National Institute for Nano Engineering

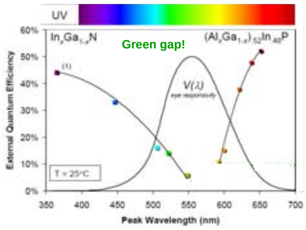
Nanoengineering for Solid-State Lighting

Applying nanoscience and nanoengineering concepts to enable energy-efficient LED-based lighting

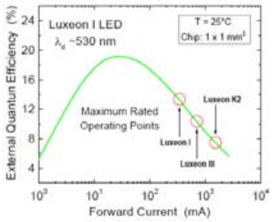
Potential for high impact: if 2025 SSL roadmap goals are met, U.S. electricity consumption will be reduced by 10% (50% reduction of electricity for lighting), saving ~$25B/ year

Technical challenges: major advances are needed to improve internal quantum efficiency (IQE) of LED materials and light extraction efficiency from LED chips

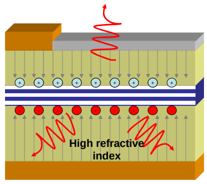
Lack of efficient LED materials across the visible spectrum



LED "Efficiency Droop" at high current densities



Light Extraction Challenges for LED chips



NINE Program on Solid-State Lighting

Partner: Rensselaer Polytechnic Institute
Professor Fred Schubert, Professor Christian Wetzel, Professor Shawn Lin, and students, Future Chips Constellation

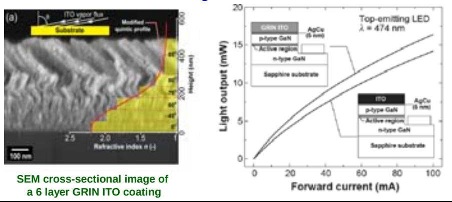
Objective: to achieve significant energy efficiency advances in Solid-State Lighting through application of nanoengineering and nanoscience to InGaN-based semiconductor materials and LEDs

Approach: two primary tasks to address both light extraction and internal quantum efficiency (IQE) challenges

Program elements: innovative materials and LED concepts, state-of-the-art semiconductor materials growth and device fabrication, materials and device characterization, advanced modeling of LED physics and photonic structures

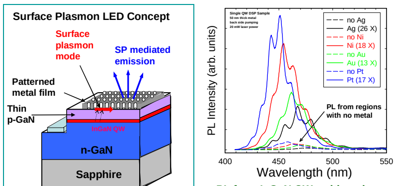
SNL team: Mary Crawford (PI), Dan Koleske, Art Fischer, Steve Lee, Nancy Missert, David Follstaedt

- Realized a 28% increase in LED output power through the development and application of novel Indium Tin Oxide graded refractive index nanorod coatings



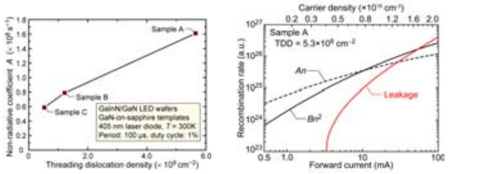
SEM cross-sectional image of a 6 layer GRIN ITO coating

- Demonstrated up to 26X photoluminescence enhancement from InGaN quantum wells through surface-plasmon-mediated emission



PL from InGaN QWs with various metal coatings leading to SP-enhanced emission

- Quantified the impact of nanoscale crystalline defects (threading dislocations (TDs)) on IQE and efficiency droop

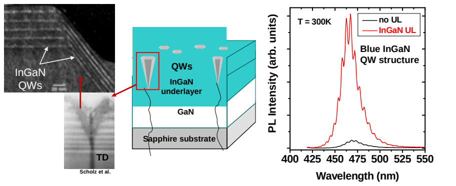


Non-radiative coefficient *A* as a function of TD density determined from photoluminescence measurements on different TD density LEDs

Carrier recombination and loss contributions as a function of current determined from LED characterization and modeling

→ *propose carrier leakage mechanism and NOT TDs as primary contributor to efficiency droop*

- Investigated nanoengineering of "V-defects" on threading dislocations and impact on IQE of InGaN quantum wells



"V-defects" can be nucleated around TDs through use of a low temperature InGaN "underlayer" beneath InGaN QWs

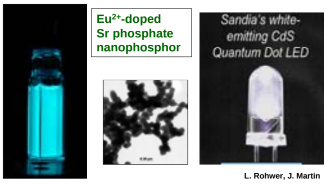
→ *Can V-defects prevent non-radiative recombination of carriers at TDs?*

~15X photoluminescence enhancement of InGaN QWs when grown on an InGaN underlayer; Shown NOT to be related to V-defects

→ *Mechanism behind underlayer-induced PL enhancements still under investigation*

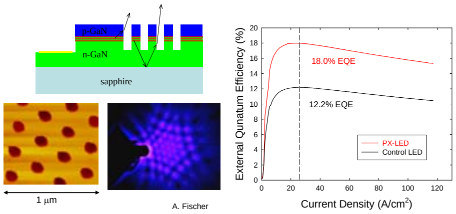
Synergistic Sandia Programs and Capabilities

Nanophosphors and nanocrystalline quantum dots



L. Rohwer, J. Martin

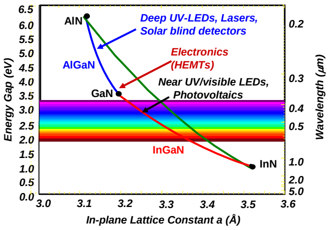
Photonic lattices for improved light extraction

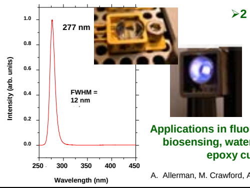


A. Fischer

Nitride semiconductors for photovoltaics, electronics, and deep UV optoelectronics

Wide bandgap Nitride Semiconductors





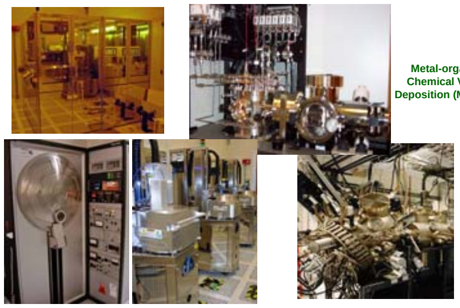
➢ 2 mW output at 275-300 nm from AlGaN LEDs (1 mm x 1mm devices)

Applications in fluorescence-based biosensing, water purification, epoxy curing

A. Allerman, M. Crawford, A. Fischer, K. Bogart, M. Banas

MESA Microfabrication Facility

State-of-the-art facility for epitaxial growth and processing of semiconductor materials and devices



Metal-organic Chemical Vapor Deposition (MOCVD)

Molecular Beam Epitaxy (MBE)

→ Applicable to a wide range of materials and device structures

Sandia is a multiprogram laboratory operated by Sandia Corporation a Lockheed Martin Company,
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