Power Nitride Doping Innovation Offers Devices Enabling SWITCHES (PNDIODES)

The projects that comprise ARPA-E's PNDIODES (Power Nitride Doping Innovation Offers Devices Enabling SWITCHES) program seek to develop transformational advances in the process of selective area doping in the wide-bandgap (WBG) semiconductor, gallium nitride (GaN), and its alloys. Wide-bandgap semiconductors have applications similar to today's popular semiconductors, such as silicon and gallium arsenide, but with properties that allow them to operate at much higher voltages, frequencies, and temperatures than these traditional materials. These qualities inherent to WBGs stand to enable high-power, high-performance power conversion hardware for a broad range of applications, including consumer electronics, the electricity grid, power supplies, solar and wind power, automotive, ship propulsion, and aerospace.

P-n junctions are the principal building block of modern electronic components like transistors. At their simplest, they consist of an "n-type" region with negatively charged free electrons participating in current flow and "p-type" regions with positively charged free "holes" carrying the current, separated by a carrier neutral (no electrons or holes to carry current) region. Their construction allows electricity to flow in just one direction and block electric current flow in the opposite direction. Both the n- and p-type regions are formed by doping a semiconductor material, which consists of adding a specific impurity to the semiconductor to change its electrical properties depending on the choice of impurity.

PROJECT DESCRIPTIONS

Adroit Materials, Inc. – Cary, NC

Selective Area Doping for Nitride Power Devices – $700,000

The Adroit Materials team seeks to establish selective area p-type doping of GaN by using ion implantation of magnesium and an innovative annealing, or heat treatment, process to remove implantation damage and control performance-reducing defects. By developing an in-depth understanding of the ion implantation doping process, the team will be able to demonstrate usable and reliable p-n junctions that meet or exceed PNDIODES program targets and enable a new generation of high-performance electronic semiconductor devices.

Arizona State University – Tempe, AZ

Effective Selective Area Doping for GaN Vertical Power Transistors Enabled by Innovative Materials Engineering – $1,500,000

The ASU team proposes a comprehensive research program to advance fundamental knowledge in the selective area growth of GaN materials in order to achieve selective area doping, leading to the development of high-performance GaN vertical power transistors. The team will develop a new fabrication process and determine the opportunities to solve the challenges of selective area growth for doping in GaN materials. The team will also conduct a materials study and investigate several issues related to GaN selective area epitaxial growth. If successful, the project will demonstrate generally usable p-n junctions for vertical GaN power devices that meet PNDIODES program targets.

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JR2J, LLC – Ithaca, NY

Laser Spike Annealing for the Activation of Implanted Dopants in GaN – $647,750

The JR2J team seeks to use a fast, high-temperature technique called laser spike annealing (LSA) to activate implanted p-type dopants in GaN. This technique allows for the high temperatures necessary to activate the dopants, as well as to repair damage done during the implantation process. By keeping the laser spike duration very short (0.1-100 milliseconds), the technique also hopes to avoid damage to the GaN lattice itself. The team will experiment with various LSA annealing conditions, exploring temperatures and time scales of the technique.

Sandia National Laboratories – Albuquerque, NM

High Voltage Re-grown GaN P-N Diodes Enabled by Defect and Doping Control – $1,894,700

The Sandia team seeks to achieve selective area doping using patterned regrowth of GaN p-n diodes with electronic performance equivalent to as-grown state-of-the-art GaN p-n diodes. The team will work to obtain a deep understanding of the growth process, including the relationship among crystal growth conditions, etching methods and post-etch treatments, impurity control, and electronic performance. The team also seeks to address challenges presented by the regrowth technique using physics-based approaches.

State University of New York Polytechnic Institute – Albany, NY

Demonstration of PN-junctions by Ion implantation techniques for GaN (DOPING-GaN) – $720,000

The SUNY Poly team will focus on ion implantation as the centerpiece of its approach. Using new annealing techniques, the team will develop processes to activate implanted silicon or magnesium in GaN to build p-n junctions. P-type ion implantation and annealing will be performed using an innovative gyrotron beam (a high-power vacuum tube that generates millimeter-wave electromagnetic waves) technique and an aluminum nitride cap. Central to the SUNY Poly proposal is understanding the impact of implantation on the microstructural properties of the GaN material and effects on p-n diode performance.

University of Missouri – Columbia, MO

High Quality Doping of GaN through Transmutation processing – $250,000

The University of Missouri team will focus on the development of neutron transmutation doping—exposing GaN wafers to neutron radiation to create a stable network of dopants within—to fabricate an extremely uniform n-type GaN wafer. Specific innovations in this proposal concern an in-depth study of neutron transmission doping and a characterization of the resulting wafer, including analyzing electrical resistance, dopant concentration, unwanted impurities, and damage to the GaN lattice.

Yale University – New Haven, CT

Regrowth and Selective Area Growth of GaN for Vertical Power Electronics – $1,150,000

The Yale team seeks to conduct a comprehensive investigation to overcome the barriers in selective area doping of GaN through the regrowth process for high-performance, reliable GaN vertical transistors. The team will demonstrate vertical GaN diodes through regrowth and selective area growth processes with performance similar to those made using current in-situ techniques, which are non-selective and therefore less flexible. Key innovations in this project will address the regrowth process at the nano scale, control of the crystal growth process to control impurities, electronic defects in the regrowth and selective area growth processes, and customizing the electronic characteristics of the selective area growth active region.