Study Session on

Phosphor-Free White LEDs for Solid State Lighting

January 11, 2013
Carrefour Sherbrooke Ballroom
475 Sherbrooke West
Montreal, QC

Future Lighting Solutions
Leapfrog Lighting
3M Canada
Meaglow Ltd.
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Program

07:30 - 08:30	**Registration and breakfast**	
08:30 - 08:45	**Welcome Remarks**	Andrew Kirk Interim Dean of Engineering McGill University
08:45 - 09:00	**Introduction to NSERC Emerging Lighting Solutions Network (ELSN)**	Zetian Mi, McGill University
09:00 - 09:40	**Keynote Talk**	*A revolution in lighting: light-emitting diodes* E. Fred Schubert Rensselaer Polytechnic Institute
09:40 - 10:20	**Keynote Talk**	*III-nitride nanowires for solid state lighting* George Wang Sandia National Labs
10:20 - 10:50	**Coffee break**	
10:50 - 11:50	**Lighting technologies: current status, challenges and emerging opportunities**	Patrick Durand, Future Lighting Solutions Lorne Whitehead, University of British Columbia Zetian Mi, McGill University William Wong, University of Waterloo
11:50- 12:50	**Lunch and networking**	
12:50 - 14:30	**ELSN: core expertise and emerging opportunities**	Kirk Bevan and Hong Guo, McGill University Thomas Szkopek, McGill University Richard Arès and Vincent Aimez, Université de Sherbrooke Lawrence Chen and David Plant, McGill University Pat Kambhampati (McGill), Richard Leonelli and Carlos Silva (Université de Montréal) Gianluigi Botton, McMaster University Ishiang Shih, McGill University
14:30 - 14:40	**Coffee break**	
14:40 - 15:10	**Overview of NSERC Strategic Network Grants Program**	Patrick Suter, Research Partnerships Program, NSERC
15:10 - 17:00	**Panel Discussion Solid state lighting rising: opportunities for Canada**	
17:00 - 18:30	**Cocktail and networking**	

KEYNOTE TALKS

9:00 - 10:20
Session Chair: Zetian Mi, McGill University

9:00 - 9:40 *A revolution in lighting: light-emitting diodes*
E. Fred Schubert
Rensselaer Polytechnic Institute

ABSTRACT: Semiconductor materials have enabled devices that assist us in a multitude of ways. During recent years, semiconductor materials have demonstrated yet another ability: The ability to generate white, pleasant light with very high efficiency. LEDs can be 10 times more efficient than conventional light bulbs and 3 times more efficient than fluorescent lamps. As a consequence, we are entering a new era in lighting, in which LED-based lighting enables a cleaner and greener world. In this presentation, I will discuss the rich history, the formidable challenges, the enormous impact, and the unprecedented opportunities offered by LED-based lighting.

E. Fred Schubert made pioneering contributions to the field of compound semiconductor materials and devices, particularly to the doping of compound semiconductors and to the development and understanding of light-emitting diodes. He is currently a distinguished professor at Rensselaer Polytechnic Institute in Troy NY. He authored the books Doping in III–V Semiconductors (1992), Delta Doping of Semiconductors (1996), and Light-Emitting Diodes (1st edition 2003 and 2nd edition 2006). He is co-inventor of more than 30 US patents and co-authored more than 300 publications. He is a Fellow of the APS, IEEE, OSA, and SPIE and has received several awards.

9:40 - 10:20 *III-nitride nanowires for solid state lighting*
George Wang
Sandia National Labs

ABSTRACT: Nanowires based on the III nitride (AlGaInN) materials system have attracted attention as potential nanoscale building blocks in LEDs, lasers, sensors, photovoltaics, and high speed electronics. Compared to conventional LEDs based on planar architectures, future LEDs based on III-nitride nanowires have several potential advantages which could enable cheaper and more efficient lighting. However, before their promise can be fully realized, several challenges must be addressed in the areas of controlled nanowire synthesis, understanding and controlling the nanowire properties, and nanowire device integration. I will discuss results involving the aligned, bottom-up growth of Ni-catalyzed GaN and III-nitride core-shell nanowires, along with extensive results providing insights into the nanowire properties obtained using cutting-edge structural, electrical, and optical nanocharacterization techniques. I will also describe a more recent "top-down" approach for fabricating ordered arrays of high quality GaN-based nanowires with controllable height, pitch and diameter. Using this top-down approach, both axial and radial nanowire device heterostructures can be realized. The fabrication, structure, optical properties, lasing characteristics, and performance of top-down-fabricated nanowires and nanowire LEDs and lasers will be discussed. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

George T. Wang is a Principal Member of the Technical Staff in the Advanced Materials Sciences Department at Sandia National Laboratories. He received his B.S. degree in Chemical Engineering, with Highest Honors, from the University of Texas at Austin in 1997, and M.S. and Ph.D. degrees in Chemical Engineering from Stanford University in 1999 and 2002, where he was awarded the National Science Foundation Graduate Fellowship and the David Sen-Lin Lee Fellowship. At Sandia, Dr. Wang's primary research efforts have focused on the synthesis, properties, and applications of III-nitride based semiconductor nanowires. Dr. Wang is a currently a Senior Leadership Council member at the $18M Solid State Lighting Science Energy Frontier Research Center (EFRC) at Sandia, where he leads an effort on nanowire-based lighting. Dr. Wang received his Ph.D. in chemical engineering from Stanford University in 2002 and has authored or co-authored 50 journal publications, which have received over 1000 citations.

Lighting technologies: current status, challenges, and emerging opportunities

10:50 - 11:50
Session Chair: Kirk Bevan, McGill University

10:50 - 11:05 *Developing applications with the optimal LED technology*
Patrick Durand, Worldwide Technical Director
Future Lighting Solutions

ABSTRACT: LED vendors have an enormous challenge in developing SSL components to address the evolving application needs from lighting OEMs. Furthermore, there is increased competitive pressure to deliver higher performing products at a lower cost. On the other hand, lighting OEMs are being challenged with an increasing number of technology choices to develop their application. High power LEDs for the past 5+ years had been the only choice for lighting OEMs. However, in the past year, mid power LEDs and chip on board (COB) LEDs have gained significant traction where different technologies can now be leveraged for the same application. The various strategic options to develop winning applications from the perspective of both the LED vendor and the lighting OEM will be covered in this brief lecture.

Patrick Durand has the global responsibility of enabling adoption of solid state lighting at Future Lighting Solutions. His role includes creating training programs for field engineers and customers, developing tools and solutions to simplify LED designs, partnering with technology vendors to define and launch new LED systems, and working directly with customers to solve application challenges. Patrick has received a Bachelor of Electrical Engineering from Carleton University as well as a Bachelor of Commerce and an MBA from the University of Ottawa. He can be reached at patrick.durand@future.ca

11:05 - 11:20 *Improving the CIE Colour Rendering Index – how this can be done and why it matters*
Lorne Whitehead
University of British Columbia

ABSTRACT: Colour rendering of light sources is a surprisingly subtle concept that many find difficult to fully understand. It is becoming increasingly important because of the unavoidable trade-off between the colour rendering quality of light sources and their luminous efficacy - which has significant economic and social consequences. A related issue is that recent observations show the current CIE Colour Rendering Index (CRI) does a poor job of assessing the colour rendering quality of the light from some narrow-band light sources. This presentation concerns a recent collaboration including R. Luo, J. Schanda, and K.Smet, in which we have found that at least part of the problem is non-uniformity of the spectral sensitivity of the current CRI metric. We have developed an improved computational procedure that eliminates that problem, and numerous groups are now assessing it. The hope is that a better measure of colour rendering will assist researchers in establishing the importance of lighting quality as opposed to quantity, in turn leading to more pleasant and sustainable interior environments.
The inadequacy of the current CRI has become particularly evident with the consideration of white light sources employing several narrow band light emitters, such as light emitting diodes. A key problem with the current CRI calculation method, and also with some previ-

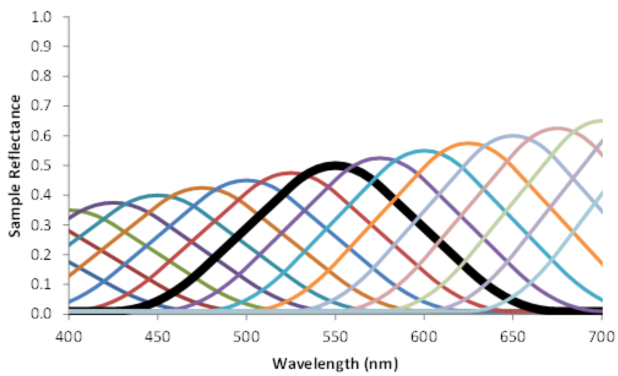

Figure 1. The HL17 reflectance spectra which optimize the spectral response uniformity for calculation of CRI. One of the spectra is shown in bold, as an example.

ously suggested improvements, has been their lack of spectral uniformity in their sensitivity to sharp spectral features. One way of obtaining greater response uniformity would be to have a series of test samples in which a fairly smooth spectral feature shifts, from one sample to the next, through the spectrum. By employing this guiding principle, we have devised an improved sample set that substantially eliminates the problem of non-uniform spectral sensitivity.

We propose the HL17 spectra as an improved sample set for more accurate evaluations of the average colour rendering difference between two spectral irradiance distributions. However, even with this improved accuracy, we are not suggesting that the CRI should be used alone for evaluation of the general level of human preference of a given light source. In particular, this new work does not imply that Planckian and/or daylight spectra are necessarily optimal for human vision. Nevertheless, the CRI has been an important tool for many years, and we feel that with a new sample set as described here, it can remain a useful metric in the future, as energy efficiency concerns grow and narrow band light emitters become common.

Lorne A. Whitehead received a Ph.D. in physics from the University of British Columbia and is also a Professional Engineer. His career has involved sustained innovation in technology, business, and administration. From 1983 to 1993 he served as CEO of TIR Systems, a UBC spin-off company that he founded and which eventually grew to 200 employees prior to being purchased by Philips in 2007. Since joining UBC in 1994, he has been a professor and held an NSERC Industrial Research Chair in the Department of Physics and Astronomy, carrying out studies of the optical, electrical, and mechanical properties of micro-structured surfaces, a field in which he holds more than 100 patents. His technology is used in many computer screens and televisions. He has also helped to start four more new companies – Brightside (recently purchased by Dolby Corporation), Boreal Genomics, SunCentral Inc. and most recently CLEAR Inc. In addition to his research at UBC, Dr. Whitehead has held a number of administrative positions including Associate Dean, Dean pro tem, Vice-President Academic and Leader of Education Innovation. He is currently UBC's Special Advisor on Innovation, Entrepreneurship and Research, and in this capacity he also serves as the Project Director for the Bay View Alliance – a group of seven major research universities collaborating on applying improvement science to the challenges of leadership in advancing pedagogical effectiveness. Dr. Whitehead has also served on the Boards of several non-profit organizations and is currently the Treasurer of the Commission Internationale de L'Eclairage, based in Vienna.

11:20 - 11:35 *Phosphor-free nanowire white LEDs*
Zetian Mi
McGill University

ABSTRACT: Phosphor-free white light emitting diodes (LEDs), that can be fabricated on low cost, large area substrates and can display high luminous flux, hold immense promise for the emerging solid state lighting. Although tremendous progress has been made for InGaN/GaN quantum well LEDs, the performance of such devices in the green, yellow, and red wavelength ranges has been plagued by very low efficiency and "efficiency droop", ***i.e.*** the decrease of the external quantum efficiency with increasing current. In this context, we have developed full-color, catalyst-free InGaN/GaN dot-in-a-wire light emitting diodes (LEDs) directly on Si substrates, with the emission characteristics controlled by the dot properties in a single epitaxial growth step. With the use of *p*-type modulation doping in the dot-in-a-wire heterostructures, we have demonstrated the most efficient phosphor-free white LEDs ever reported, which exhibit an internal quantum efficiency of ~ 56.8%, nearly unaltered CIE chromaticity coordinates with increasing injection current, and virtually zero efficiency droop at current densities up to ~ 2,000 A/cm^2. The remarkable performance is attributed to the superior 3-dimensional carrier confinement provided by the electronically coupled dot-in-a-wire heterostructures, the nearly defect- and strain-free GaN nanowires, and the significantly enhanced hole transport due to the *p*-type modulation doping.

Zetian Mi is an Associate Professor in the Department of Electrical and Computer Engineering at McGill University. He received the Ph.D. degree in Applied Physics from the University of Michigan in 2006. His teaching and research interests are in the areas of III-nitride semiconductors, solid state lighting, low dimensional nanostructures, nanophotonics, and artificial photosynthesis. He has published 5 book chapters, 70 refereed journal papers, and more than 120 refereed conference papers. Prof. Mi has received the Hydro-Quebec Nano-Engineering Scholar Award in 2009, the William Dawson Scholar Award in 2011, and the Christophe Pierre Award for Research Excellence (Early Career) in 2012 at McGill University. He has also received the Young Investigator Award from the 27th North American Molecular Beam Epitaxy Conference in 2010. Prof. Mi currently serves as the Associate Editor of IEEE Journal of Lightwave Technology.

11:35 - 11:50 *Laser processing for materials integration*
William Wong
University of Waterloo

ABSTRACT: In many cases, the integration and enhancement of thin-film and nanomaterials by direct deposition involves substantial sacrifices in the materials quality and subsequent device performance. The ability to combine III-nitride light-emitting devices with dissimilar substrates through a lift-off and transfer process allows for the direct integration of materials systems selected and pre-fabricated exclusively for optimal device performance rather than for growth compatibility. For example, integrating silicon with GaN-based devices creates opportunities to combine Si-based integrated-circuit technology with III-nitride optoelectronics for display and sensor applications. Furthermore, transferring pre-fabricated devices from common sapphire growth substrates onto more thermally and electrically conductive substrates such as Cu may achieve enhanced GaN-based device performance.
A review of the laser liftoff process will be given with an overview of how the technology

enables novel integration of disparate materials. Examples ranging from the integration of (In,Ga)N-based light-emitting diodes (LEDs) with Si by means of transient liquid phase (TLP) Pd-In bonding and LLO, in which the separation of the GaN is accomplished by laser irradiation through the transparent sapphire substrate, to blue lasers on copper substrates will be discussed. By using a low-temperature TLP bonding process in conjunction with LLO, one of the first demonstrations of blue LEDs on Si was demonstrated in 2000. This process is now used in commercial applications and enables ultra-high brightness white LEDs having > 100 lumens/Watt efficiency. In addition, the fabrication of continuous-wave InGaN multiple-quantum-well laser diodes on Cu substrates with light output three times greater than comparable conventional blue LDs has demonstrated the effectiveness of the “paste and cut” methodology to enhance thin-film microsystems. The integration of InGaN-based nanowire LEDs onto different platforms provides exciting new opportunities for LLO in applications for solid-state lighting and display applications.

William S. Wong is an Associate Professor in the Department of Electrical and Computer Engineering and Director of the Giga-to-Nanoelectronics Center at the University of Waterloo. Professor Wong received his Ph.D. from the University of California, Berkeley in 1999. From 2000-2010, William was a Senior Member of Research Staff at the Palo Alto Research Center (formerly Xerox PARC). His work includes laser liftoff techniques that enable the present generation of ultra-bright LEDs for solid-state lighting. While at PARC, he pioneered novel processing technologies for printed large-area flexible electronics for image sensor arrays and displays. He is the holder of 50 U.S. patents (with 35 pending) and 80 publications in the area of electronic materials growth, processing, and characterization. He is a member of the IEEE, the Materials Research Society, and is on the Editorial Board of IEEE Electron Device Letters. He also is an invited organizer and elected committee member of the Electronic Materials Conference (EMC/TMS).

ELSN: core expertise and emerging opportunities

12:50 - 14:30
Session Chair: William Wong, University of Waterloo

12:50- 13:05 *Technology computer aided design (TCAD) of phosphor-free nanowire white LEDs*
Kirk Bevan and Hong Guo
McGill University

ABSTRACT: In this talk we will briefly review the general application of technology computer aided design (TCAD) in the semiconductor industry and expand upon its potential application to the solid state lighting industry. This natural metamorphosis follows directly from the ongoing cross over of semiconductor fab technology to the burgeoning solid state lighting industry. In particular, we expand on the possible development of new atomistic based TCAD models which offer a "bottom-up" approach to solid sate materials and device design, promising faster research and development turn around in the highly competitive global marketplace.

Kirk H. Bevan received his doctorate in electrical engineering at Purdue University in July 2008. From 2008 to early 2011 he was a joint post-doctoral fellow at Oak Ridge National Laboratory and McGill University. Since 2011 he has been on the faculty of engineering at McGill University in Materials Engineering. His research is focused on enabling the crossover of novel physical phenomena into real world engineering applications with an emphasis on electronic device materials design.

Hong Guo obtained Ph.D in theoretical condensed matter physics in 1987 from the University of Pittsburgh. He joined the faculty of McGill University in 1989 and is currently a James McGill Professor of Physics. His research spans the fields of nonequilibrium phenomena, materials physics, mesoscopic physics, quantum transport theory, nanoelectronic device physics, correlated electrons in low dimensional nanostructures, density functional theory, computational physics and applied mathematics. His group pioneered the state-of-the-art quantum transport modeling formalisms and software methods based on atomistic first principles. Guo has received three national research awards of Canada: the Killam Research Fellowship Award from the Canadian Council for the Arts in 2004; the Brockhouse Medal for Excellence in Experimental or Theoretical Condensed Matter Physics from the Canadian Association of Physicists in 2006; and the CAP-CRM Prize in Theoretical and Mathematical Physics from Canadian Association of Physicists in 2009. He was elected to Fellow of the American Physical Society in 2004, and elected to Fellow of the Royal Society of Canada in 2007.

13:05 - 13:20 *Graphene as transparent electrode and growth substance*
Thomas Szkopek
McGill University

ASBTRACT: Graphene, an atomic monolayer of carbon, is imbued with unique optical, electrical, mechanical and chemical properties. In the visible range, the optical response of graphene is well described by a quantized optical conductance $e^2/4\hbar$, resulting in an absorption of $\pi\alpha/n$ per graphene layer, where α is the fine structure constant and n the index of the

surrounding medium. The electrical sheet resistance of graphene can be brought down to <1000Ω by doping, suggesting application as a transparent electrode. Large-area monolayer graphene can be prepared by chemical vapour deposition at ~900°C using common hydrocarbon precursors such as alcohols. The chemical inertness and mechanical strength of graphene allow for relatively easy transfer to any target substrate. The prospects of graphene and related materials as a transparent, flexible, electrode for optoelectronics will be discussed.

Thomas Szkopek received his PhD from UCLA in 2006 in Electrical Engineering, and is presently an Associate Professor at the Department of Electrical and Computer Engineering at McGill University. He has made contributions to optoelectronics, quantum information, and more recently to the physics and applications of graphene and related materials. He holds a Canada Research Chair (tier 2) in Nanoscale Electronics, and has been a Nanoelectronics Scholar of the Canadian Institute for Advanced Research since 2007.

13:20 - 13:35 *LED research activities at Université de Sherbrooke*

Richard Arès and Vincent Aimez
Université de Sherbrooke

ABSTRACT: The Université de Sherbrooke has been active in GaN-based LED research since 2006. We are establishing a full fabrication process, from epitaxy to full packaged devices within our new research institute (3IT). This presentation will outline some of the current research activities surrounding LEDs. Light extraction remains a challenge for GaN -based LED because of the refractive index of the device materials that favour total internal reflection and light trapping within the structure. Several techniques have been proposed to increase light extraction from LEDs like chemical etching, surface nanostructuring or photonic crystals. Our approach is inspired by nature. In order to perform its fiery dance, the firefly must emit light in a very efficient manner. Studies have shown that the surface of its abdomen has a microstructure that is optimized to facilitate the emission of photons in the right spectral region. Through a collaboration with a Belgian research team, we have determined the corresponding microstructure to be fabricated on GaN to produce a similar effect. The structures were designed, modelled, fabricated and characterized. The results will be presented.

Richard Arès is a Professor in the Department of Mechanical Engineering and director of the laboratoire de synthèse et caractérisation des matériaux (LCSM) of the Institut Interdisciplinaire d'Innovation Technologique (3IT). He received his PhD in condensed matter Physics from Simon Fraser University in 1998. His research interests are in the areas of III-V semiconductor epitaxy processes and technology and concentrated photovoltaics. He has published 45 refereed journal papers, more than 100 conference presentations and has 6 patents pending.

Vincent Aimez is a Professor in the Department of Electrical Engineering and director of the laboratoire de nanofabrication et nanocaractérisation (LNN) of the Institut Interdisciplinaire d'Innovation Technologique (3IT). He is also joint director of the CNRS Unité Mixte Internationale - LN2. He is director of scientific partnerships at C2MI. He received his PhD in Electrical Engineering from the Université de Sherbrooke in 2000. He has published more than 80 refereed journal papers, more than 150 conference presentations and has 3 patents pending.

13:35 - 13:50 *White LEDs for visible light communications*

Lawrence Chen and David Plant
McGill University

ABSTRACT: There is considerable interest in the use of high brightness visible LEDs to develop indoor wireless communication systems capable of providing broadband connectivity. To date, there are two primary approaches for visible light communications, those based on (1) using blue phosphor-based LEDs and (2) separate red, greed, and blue LEDs. While the latter offers the possibility to exploit WDM strategies to increase overall transmission capacity, the former is preferred in terms of simplicity. However, phosphor-based white LEDs are limited in terms of modulation bandwidth and thus, spectrally efficient modulation formats, e.g., 4-ASK or M-QAM OFDM. The highest transmission capacity reported to date for visible light communications based on white LEDs is about 1.5 Gb/s. In this context, we propose to explore the use of phosphor-free nanowire white LEDs for broadband visible light communications. The project will serve to unite the technologies developed in other projects, e.g., phosphor-free nanowire white LEDs with graphene transparent electrodes, in the form of practical systems demonstrations. In this presentation, we will disucss briefly the approaches to develop a visible light communication system/testbed for broadband indoor wireless communications and the method to characterize the modulation bandwidth of phosphor-free nanowire white LEDs. Our objective is to demonstrate visible light communications using phosphor-free nanowire white LEDs at transmission speeds in excees of 5 Gb/s, thereby providing a promising approach for broadband indoor wireless connectivity.

Lawrence R. Chen has been a professor in the Department of Electrical and Computer Engineering at McGill University since 2000. He received his BEng in Electrical Engineering and Mathematics from McGill University in 1995, and the M.A.Sc. and PhD. in Electrical and Computer Engineering from the University of Toronto in 1997 and 2000, respectively. His research interests are in ultrafast photonics, fiber optics, and optical communications and include all-optical signal processing, arbitrary waveform generation, fiber lasers and amplifiers, and fiber gratings. He is an Associate Editor (Canada) for the IEEE Photonics Society Newsletter, a Topical Editor for Optics Letters, and a member of the editorial advisory board for Optics Communications. He is a Fellow of the Optical Society of America.

David V. Plant has been a professor in the Department of Electrical and Computer Engineering at McGill University since 1993. He received his B.Sc., with honors, M.Sc., and Ph.D. from Brown University in 1985, 1986, and 1989, respectively. He was a Research Engineer in the Department of Electrical and Computer Engineering at the University of California at Los Angeles (UCLA), before moving to McGill University in 1993. Dr. Plant is an accomplished leader who has created several large broadband communications research initiatives whose objectives are to deliver transformative results for the benefit of Canadians. To date, he has received several national and international awards and he has been recognized with Fellow status in the Institute of Electrical and Electronics Engineers (IEEE), the Optical Society of America (OSA), the Canadian Academy of Engineering (CAE), and the Engineering Institute of Canada (EIC) for his efforts.

13:50 - 14:05 *Optical characterization of nanowire LEDs*

Pat Kambhampati[1], Richard Leonelli[2] and Carlos Silva[2]
[1]McGill University, [2]Université de Montréal

ABSTRACT: Nanowire LEDs have shown great promise for a wide variety of lighting applications. While there exists a generic phenomenological understanding of the aspects of nanowire formation that govern device performance, rigorous spectroscopic identification of the key processes is currently lacking. Our objective here is to perform a detailed spectroscopic characterization of III-nitride nanowire based LEDs with the aim of establishing a microscopic picture of the key processes from charge injection to radiative and non-radiative recombination over a span of temperatures and carrier concentrations. We have performed low temperature photoluminescence (PL), time correlated single photon counting of PL lifetimes, Raman measurements of polarization based phonon coupling. Our next steps will include time resolved PL measurements with 1 ps time resolution and pump/probe femtosecond laser spectroscopy. With these methods, we aim to produce a detailed picture of the growth factors which govern device performance.

Patanjali Kambhampati is an Associate Professor of Chemistry at McGill University. He received his PHD in 1998 from the University of Texas at Austin and has been at McGill since 2003. His group focuses on the spectroscopy of excitons in semiconductor quantum dots. Richard Leonelli is a Professor at Universite de Montreal. His group focuses on semiconductor physics. Carlos Silva is an Associate Professor at Universite de Montreal. His work focuses on spectroscopy of organic semiconductors.

14:05 - 14:20 *Electron microscopy of LED nanostructures*

Gianluigi Botton
McMaster University

ABSTRACT: Electron microscopy is an invaluable tool to study the detailed structure of materials. Many of the analytical methods available in the transmission electron microscope provide detailed compositional and spectroscopic information with unprecedented spatial resolution. In the particular case of nanoscale materials used for LED applications, electron microscopy can be used to provide quantitative structural information on the compositional modulations used to confine electrons, the local strain, the strain relaxation and local changes in the bandgap. Using a combination of electron energy loss spectroscopy (EELS) and electron holography, one can ultimately determine the local carrier concentration and local potentials. With quantitative high-angle annular dark-field (HAADF) imaging and EELS (e.g. Figure 1), we have been able to see atomic-level compositional fluctuations providing insight on the growth mechanisms and strain relaxation. These examples demonstrate that compositional and chemical state (valence and coordination) information can be obtained down to the Ångstrom level. The relationship between the structural observations and the electronic and optical properties are discussed.

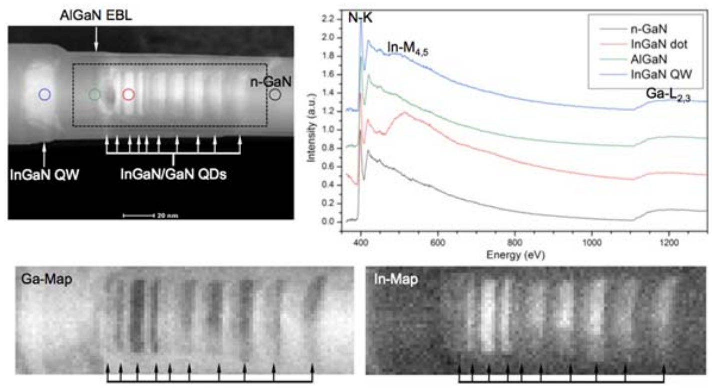

Figure 1. HAADF image and elemental maps of Ga and In in a dot-in-wire (sample courtesy of Z. Mi).

Gianluigi Botton was awarded a degree in Engineering Physics in 1987 and a PhD in Materials Engineering in 1992 at Ecole Polytechnique of Montreal, Canada. He was Postdoctoral Fellow and Senior Research Associate in the Department of Materials Science and Metallurgy at the University of Cambridge from 1993 to 1998. He joined the Materials Technology Laboratory of Natural Resources Canada (NRCan) in 1998 as a research scientist. In 2001 he moved to the Department of Materials Science and Engineering at McMaster University where he was awarded a Canada Research Chair in Electron Microscopy of Nanoscale Materials in 2002. He established and currently leads the Canadian Centre for Electron Microscopy- a national facility for ultrahigh resolution electron microscopy at McMaster University. His areas of expertise are Electron Energy Loss Spectroscopy and Analytical Electron Microscopy.

14:20 - 14:30 *Solid state lighting in Asia*
Ishiang Shih
McGill University

Panel discussions

15:10 - 17:00
Moderator: Zetian Mi, McGill University

Solid State Lighting Rising: Opportunities for Canada

Patrick Durand, Worldwide Technical Director, Future Lighting Solutions

Chris Hart, VP, Research and Development, Leapfrog Lighting

Solid state lighting: inorganic LED
Po Lau, CEO, CIS Scientific Inc.

Jessica Zhang, CMC Microsystems

LED applications and roadmap at INO
Nathalie Renaud, Programs Manager, Energy and Natural Resources and Optical Design, INO

> Nathalie Renaud has been working with INO, also known as the National Optics Institute, since 1988. In 1999 she became scientific director covering many fields of applied photonics. She managed the business development, R&D and resources for technological programs in the fields of optical design, mechanical design, assembly and testing, 2D vision, software programming, 3D sensors, laser micromachining, active sensing, biophotonics, and laser technologies. In 2009 she acted for 2 years as a senior business development manager for the East of Canada. Presently, she is responsible of Program Management in the field of Energy and Natural Resources, along with the Program Management in Optical Design. Since 2011, activities developed in the Optical Design program, and more precisely regarding Leds, their development, characterization and applications, are under her responsibilities.

David J. Hastings, Laboratory Manager, Safety and Graphics Business Group, 3M Canada Company

Opportunities for thick INGaN layers
Scott Butcher, President and Chief Scientist, Meaglow Ltd., ON

> Prof. K. Scott Butcher has been active in group III nitride research for 21 years, and has been a founder of three companies in the area, including a publicly listed company. Dr Butcher is currently the Chief Scientist of Meaglow Ltd, a Canadian startup company which is developing low temperature nitride deposition techniques suitable for high indium content InGaN.

TACD tools for material and device design
Eric Zhu, CEO and President, NanoAcademic Technologies Inc., Quebec

Jack Wu, JYS Technologies Inc.

Xuejun Zou, Research Manager, FPInnovations, Quebec

Vincent Fortin and Vincent Aimez, C2MI