ABSTRACT

Current and Future Directions in Power Electronic Devices and Circuits based on Wide Band-Gap Semiconductors

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Electricity generation currently accounts for 40% of primary energy consumption in the U.S., and over the next 25 years is projected to increase more than 50% worldwide. Electricity continues to be the fastest growing form of end-use energy. Power electronics are responsible for controlling and converting electrical power to provide optimal conditions for transmission, distribution, and load-side consumption. Estimates suggest that the fraction of electricity processed through power electronics could be as high as 80% in the US by 2030 (including generation and consumption), approximately a twofold increase over the current proportion. The U.S. Department of Energy's Advanced Research Project Agency for Energy (ARPA-E) was established in 2009 to fund creative, out-of-the-box, transformational energy technologies that are too early for private-sector investment, at make-or break points in their technology development cycle. ARPA-E's investment portfolio aims to generate options to address specific energy challenges that could provide dramatic benefits for the nation. Development of advanced power electronics with unprecedented functionality, efficiency, reliability, and reduced form factor will provide the U.S. a critical technological advantage in an increasingly electrified world economy. Fast switching power semiconductor devices are the key to increasing the efficiency and reducing the size of power electronic systems. Recent advances in wide-band gap semiconductor materials, such as silicon carbide (SiC) and gallium nitride (GaN) are enabling a new generation of power semiconductor devices that far exceed the performance of silicon-based devices. Past ARPA-E programs (ADEPT, Solar ADEPT, SWITCHES) have focused on challenges associated with fabricating WBG high-performance switching devices. Program developments led to a new generation of devices that operate at much higher powers, voltages, frequencies, and temperatures than traditional silicon-based semiconductor devices. Two most recent programs recently launched by ARPA-E in the area of power electronics are CIRCUITS and PNDIODES. The projects that comprise ARPA-E's CIRCUITS (Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors) program seek to accelerate the development and deployment of a new class of efficient, lightweight, and reliable power converters, based on wide-bandgap (WBG) semiconductors. CIRCUITS projects build on the earlier ARPA-E programs by designing circuit topologies and building blocks optimally suited for WBG attributes to maximize overall electrical system performance and reliability. In addition, a reduced form factor (size and weight) will drive adoption of higher performance and more efficient power converters relative to today's state-of-the-art systems. Innovations stemming from CIRCUITS projects have the potential to affect high-impact applications wherever electrical power is generated or used, including the electric grid, industrial motor controllers, automotive electrification, heating, ventilation, air conditioning, solar and wind power systems, datacenters, aerospace control surfaces, wireless power transfer, and consumer electronics. PNDIODES (Power Nitride Doping Innovation Offers Devices Enabling SWITCHES) funds transformational advances and mechanistic understanding in the process of selective area doping in the III-Nitride wide band gap (WBG) semiconductor material system and the demonstration of arbitrarily placed, reliable, contactable, and generally useable p-n junction regions that enable high-performance and reliable vertical power electronic semiconductor devices. The microscopic mechanistic understanding and transformational technologies will address the major obstacle in the fabrication of vertical GaN power electronic devices.