Silicon's Last Battle in Power Devices: The Superjunctions and IGBTs

Prof. Florin Udrea, University of Cambridge

Florin Udrea is a professor in semiconductor engineering and head of the High Voltage Microelectronics and Sensors Laboratory at University of Cambridge. Prof. Florin Udrea has been an academic with the Department of Engineering, University of Cambridge since 1998. He is currently leading a research group in power semiconductor devices and solid-state sensors that has won an international reputation during the last 30 years. Prof. Udrea has published over 500 papers in journals and international conferences. He holds over 200 patents in power semiconductor devices and sensors. Prof. Florin Udrea founded five companies, Cambridge Semiconductor (Camsemi) in power ICs – sold to Power Integrations, Cambridge CMOS Sensors (CCS) in the field of smart sensors – sold to ams, Cambridge Microelectronics in Power Devices, Cambridge GaN Device in high voltage GaN technology and Flusso in Flow and thermal conductivity sensors. For his outstanding personal contribution to British Engineering, he has been awarded the Silver Medal from the Royal Academy of Engineering. In 2015, Prof. Florin Udrea was elected a Fellow of Royal Academy of Engineering. In 2018, Prof. Udrea has been awarded several major prizes, including the Mullard medal from the Royal Society. In 2020, he received the Ohmi award as a co-author of the ISPSD paper on Silicon Carbide FinFETs. In 2021, he was awarded the academic entrepreneur of the year in UK by Business Weekly. In 2022, he received the Ohmi award for the second time as a first author of a paper in SiC FinFET power devices. At the same conference, he also received the best poster award for the development of ICeGaN smart power devices with Cambridge GaN Devices Ltd.

Abstract: The power devices field has seen tremendous changes in the last decade. The traditional power MOSFET has been largely replaced by a new class of power devices based on the Silicon Superjunction (SJ) concept, while the Insulated Gate Bipolar Transistors (IGBTs) are now fabricated on 12 inch wafers and have access to the latest thin wafer/trench/fine dimension technologies. However most of the innovation and flavour in the field comes from the emergence of Wide Band Gap (WBG) semiconductors – and in particular the Gallium Nitride and Silicon Carbide. Extensive research is also carried out in single crystal Diamond and Gallium Oxide materials. The market of power devices has reached ~$35M with exponential growth in wide bandgap materials reaching CAGRs in excess of 50% in the next 3-5 years. However, in spite of this extraordinary impact of WBG, silicon is still growing in the market and the relentless demand of silicon SJ FETs and IGBTs has surprised even the most committed silicon enthusiasts.

This seminar will cover the SJ and IGBTs from concept to devices and detailed operation. The IGBTs and SJ will then be assessed against the WBG competitors. The seminar will end with an outline of the challenges for the power electronics future and a vision of different technologies for the next 10 years.

Smart Gate Drivers for GaN and SiC Power Transistors

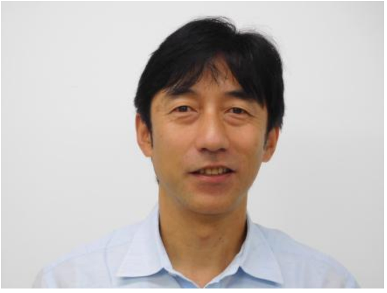
Prof. Wai Tung Ng, University of Toronto

Wai Tung Ng received his B.A.Sc., M.A.Sc., and Ph.D. degrees in Electrical Engineering from the University of Toronto, in 1983, 1985 and 1990, respectively. Prof. Ng is with the Edward S. Rogers Sr. Dept. of Electrical and Computer Engineering from the University of Toronto. He is also the director for the Toronto Nanofabrication Center (TNFC), and open access research facility. Prof. Ng's research is focused in the areas of power semiconductor devices and smart power integrated circuits. His research group has demonstrated many world-first innovative designs, including a digitally reconfigurable DC-DC power converter with resizable output stage [ISPSD 2006], a superjunction power FinFET [IEDM 2010], and a series of smart gate driver integrated circuits for Insulated Gate Bipolar Transistors (IGBTs) and Gallium Nitride (GaN) power transistors. Currently, Prof. Ng's group is actively engaged in the promotion of digitally reconfigurable gate driver circuits to improve the switching characteristics of GaN and Silicon Carbide (SiC) power transistors. These include many novel features such as one-step dead-time correction, indirect current sensing, dynamic driving strength to suppress Electromagnetic Interference (EMI), liquid-cooled packaging for intelligent power modules (IPMs), etc.

Abstract: GaN and SiC power transistors offer high switching speed, low on-resistance and much better FOM when compared to silicon power MOSFETs. The ability to operate with high power density in a smaller form factor presents new challenges for reliable and robust operation. Traditional gate driver designs for silicon-based power devices are catered to lower frequencies with large tolerance on the gate voltage swing. They are not adequate to address some of the reliability and timing requirements that are unique to power transistors fabricated using Wide Bandgap (WBG) materials. This talk will provide a quick review on the gate driving requirements and limitations of WBG power transistors. This is followed by a discussion on dynamic gate driving with precision timing and deadtime correct technique to fully exploit the performance of GaN and SiC power transistors. An application example on how dynamic gate drive can be used to relax the trade-off between electrical and thermal performance due to conflicting die placement requirements in liquid-cooled GaN power modules will also be presented.

Advances in SiC Super Junction MOSFET

Dr. Shinsuke Harada, National Institute of Advanced Industrial Science and Technology



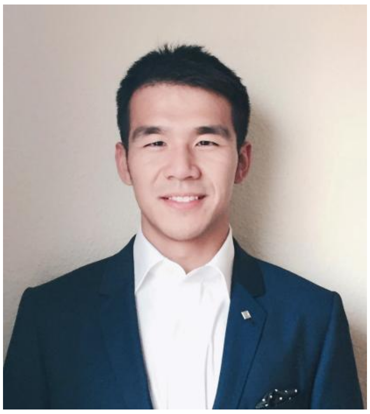
Shinsuke Harada received the Ph.D. degree from Kyushu University, Japan in 2000. He has been with National Institute of Advanced Industrial Science and Technology (AIST) since 2004, where he is currently a leader of Power Device Team of Advanced Power Electronics Research Center, and also is a vice-chair of Tsukuba Power-Electronics Constellations (TPEC) established by AIST as industry-funded consortium to promote Power-Electronics Open Innovation. He has developed SiC planer gate and trench gate MOSFETs, and SBD-integrated MOSFET. His current research interests include SiC SJ-MOSFET, power IC, and hybrid device with GaN.

Abstract: On-resistance of SiC-MOSFETs is dominated by the channel resistance, and has been reduced by adopting trench gate and improving the MOS interface. As a result, in recent years, the channel resistance has been reduced to the same level as the drift resistance even in a relatively low blocking voltage class. Superjunction (SJ) has been widely demonstrated in Si-MOSFETs, and are expected as next-generation devices for SiC-MOSFETs. This short course reviews SiC SJ-MOSFETs reported in recent years, and introduces their advantages over SiC conventional MOSFETs and Si SJ-MOSFET, as well as process technology.

Test-to-Fail Methodology for Accurate Reliability and Lifetime Evaluation of GaN Power HEMT

Dr. Shengke Zhang,

Efficient Power Conversion Corporation (EPC)



Shengke Zhang is Vice President of Reliability at Efficient Power Conversion where he leads the product reliability and failure analysis for GaN transistors and ICs. Prior to joining EPC, he worked on RF-MEMS devices in the mobile industry. He earned his Ph.D. degree in Materials Science and Engineering from Arizona State University investigating low-loss dielectrics for cellular and advanced computing applications. He was the author and co-author of more than 30 technical papers. He also serves as a committee member for JEDEC's JC-70 Wide Bandgap Power Electronic Conversion Semiconductors Committee.

Abstract: Modern solar panels are demanding increasingly higher power density and longer operating lifetimes. Solar applications including power optimizers and microinverter are becoming the prevailing trend for increasing number of solar customers with low-voltage GaN power devices (V_{DS} < 200V) being extensively used. GaN power transistors and integrated circuits offer solutions that can make the solar power systems smaller, cooler, more efficient and more reliable. Greater than 25 years of reliable operation is a typical requirement for solar installations. The test-to-fail methodology stresses devices under extremely accelerated test conditions. The goal is to fail the devices quickly and conduct failure analysis to determine the underlying failure modes. This approach acquires an understanding of the intrinsic failure mechanisms and development of physics-based mathematical models that accurately predict device lifetime under all mission profiles. In this short course, we use these physical insights and apply them to the unique demands of solar applications.

Gallium Oxide Vertical Power Devices: Technology, Design and Applications

Prof. Shibing Long,

University of Science and Technology of China

Shibing Long received the B.S. degree in applied physics in 1999 and M.E. degree in materials physics in 2002 from the University of Science and Technology Beijing and the Ph.D. degree in microelectronics and solid state electronics in 2005 from the Institute of Microelectronics, Chinese Academy of Sciences (IMECAS). From 2005 to 2018, he worked in IMECAS as assistant professor, associate professor and professor. During 2011 to 2012, he was a visiting scholar in Universitat Autònoma de Barcelona (UAB), Spain. From 2018, he is a professor in the School of Microelectronics, University of Science and Technology of China. He has been involved in the research of nanofabrication technology, memory (RRAM, DRAM) and ultrawide bandgap semiconductor devices. He is currently leading a research group in gallium oxide semiconductor power devices and UV photodetectors. Up to date, he has published over 100 papers in journals and international conferences, holds more than 100 patents. He is a Senior Member of IEEE, also a Member of the Power Devices and Systems (PDS) sub-committee for IEDM 2021-2022, and gets the National Science Fund for Distinguished Young Scholars.

Abstract: Gallium oxide (Ga_2O_3) ultrawide bandgap semiconductor material has important applications in power electronic devices such as Schottky barrier diodes (SBD), hetero-PN-junction diode (PND), field-effect transistors (FET) and power IC. Compared with SiC and GaN material, gallium oxide semiconductor has the advantages of low-cost melting growth, ultrawide bandgap (~4.8eV), ultrahigh breakdown electric field (8MV/cm), and high Baliga's figure of merit ($BFoM = \varepsilon\mu E_{br}^3$ ~3444), so it's very promising in the application in power devices. This seminar will systematically introduce the development of Ga_2O_3 based power devices, including the Ga_2O_3 single crystal substrate and epitaxial film growth, the simulation, design and fabrication of SBD, PND and MOSFET power devices, and also the emergence of Ga_2O_3 power modules. The seminar will end with the challenges for the power electronics applications of Ga_2O_3 devices.

Design and Technology of Automotive Power Modules — An Introduction

Dr. Stefan Oehling, Semikron Elektronik

Stefan Oehling received his M.S. and Ph.D. degrees in solid-state physics from Julius-Maximilians-University, Würzburg, Germany in 1993 and 1997, respectively. From 1998 to 1999, he was with Siemens Halbleiter (later Infineon) working on high resolution masks for photolithography, including NGL research. In 2000, he joined Altis Semiconductor, Corbeil-Essonnes, France (Joint Venture of IBM and Infineon) working on CMOS production. Since 2001, he is with SEMIKRON Elektronik, Nurembourg, Germany, starting as a photolithography engineer. Later he headed the Front End engineering group, including high temperature diffusion and etching processes, for both production and development. Here, he and colleagues developed later variants of the SEMIKRON CAL-diode and its successor CAL4-diode. In 2014, he took over as the head of the R&D group Sintermodules, where he was responsible for the development of the SEMIKRON SKiN technology, for both automotive and industrial applications. Here, the activities to develop the latest SEMIKRON Automotive module, the eMPack system, were also started. Dr. Oehling is the author and co-author of about 20 scientific and technical publications. As of 2022, he is a member of ISPSD review team.

Abstract: As E-Mobility is taking its path, specific power modules fulfilling the Automotive requirements are needed. Following the evolution path of module developed by SEMIKRON-Danfoss features, design solutions and accomplished processes will be discussed. Based on a popular industrial power module, the introduction of modern solutions for Skip, Skin and eMPack modules is explained. Also, a cross-reference of the two modern solutions eMPack and DCM-platform will give an insight into the topic. The possibilities of cooler connection, die-attach and front side contacting are discussed. Finally, an outlook is given on the requirements of WBG materials and their influence on material selection and assembly and connection technology.

The System Application Benefits of GaN Versus Si and SiC and The Potential of GaN Bi-directional Switch

Dr. Kennith K. Leong, Infineon Technologies

Kennith K. Leong received the M. Eng degree in Telecommunications Engineering and Ph.D. in Power Electronics Devices from the University of Warwick, UK in 2007 and 2011 respectively. In 2011, he joined the Electric Drives and Machines Institute in Graz, University of Technology (TUGraz), as a Research Associate. He was a Visiting Scholar at Centre of Power Electronics System (CPES), Virginia Tech, during 2013. In 2014, he joined the System Innovation Lab, Infineon Technologies Austria AG, in Villach. Dr. Leong is currently a Lead Principal System Engineer with current research interests include GaN Bi-directional switch, GaN integration, power converter topologies and control, with over 28 granted patents and numerous technical publications.

Abstract: Si Super-junction devices have dominated the mass market for the past decades, it can be found from adaptors to datacenters, from super-chargers to renewables. However, as the mass market explore wide-bandgap technologies like SiC and GaN, key performance indicators are needed to differentiate the three technologies at the application and system levels. The justification to jump to GaN or SiC are different and this short course will present application benefits between the technologies and where they come from. The benefits of lateral GaN and monolithic integration will also be discussed. Finally, the latest development in GaN bi-directional switch and its potential to enable new AC topologies.