Research Frontiers of Solid State Lighting

Feature the latest development and future direction in solid state lighting technologies and applications

Organized by:

Photonics Research Center, School of EEE, Nanyang Technological University

Society for Information Display

IEEE Photonics Society

Invited overseas speakers:

Dr. Jeff Y. Tsao (Sandia National Lab)

Professor Xu Jian (Pennsylvania State University)

Professor Liao Liang-Sheng (Kodak and Suzhou University)

Professor Kuo Hao-chung, Henry (National Chiao Tung University)

Date: 1 Dec 2009 (Tuesday)

Venue: LT24@NTU

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Research Frontiers of Solid State Lighting (1st December 2009@LT24, NTU)

08:30-08:55	Registration	
08:55-09:00	Opening Address	
09:00-10:00	Dr. Jeff Y. Tsao Sandia National Lab	Solid-State Lighting: Science, Technology and Economic Perspectives
10:00-11:00	Prof. Xu Jian Penn State Univ	Colloidal Nanocrystal-Based LEDs and LED Matrix Arrays Fabricated on Plastic
11:00-11:15	Tea Break	
11:15-12:15	Prof. Liao Liang-Sheng Suzhou University	Tandem Organic Light-Emitting Diode and Its Application in Solid-State Lighting
12:15-13:15	Prof Kuo Hao-Chung, Henry National Chiao Tung University	High Brightness GaN-based LEDs for Solid State Lighting Applications
13:15-14:00	Lunch	
14:00-14:30	Prof. Hilmi Volkan Demir NTU	Nanostructured White LEDs of Nanocrystal Quantum Dot Emitters for High Quality Mesopic Solid State Lighting
14:30-15:00	Dr. Sudhiranjan Tripathy IMRE	GaN-on-silicon approach for cost effective Solid State Lighting
15:00-15:30	Prof. Sun Xiaowei NTU	ZnO nanorod homojunction LEDs
15:30-15:45	Tea break	
15:45-16:15	Prof. Aaron Danner NUS	Surface texturing in LEDs
16:15-16:45	Dr. Yoga Divayana NTU	The Förster-type exciton quenching mechanism and its impact to the quantum efficiency and exciton diffusion in organic semiconductor
16:45-17:15	Prof. Andrew Clive Grimsdale NTU	Optimising bridged phenylenes as blue-light emitters
17:15-17:45	Dr. Soh Chew Beng IMRE	A unique way to achieve phosphor-less white light emission and the challenges

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Dr. Jeffrey Y. Tsao

Presentation: Solid-State Lighting: Science, Technology and Economic Perspectives

Throughout its history, lighting technology has made tremendous progress: the efficiency with which power is converted into usable light has increased 2.8 orders of magnitude over three centuries. This progress has, in turn, fueled large increases in the consumption of light and productivity of human society. In this talk, we review an emerging new technology, solid-state lighting: the underlying advances in physics and materials that have enabled its current performance; its frontier performance potential; the energy consumption and human productivity benefits associated with achieving this performance potential; and scientific challenges that lie enroute

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Prof. Xu Jian

Presentation: Colloidal Nanocrystal-Based LEDs and LED Matrix Arrays Fabricated on Plastic

We report in this conference the first demonstration of mechanically flexible quantum dot light emitting-diodes (QD-LEDs) of all three primary colors (red, green and blue). The QD-LEDs have been fabricated over poly(ethylene-terephthalate) (PET) substrates and exhibited high brightness, saturated colors and pronounced flexibility with a critical bending radius of ~5mm. The efficiencies of the flexible QD-LEDs are comparable to the devices fabricated on rigid substrates, suggesting the intrinsic flexibility of the quantum dot-based displays.

Prof. Liao Liang-Sheng

Presentation: Tandem Organic-Light Emitting Diode and Its Applications in Solid-State Lighting

Complementary to inorganic light-emitting diode (LED) which is an excellent point lighting source, organic light-emitting diode (OLED) is a potentially useful areal lighting source due to its unique features, such as simple device structure, areal emission, and soft white color. However, OLED is basically a current-driven device. Its brightness increases with increasing current density, but its operational lifetime decreases with increasing current density. It is therefore a great challenge to improve both luminance and operational lifetime. As an areal lighting source, OLED needs to produce high brightness (about or higher than 2000 cd/m^2). Thus, it is even more difficult for OLED to maintain a required lifetime in the lighting applications.

In order to cope with the dilemma situation between high brightness and long lifetime, a tandem OLED, which is constructed by vertically stacking several individual electroluminescent (EL) units, each with a structure of hole-transporting layer/light-emitting layer/electron-transporting layer, can be used to produce white color with both high brightness and long lifetime.

In this talk, the speaker will describe how to design a tandem OLED and how to make an organic solid-state lighting source using the tandem structure.

Liao Liang-Sheng (Larry) is a Professor and the Associate Director of Functional Nano & Soft Materials Laboratory (FUNSOM) at Soochow University, Suzhou, P.R. of China. He was trained as a semiconductor physicist from Nanchang University and Nanjing University, respectively. After his Ph.D. program at Nanjing University, he finished his post-doctoral research at Fudan University in 1997 and was appointed as an Associate Professor in the Department of Physics at Fudan University. From 1998 to 2000, he was a Research Fellow in the Center Of Super-Diamond and Advanced Films (COSDAF), City University of Hong Kong. From December 2000 to March 2009, he worked as a Senior Research Scientist in the Research Laboratories, Eastman Kodak Company in USA.

Dr. Liao’s research interests are semiconductor physics and semiconductor device physics; organic semiconductor devices; surface and interface studies of thin films; semiconductor thin film materials.

Dr. Liao has published over 100 papers with more than 1500 citations (SCI h-index = 20). Within the 8 years working at Kodak, he filed 58 US patent applications (24 of which have been granted). He invented organic tandem OLEDs with full organic intermediate connectors; fabricated high-performance full-color OLEDs for display applications; fabricated high-performance white OLEDs for solid-state lighting applications; investigated coherence characteristics of electrically excited tandem OLEDs. Awards include: "First Rate Award in Progress of Science and Technology", by Jiangsu Provincial Government in 1998, and “Distinguished Inventor”, by Eastman Kodak Company in 2007.

Prof Kuo Hao-chung, Henry

Presentation: High Brightness GaN-based LEDs for Solid State Lighting Applications

GaN-based Light emitting diodes (LEDs) have considered the best candidate for replacing traditional lighting sources in the future for the properties of energy efficient and environmental friendly. The main reason obstructs the realization of solid state lighting so far was the low external quantum efficiency resulting from low internal quantum efficiency (IQE) and poor extraction efficiency (EXE). Several methods have been demonstrated for improving the efficiencies. Combining patterned sapphire substrate and epitaxial lateral overgrowth techniques has proposed to reduce threading dislocation effectively and has great benefit in improving IQE and current droop issues. Regarding to EXE, a novel structure called thin-GaN fabricated by wafer bonding and laser lift-off shows a great enhancement over 60% than the traditional devices after package. Fabrication nano-structures on the surface also brings remarkable enhancement in EXE due to eliminate the internal total reflection and photon scattering phenomenon. Besides, these techniques were also suitable to apply on the III-V or Si solar cells to increase the device performance as well. Finally, some recent results on GaN substrate prepared by HVPE and GaN based LED and near RT CW GaN based VCSEL will be presented.

Kuo Hao-Chung (M'98–SM'06) received the B.S. degree in physics from National Taiwan University, Taiwan, R.O.C., the M.S. degree in electrical and computer engineering from Rutgers University, New Brunswick, NJ, in 1995, and the Ph.D. degree from Electrical and Computer Engineering Department, University of Illinois at Urbana Champaign, in 1999. He has an extensive professional career both in research and industrial research institutions that includes: Research Consultant in Lucent Technologies, Bell Laboratories (1993–1995); and a Member of Technical Staff in Fiber-Optics Division at Agilent Technologies (1999–2001) and LuxNet Corporation (2001–2002). Hong Kong ASTRI (2004). Since October 2002, he has been with the National Chiao Tung University as a Faculty Member of the Institute of Electro-Optical Engineering. He is now the Director, Department of Photonics and Institute of Electro-Optical Engineering, NCTU. His current research interests include semiconductor lasers, VCSELs, blue and UV LED lasers, quantum-confined optoelectronic structures, optoelectronic materials, and Solar cell. He has authored and coauthored 180 SCI journal papers, 200 conference papers and 6 granted and 10 pending patents. Prof. Kuo is the IEEE Senior member and Assoc. Editor of IEEE/OSA J. of Lightwave Technology and JSTQE-special issue Solid State Lighting. He received Ta-You Wu Young Scholar Award from National Science Council and Young Photonics researcher award in 2007.

Prof. Hilmi Volkan Demir

Presentation: Nanostructured White LEDs of Nanocrystal Quantum Dot Emitters for High Quality Mesopic Solid State Lighting

Förster-type nonradiative resonance energy transfer enables fast energy transportation at the nanoscale. For colloidal semiconductor nanocrystal quantum dot (QDs), this allows for zipping excitons from electronically excited donors to luminescent acceptor QDs over a distance of <10 nm. Using energy transfer, we develop and demonstrate a new class of mesopic solid state lighting white LEDs that employ these quantum dot luminophors, leading to high-quality photometric properties such as high scotopic-to-photopic ratio, high color rendering index, and high luminous efficacy of optical radiation, to enhance visual acuity and energy efficiency, which is strategically important for Singapore and around the globe. In this talk, we will present our results on the development and demonstration of these QD-integrated LEDs for high-quality lighting

References

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2. N. Cicek, S. Nizamoglu, T. Özel, E. Mutlugun, D. U. Karatay, V. Lesnyak, T. Otto, N. Gaponik, A. Eychmüller, and H. V. Demir, *Applied Physics Letters* **94**, 061105 (2009).
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4. S. Nizamoglu, E. Sari, J.-H. Baek, I.-H. Lee, and H. V. Demir, *IEEE Journal of Special Topics in Quantum Electronics* (special issue on *Solid State Lighting -- SSL*) **15**, 1163 (2009).

Hilmi Volkan Demir received his B.Sc. degree in electrical and electronics engineering from Bilkent University in 1998, and his M.S. and Ph.D. degrees in electrical engineering from Stanford University in 2000 and 2004, respectively. He received his Docent title (assoc. prof.) in optics and photonics from the Turkish Council of Higher Education in 2007. Since September 2004, he has been working as a faculty member at the Department of Electrical and Electronics Engineering and at the Department of Physics at Bilkent University. In August 2009, he is assigned as Nanyang Associate Professor at the School of Electrical and Electronic Engineering (Microelectronics Div.) and the School of Physical and Mathematical Sciences (Physics and Applied Physics Div.). Along with his colleagues, he is currently working on the establishment of Nanyang Centre for Solid State Lighting and Displays. His present research interests and projects include the development and demonstration of high-quality solid state lighting and high-efficiency photovoltaics using semiconductor quantum dot nanocrystals, resonance energy transfer driven devices, plasmonic devices, biomimetic optoelectronic devices, and bioimplant metamaterial sensors. Dr. Demir is a recipient of 2009 National Research Foundation Fellowship Award (NRF RF) and 2007 European Young Investigator Award (European Science Foundation ESF-EURYI).

Dr. Sudhiranjan Tripathy

Presentation: GaN-on-silicon approach for cost effective Solid State Lighting

InGaN/GaN-based light emitting diodes (LEDs)-based solid state lighting has emerged as the most energy efficient technology for general illumination. To reduce cost of such lighting technologies, majority of LED manufacturing companies are now planning to scale up the GaN epitaxy to large area substrates. For large scale commercial applications, GaN-on-silicon approach would be quite attractive compared to bulk GaN, SiC, and sapphire substrates. However, for the realization of high brightness LEDs from Si, substrate removal is a necessary step. This demands additional processing steps and difficulties while transferring large area GaN. Recently, we have explored an alternate solution by switching the epitaxy to large area silicon-on-insulator (SOI) substrates for nitride devices. The absorption of visible light from LEDs will be much lower on very thin SOI due to a large dielectric contrast at the Si/SiO2/Si substrate-interfaces, which leads to strong EL intensity modulation. In this talk, we will present our recent work on InGaN/GaN light emitters with photonic crystal (PhC) structures on thin silicon-on-insulator (SOI) substrates. In order to improve light extraction, surface nanopatterning has been carried out on green and deep green LED surfaces. The processing conditions are varied to improve the outcoupling of visible emission from these PhC LED structures on SOI. The combination of PhC structures and a higher substrate reflectance in the longer wavelength regions results in substantial increase in emission intensity from green LEDs on SOI.

Sudhiranjan Tripathy is a Project Leader in the Solid State Lighting Programme at Institute of Materials Research and Engineering, Agency for Science, Technology, and Research (A*STAR) Singapore. His research interests include R & D on III-nitride materials and devices, Optical spectroscopy, ZnO-based nanostructures, nanophotonics, and plasmonics. He has collectively contributed to more than 140 research papers published from IMRE Singapore.

Prof. Sun Xiaowei

Presentation: ZnO nanorod homojunction LEDs

In this talk, we report our recent results on fabrication of reliable ZnO vertically aligned rod-based homojunction UV/visible light-emitting diodes. The nanorod were uniformly grown on both Si and sapphire substrates by metal catalyst-free vapor phase transport method, followed by As^+/P^+ ion implantations and thermal activation to convert top layer of the intrinsic nanorod into *p*-type. Devices doped with either As or P ions give similar electrical and electroluminescence properties. Single homojunction nanorods have been probed by nanomanipulator and show typical rectifying behavior. The electroluminescence of as-prepared diodes shows a strong UV ZnO band-edge emission, which is still detectable five months after fabrication. Our results indicate that we are probably close to a p-type doping solution of ZnO, and these ZnO LEDs can potentially be used in extremely low cost indicators.

Sun Xiaowei was born in Beijing, China. From 1986 to 1994, he studied at Tianjin University, China, where he received his B.Eng., M.Eng. and Ph.D. degrees all in photonics. From 1994 to 1998, he studied at the Hong Kong University of Science and Technology where he received his second Ph.D. degree in electrical and electronic engineering. He has been with the Division of Microelectronics in the School of Electrical and Electronic Engineering of Nanyang Technological University since 1998 first as an Assistant Professor, and was promoted to Associate Professor in 2006. His research interests focus on MOCVD growth of ZnO, display technologies, and nanotechnology. Dr. Sun is a Fellow of Institute of Physics (FInstP), a Senior Member of IEEE and a member of Society for Information Display (SID). He is the founding Chair of SID Singapore and Malaysia Chapter.

Prof. Aaron Danner

Presentation: Surface texturing in LEDs

A number of techniques for improving light extraction from the surface of inexpensive LEDs will be described and compared, including chemical surface roughening, patterned photonic crystals, semi-random photonic crystals, and antireflection coatings. Different methods for reducing surface reflections are appropriate for different types of LEDs, given the comparative costs of their respective manufacture.

Aaron Danner is an Assistant Professor at the National University of Singapore where his research group focuses on solar cell packaging and gradient index optics. Prior to his appointment to NUS, he was employed at Agilent (now Avago) Technologies, where he worked on vertical cavity lasers and LEDs. He received his Ph.D. in Electrical Engineering from the University of Illinois at Urbana-Champaign in 2005. He is a fellow of the U.S. National Science Foundation and a member of the IEEE-Lasers and Electro-Optics Society (LEOS) and the Optical Society of America (OSA).

Dr. Yoga Divayana

Presentation: The Förster-type exciton quenching mechanism and its impact to the quantum efficiency and exciton diffusion in organic semiconductor

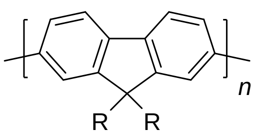
Organic light-emitting diodes (OLEDs) have emerged as one of the most important general lighting technologies of the future. The current state-of-the-art OLED utilizes various different layers which function separately as carriers transport, carriers and excitons blocker, and emitting layer. The emission layer of the OLED is normally formed by a host-guest system obtained by co-evaporating a small amount of guest molecule in the matrix of host material. It is generally accepted that in a host-guest system, concentration quenching is caused by molecules aggregation. As concentration of guest molecule increases, a drop in quantum efficiency is followed by a red-shift in the emission spectrum, characteristics of aggregate state. Here we show that concentration quenching is also caused by another Förster-type interaction. We investigate this Förster-type exciton quenching process in various organic molecules and its effect to the exciton diffusion.

Yoga Divayana is a Singapore Millennium Foundation (SMF) Research Fellow at the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He obtained his B. Eng (1st class) and PhD with the same school in 2004 and 2008, respectively. He is recipient of the prestigious Institute of Electrical and Electronics Engineers, Laser and Electro-Optics Society Graduate Student Fellowship and Singapore Millennium Foundation Post-Doctoral Fellowship.

Prof. Andrew Clive Grimsdale

Presentation: Optimising bridged phenylenes as blue-light emitters

Bridged phenylene polymers such as polyfluorenes (1) are an important class of wide bandgap conjugated materials for use in optoelectronic applications such as light-emitting diodes, polymer lasers, and organic solar cells. In this talk, work on optimizing the performance of polyfluorenes and related materials such as poly(indeonfluorene)s (**2**) and poly(ladder-type pentaphenylene)s (3) in blue-light emitting devices will be presented. Issues such as color purity, efficient charge injection, and avoidance of defect formation will be addressed..



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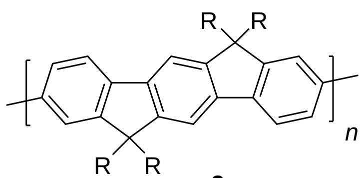

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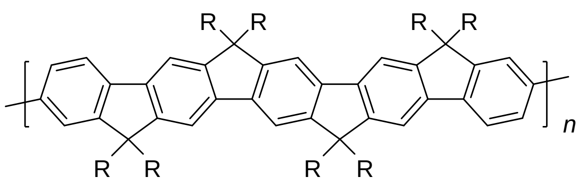

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Andrew Grimsdale was born in Waiouru, New Zealand in 1963 and graduated from the University of Auckland. He received his PhD there under the supervision of Professor R. C. Cambie in 1990 for work on the synthesis of analogues of biologically active drimane sesquiterpenes. He then undertook postdoctoral work on photochromic and electroactive materials with Professor Andrew Pelter at the University of Wales, Swansea (1990-1994), and with Professor Andrew Holmes at the University of Cambridge on electroluminescent polymers (1994-1997). From 1999-2005 he was project leader in charge of research into conjugated polymers in the group of Professor Klaus Müllen at the Max-Planck Institute for Polymer Research at Mainz. He rejoined the group of Professor Holmes in Melbourne in 2005 to work on materials for photovoltaic devices, before moving to Nanyang Technological University, in Singapore in November 2006. He is currently an Assistant Professor in the School of Materials Science and Engineering there, where his research interests are into synthesis of materials for optoelectronic applications and on the formation of nanomaterials by self-assembly.

Dr. Soh Chew Beng

Presentation: A unique way to achieve phosphor-less white light emission and the challenges

White LEDs are the engine of solid state lighting and currently the phosphors-converted white LEDs are dominant in the research and industry of solid state lighting. Due to the limiting factors of phosphors and the heavily protected IP mines, alternative technologies of achieving white light emissions are desired to move the solid state lighting technology forward and meet the demand of mass markets.

In this presentation an all nitride semiconductor white LED was proposed and fabricated using the InGaN quantum dots. The InGaN quantum dots, grown by MOCVD, possess the advantages such as three-dimensional confinement, less strain, and less exposure to defects, and thus have the potential of achieving high quantum efficiency and high stability which are essential characteristics of LEDs. In addition, the InGaN quantum dots provide freedom to adjust the color properties of white light emission and therefore are capable to achieve high color rendering index. A few examples will be showcased on the high internal quantum efficiency of InGaN quantum dots, red nitride-based LEDs, white all nitride LEDs, and color tuning flexibility. We will also address the challenges facing the InGaN quantum dots-based white LEDs such as lighting extraction efficiency and heat dissipation and demonstrate our preliminary work to solve the problems.

Soh Chew Beng obtained his PhD from the ECE, NUS in 2006. He is currently doing his research in IMRE as a Senior Research Engineer under the Solid State Lighting Program and the Materials Growth Group. He has involved in the White LEDs Flagship project as the co-PL and has published more than 30 international papers as well as having filed four patents in the area of nitride-based materials and LEDs growth. He also served as the reviewer for several international journals. His current research interest is in the area of nitride growth, characterization and fabrication as well as patterning to generate nanostructures and devices.