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ENMA365: Wide bandgap Materials and Devices

Philosophy of the Course:

For nearly three decades wide bandgap (WBG) semiconductors with significantly improved electrical and thermal characteristics have been researched to overcome the performance and reliability barriers of silicon in advanced energy applications. This is especially true for high-voltage and high-temperature devices used in electrical power switching, computing, communication, and sensing applications subjected to high voltages and temperatures. These devices are made from diamond, silicon carbide (SiC) and Group III-Nitride semiconductors such as gallium nitride (GaN) . However, many of the most energy-important system benefits, including the energy efficiency predicted for WBG semiconductors, have been prevented because of a high density of crystal defects in the semiconductor bulk and interfaces. This course presents the materials science of wide bandgap materials and analyzes the defects present in such materials from a device performance point of view. Increased temperature often compromises performance and when combined with the higher voltages, current densities, and heat dissipations associated with power electronics can result in an increased susceptibility to oxide breakdown, electromigration, and other catastrophic on-chip failure mechanisms. The course presents the materials science and physics of up-to-date switches (MOSFETs and IGBTs), their properties and limitations are emphasized.. The course covers techniques to increase current or voltage with serial or parallel associations of elementary components. Thermal aspects relating to the use of power electronics are presented, as well as packaging approaches and analysis.

Included will be issues related to the effect of high and low operating temperatures on device and packaging reliability, power device (IGBT, MOSFET, BJT) and material (Si, SiC, GaN) selection, passive component and packaging materials selection, thermal management, and assembly of reliable high power and extreme temperature electronic systems. Finally, failure mechanism models for high temperature and power electronics will be presented together with a discussion of design options to mitigate failure.

Pre-requisites: ENMA 300, ENMA 460 (co-requisite), ENMA 465, ENMA 460 (or equivalent). If missing these courses, the student will need permission from the instructor.

Topics covered in this course:

Materials Science of wide bandgap materials: GaN and related compounds, SiC and related compounds

Semiconductor Properties under extreme electric field conditions

Introduction to Power Device Technology: Operating Near Breakdown

Material growth of GaN and SiC: MOCVD, MBE and HPVPE, Thick Epitaxial Layers.

Defects in GaN and Transition Metal Nitrides: Dislocations and point defects.

Material design for transistor switches: HEMT, MOSFET and IGBT

Reliable design and fabrication of power semiconductor devices. Overcoming Key failure mechanisms

Reliable design of power inverters and converters

Reliability of Power Devices and material related non linear phenomena

Outline of Classes

Week	Topic
01, 02	Introduction to Wide band gap Material Science, physics, processing technologies and semiconductor properties
03, 04	Fundamentals of Power Electronic Switching Devices (IGBT, SIT, JFET, MOS, HEMT, Diode)
05	Device Physics of the HEMT and MOSFET
06	Device Physics of the IGBT
07	GaN versus SiC versus TMNs (Transition Metal Nitrides)
08, 09	Power Device Technology: Crystal growth, epitaxial growth, ohmics and metal interconnects at the device level.
10	Substrates: for Wide bandgap Semiconductors
11	Defects: Substrate, epi layers, interfaces, defect management
12,13	Power Electronic Device Failure Mechanisms, Reliability Measures, Strategies to improve reliability
13	Failure mechanisms of power devices: thermal, surge current, over-voltage, short circuit and over-current in IGBTs, failure analysis.
14	Student Project Presentations

Grading: There will be two exams (midterm and final), homework assignments, and a technical paper. Grading will be as follows:

Mid-term Exam: 20%
Final Exam: 35%
Paper: 35 %
Homework: 10%

Textbook: " Semiconductor Power Devices", by Josef Lutz et al , Published by Springer, 2011.

Term Paper: Each student will write a term paper detailing material growth, device processing, failure modes and mechanisms for the device and packaging elements below. Only one student will be permitted to write on each topic.

1) Material Growth: MBE for Nitride Semiconductors
2) Material Growth: MOCVD for Nitride Semiconductors
3) Material Growth:HPVPE
4) Vertical vs Laterial Devices
5) Diode switches and transistor switches

6) Substrates for Epitaxial Growth
7) Surfaces and Interfaces, Control of High Fields
8) Ceramic Substrates and attach technologies, Enhancing Heat Transfer
9) Encapsulants for individual devices, Reducing Surface Breakdown.
10) Uniqueness of the NbN/Tranition Metal Nitride system.