Guest Editorial
Special Issue on Light-Emitting Diodes

Although the origins of light-emitting diodes (LEDs) go back to the beginning of the 20th century, the real interest in the study of LEDs began only in the early 1950s, coinciding with the developments taking place in microelectronics. By changing the chemical composition of GaAs to GaAsP, it was observed in 1962 that the light wavelength could be shifted from infrared to visible spectrum. The first commercial LEDs appeared around the late 1960s. Compared to the conventional light sources such as incandescent bulbs (visible light) and mercury lamps (deep UV light), inorganic LEDs offer several advantages such as wide wavelength operation, light weight, low power consumption, low maintenance, long operating lifetimes, and high vibration resistance.

Organic LEDs (OLEDs) could become even more useful because they can be made on transparent and flexible substrates and can be mass produced by printing techniques. Serious interest in OLEDs began with the demonstration of a relatively efficient OLED in 1987 based on the idea of maximizing the electron and hole recombination between two organic semiconductor layers. It is believed that OLEDs will become the dominant choice for the future-generation flexible and flat-panel displays. Stability, degradation in device luminance, and high operating voltages are the major problems that hinder the rapid commercialization of OLEDs. There is a great need for the development of the synthesis of better materials and encapsulation schemes to improve the operating lifetimes and reliability of OLEDs.

While LEDs are predominantly used for visible-spectrum lighting applications, they are also used in other important applications, e.g., optical communications, medical applications, biosensing, water/air purification, disinfection, and large-area displays. The rapid increase in the efficiency and brightness of LEDs may make them suitable in ever-growing newer applications. Due to the rapid advances taking place in the development and application of LEDs, there is an immediate need to take cognizance of the recent technological improvements and get across the likely opportunities that exist in the area of LEDs to a wider device community. The principal objective of this special issue is, therefore, to put together works in different aspects of inorganic LEDs and OLEDs, making it a valuable archival resource as well as a source for new research results. There are eight invited papers and 12 contributed papers in this Special Issue.

The first three papers are invited review papers. Compact solid-state UV-light sources have potential applications in water purification and sterilization, bioagent detection, and analytical instrumentation. In the review paper entitled Deep Ultraviolet Light Emitting Diodes, Shur et al. discuss recent progress in material growth, device physics, design, fabrication, and performance of DUV LEDs with wavelengths ranging from 210 to 365 nm. ZnO and ternary ZnMgO solid solutions are group II–VI wide-bandgap materials that are currently under intense study as a viable alternative to GaN-based blue and ultraviolet LEDs. This material system has several potential advantages over GaN, such as commercial availability of bulk single crystals and a larger exciton binding energy (∼60 meV compared with ∼25 meV for GaN). Park et al. summarize recent progress in ZnO LEDs and demonstrate that robust p-type doping is still a limiting factor in their paper entitled Recent Advances in ZnO Based Light-Emitting Diodes: P-type ohmic contacts play a key role in the performance of LEDs. Song et al., in the review paper entitled Ohmic Contact Technology For GaN-Based Light Emitting Diodes: Role of P-Type Contact, present a review of the development of low-resistance p-type ohmic contacts for GaN-based LEDs. Various methods, such as the use of large work function, surface treatments, superlattice and strained layers, hydrogen extraction, and use of interlayers, are described.

The next five papers are invited papers describing original research. Design approaches intended for optimizing the internal quantum efficiency (IQE) of LEDs based on InGaN quantum wells emitting in the near-ultraviolet region are investigated by means of numerical simulations by Chiaria et al. in Design Criteria for Near-Ultraviolet GaN-Based Light-Emitting Diodes. The impact of the Auger recombination on IQE and its role in the experimentally observed efficiency droop is also studied. Practical design criteria to optimize the device structures are also suggested. The invited paper entitled Nitride Nanocolumns for the Development of Light-Emitting Diode by Tang et al. focuses on the material quality and novel growth technique for III-nitride semiconductors. The paper reviews the progress made in the field of nanocolumnar growth of III-nitride material for LEDs. Exciting experimental results relating material quality and LED performance to the nanocolumn size and spacing are presented. Laubsch et al. report on the latest advancements on the AlGaN-based visible LED from the point of view of efficiency, epitaxy, chip, and packaging in their paper entitled High Power and High Efficiency InGaN Based Light Emitters. The fundamental origin of the typical efficiency “droop” observed at high-current densities is discussed, and possible solutions are also proposed. The paper entitled Nonpolar and Semipolar III-Nitride Light-Emitting Diodes: Achievements and Challenges by Masui et al. demonstrates the feasibility and reports the advantages of using nonpolar and semipolar InGaN/GaN material for the development of high-performance LEDs. It will be demonstrated how nonpolar and semipolar orientations provide not only LEDs with high performances but also unique functions like polarized light.
emission, which can allow the penetration of these devices in unexplored application fields. The paper entitled High Efficiency Blue Emitting Phosphorescent OLEDs by Chopra et al. reviews blue phosphorescent OLEDs and the different chemistry within.

The contributed papers present some very interesting new results. Meneghini et al. review the failure modes and mechanisms of GaN-based LEDs in their paper entitled A Review on the Physical Mechanisms That Limit the Reliability of GaN-Based LEDs. A number of reliability tests are presented, and specific degradation mechanisms of state-of-the-art LED structures are analyzed. ESD is a serious problem in the field of LED fabrication and is particularly true for the power LED fabrications. Chang et al. present new results on the electrostatic reliability characteristics of GaN polymer LEDs (PLEDs) in their paper entitled Electrostatic Reliability Characteristics of GaN Flip-Chip (FC) Power Light Emission Diodes (PLED) with Metal Oxide Silicon (MOS) Submount.

Highly efficient blue-light organic light-emitting devices have wide utility for solid-state lighting and full-color display applications. Zhang et al. report impressive results on the realization of high-power-efficiency blue fluorescent organic light-emitting devices in Blue Organic LEDs with Improved Power Efficiency. While some of the papers in this Special Issue are based on traditional wideband gap materials, in the paper entitled Sn-ZnO/n-GaAs Heterostructured White Light-Emitting Diode: Nanoscale Interface Analysis and Electroluminescence Studies, Tan et al. presented a simple and low-cost spray pyrolysis method to obtain bright structures emitting in red and white regions.

In the paper entitled III-Nitride Based Light Emitting Diodes with GaN Micro-Pillars Around Mesa and Patterned Substrate, Peng et al. discuss the optoelectronic characteristics of III-nitride LEDs grown on patterned sapphire substrates with textured sidewall mesa and microsize pillars (μ-pillars) around the mesa region. They found that the power enhancement of these LEDs was about 65% larger than conventional LEDs.

Packaging is a key aspect for any technology as well as hybrid integration. In Polymer MEMS Based Optoelectronic Display by Gokdel et al., an all-polymer demonstration of low-cost 2-D displays is presented. This was achieved by the integration of polymer composite MEMS actuators and 1-D PLED array. Subbarao et al. discuss encapsulation approaches using polymer/ceramic and polymer/metal thin-film barriers in their paper entitled Laboratory Thin Film Encapsulation of Air Sensitive Organic Semiconductor Devices and present an approach to in-laboratory handling and intralaboratory shipping of air-sensitive organic semiconductors compatible with both glass and polymer substrates.

Lee et al. present a performance comparison of LED structures grown on a patterned sapphire substrate with cone-shaped features in the paper entitled Comparison of InGaN-Based LEDs Grown on Conventional Sapphire and Cone Shaped Patterned Sapphire Substrate. Highly interesting results are shown for the reduction of the dislocation density and the improvement of the light-extraction efficiency in InGaN-based LEDs. The electronic structure of wurzite InN quantum dots (QDs) self-assembled on GaN substrate is investigated by means of fully atomistic and quantum—mechanical simulations by Ahmed et al. in Electronic Structure of InN/GaN Quantum Dots: Multimill-
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From 1991 to 1994, he performed a postdoctoral research in the modeling and processing of high-speed bipolar transistors with the Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, Canada, where he also did a research on amorphous-silicon TFTs. From July 1994 to December 1995, he was initially with the Department of Electronics and Electrical Communication Engineering, IIT, Kharagpur, India, and then, he joined the Department of Electrical Engineering, IIT, Delhi, India, where he became an Associate Professor in July 1997 and has been a Full Professor since January 2005. He is the Coordinator of the VLSI Design, Tools and Technology interdisciplinary program at IIT Delhi. He has published extensively in his areas of research interest with three books chapters and more than 135 publications in refereed journals and conferences. His teaching has often been rated as outstanding by the Faculty Appraisal Committee, IIT Delhi. He is the Editor-in-Chief of the IETE Technical Review and an Associate Editor of the Journal of Computational Electronics. He is also on the editorial board of Recent Patents on Nanotechnology, Recent Patents on Electrical Engineering, Journal of Low Power Electronics, and Journal of Nanoscience and Nanotechnology. He has reviewed extensively for different international journals. His research interests include nanoelectronic devices, VLSI device modeling and simulation for nanoscale applications, integrated-circuit technology, and power semiconductor devices.

Dr. Kumar is a Fellow of the Indian National Academy of Engineering and the Institution of Electronics and Telecommunication Engineers (IETE), India. He is an IEEE Distinguished Lecturer of the Electron Devices Society. He is a member of the EDS Publications Committee and the EDS Educational Activities Committee. He is an Editor of the IEEE TRANSACTIONS ON ELECTRON DEVICES. He was the lead Guest Editor for the joint special issue of the IEEE TRANSACTIONS ON ELECTRON DEVICES and IEEE TRANSACTIONS ON NANOTECHNOLOGY (November 2008 issue) on Nanowire Transistors: Modeling, Device Design, and Technology. He was a recipient of the 29th IETE Ram Lal Wadhwa Gold Medal for his distinguished contribution in the field of semiconductor device design and modeling. He was also the first recipient of the ISA-VSI TechnoMentor Award given by the India Semiconductor Association to recognize a distinguished Indian academician for playing a significant role as a Mentor and Researcher. He is also a recipient of the 2008 IBM Faculty Award. He was the Chairman of the Fellowship Committee of The Sixteenth International Conference on VLSI Design (January 4–8, 2003, New Delhi, India), the Chairman of the Technical Committee for High Frequency Devices of the International Workshop on the Physics of Semiconductor Devices (December 13–17, 2005, New Delhi), the Student Track Chairman of the 22nd International Conference on VLSI Design (January 5–9, 2009, New Delhi), and the Program Committee Chairman of the Second International Workshop on Electron Devices and Semiconductor Technology (June 1–2, 2009, Mumbai, India).

Leda Lunardi (F’02) received the B.S. and M.Sc. degrees in physics from the University of São Paulo, São Paulo, Brazil, in 1976 and 1980, respectively, and the Ph.D. degree in electrical engineering from Cornell University, Ithaca, NY, in 1985.

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Dr. Lunardi has served in several IEEE committees, technical committee conferences, and national and international government ad hoc committees for grants and project reviews. She has given invited talks and short courses at conferences. She was elected AdCom for IEEE EDS from 2000 to 2006 and has since been a Technical Volunteer in numerous EDS and Photonics Society committees and more recently on the Optoelectronics Devices, Publications, Fellowships, Fellow Promotion, and Awards Committees. She was also the 2002 IEEE/Lester Eastman Conference on High Performance Devices Conference Chair and the 2003 IEEE IEDM General Chair (of which she was the Technical Chair in 2002). She was a member and, later on, the Chair of the 2008-05 Photonics (former LEOS) Annual Meeting Photodetectors and Imaging Technical Committee. She was a recipient of the 2000 IEEE/LEOS Engineering Achievement Award. She is the Editor for the IEEE TRANSACTIONS ON ELECTRON DEVICES, a member of the Editorial Board for IEEE PROCEEDINGS, and the Associate Editor of the IEEE PHOTONICS JOURNAL.
Stephen J. Pearton (A’91–SM’93–F’01) received the B.S. degree in physics from the University of Tasmania, Hobart, Australia, in 1978 and carried out his Ph.D. work at the AAEC near Sydney. He moved to the U.S. in 1982 and was a Postdoc with the University of California, Berkeley, prior to joining AT&T Bell Laboratories, Murray Hill, NJ, as a member of Technical Staff working on high-speed compound semiconductor electronics. After a decade at Bell Labs, he joined the University of Florida (UF), Gainesville, in 1994, where he is a Distinguished Professor and the Alumni Chair with the Department of Materials Science and Engineering. His research is in developing processing techniques used in compound semiconductor electronics and photonics. At Bell Labs, he developed the use of ion implantation in successive generations of GaAs MESFETs, AlGaAs/GaAs and InP/InGaAs HBTs, and HEMTs for both device doping and interdevice isolation. He also developed ohmic and Schottky contact technologies for these devices. He has been involved in the development of most of the standard dry-etching processes used for selective and nonselective patterning of the device technologies aforementioned, in addition to those for long-wavelength laser diodes used for optical communication systems. Most companies that manufacture microwave GaAs chips used in cell phones and radar systems use fabrication processes initially developed by Pearton et al. at Bell Labs. At UF, he has primarily focused on fabrication processes for blue/green/UV GaN-based LEDs, laser diodes, and power electronics. His most recent interests have been in developing solid-state sensors. He has published over 1400 publications and given over 250 invited talks. His publications have been cited over 29 000 times in the literature.

Dr. Pearton is a Fellow of the MRS AVS, ECS, APS, and TMS. He is the recipient of the 2005 Electronics Division Award from ECS, the 2007 John Thornton Award from AVS, and the 2007 J. J. Ebers Award from IEEE.

Gaudenzio Meneghesso (S’95–M’97–SM’07) was born in Padova, Italy, in 1967. He received the Laurea degree in electronics engineering, working on the failure mechanism induced by hot electrons in MESFETs and HEMTs, and the Ph.D. degree in electrical and telecommunication engineering, working on hot-electron characterization, effects and reliability of GaAs- and InP-based HEMTs, and pseudomorphic HEMTs, from the University of Padova, Padova, 1992 and 1997, respectively.

In 1995, he was with the University of Twente, Enschede, The Netherland, with a Human Capital and Mobility fellowship (within the SUSTAIN Network), where he worked on the dynamic behavior of protection structures against electrostatic discharge (ESD). Since 2002, he has been an Associate Professor with the Department of Information Engineering, University of Padova. Within these activities, he published over 350 technical papers (of which more than 35 were invited papers and 5 received best paper awards). He is a Reviewer of several international journals, such as IEEE Electronics Letters, Journal of Applied Physics, Applied Physics Letters and Semiconductor Science and Technology (IOP), and Microelectronics Reliability (Elsevier). His research interests are as follows: 1) electrical characterization, modeling, and reliability of microwave devices on III–V semiconductors such as GaAs and InP (MESFETs, HEMTs, and PHEMTs); 2) electrical characterization, modeling, and reliability of electronic and optoelectronic devices grown on GaN; 3) electrical characterization, modeling, and reliability of RF-MEMS switches for reconfigurable antenna switches; 4) design characterization and modeling of ESD protection structures for CMOS and SMART POWER integrated circuits including electromagnetic interference issues; and 5) characterization and reliability evaluation of devices processed on organic semiconductors.

Dr. Meneghesso was the recipient of the Italian Telecom Award for his thesis work in 1993. He is a Reviewer of the IEEE TRANSACTIONS ON ELECTRON DEVICES and the IEEE ELECTRON DEVICE LETTERS. He has been the Technical Program Chair of the Workshop on Compound Semiconductors Devices and Integrated Circuits held in Europe (WOCSDICE) 2001, the General Chair of the Heterostructures Technology Workshop (HETECH) 2001 and 2008, and the General Chair of WOCSDICE 2007. He is in the steering committee of several European conferences, such as European Solid State Device Conference, HETECH, and WOCSDICE. Since 2005, he has been serving for the IEEE International Reliability Physics Symposium in the TPC, and in 2009, he entered into the management committee. He also served for several years for the IEEE International Electron Device Meeting. He was in the Quantum Electronics and Compound Semiconductors subcommittee as a member in 2003 and as Chair in 2004 and 2005, while in 2006 and 2007, he has been in the Executive Committee as European Arrangements Chair. He has also been involved in the Technical Program Committee of several international conferences, such as the European Symposium on Reliability of Electron Devices, Failure Physics and Analysis, Electrical Overstress/Electrostatic Discharge (EOS/ESD) Symposium, the International EOS/ESD Workshop, and the International Conference on Solid State Devices and Materials. Finally, he has been the Editor of the IEEE ELECTRON DEVICE LETTERS for the compound-semiconductor-device area since 2007.
E. Fred Schubert (S’93–F’99) received the Ph.D. degree in electrical engineering from the University of Stuttgart, Stuttgart, Germany, in 1986.

From 1981 to 1985, he worked on compound semiconductor crystal growth with the Max Planck Institute for Solid State Research, Stuttgart, as a member of Scientific Staff. During 1985 to 1995, he was a Postdoctoral Fellow, member of Technical Staff, and Principal Investigator with AT&T Bell Laboratories in Holmdel and Murray Hill, NJ. In 1995, he entered the academia at Boston University, Boston, Massachusetts, as a Professor of Electrical Engineering. He joined Rensselaer Polytechnic Institute, Troy, NY, in 2002, where he is the Wellfleet Senior Constellation Professor of the Future Chips Constellation with appointments in the Electrical Engineering and Physics Departments. He is the founding Director of the Smart Lighting Engineering Research Center awarded by the National Science Foundation to Rensselaer Polytechnic Institute in 2008. He has made pioneering contributions to the field of compound semiconductor materials and devices, particularly to the fields of alloy broadening, delta doping, resonant-cavity light-emitting diodes, enhanced spontaneous emission in Er-doped Si/SiO\(_2\) microcavities, elimination of unipolar heterojunction band discontinuities, p-type superlattice doping in AlGaN, photonic-crystal light-emitting diodes, polarization-enhanced ohmic contacts, omnidirectional reflectors, low-refractive-index materials, antireflection coatings, light-emitting diodes with remote phosphors, and solid-state lighting. He is the Inventor or Coinventor of 30 U.S. patents and has authored or coauthored more than 275 publications. He authored the books *Doping in III–V Semiconductors* (1993), *Delta Doping in Semiconductors* (1996), and the first and second editions of *Light-Emitting Diodes* (2003 and 2006); the latter book was translated into Russian and Japanese.

Dr. Schubert is a Fellow of SPIE (1999), OSA (2000), and APS (2001) and an honorary member of Eta Kappa Nu (2004). He is the recipient of the Literature Prize of Verein Deutscher Elektrotechniker for the book “Doping in III–V Semiconductors” (1994), the Alexander von Humboldt Senior Research Award (1999), the Boston University Provost Innovation Award (2000), the Discover Magazine Award for Technological Innovation (2000), the R&D 100 Award for RCLED (2001), the RPI Trustees Award for Faculty Achievement (2002 and 2008), the 25 Most Innovative Micro- and Nano-Products of the Year Award of R&D Magazine (2007), and the Scientific American 50 Award (2007).