POETS REU Projects
Summer 2019

REU Project Title: 3D integrated power electronics and microfluidic cooling for future electric aircraft.
Faculty Mentor: Ken Goodson (lead) and Robert Pilawa-Podgurski
REU Project Title Description: This project will develop novel 3D integrated power converters and advanced thermal management solutions for future electric aircrafts, enabling radically new aircraft designs with up to 40% fuel savings. REU students will participate in the design (EDA, CAD, CAM), fabrication (soldering, 3D printing, assembly) and testing (electrical wiring, measurements, data analysis) of high power inverters and advanced heatsink designs.

REU Project Title: Additive manufacturing advantages in Electronics Heat Dissipation
RE Faculty mentor: David Huitink (lead), Fang Luo, Sonya Smith
REU Project Title Description: In this project, the REU student will employ additive manufacturing principles to developing novel geometries for heat conduction, convection and associated energy transport, for implementing with electronic assemblies. It will require creative thinking, experience and familiarity with solid modeling tools and heat transfer behavior. The developed designs will be evaluated for performance compared to existing heat sink designs by FEA and experimental techniques. Students will have the opportunity to work across disciplines in delivering innovative cooling technology for electronics packaging designs, and gain valuable experience in additive manufacturing processes as well as electro-thermal co-design of traction inverter systems.

REU Project Title: Carbon Nanotube – Copper Composites
Mentor: Joseph Lyding
REU Project Title Description: Carbon nanotubes integrated with copper represent an intriguing pathway to enhance thermal conductivity while reducing material mass density. Applications include high thermal conductivity cabling and metal layers such as ground planes on printed circuit boards. This project involves both the fabrication of the carbon-copper composite structures as well as measuring their properties and working with a high-power electronics group for printed circuit board applications.

REU Project Title: Characterization of GaN-based Magnetic Field Sensors within Dynamic Motor Environments
Faculty Mentors: Andrew Alleyne (lead), Kiruba Haran, Greg Salamo, Debbie Senesky
REU Project Title Description: Electric transportation systems of the future (e.g., aircraft, UAVs, automobiles) require advanced electronics (e.g., sensors) to monitor the state of the complex motor systems. Data from these electronics can be used to actively, control, protect and diagnose safety critical motors. The POETS center is developing Hall-effect sensors that can remotely detect magnetic field and electrical current within motor assemblies. For example, the Hall-effect magnetic field sensors (solid-state devices) can be used for sensing position, velocity or directional movement within motors during the start-up phase and during flight. This is especially important for monitoring the position of crank shaft or motor in moving objects. They also offer advantages over other sensors due to their non-contact wear free character and their comparatively low maintenance. Due to packaging they can also be less subject to error due to vibrations. In this project the student will investigate the effectiveness of packaging to reduce error due to vibrations which can cause small changes in the magnitude of the magnetic field that is sensed and therefore introduce error in the positioning data. The student will learn about high power electronics, Hall-effect sensors, and performance analysis as well as develop creativity by proposing explanations for observed data that the student will take under vibration circumstances and techniques to make improvements.

REU Project Title: Electro-Thermal Systems Modeling and Validation
Faculty Mentors: Andrew Alleyne (leader), Mehdi Asheghi, Ken Goodson
REU Project Title Description: Modern mobility systems are becoming more and more electrified. One only has to look at the increase in electrified vehicles on the roads today to understand. With this electrification comes an interplay between the electrical power transported throughout the vehicle and the thermal power management that is necessary. What is needed is a thorough understanding, from a dynamic systems perspective, to enable better system design and control. This project will create models of complex power systems such as those found in modern on-highway vehicles and aircraft. This includes electrical and thermal elements as well as the interaction between them. Existing simulation tools and model-modules based on Matlab/SIMULINK will be utilized. The project will also validate these models from data taken off laboratory testbed platforms. The student will perform both the modeling and the experiments to validate the models. It may be possible to gain access to industry data and, if so, the summer project may focus on an actual production system in lieu of the laboratory testbeds.

REU Project Title: Fabrication and Testing of High Temperature Rechargeable Batteries and Supercapacitors at Illinois
Mentor: Paul Braun (lead), Thomas Searles
Project Description: In this project, the student will fabricate high temperature rechargeable batteries and supercapacitors. The energy storage devices will be fabricated in either coin cell or swagelok configurations and tested at both room temperature and the higher temperatures present within many electrothermal systems. The student will perform post-mortem analysis of cells using optical microscopy and scanning electron microscopy.

REU Project Title: Fabrication of 3D Phononic and Photonic Crystals
Faculty Mentor: Paul Braun (lead), David Cahill, Nenad Milkjovic
REU Project Title Description: In this project, the student will fabricate 3D phononic and photonic crystals and measure their thermal conductivity and optical properties. The materials will be formed via either MOCVD or electrodeposition depending on the interests of the student, and their thermal and optical properties will be measured via non-contact optical probes.

REU Project Title: High Power Density, High Speed motor drive design, control and testing
Mentors: Luo Fang (lead), Simon Ang, Huitink David, Kiruba Haran
Project Title Description: The PI will organize a summer program and help the REU students to get hands-on experiences in high density motor drive design and joint-testing tasks. Through this training, the students will get familiar with multi-disciplinary design philosophy and procedures in power electronics converter design, assembly control and testing. The PI is already involved in POETS iREU programs. he will further extend his experience in the REU program associate with this proposed project.

REU Project Title: High Temperature Capacitors
Mentors: Morgan Ware (lead), Yue Zhao
REU Project Title Description: We have spent many years developing the growth of III-V semiconductors through molecular beam epitaxy and are focusing on high temperature electronics through the wide bandgap family of III-nitride semiconductors. REU students will gain experience in device development from the most fundamental level of the crystal growth. Materials characterization including, for example, structural, electrical, and optical, through xray diffraction, capacitance-voltage measurements, and photoluminescence, respectively, will be heavily relied upon. Specific focus will be on the high temperature response of these characteristics.

REU Project Title : High-temperature characterization of GaN and MoS2 temperature sensors
REU Mentors: Debbie Senesky (lead); Eric Pop
Project Description: Temperature-tolerant sensing devices are needed to advance state-of-the-art power electronics and reach new milestones in space exploration. While silicon has been used successfully to create sensors in the past, these sensors are limited to operation temperatures below 200°C. Emerging materials such as AlGaN/GaN and MoS2 are able to withstand high temperatures, making them ideal for high-temperature electronics applications. This project focuses on the high-temperature characterization and evaluation of GaN and MoS2 sensors, with the goal of determining potential degradation pathways. A high-temperature probe station (600°C capability) will be used to conduct these experiments.

REU Project Title: High temperature phase change materials for passive electronic temperature control
Faculty Mentor: David Huitink (lead), Simon Ang, Nenad Miljkovic, Yarui Peng
REU Project Title Description: Phase change materials (PCMs) are materials that can be used to remove or store heat during a transformation between solid and liquid phases. These transitions can passively remove heat without need for pumps or fans, which makes them useful for mobile systems which need to reduce the total system weight and complexity for overall efficiency. Additionally, the relative low spatial requirements for PCMs to be integrated into electronic systems lends itself to opportunity in designing innovative solutions for 3D patterning and integration for applications in electric vehicles, aircraft and spacecraft, where air cooling is not available. In this REU Project, the researcher will partner with graduate students working on Power Electronics for developing next generation PCMs that perform latent heat exchange at temperatures ranging from 150-250C, and develop additive manufactured housings for implementing PCM heat transfer optimization.

REU Project Title: Infrared imaging of power electronics systems
Mentors: Bill King (lead), Alan Mantooth, Nenad Miljkovic, Yue Zhao
REU Project Title Description: This project focuses on thermal characterization of power electronics systems and the evaluation of novel cooling systems. The electronics are circuit boards with several types of electronic devices, each device dissipating a different power level. The circuit boards are cooled with either liquid cooling or air cooling. We will use an infrared camera to characterize the microscale temperature distribution on the circuit board. The measured temperatures will be analyzed to calculate local heat flux and the thermal properties of the circuit board. The measurements and analysis will be performed under different cooling conditions and for different circuit board layouts. The results of this work will be used to develop electro-thermal design guidelines for circuit board layout and the cooling system.

REU Project Title: Integration of a Large Footprint µ-cooler and Multi-chip Silicon Carbide Power Module
Research Advisor(s): Profs. Simon Ang and Kenneth Goodson
REU Project Title Description: Recent trends towards smaller electronics packaging and high power devices result in increasing power densities which require aggressive thermal management including special consideration for reliability, size, noise and power consumption issues. This project examines cooling strategies for high power electronics devices using chip level-embedded cooling solutions with micro-channels directly fabricated into Si or SiC substrates compatible with fabrication of power electronic devices thus eliminating any thermal interface and decreasing overall thermal resistance. Tight integration of advanced microfluidic cooling solutions with heat generating devices offers potential for dramatic improvements in the thermal management of power electronics with attendant gains in

performance and efficiency. Specific tasks include but not limited to basic calculation and measurement of temperature and pressure drop in microheat exchangers.

REU Project Title: Jumping Droplet Vapor Chambers for Inverter Cooling
Mentor: Nenad Miljkovic
REU Project Title Description: Coalescence induced droplet jumping has the potential to act as an ideal liquid supply mechanism in vapor chamber devices integrated with electronics components. This REU project will involve the thermal testing of active jumping droplet vapor chambers integrated with gallium nitride transistors to achieve cooling heat fluxes approaching 100 W/cm^2. The student will be required to learn and use thermal characterization tools such as high speed imaging, thermography, and LabVIEW electrical control to characterize the integrated device performance. Surface nanostructure fabrication will be learned and utilized prior to testing while thermal and error analysis will be learned and utilized after testing.

REU Project Title: Liquid Metal Phase Change Material Thermal Characterization
Mentor: Nenad Miljkovic
REU Project Title Description: The utilization of relatively high thermal conductivity liquid metals as phase change materials (PCMs) is a promising avenue to increase the figure of merit of thermal capacitor devices. However, the melting and solidification behavior of novel and promising liquid metal alloy combinations has not been studied and thermal conductivity not well characterized. This project will utilize infrared (IR) microscopy to analyze the thermal response of liquid metal layers for the characterization of phase-change behavior, thermal conductivity, and heat capacity based on the temperature response. The student will learn to use an IR Microscope, calibrate emissivity data, fabricate samples with the assistance of a senior graduate student, and perform experiments and data analysis.

REU Project Title: Machine Learning Model Calibration for High-Density Power Systems
Mentor: Yarui Peng
REU Project Title Description: One task would be to take many representative circuit topology and device types and create a circuit creation tool that can automatically change circuit parameters and export for circuit simulations. Another similar task is to use PowerSynth to generate as many layout cases and evaluate them through the built-in electrical and thermal models. These training data will be used for calibration of the technology library for the system integration tool

REU Project Title: Microporous Copper Inverse Opal (CIO) Wick Technology for High-heat Flux Vapor Chamber Application
Research Advisor(s): Prof. Kenneth Goodson
REU Project Title Description: Recent trends towards smaller electronics packaging and high power devices result in increasing power densities which require aggressive thermal management including special consideration for reliability, size, noise and power consumption issues. This project examines cooling strategies for high power electronics such as “passive” heat spreading technology. While vapor chambers attempt to address this need, they have reached fundamental limits in peak heat flux, thermal resistance, and thickness. The goal of this project is to make a device that spreads 1000 W from an area of 1 cm x 1 cm (1000 W/cm^2) to an area of ~100 cm^2 (10 W/cm^2) with only 40 °C temperature drop from hot spot to condenser side of the of spreader. We implement a combination of high heat flux evaporative tiles and with silicon pin fin array coated with CIO wick that serves as liquid delivery wick structure. We will integrate critical components to manufacture and test a fully assembled vapor chamber. Specific tasks for REU student include but not limited to basic calculation and measurement of temperature and pressure drop in the heat spreader.

REU Project Title: Multi-Physics Evaluation of Electric Motor Insulation
Mentor: Joseph Lyding (lead) and Kiruba Haran
REU Project Title Description: Power densities of electric motors are inherently limited by low-temperature insulation, which requires strict monitoring of dielectric, thermal, mechanical, and electromechanical performance. In the past, advanced designs in control systems, drivers, and cooling systems have compensated for this intrinsically low performance. However, electrical insulation which is stable above 700°C will enable power densities that are impossible to achieve with state-of-the-art technology. As a technology that spans many physical domains, this new generation of motor insulation will require multi-physics testing to ensure dielectric strength, thermal stability, and mechanical integrity under cyclic stress and high atmosphere conditions. This evaluation process is critical to ensure reliable operation of high power density electric motors in extreme environments.

REU Project Title: Narrow Diameter Vertically-Aligned Carbon Nanotubes for Rechargeable Battery Applications at Howard University
Mentor: **Thomas Searles (lead), Paul Braun**
Project Description: In this project, the student will fabricate narrow diameter (< 2 nm) vertically-aligned carbon nanotubes for high temperature rechargeable batteries using a new method for nonmetallic catalyst growth. A key result of this study will be the influence of diameter and packing density of the carbon nanotube forest anodes directly related to the proposed Y4 POETS project. The student will perform analysis of the nanotube forests with Raman spectroscopy, UV-Vis, SEM and then work towards integration of these forests as anode materials in coin-cells to be fabricated at Howard.

REU Project Title: Novel Solution Methods for Optimal Spatial Packaging and Routing of Electro-Thermal Components.
Faculty Mentor: James Allison
Project Description: The objective of this project is to improve design tools for packing and routing problems. A case study based on a hybrid-UAV thermal system is currently under investigation. This includes analysis of both heat transfer and hydraulic performance. Our packing and routing algorithms are currently designed to demonstrate functionality in 2-dimensions. We are looking for a motivated undergraduate student to assist in scaling our 'force-direct-layout' algorithm to 3-dimensions. Helpful background for a student applying for this project include: programming experience (Matlab preferred), introductory heat transfer and fluid mechanics, and numerical methods.

REU Project Title: Numerical Analysis of Hydrophobic Nanostructures in Microchannel Heat Sinks
Mentor: Sonya Smith (lead), Mehdi Asheghi, James Allison
REU Project Title Description: The REU student will conduct thermal analysis of high fidelity heat sink models under operating conditions specified by the peer mentor. The student will explore the impact of hydrophobic nanostructures on microchannel flow. The student will generate trends and plots extrapolated from data provided by the numerical analysis. The student will also give weekly presentations about their progress.

REU Project Title: Power Module Analysis and Fabrication
Faculty Mentor: Simon Ang (lead) and Fang Luo
REU Project Title Description: REU students will be exposed to fabrication methods and processes in power modules at the High Density Electronics Center (HiDEC). A simple power module will be designed and fabricated by the REU students under the guidance of POETS graduate students and HiDEC staff.

REU Project Title: Set-up DAQ for pump-back tests on high frequency motor and drive
Faculty Mentor: Kiruba Haran (lead), Andrew Alleyne, Fang Luo
REU Project Title Description:
Assist graduate students in setting up National Instruments data acquisition system, and developing Labview based programs to acquire and process electrical, thermal and mechanical sensor data to compare with predictions and operating limits. Extract data to be displayed in control room, highlighting key performance data as well as alarm signals.

REU Project Title: Testing "Gen 1" Traction Inverter in Testbed 2
Faculty Mentor: Juan Balda(lead), Mehdi Asheghi, Kenneth Goodson, Yue Zhao
REU Project Title Description: "Gen 1" traction inverter has gone through preliminary testing in one of our testbeds. Based on the initial testing, the REU student will revise the User Manual of this Testbed to make sure that a third-party not familiar with the Testbed operation can use it without major difficulties. The REU student will be guided by Mr. Chris Farnell, NCREPT test engineer.

REU Project Title: Thermal Management of Lithium Ion Battery Packs
Mentor: Sonya Smith, Paul Braun
REU Project Title Description: The REU student will conduct simulations and optimization of candidate battery pack thermal management designs. The student will explore the impact of vehicle operating temperature as well as active and passive cooling designs on a small battery pack. The summer student will generate trends and plots extrapolated from data provided by experiments and computations. The student will also give weekly presentations about their progress.