The Importance of Ternary Group III-Nitrides for Advanced Solid State Lighting and High-Efficient Photovoltaics

Andrew Melton[1], Bahadir Kucukgoka[1], Na Lu[1,2] and Ian Ferguson[1,*]

[1]Department of Electrical and Computing Engineering,
University of North Carolina at Charlotte, NC, 28213, USA
[2]Department of Engineering Technology
University of North Carolina at Charlotte, NC, 28213, USA
*ianf@uncc.edu

Development of wide-band gap compound semiconductors materials and structures led by the III-Nitrides are fueling a revolution in the areas of energy related areas of lighting, solar cells, and more recently thermoelectric applications. This talk will show that the III-Nitrides can provide a possible solution for many applications were traditionally III-V materials and devices are used and, in particular, energy related applications.

Light emitting diodes (LEDs) use in lighting, also known as solid state lighting (SSL) has been very successful in niche markets such as signage and displays, but has still not seen significant penetration in the general illumination market. LEDs have advantages over conventional light sources, such as higher efficiency, longer life, smaller size, and enhanced controllability. The key limitations of the first generation SSL in general illumination such as a high color rendering capability, and appropriate correlated color temperature are being addressed in the current generation of SSL solutions. However, to achieve high quality white light gaps in the power spectrum of typical LED sources have to be eliminated. Broadband spectrally dynamic solid state illumination source comprising of a three or two terminal dual LED structure has been developed. A combination of multiple phosphors are then "pumped" by either or both of the wavelengths emitted from the dual LED to produce white light of a variable power spectrum. Such innovations will help SSL sources further increase it competitive advantage over conventional illumination sources.

The III-nitride technology is also the base in development of a new generation of highly efficient solar cells. Wide-band gap InGaN based solar cells in the 2.4-2.9 eV range for integral photovoltaic devices component are projected to achieve efficiencies greater than 50% making solar energy more feasible and competitive. InGaN with indium compositions up to 30% (2.5 eV band gap) are developed for photovoltaic applications by controlling defects and phase separation using metal-organic chemical vapor deposition. Subsequent generations of solar cell designs involve an evolutionary approach to enhance their open-circuit voltage and internal quantum efficiencies. Second generation InGaN solar cell design involving a 2.9 eV InGaN p-n junction sandwiched between p- and n-GaN layers yields internal quantum efficiencies as high as 50%; while third generation devices utilizing the novel n-GaN strained window-layer enhance the open circuit voltage of a 2.9 eV InGaN solar cell to 2 V. These results establish the potential of III-nitrides in ultra-high efficiency photovoltaics.

Some recent measurements of the thermoelectric properties–the Seebeck coefficient, the electrical conductivity and the power factor – of GaN and InGaN thin films will also be reported. GaN:Si exhibited a maximum power factor of $9.1x10^{-4}$ W/m-K with a carrier concentration of $1.6x10^{18}$ cm^{-3}, and $In_{0.1}Ga_{0.9}N$ exhibited a maximum power factor of $109x10^{-4}$ W/m-K with a carrier concentration of $1.2x10^{18}$ cm^{-3}. The results also indicate that GaN and InGaN-based materials could potentially be useful materials for TE applications at high temperatures.

Ian T. Ferguson: Biography

Dr. Ian T. Ferguson is a currently a Professor and the Chair of Electrical and Computer Engineering at the University of North Carloina at Charlotte. He is a Fellow of Institute of Electrical and Electronic Engineering (IEEE), Fellow of Institute of Physics (FInstP), and Fellow of the International Society for Optical Engineering (SPIE).Prior to this he has held leadership positions in both academia (St Andrews, Imperial College, Northwestern, Georgia Tech, etc.) and industry (GEC, EMCORE, etc.). His current research currently focuses on the area of wide bandgap materials and devices (emitters, detectors and electronics) using GaN and ZnO, and developing these materials for energy and nanotechnology applications in the area of illumination, solar, spintronic and nuclear detection applications. Dr. Ferguson has have authored over 400 refereed publications (current H-Index is >34), seven book chapters, eleven conference proceedings, one book and multiple patents. He has have given over 300 invited and contributed talks and seminars throughout the US, Europe and Asia. He founded the International Conference on Solid State Lighting which is now in its twelfth year. Dr. Ferguson received a National Small Business Association Award at the White House in Washington DC for contributions to the SBIR program. He was awarded a Technology Utilization Foundation Technology Transfer Award for contributions to the development of light emitting diodes. Most recently Dr. Ferguson co-founded and is the Chairman of the Board for PiES, Project for innovation, Energy and Sustainability, a non-profit green business incubator in Davidson (http://www.pies-northcarolina.org). He was selected by the *Charlotte Business Journal* for 'General Excellence in Sustainable Leadership' in the 2011 Sustainable Business Awards for this work.