Physics of Power Electronics

123rd Topical Symposium of the New York State Section of the APS
College of Nanoscale Science & Engineering
SUNY Polytechnic Institute
Virtual Symposium via Zoom

Schedule of Events

Friday, April 23, 2021

2:00 PM – 2:05 PM  Introduction
Ken Podolak
Chair, New York State Section of the American Physical Society

2:05 PM – 2:10 PM  Andre Melendez
Dean, College of Nanoscale Science and Engineering

2:10 PM – 2:40 PM  Charles R. “Chip” Eddy, Jr.
U.S. Naval Research Laboratory, Washington, DC
Power Electronic Materials Research to Enable Next Generation GaN
Power Switches

2:40 PM – 3:10 PM  Huili Grace Xing
School of Electrical and Computer Engineering, Cornell University
GaN Power Electronics and Associated Fundamental Limits

3:10 PM – 3:40 PM  Reza Ghandi
GE Global Research
Silicon Carbide: Enabling a New Era for Power Electronics

3:40 PM – 4:10 PM  T. Paul Chow
Department of Electrical, Computer, and Systems Engineering, Rensselaer
Polytechnic Institute
Design and Fabrication of SiC Power Devices

4:10 PM – 4:15 PM  Concluding Remarks
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Power Electronic Materials Research to Enable Next Generation GaN Power Switches
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Due to the inherently high mobility and high breakdown field of GaN-based power transistors, they have the potential to revolutionize power conditioning hardware including switch mode dc-dc power converters, motor drive components, and class-D amplifiers for sonar. The performance of GaN-based power transistors has evolved at a rapid rate by exploiting previous progress in microwave transistor development while raising the blocking voltage to impact key applications. Further progress is challenged by the need to solve materials issues beyond microwave transistor needs including: complex heterojunction barriers for normally-off operation; gate recess and dielectric development; passivation of high-field traps; thermal management; and, reduced non-alloyed ohmic contact resistance. In addition, higher voltage applications will require vertical device designs involving thick, low-doped drift regions, surface recesses and field terminations. Many of these materials challenges have existed for decades.

Here we report on highlights of materials advances in many of these areas in our pursuit of both lateral and vertical advanced power switch development. In some cases, new growth approaches, such as atomic layer epitaxy (ALE) are being developed to address advanced heterostructure designs. Efforts to improve high-k gate dielectrics and passivation of surface traps have required both surface process development and advanced materials that provide the added benefit of threshold voltage shifts in the device. Thermal management challenges have required integration of nanocrystalline diamond in device structures. In addition, and for vertical power switch development, we’ve demonstrated thick, low-doped homoepitaxial GaN layers, novel growth approaches for distributed, recessed gates and electrical activation of ion implanted regions for management of high electric fields. Many of these advances are first-ever demonstrations for III-N semiconductor materials.
GaN Power Electronics and Associated Fundamental Limits
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It is increasingly more difficult to realize both $n$-type and $p$-type doping in wider bandgap semiconductors. How does this impact the design principles of power electronics in ultra-wide bandgap semiconductors? What fundamentally different roles does a $p$-region play in a power electric device in comparison to a semi-insulating region, for example, in the popular GaN HEMT based power transistors? What are the practical fundamental limits for unipolar devices such as Schottky barrier diodes without the help of $p$-type doping? What are the unique advantages that a polar semiconductor family like GaN can offer? What is polarization doping and how is polarization-doping fundamentally different from impurity doping? I will reflect on our efforts in seeking answers to these questions in the past 20 years in GaN power electronic devices as well as realizing state-of-the-art devices [1-12].

Our work has been in part supported by ARPAe SWITCHES, AFOSR FA9550-17-1-0048, and NSF DMREF 1534303, making use of shared facilities at CNF (NSF ECCS-1542081), CCMR (NSF MRSEC DMR-1719875) and equipment supported by DMR-1338010.

References:
Silicon Carbide: Enabling a New Era for Power Electronics
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Wide bandgap Silicon Carbide (SiC) power switches and diodes offer the promise of lower switching losses and more efficient power conversion for a wide range of applications that include but not limited to hybrid vehicles, renewable technologies, industrial motors and data centers. In this talk, we will review significant progresses that have been made in SiC technology, including production of high quality and large diameter wafers and development of high power and reliable switches and modules. We will also present recent examples on adoption of SiC in few commercial applications and discuss new trend for next generation of medium-voltage switches and diodes.
SiC high voltage power devices are emerging as a new class of power switching devices, offering superior performance and excel at harsh operating conditions. In this talk, we will review its materials properties, present the relevant device structures, active area and termination design, projected performance, fabrication processes and reliability/robustness. Also, we will discuss the future trend and technology obstacles that need to be addressed and overcome for the success of widespread commercialization of these power devices.