SAND2012-5197P

Nano-engineering for Solid-State Lighting

Science to Make Solid-State Lighting a Global Reality

Sandia National Laboratories
Mary Crawford, Daniel Koleske, Arthur Fischer, Stephen Lee, Nancy Missert and David Follstaedt
Rensselaer Polytechnic Institute
E. Fred Schubert, Christian Wetzel, and Shawn Lin

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT
NNSA National Nuclear Security Administration

Challenge

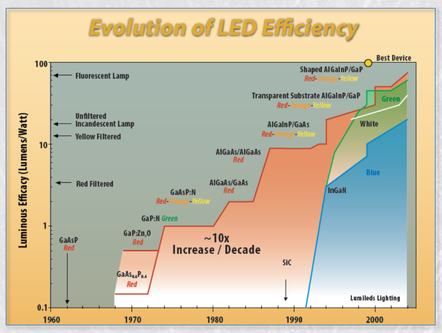
Motivation for a Lighting Revolution

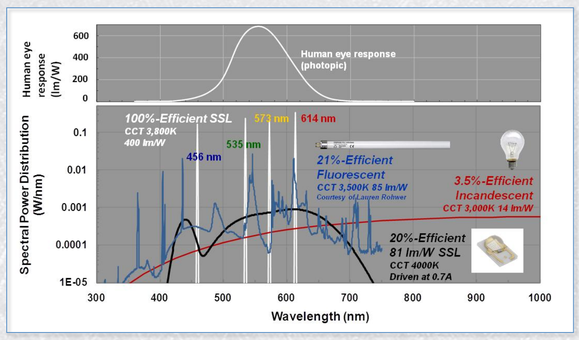
Efficiencies of Energy Technologies in Buildings

Heating:	70 – 80%
Electric motors:	85 – 95%
Fluorescent:	18 – 25%
Incandescent:	3 – 5%

- ~22% of electricity consumption is for general illumination
- Lighting is one of the most ***inefficient*** energy technologies in buildings
- Achieving 50% efficient lighting would have tremendous global impact:
  - ➢ decrease electricity consumed by lighting by > 50%
  - ➢ decrease total electricity consumption by 10%

Next Generation Solution: Solid-State Lighting

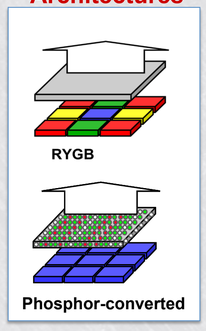




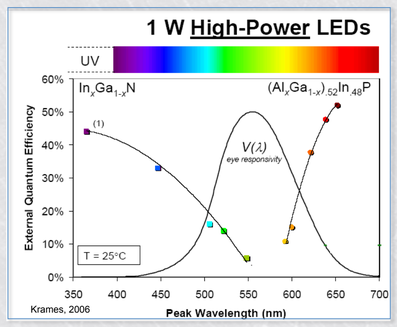
Major Technical Challenge: Improve LED Efficiency

US DOE target: 50% "Ultra-efficient" SSL ≥ 70%

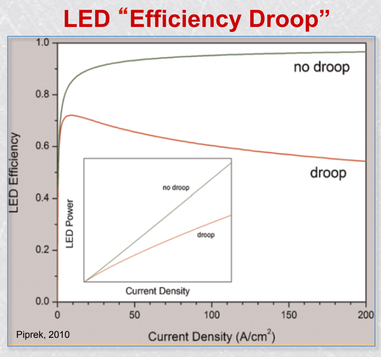
LED Architectures



Green-yellow gap

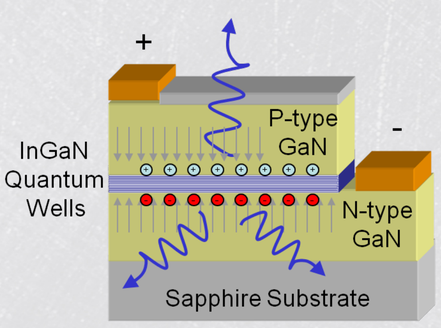


LED "Efficiency Droop"



Approach

Apply nanoengineering and nanoscience concepts to improve the efficiency of InGaN LEDs in two ways:



InGaN Semiconductor LED Structure

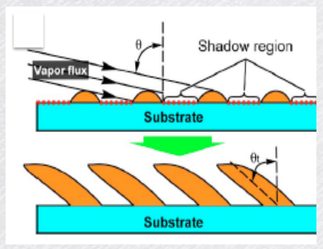
1) **Study of nanoscale InGaN materials properties to improve efficiency of light generation (*focus on nanoscale crystalline defects*)**

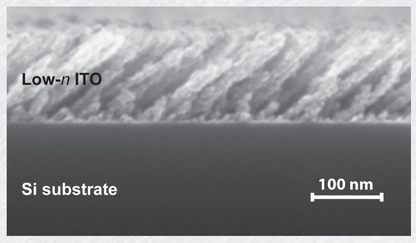
2) **Nanoscale engineering of dielectric and metal materials to enhance light extraction**

Results

Nano-engineering Concepts for Enhanced Light Extraction

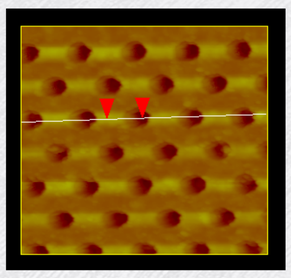
Dielectric Nanorods: 24% enhanced light output via GRIN coatings

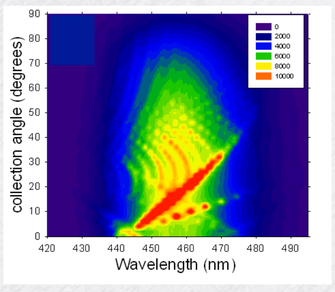




Photonic Lattices: 1.6X enhanced light emission at select output angles

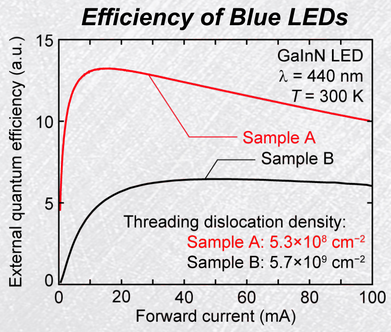
TiO_2 315 nm spacing



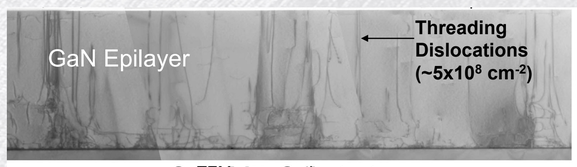


Impact of Nanoscale Crystalline Defects

Efficiency of Blue LEDs



Do threading dislocations contribute to "efficiency droop" at high currents?



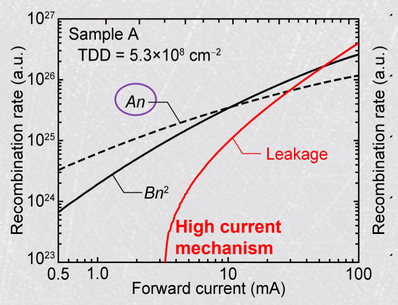
Efficiency Model:

$$\varepsilon_{IQE} = \frac{Bn^2}{An + Bn^2 + Cn^3 + Dn^m + \ldots}$$

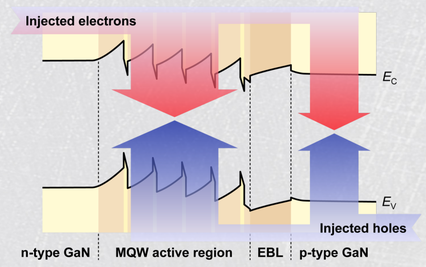
Nonradiative at Defects (SRH) | Radiative | Higher order processes

★ ***Propose Carrier Leakage Mechanism***

Dislocations impact low current regime



Carrier leakage may dominate at high currents



Significance

Potential for high impact: if SSL > 50% efficient

- ➢ U.S. electricity consumption reduced by 10% (50% reduction of electricity for lighting),
- ➢ saving > $25B/ year,
- ➢ reducing carbon-equivalent emissions by ~100 Megatons/year

New Programs:

- ➢ **DOE/BES Energy Frontier Research Center**
  - → efficiency droop models, defect spectroscopy, nanowire LEDs, plasmonics, ultra-low threshold lasers for SSL
- ➢ **UV (AlGaN) Optoelectronics** for National Security Applications

SSLS EFRC SOLID-STATE LIGHTING SCIENCE ENERGY FRONTIER RESEARCH CENTER

U.S. DEPARTMENT OF ENERGY

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