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Growth of III-Nitride Semiconductor Materials and Devices

S&T Campaign: Materials Research
Photonics

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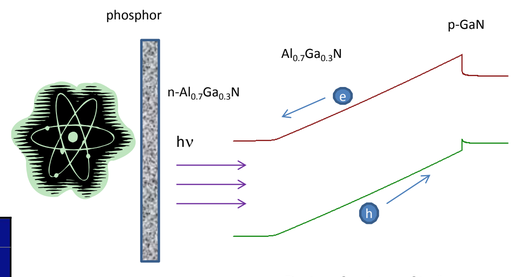
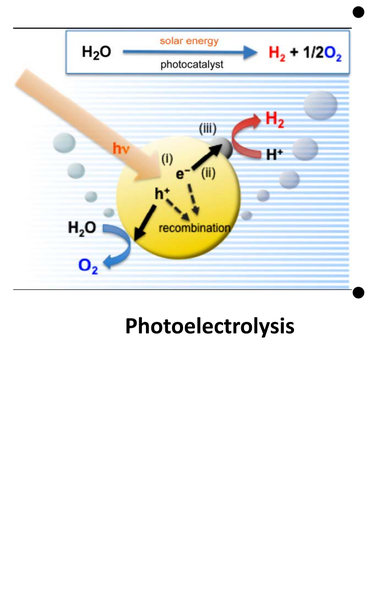
Research Objective

- **Leverage unique properties of III-Nitride materials and heterostructures to push state-of-the-art in optoelectronic devices**
  - **Ultraviolet Optoelectronics (LEDs, LDs, APDs)**
  - **Energy (Unassisted solar water splitting, full spectrum solar cells, betavoltaics/betaphotovoltaics**
  - **Quantum (Rare-earth doped alloys)**

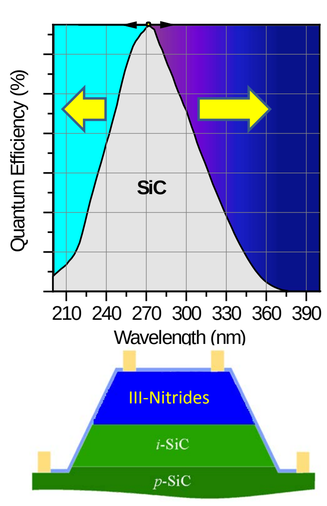


Betaphotovoltaics



III-Nitrides Semiconductors cover a large spectral range

Photoelectrolysis

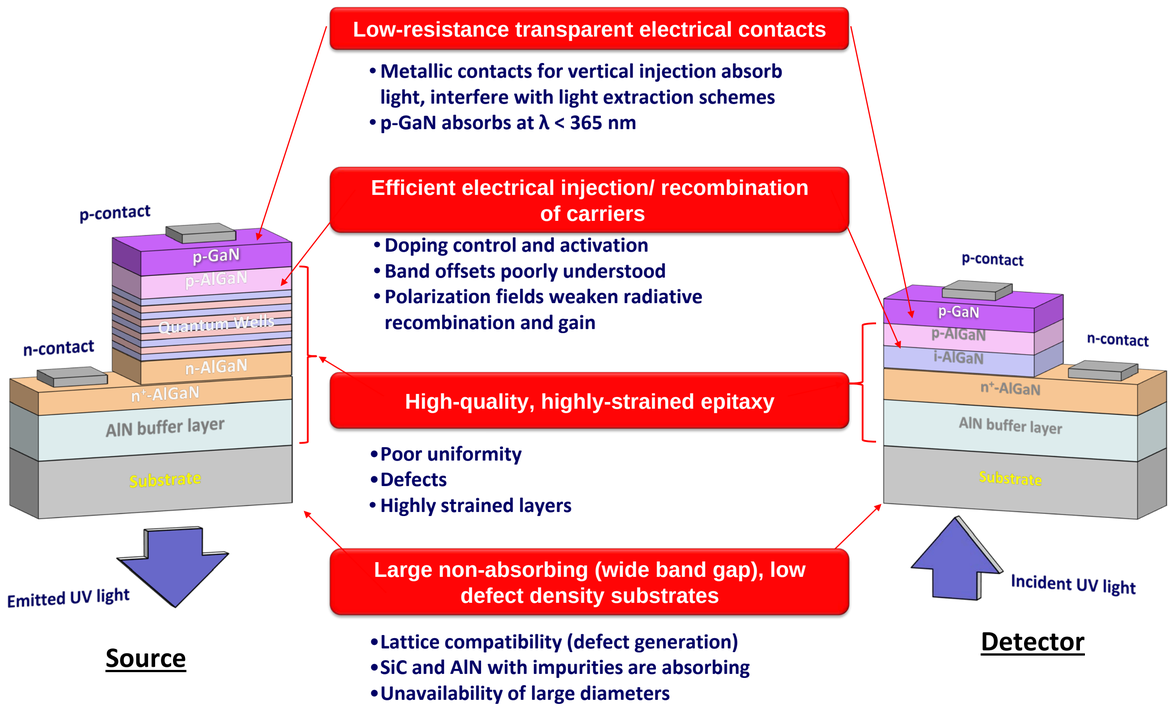


Heterojunction Avalanche Photodiodes

Challenges

- **Heteroepitaxial growth on lattice-mismatched substrates**
  - Understanding the role of defects on device performance
  - ✓ Engineering heterojunction devices for improved tolerance
- **Spontaneous and Piezoelectric polarization**
  - Understanding the role of built-in E-fields and interface charge
  - ✓ Leveraging these phenomena for improved performance
- **Difficulty in doping larger band gap alloys n- and p- type**

Diode sources and detectors have common core challenges



ARL Facilities and Capabilities Available to Support Collaborative Research

- **Two Veeco GenII Molecular Beam Epitaxy Systems**
  - **Custom high temperature substrate heaters (up to 1200 °C) useful for growth of Al containing alloys**
  - **Auto-tuning RF N Plasma Source for dynamic compositional tuning**
  - **KSA Bandit, Band Edge Thermometry for reproducible substrate temperature**
  - **Rare-earth effusion source (currently Nd)**
  - **High temperature effusion source (currently B)**
  - **Al, In, Ga sources; Mg, Si dopant sources**
- **Metalorganic Chemical Vapor Deposition**
  - **High temperature growth (1300°C)**
  - **Atmospheric and low pressure operation**
  - **Closed Loop Control and In-Situ monitoring**
  - **Ga, In, Al, Mg and Si dopant sources**
  - **2" wafer growth**
- **Research Highlights and Significant Findings**
  - **Beneficial carrier localization in AlGaN through incorporation of self-assembled nano-scale compositional inhomogenieties** (C. J. Collins et al., *Appl. Phys. Lett* 86, 031916 (2005)), US Patents 7,498,182; 7,812,366;
  - **Suppressed efficiency droop in visible III-polar Nitride LEDs grown p-down** (M.L. Reed, et al., *Appl. Phys. Lett* 93, 13305 (2008)), US Patent 7,956,369
  - **First GaN/SiC Separate Absorption Multiplication Avalanche Photodiode** (A. V. Sampath, et al., *Appl. Phys. Lett.*, 101, 093506 (2012)), U.S. Patents 8,269,222; 8,269,223
  - **High Deep Ultraviolet Quantum Efficiency AlGaN/SiC Avalanche Photodiodes** (A.V. Sampath, et al., *Electron. Lett.*, 49, 1629 (2013)) US Patent pending
  - **Polarization Induced Electron Filter in III-Nitride/SiC Photodiodes** (L. E. Rodak, et al.", *Appl. Phys. Lett.*, 103, 071110 (2013)) US Patent pending

Complementary Expertise/ Facilities/ Capabilities Sought in Collaboration

- **Study of defects in semiconductors (DLTS, SIMS)**
- **Study of microstructure in semiconductors (Z-contrast TEM)**
- **Epitaxial growth of complimentary semiconductor materials (Oxide Semiconductors, Silicon Carbide, …)**
- **Modeling of gas flows within a CVD environment**
- **Substrate technologies for III-Nitride semiconductors**
  - **Non-polar, semi-polar orientations**
  - **AlN, GaN, AlGaN**
- **Wide band gap semiconductor substrate temperature monitoring**
- **Development of electron pumped phosphors**
- **Nanowire based betavoltaics**
- **Potential future research directions: topological insulators, plasmonics, neutron detection, and 2D materials**

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