# *Commercial Leap Ahead (CLA) Projects*

## High Permittivity Dielectrics to Increase the Performance of III-Nitride Transistors (HPERM) - $3.83M, Lead: Commercial Leap Ahead for Wide Bandgap Semiconductors hub (CLAWS)-North Carolina State University-

The objective is to integrate high permittivity dielectrics (HPDs), defined as dielectrics with relative permittivity greater than 20, into lateral GaN High Electron Mobility Transistors (HEMTs) for RF and power electronics. Prior lab demonstrations have pointed to potential advantages of HPD integration; we will transition this technology from lab-to-fab by developing fabrication processes with commercial HEMT wafers sourced from and co-developed with EPC Space (EPCS) and MACOM. To this end, we will ensure process compatibility with each device's materials and geometry, such as the low thermal budget of a T-shaped Schottky gate structure in RF devices and the p-type gate structure used in normally-off power devices. The HPD smoothens the electric field profile between the gate and drain to prevent or delay device breakdown. This opens the door to improved device efficiency. Also, by using HPDs to reduce peak E-field, we will investigate pathways towards enhanced resilience against radiation effects, in particular single-event effects. The processes will be evaluated for adoption in the core partner foundries and will become part of a new domestic foundry process at CLAWS for RF and Power GaN HEMTs.

## Transition Readiness for NITride RF Overmatch (T/R NITRO) - $3.68M, Lead: CLAWS-MACOM-

TR NITRO will deliver production prototypes of advanced mmW devices with high output power density by addressing materials-related challenges that prevent today's SOTA GaN HEMTs from achieving their predicted performance peaks. The proposed effort leverages the CLAWS Research Foundry's baseline GaN RF capabilities and expands those capabilities to include novel epitaxial materials and prototyping of advanced RF devices and circuits. TR NITRO will address the challenge of creating high output power mmW devices with parallel tracks of epitaxial materials and device development. In the first track, RF devices in the strategic and underutilized E- and W-bands will be realized with a production prototype for <60nm gate length ScAlN/GaN HEMTs on 150 mm SiC substrates (MRL 6 by program end).The second track will leverage AlGaN/AlN epitaxial structures on AlN single crystal substrates, to demonstrate ultra-high-power density HEMTs optimized for C-Band and associated radar, SatCom, and cellular infrastructure applications.

## Nitride RF Next-Generation Technology (NITRIDER) - $8.4M, Lead: Cornell University-

Today's military radar systems use AlGaN/GaN HEMTs on SiC substrates. In addition to these HEMTs being widely available to our adversaries, they are breakdown and thermally limited in output power. The Nitride RF Next-Generation Technology (NITRIDER) project will unleash the 90% of untapped RF output power using novel and patented nitride HEMTs and aluminum nitride (AlN) substrates. By the end of the project, the AlScN SLCFETs will mature from TRL/MRL 3 to TRL/MRL 5, and the AlN XHEMTs will mature from TRL/MRL 2 to 4/5. This transition from lab-to-fab will be accomplished with the close collaboration of domestic transition partners Northrop Grumman, Qorvo, and Teledyne. In addition to the physical prototypes, this project will prepare research design kits for E-Band and C- Band (radio frequencies from 60GHz-90GHz and 2.4GHz-5GHz, respectively) MMICs, or monolithic microwave integrated circuits which perform functions such as power amplification, to improve radar and communication systems.

## AlGaN_Channel_FET (AlGaN) - $4.5M, Lead: NEMC-Analog Devices-

This project will transition UWBG technology developed under DoD research funding at leading university labs to prototyping fabs with DIB and FFRDC partners, and then to a commercial 8" silicon manufacturing fab. This transition will demonstrate the use of the technology in high performance, high voltage switches. Wide Band Gap materials (GaN and SiC) are already replacing silicon to improve the size, weight and efficiency of high voltage power converters in DoD and commercial systems. UWBG materials like AlGaN have a band-gap up to 2x beyond GaN or SiC, allowing electric fields up to 5x higher, potentially enabling power switches with far smaller size and capacitance than even GaN and SiC. This program will include work by a wide range of organizations with deep expertise in the field including Analog Devices Inc., Lockheed Martin, IQE Inc., MIT, University of South Carolina, University of Connecticut, MIT-LL, the NRL, the ARL, Ephemeron Labs, and SoundSide Partners. Major thrusts of this effort include: achieving the device's mobility and contact resistance targets, developing commercially relevant 8" AlGaN/AlN/Sapphire wafers, developing a version of the process suitable for high temperature (300 °C) operation, developing a silicon-fab-compatible version of the process on 8" wafers, developing TCAD models for field management at high fields, growing n+ GaN to enable low resistance contacts, integrating diamond coatings to reduce thermal resistance, providing dislocation imaging to understand potential reliability issues, and developing thermal models. Success in this program will enable smaller, more efficient power converters at voltages 650 V and above, which will reduce the size and weight of a broad range of increasingly electric-power hungry DoD systems, from UAVs to hybrid-electric terrestrial vehicles to next-generation Navy ships.

## Process Development for Heterogeneous Integration of GaN on Diamond (HIGaD) - $1.7M, Lead: AFRL-

This project will develop the technology to increase GaN solid-state power amplifier power density by >4X for compact high-power microwave directed energy sources for disabling multiple, faster moving targets not yet possible. These major improvements will be achieved through significant reduction in device self-heating by integration of GaN high electron mobility transistors on to high thermal conductivity diamond using a combination of AFRL, ARL, and NRL in house device, integration and diamond substrate technology.

## Foundry Scalable Advanced Ultra High Power GaN HEMT Technology (SCALUP)- $1.10 Lead: NRL-

The goal of the proposed program is to overcome GaN device reliability limitations by placing it within a protective heat-spreading enclosure of chemical vapor deposited (CVD) diamond. CVD diamond substrates and top-side coatings have been shown to suppress performance-limiting factors such as self-heating and premature breakdown. We propose to demonstrate for the first time a GaN HEMT that 1) is encapsulated by CVD diamond on all three-dimensional sides, 2) includes a dramatically reduced interfacial thermal boundary resistance (TBR) between diamond heat spreader and GaN semiconductor, 3) comprises a high polarization GaN alloy (ScAlN) for high current density, and 4) comprises a high-voltage GaN buffer below the electron channel for high power operation. The platform technology for this project is a foundry-compatible, ISO certified 4-inch GaN-on-diamond wafer process.

## Advanced High Voltage Silicon Carbide Switches (Super SiC), $7.82M, Lead: CLAWS-GE Aerospace-

The development of 6.5kV-10kV SiC switches and diodes is currently limited in the U.S. due to the availability of high-quality, uniformly doped SiC thick epitaxial layers and low-volume production capabilities. The objective of this project is to address DoD technology needs for high-power systems and establish a U.S.-based supply chain for 6.5kV-10kV SiC planar and superjunction (SJ) MOSFETs. The project will focus on advancing thick SiC epitaxial growth and characterization capabilities, as well as developing low-volume device production capacity for 6.5kV-10kV SiC MOSFETs.

Additionally, a cost-effective approach for fabricating 6.5kV-10kV SiC superjunction devices will be prototyped. The broad approach involves a collaborative effort to develop and characterize thick SiC epi layers, develop Schottky integrated SiC processes, prototype high-voltage 6.5kV-10kV SiC MOSFETs, and demonstrate novel high-energy implantation techniques for superjunction devices. This will ultimately enable domestic low-volume production capability and provide a device toolkit for customers. The dual-use and payoff of this technology are significant. Medium-voltage power conversion systems (greater than 3.3 kV) for marine converters and propulsion systems will benefit substantially from advanced SiC switches, as this technology reduces system size and installation costs while enhancing design flexibility. Additionally, renewable power grid converters can significantly enhance efficiency through the adoption of high-voltage SiC switches. This effort aligns with the CLAWS mission by establishing a pathway for lab-to-fab transition, thereby enhancing U.S. strategic capabilities in SiC technology.

## High Temperature SiC JFETs for Improved Engine Reliability (E3MACS) - $2.4M, Lead: SCMC-University of Michigan-

Current high-temperature devices are rated to only 210 °C and operation lifetimes are heavily de-rated at high temperature due to degradation and excessive junction leakage currents. Even the most advanced silicon-on-insulator (SOI) devices are normally rated to only 225 °C. Advancements with SiC can be used to build devices capable of operation at significantly higher temperatures due to its fundamental material properties to meet operational requirements of extreme applications. A multitude of applications require systems such as high-temperature actuators, from emerging hypersonic systems to next generation turbines for fixed-wing, rotary, and unmanned aircraft. Other applications include geothermal environments (such as geothermal well drilling) where ambient temperatures can exceed 400 °C for extended periods of time. This project seeks to leverage the reliability advantages of Junction Field Effect Transistors (JFET) over the metal-oxide semiconductor field effect transistor (MOSFET) at high operating temperatures. The proposed solution is based on complementary enhancement mode SiC JFETs that are free from gate oxide related high temperature reliability concerns and can utilize the full potential of SiC material to provide the ultimate high temperature capability. This, coupled with advanced packaging and design will provide a solution that can survive environments at 500 °C for thousands of hours, or potentially up to 800 °C for at more than 100 hours. This project leverages the SCMC model and Commons mission by aligning leading edge expertise at the university level with capabilities in industry and government. This project is will also incorporate Commons-funded equipment to enable the fabrication at GE Aerospace. Finally, through the hub model and partner alignment efforts, this project also will redomesticate relevant SiC wafer production for these types of applications with the inclusion of Wolfspeed on this project.

## Prototype Demonstration of Manufacturable, High Yield, High Reliability 3.3-10 kV SiC MOSFETs for DoD power applications (Project Shasta) - $946k, Lead: NRL-

This FY 2024 T3 effort is to perform advanced technology development to establish high yielding SiC epitaxial materials, and a demonstrated lab-to-fab transition of 3.3-10 kV SiC MOSFET technology from Service laboratories (NRL) to the Defense Microelectronics Activity (DMEA), a DoD Trusted Foundry, using 150mm SiC wafers, which will enable development of compact wide bandgap power convertor solutions for enhanced SWaP shipboard power, high energy weapon systems, tactical high energy lasers, hypersonic drive electronics and other electrified aircraft systems. These SiC-based convertors will be capable of supplying several megawatts of continuous power, with ~20X reduced cooling requirement, 20-50 kHz switching frequency with reduced passive components resulting in SWaP improvement greater than 400X. Key demonstrated metrics are: 1) Epitaxial yield >75% stacking fault free area; 2) less than 5 epitaxial inclusions; 3) below 5 cm-2 triangle defects for 150 mm diameter wafer; 4) breakdown voltages greater than 3.3kV, 6.5kV or 10kV for such rated devices; 5) current density > 200 A/cm2; 6) Surge current rating: 10,000 A/cm2; 7) threshold voltage Vth: ≈1 V. Stability: ± 10%; and 8) other electrical parameter uniformity across wafer and lot-to-lot = +/- 5%.

## Development of 20+ kV SiC IGBTs (Insulated Gate Bipolar Transistors) in Support of EW and High-Voltage Platforms (SIGSEW)- $0.87M Lead: ARL-

Develop and demonstrate the successful design and fabrication of very-high-voltage (20+ kV) power devices (IGBTs—Insulated Gate Bipolar Transistors) enabled by silicon carbide (SiC) semiconductor technology, for power conditioning in support of EW and High-Voltage Platforms.

## Advanced Power Switches using UWBG Gallium Oxide (HVGa203) - $3.52M, Lead: CLAWS- Kyma Technologies-

The Advanced Power Switches Using UWBG (ultrawide bandgap) Gallium Oxide ($Ga_2O_3$) project seeks to develop a domestic supply of high voltage, >10 kV power switches with decreased size and reduced losses for defense power systems including directed energy weapons (DEWs), naval electric ships, and utility applications. Current high voltage power switches are bulky and have high losses in power conversion applications, leading to increased overall system costs for mobile operations in particular. $Ga_2O_3$ enables decreased size and weight while additionally having 10X decreased losses over what is possible with current switches. Improvements to efficiency translate into additional size and weight reduction for power systems, which extends mission duration and survivability. Two primary innovative improvements are being pursued: 1) design, material development, and fabrication for two- and three-terminal vertical $Ga_2O_3$ power switches; 2) thermal management and vertical conduction utilizing readily available substrates through composite wafer production. The products developed in this project will be available commercially at the end of the program and as engineering samples for defense applications.

## Multi-MHz, High Density, Ultra-fast RADAR Power Converter (Multi-MHz) - $5M, Lead: SWAP- Arizona State University-

This SWAP project is advancing a comprehensive suite of technology innovations to unlock the multi-MHz promise of gallium nitride (GaN) devices, to achieve ultra-low size, high efficiency, and an order of magnitude improvement in transient response of power conversion systems used in advanced radar and other defense/dual-use applications. High SWaP loss in state-of-the-art radar power supplies severely limits system performance, and therefore, mission capability. This is mainly due to the low switching frequency (few hundred kHz) used in power converters with predominantly Si devices. High switching frequencies, in the multi-MHz range, using GaN devices can enable next-generation miniaturization of radar power systems. However, mission-critical advancements are needed in circuits and control, magnetics, packaging and thermal management to fulfill this promise. The project has challenging end goals of >20 MHz effective system frequency at multi-kW power levels, 300 W/inch$^3$ power density (6X higher than SOTA), >95% efficiency and 10X faster transient response to pulsed power loads. The main technical areas of the project that leverage the circuits, HI and high-power capabilities of SWAP are: soft-switching topologies capable of sub-us response times, characterization of advanced GaN devices for multi-MHz operation, advanced planar magnetics using low-loss, additive-manufactured nanocomposite core materials and windings, active gate driver IC (130nm BCD HV CMOS process) that optimizes the drive strength to achieve high efficiency and low emissions, heterogeneous integration of the gate driver and advanced GaN switches, and three-dimensional, oscillating heat pipes (3D-OHP)-based thermal management solutions to support the required high heat flux with volume and weight that are 50% lower than conventional cooling methods.

## Development and Prototype Demonstration of a Radiation-Hardened Ultra-Thin Body and BOX (UTBB) SOI Wafer (RH UTBB SOI) - $828k, Lead: NRL-

The goal of this effort is to develop radiation-hardened, fully-depleted SOI wafers. This includes optimization of the radiation hardness of the buried oxide layer, and efforts towards improving the technical quality of the finished wafers, resulting in finished SOI wafers that meet the acceptance requirements of a state-of-the-art commercial fab.

## On-Shore Manufacture of Radiation-Hardened SOI Wafers (RHSOI) - $0.64M Lead: Navy-

The objective of this effort was to develop an on-shore, commercial manufacturing path for radiation-hardened SOI wafers for the Skywater RH90 program (OUSD(R&E)'s Trusted and Assured Microelectronics (T&AM) Program). The NRL portion of the effort involved working with Skywater, Inc. to develop a hardened oxide, using their in-house tools, to transfer the prior NRL IP to the Skywater Trusted Foundry. Wafer bonding and finishing was to be completed by MEMC, LLC, with the finished wafers being returned to Skywater for further processing. This effort has established a fully on-shore, all-commercial manufacturing pathway for radiation-hardened SOI wafers. All NRL tasks have been completed, and the hardened oxide performance is exceeding is expectations. Skywater and MEMC continue to optimize and refine the process, with NRL providing radiation characterization and SME feedback, as appropriate (continuing NRL efforts funded through T&AM).

## Integrated Ultra-low Power Magnetoelectric Sensor (HIM2ERS) - $438k, Lead: NRL-

In this project NRL teaming with NAWC-WD plan to produce and validate fieldable prototype on-chip magnetic field sensing modules for operation in underwater environment enabling persistent detection and surveillance. The project will build on successful demonstration of our IP-protected ultra-low power magnetometry based upon micrometer-scale multiferroic magneto-electric resonators. Integrating the resonator sensor with supplemental circuitry reduces the signal-to-noise ratio and thus greatly enhances transition opportunities to commercial fabrication.

## Microelectronics Commons Equipment for Collaboration (MECEFC) - $1.46M Lead: NRL-

The NRL hosts a 5000 sq ft, Class 100 cleanroom implemented with a critical toolset to support discovery phase research of functional materials at the nanoscale. This T3 project goal is to provide 200mm compatibility that is in line with Commons guidance for silicon wafer sizes and to ensure compatibility with our research partners. A 200mm dual chamber sputtering system having 6 sputter guns (in each chamber) has been placed under contract (28 SEP 2024) with expected delivery SEP 2025 and NRL is currently finishing draft specifications for a 200mm direct write lithography tool with anticipated award of FEB 2025. These items will greatly enhance the capabilities of NRL's Institute for Nanoscience cleanroom and processing facility and make full use of the $1.455M allotment to this project.

## Prototype Development and Demonstration of Deep Diffusion Diodes Utilizing the Semiconductor Opening Switch Effect (PD5-SOS)- $2.07M Lead: NRL-

This effort is establishing a lab-to-fab transition of a manufacturable, wafer-scale, semiconductor opening switch (SOS) technology from Service laboratories (NRL and ARL) to the DMEA, a U.S. Government DoD Trusted Foundry, on medium volume production line, using 150mm silicon wafers, will enable development of solid-state high-power microwave (HPM) weapon systems, capable of generating terawatts (TWs) of peak radiated power, with 100s of MHz of instantaneous bandwidth, at pulse repetition frequencies ~1 kHz, for long-range ship or ground-based air defense against unmanned aerial systems and precision guided munitions.