thermal interface materials such as thermal greases, gels, phase-change materials, other polymeric materials, carbon nanotube interface material, bonded interface materials, and others. It is capable of measuring both solids and grease but has limitations in measuring for powders and liquids. The TIM stand in the APEEM group is a custom build so that there is no question about how the measurement is being calculated. There are a variety of fixtures to accommodate different sample geometries but the most common are 1.25-inch diameter round samples and 1x1 inch square samples.



Thermomechanical Reliability Analysis

Vertical Thermal Shock Chamber

The vertical thermal shock chamber is used to study thermally induced stresses in novel bonded interfaces and advanced electrical interconnects. The equipment includes an upper hot chamber and a lower cold chamber, and a conveyor system moves samples between the two chambers, inducing thermal stresses under controlled conditions. The chamber contains a workspace volume of 38 × 26.7 × 28 cm and can operate from -75°C to 210°C.

Thermal Cycle Testing Array

The thermal cycle testing array is used to study thermally induced stresses in novel bonded interfaces and advanced electrical interconnects at slower ramp rates (3 to 5 °C/min) than the vertical thermal shock chamber. Multiple chambers allow for simultaneous testing of samples at various ramp rates, dwell times, or mean cyclic temperatures. The chambers contain workspace volumes of 50 × 28 × 30 cm and can operate from -70°C to 180°C.

Highly Accelerated Stress Test (HAST) Chamber

The Highly Accelerated Stress Test (HAST) Chamber is used to evaluate humidity resistance for electronic components. A pressure vessel allows for a humidity range of 75 to 100% relative humidity up to 143°C. Signal terminals allow for measurement of samples while they are enclosed within the pressure vessel. The chamber contains a workspace volume of 38 × 26.7 × 28 cm.

Electrodynamic shaker with environmental control

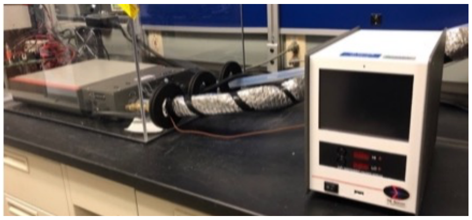
The combination of thermally-induced stresses with humidity and vibration stresses can highlight weaknesses within a package design that cannot be identified with thermal tests alone. The Accelerated Drive Cycle Platform is a single-axis electrodynamic shaker with an AGREE-style environmental chamber. The environmental chamber can operate from -40°C to 180°C and 95% relative humidity up to 85°C. It can be placed directly over the electrodynamic shaker or its slip table for simultaneous temperature, humidity, and vibration control. The shaker has a rated sine force of 6,800 lbf at 92 g, random force of 6,800 lbf at 65 grms, or shock force of 13,500 lbf at 153 g and a displacement up to 3.0 inches.

High-Temperature Oven

For high-temperature thermal aging of components, a ceramic oven has the capability of heating samples up to 800°C through radiative heat. Internal dimensions of the oven are 35 × 23 × 25 cm (L × W × H). A feed-thru port is also located on the top of the oven for external monitoring equipment to directly connect to samples during tests.

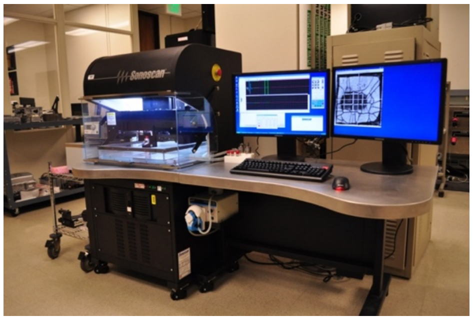
Hot/Cold Plate

A combination hot/cold plate allows for thermal cycling of test samples between -100°C and 250°C through a PID controller. The work surface is 28 × 28 cm and provides a hole pattern for securing samples.



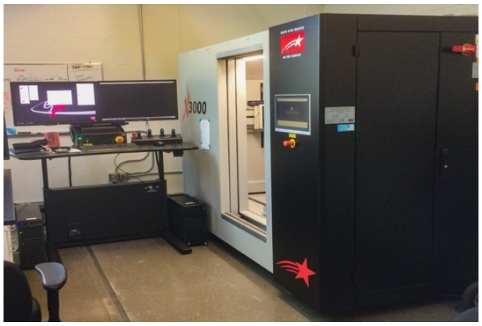
C-Mode Scanning Acoustic Microscope

The C-Mode Scanning Acoustic Microscope (C-SAM) is an instrument that uses ultrasound in the frequency range of 5 MHz to 230 MHz to nondestructively inspect samples for defects. The technique relies on the acoustic impedance mismatch of materials and can generate images within a sample based on scattering, refraction, and/or absorption of the acoustic signal within various material layers. Ultrasound cannot travel through air or a vacuum; therefore, it can find voids, cracks, and/or delamination of layers within a sample.



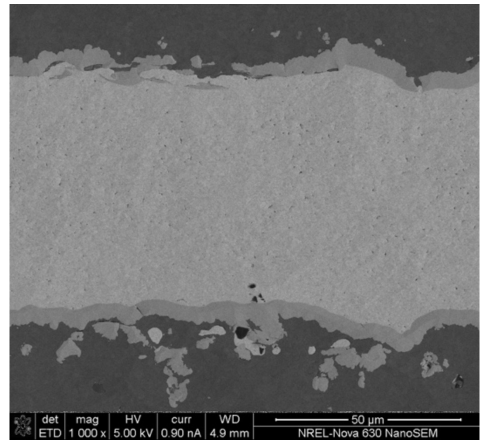
Computerized Tomography (CT) Scanner

CT scanner technology allows for non-destructive, high-precision, and high-speed inspection for applications in energy storage, power electronics, photovoltaics, hydrogen, and basic sciences. This state-of-the-art X-ray imaging system housed in the Materials Characterization Lab in the ESIF is capable of advanced 2D X-ray inspection, 2D CT slice reconstruction, CT volume reconstruction for 3D inspection, 3D internal and external surface scanning, measurement and analysis tools, 360-degree rotation, and tomography scanning.



Scanning Electron Microscopy

In basic scanning electron microscopy (SEM), a beam of highly energetic (0.1-50 keV) electrons is focused on a sample surface. This can produce several interactions including the emission of secondary electrons, backscattered electrons, photons, and X-rays; excitation of phonons; and diffraction under specific conditions. Topography of the surface under observation can be recorded with resolution on the order of 1-2 nm and magnification range from 10x to 500,000x. An energy-dispersive X-ray spectroscopy (EDS) detector can capture high-resolution compositional maps.

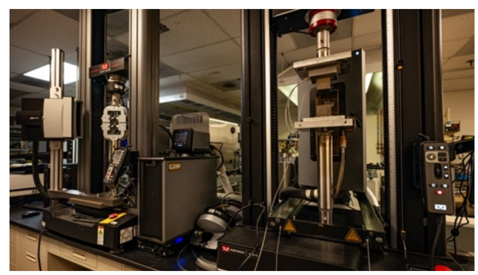


Digital Microscope and Elemental Analyzer

The digital microscope allows imaging of a sample's surface features at high levels of magnification. Lenses can enlarge an object 20x to 2,500x of its original size. A motorized X-Y axis stage allows for sample features larger than the microscope's field of view to be digitally stitched together. In addition to the optical microscope, this setup includes a Keyence EA-300 which utilizes laser induced breakdown spectroscopy (LIBS) to perform material elemental analysis.

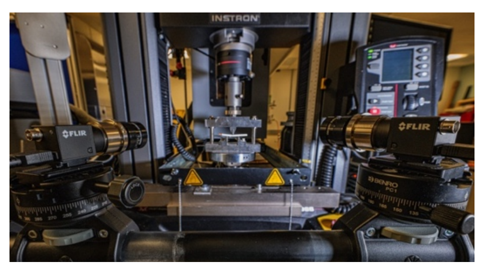
Dual Column Tabletop Universal Testing System

An Instron 5966 dual column testing system is configured with 100 N and 10 kN load cells. With appropriate fixtures, tensile, compression, shear, flexure, peel, tear, cyclic, and bend tests are can be performed. An environmental chamber has a temperature range from -100°C to 350°C for capturing temperature-dependent material properties. A noncontact video extensometer is used for strain measurements. A shear test fixture is used for obtaining material properties of solders and other bonded interface materials.



Digital Image Correlation (DIC) System

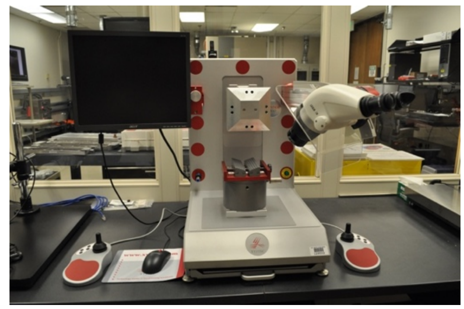
Digital image correlation is an optical-numerical measuring technique, which offers the possibility of determining complex shape, displacement and deformation fields at the surface of objects under any kind of loading. A camera system monitors a speckled pattern on the surface of a part. Changes in displacement are measured and strains can be calculated through software.



Laser Profilometer

The laser profilometer provides a noncontact surface profile measurement of samples under 15 × 15 × 12 cm (L x W x H) in size. A sample is first placed on a 2-axis motorized stage in the X and Y axis, and then a 1, 0.2, or 0.01 µm resolution red laser scans its surface. As an example application, the laser profilometer is used to measure the curvature of samples for power electronics applications at room temperature after they have been bonded together at processing temperatures.

Multifunction Bond Tester



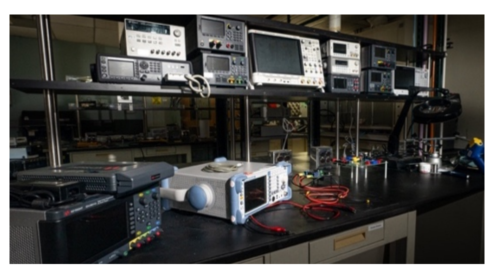
The multifunction bond tester allows for pull and shear force testing of electrical components. A sample work holder is secured to a motorized stage with maximum travel in the X-Y axes of 100 mm. A revolving measurement unit allows for the selection of two pull sensors and one shear sensor, each with a maximum load capability of 100 N. The bond tester has been used to evaluate the reliability of ribbon bond interconnects.

Micro- and Power Electronics Measurement & Characterization

Power Device Analyzer/Curve Tracer

The Keysight B1505A Power Device Analyzer/Curve Tracer can perform various types of IV, CV, pulsed IV, and transient characterization of high-power devices up to 10 kV of reverse voltage and up to 1,500 A of on-state current with a resolution of sub-pico amps. An accessory probe-station can characterize bare semiconductor dies and patterned wafers while a ThermoStream can control sample temperatures between -100°C to 300°C. Multi-frequency AC measurements for inter-electrode device-capacitances can be performed for a wide frequency range from 1 kHz to 5 MHz.

Electronics Analysis Equipment

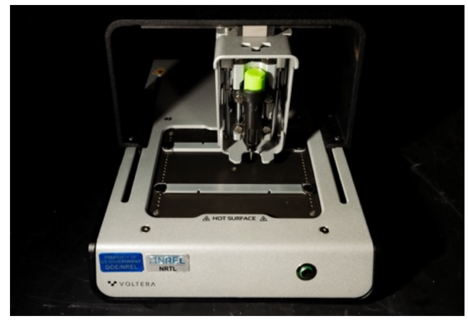


The APEEM group employs a wide range of electronic analysis equipment such as: the Keyence InfiniiVision 4000 X-series oscilloscope, Vector network analyzer, spectrum analyzer, arbitrary function generator, LCR meter, power supplies, and electronic loads. With this equipment, APEEM can test components such as advanced gate drivers, device health monitoring components, and custom-built converters.

Bi-directional power supplies

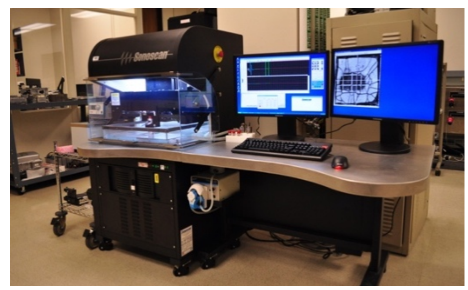
Two 15000W bi-directional power supplies allow the APEEM group to perform high-powered functional analysis on inverters and converters without wasting energy or heating up the laboratory space from standard resistive loads. The bi-directional power supplies can provide a source and a sink for the energy required to characterize converters and it is able to put that energy back into the power grid to operate more efficiently. These combined with the standard 1500W Keysight power supply offer substantial testing power.

Two-sided Printed Circuit Board (PCB) prototyping



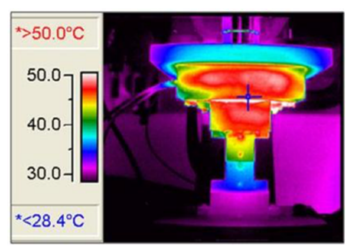
The Voltera V1 allows the APEEM group to produce prototype two-sided printed circuits by utilizing a conductive ink dispensing system, hot plate, and through hole drill all in one package. This system is also able to print circuits on flexible substrates such as Kapton tape to accommodate 3D architectures.

C-Mode Scanning Acoustic Microscope



The C-Mode Scanning Acoustic Microscope (C-SAM) is an instrument that uses ultrasound in the frequency range of 5 MHz to 230 MHz to nondestructively inspect integrated circuits for defects. The technique relies on the acoustic impedance mismatch of materials and can generate images within a sample based on scattering, refraction, and/or absorption of the acoustic signal within various material layers. Ultrasound cannot travel through air or a vacuum; therefore, it can find voids, cracks, and/or delamination of layers within a sample.

Infrared (IR) Imaging

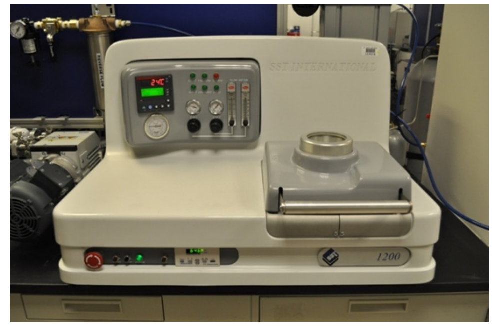


The infrared camera is used to understand the temperature distribution in devices and equipment for a variety of applications. This is a very useful tool to identify hotspots in an integrated circuit. Therefore, this characterization ensures temperature uniformity to semiconductor devices and integrated circuits for performance and reliability.

Wire Bonder

The TPT HB30 Heavy Wire Bonder is capable of bonding round wires from 100 µm to 500 µm and ribbons sizes up to 300 × 2000 µm with a bond force between 50 -1800 cN. This wire bonder is a programable semi-automatic system which provides consistency and accuracy between samples. The Z and X axes are automated to allow for repeatable loop profiles that can consist up to 10 movement steps.

Vacuum Solder Reflow Station

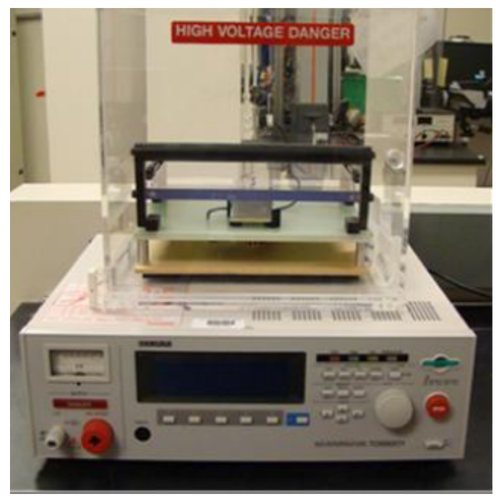


The vacuum solder reflow station allows for building high-density PCBs with surface-mount components as well as power electronic package development through the synthesis of flux-free and void-free solder joints. Heat is applied to a sample by a resistive graphite heating element and the process temperature is controlled by a ramping temperature controller with preprogrammed reflow recipes. An external vacuum pump and argon gas are used to control the chamber pressure. Samples up to 11.5 × 9 cm can be placed within the chamber and heated up to a maximum operating temperature of 450°C.

ABC1000 Dual Channel Power Supply

The ABC1000 is a bi-directional, programmable computer-controlled two-channel DC power supply. It provides power up to 125 kW, with a voltage range of 8 to 420 VDC and a current range of ±1000 A. Bi-directional power receptacles are distributed throughout the lab to connect the ABC1000 to test benches including the cooling test loops and environmental chambers. This is an ideal test system for a wide range of high-power DC loads. In addition to evaluating power electronics, it can be used for energy storage testing, including fast charging and fuel cell systems testing.

High-Potential Tester



The high-potential (hipot) tester measures the electrical insulating properties or dielectric strength of sample substrates such as aluminum nitride direct-bond-copper (DBC) substrates. When subjected to temperature cycling and/or thermal shock, the substrates can fail via cracking, fracture, or delamination. These failure sites provide pathways of lower resistance for electric current. An increase in electrical conductivity in the hipot tester signals a failure of the substrate.

Transient Thermal Tester

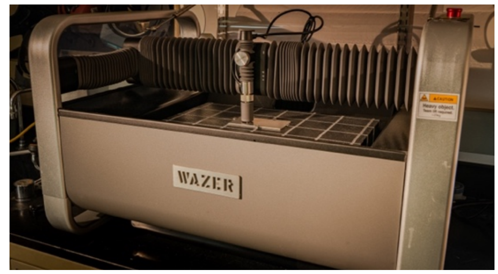
The Mentor Simcenter POWERTESTER 2400A 16C 12V has four heating channels each with a maximum output of 600 A, 12 V for a total maximum current of 2,400 A and 16 (4 × 4) measurement channels. A POWERTESTER allows in-situ measurement of the thermal resistance of a power electronics package (IGBT, MOSFET). Transient conduction analysis can be used to compute the resistance-capacitance network for the package and identify the resistance of select package materials. The system can power cycle devices per the AQG 324 standard and evaluate for thermal degradation via thermal resistance measurements.

Prototype Fabrication

Computer Numerical Control (CNC) Router

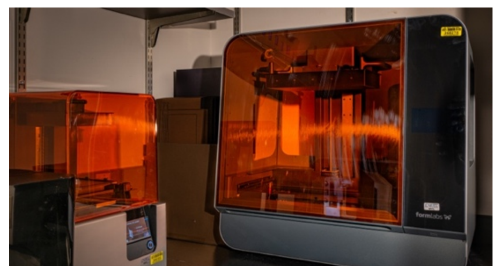
The Carbide 3D Nomad 3 is a desktop CNC machine with a working area of 20 cm (X and Y) and working depth of 7.6 cm (Z). This machine has a 130 W spindle motor with a maximum speed of 24,000 rpm and can be used for PCB etching, rapid prototyping, and substrate etching. The Nomad can machine both 2D and 3D parts and can handle parts up to 29.5 kg.

Waterjet



The Wazer benchtop waterjet provides a cutting area of 30.5 × 46 cm and can be used for precision cutting of metals, ceramics, plastics, and carbon fiber. This allows for quickly prototyping designs and destructive analysis such as cross-sectioning.

Stereolithography (SLA) Printer

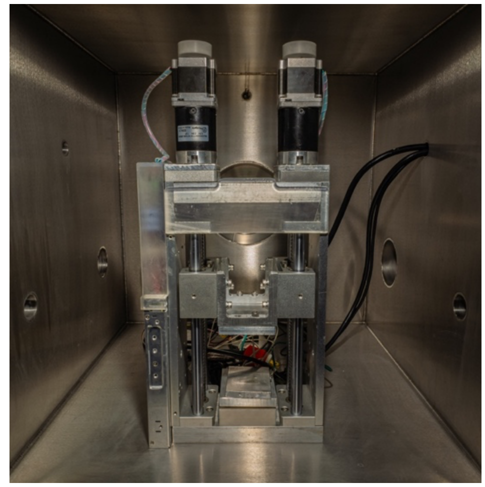


The Formlabs Form 3L is a stereolithography (SLA) 3D printer with a build volume of 33.5 × 20 × 30 cm (W × D × H). SLA printing has the advantage of high precision, fine details, and being liquid/airtight without further post processing. The printer has a wide variety of resins to choose from based on requirements of maximum loading, resistance to deformation, or stability under high temperatures.

Wire Bonder

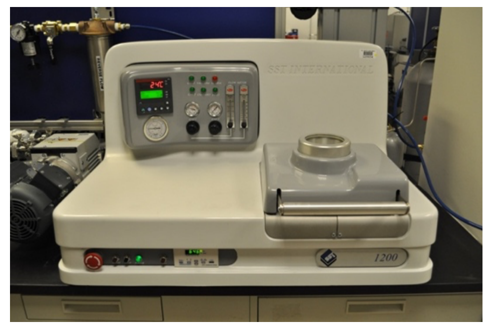
The TPT HB30 Heavy Wire Bonder is capable of bonding round wires from 100 µm to 500 µm and ribbons sizes up to 300 × 2000 µm with a bond force between 50 -1800 cN. This wire bonder is a programable semi-automatic system which provides consistency and accuracy between samples. The Z and X axes are automated to allow for repeatable loop profiles that can consist up to 10 movement steps.

Electro-mechanical Hot Press with Vacuum / Intert Environment



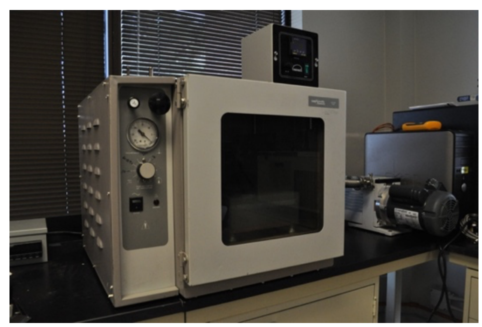
This custom-built hot press is capable of applying up to 12 kN of force and reaching temperatures up to 300°C. It is housed inside of a large vacuum chamber to achieve bonding under both vacuum and inert gas environments. This capability is used to bond materials such as sintered silver, sintered copper, carbon nanotube interface materials, polyimide materials and more.

Vacuum Solder Reflow Station



The vacuum solder reflow station allows for power electronic package development through the synthesis of flux-free and void-free solder joints. Heat is applied to a sample by a resistive graphite heating element and the process temperature is controlled by a ramping temperature controller with preprogrammed reflow recipes. An external vacuum pump and argon gas are used to control the chamber pressure. Samples up to 11.5 × 9 cm can be placed within the chamber and heated up to a maximum operating temperature of 450°C.

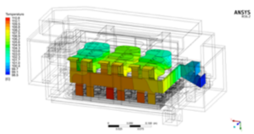
Vacuum Oven



The vacuum oven with integrated hot plate allows for synthesis of flux-free and void-free solder joints for samples that would not fit within the vacuum solder reflow station. An external vacuum pump and argon gas are used to manually control the chamber pressure. The hot plate has a footprint of 140 × 20.5 cm and is capable of heating continuously up to 375°C and intermittently to 400°C.

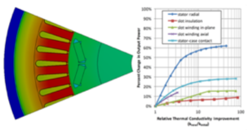
Modeling Capabilities

Modeling and simulation are performed using the industry standard software including ANSYS Mechanical Enterprise for thermal, reliability, and structural finite element analysis and ANSYS Fluent for flow analysis and conjugate heat transfer computational fluid dynamics. Mutiphysics modeling tools within Siemens are also used. Customized tools written in MathWorks MATLAB extend the functionality of ANSYS for design exploration and optimization. Computational hardware includes state-of-the art workstations and NREL's current flagship HPC system, and Peregrine.



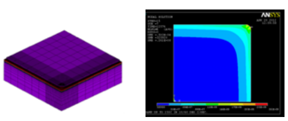
Inverter Thermal Management

Inverter-scale thermal model showing component temperatures.



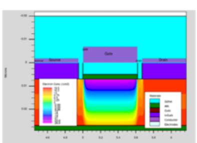
Electric Machine Thermal Management

Electric machine thermal models are utilized to find thermal bottlenecks and optimize designs.



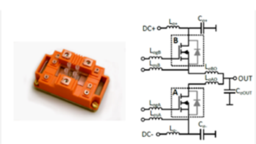
Packaging Thermo-Mechanical Reliability

Viscoplastic material models are applied to substrate-attach materials to estimate the lifetime of solder, sintered silver, and other materials.



Power Device Modeling

Semiconductor computer-aided modeling is performed at micro-and nanoscales for emerging wide-bandgap (WBG) and ultra-wide-bandgap (UWBG) devices.



Electro-Magnetic Design for Power Electronics Packages

Electrical and electro-magnetic modeling is performed, and parasitics extraction is performed for high-frequency, low-loss WBG (and UWBG) power modules.

Partner with NREL

To explore what NREL researchers are working on today, or to join in powering what's next, visit **nrel.gov/transportation/peem.html** or contact Sreekant Narumanchi, APEEM Group Manager, or Faisal Khan, Power Electronics Chief Researcher.

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