Ultraviolet semiconductor diode lasers for novel applications

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LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

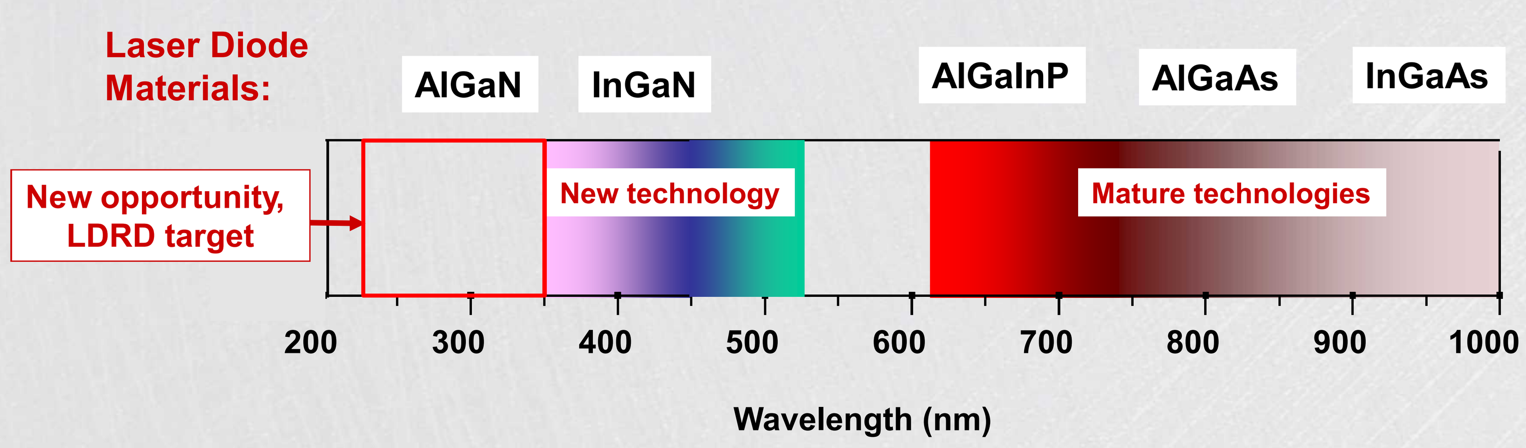
Mary Crawford, Andrew Allerman, Andrew Armstrong, Tania Henry, Weng Chow, Blythe Clark, Michael Smith, Karl Westlake and Karen Cross

Nuclear Weapons EAB Review

Problem

Opportunity:

- A number of mission-critical applications would greatly benefit from extending semiconductor laser diode technology to deep UV wavelengths (≤ 340 nm)
- AlGaN semiconductor alloys are emerging as the most promising candidate materials to enable a compact, high-performance mid-to-deep UV laser source



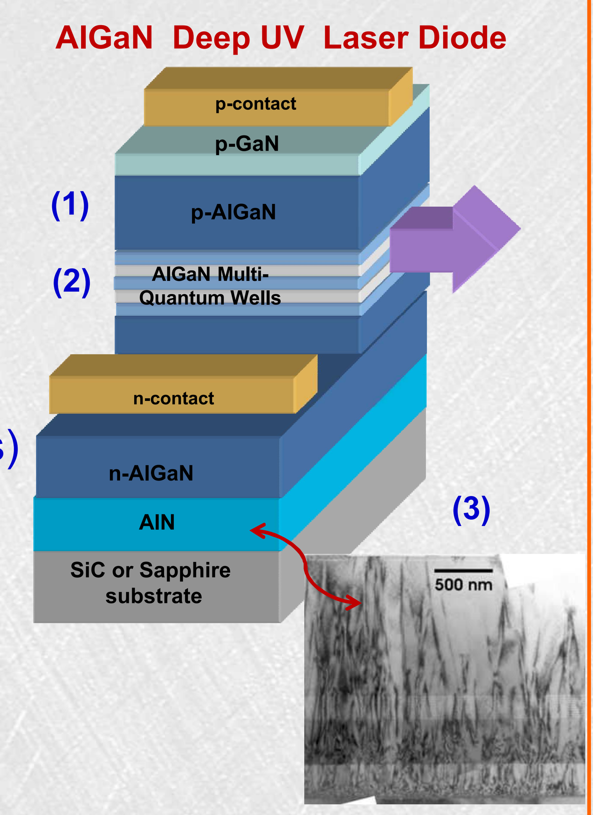
Problem:

- AlGaN semiconductors present several **major materials roadblocks** to laser demonstration:

(1) Ineffective p-type doping of AlGaN epilayers
→ large (> 200 meV) acceptor ionization energies

(2) Non-radiative point defects (vacancies, impurities)
→ reduces efficiency, impacted by growth conditions

(3) Lack of a lattice-matched substrate
→ high threading dislocation density > $1x10^9$ cm^{-2}; reduces efficiency, reliability

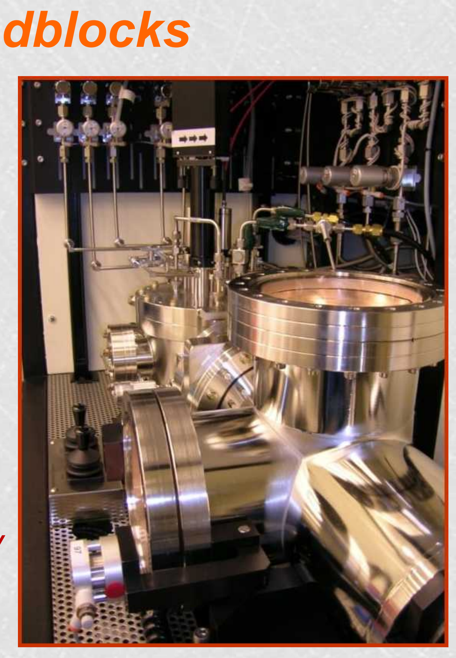


Approach

Explore innovative, science-based approaches to overcoming major AlGaN roadblocks

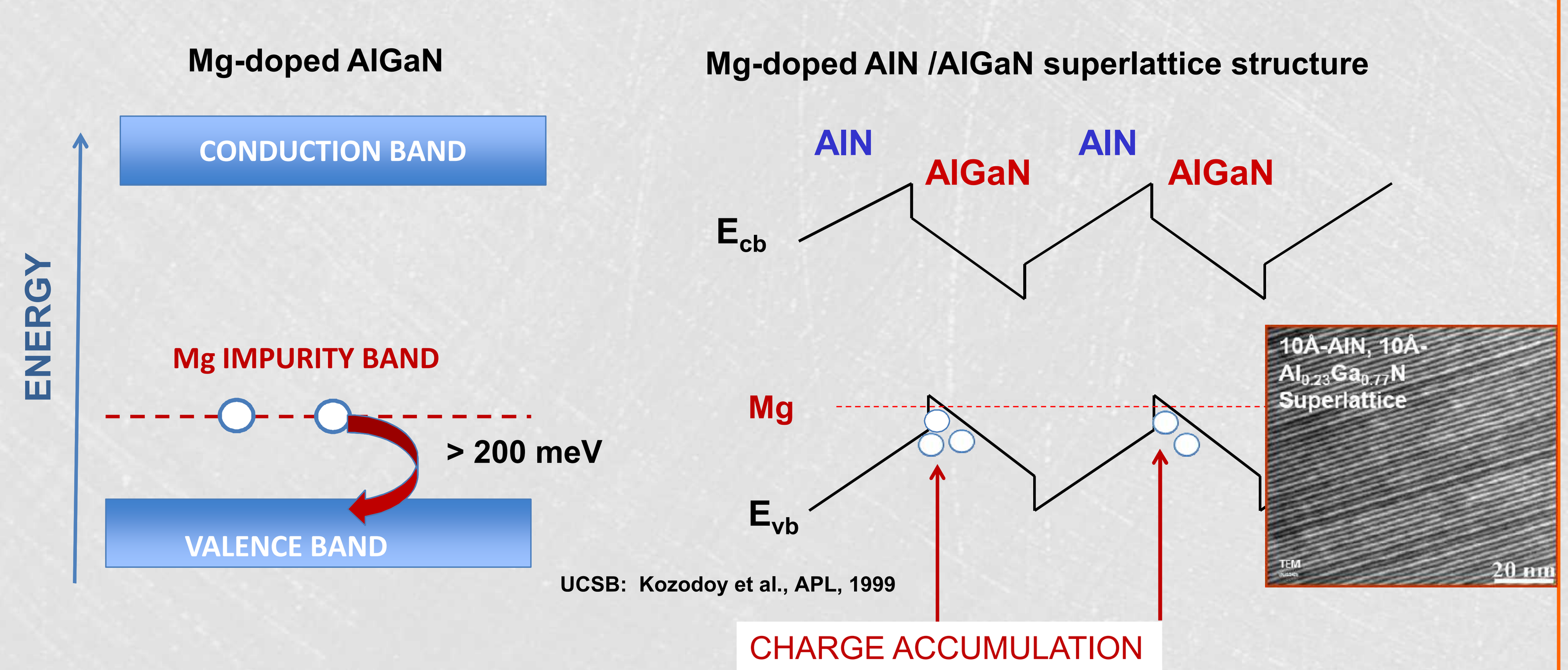
Enabling Capabilities:

State-of-the-Art MESA facility for:
→ **Epitaxial materials growth**
→ **Device processing**
→ **Materials and device characterization**



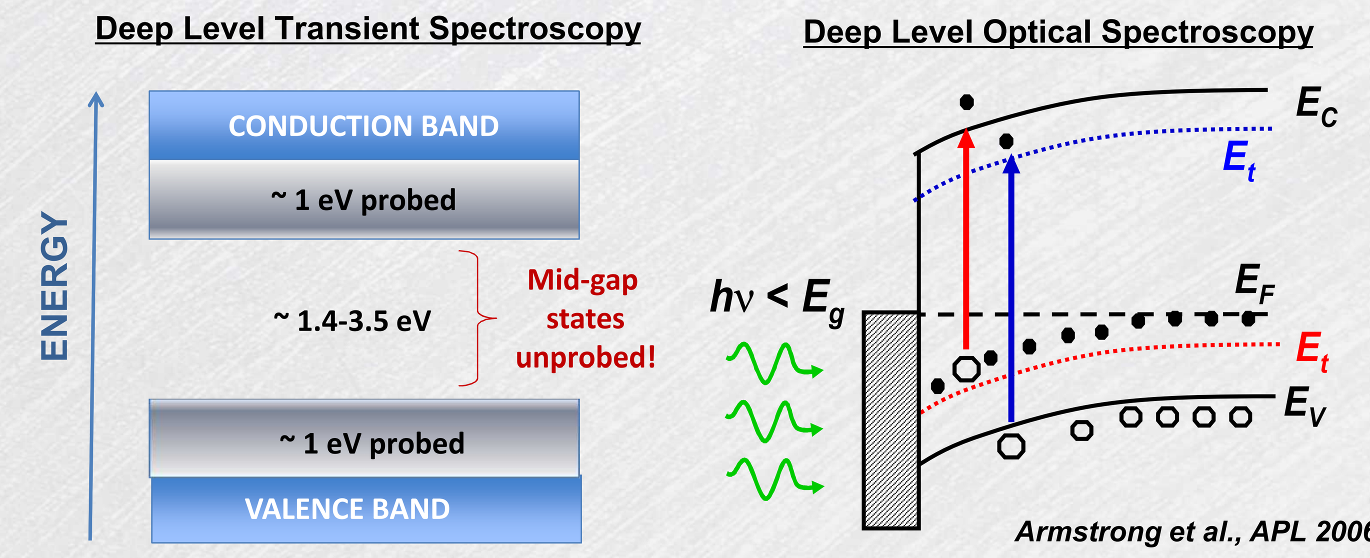
Metal-organic vapor–phase epitaxy system for growth of AlGaN alloys and device structures

(1) AlGaN/AlN Mg-doped superlattices for improved hole injection



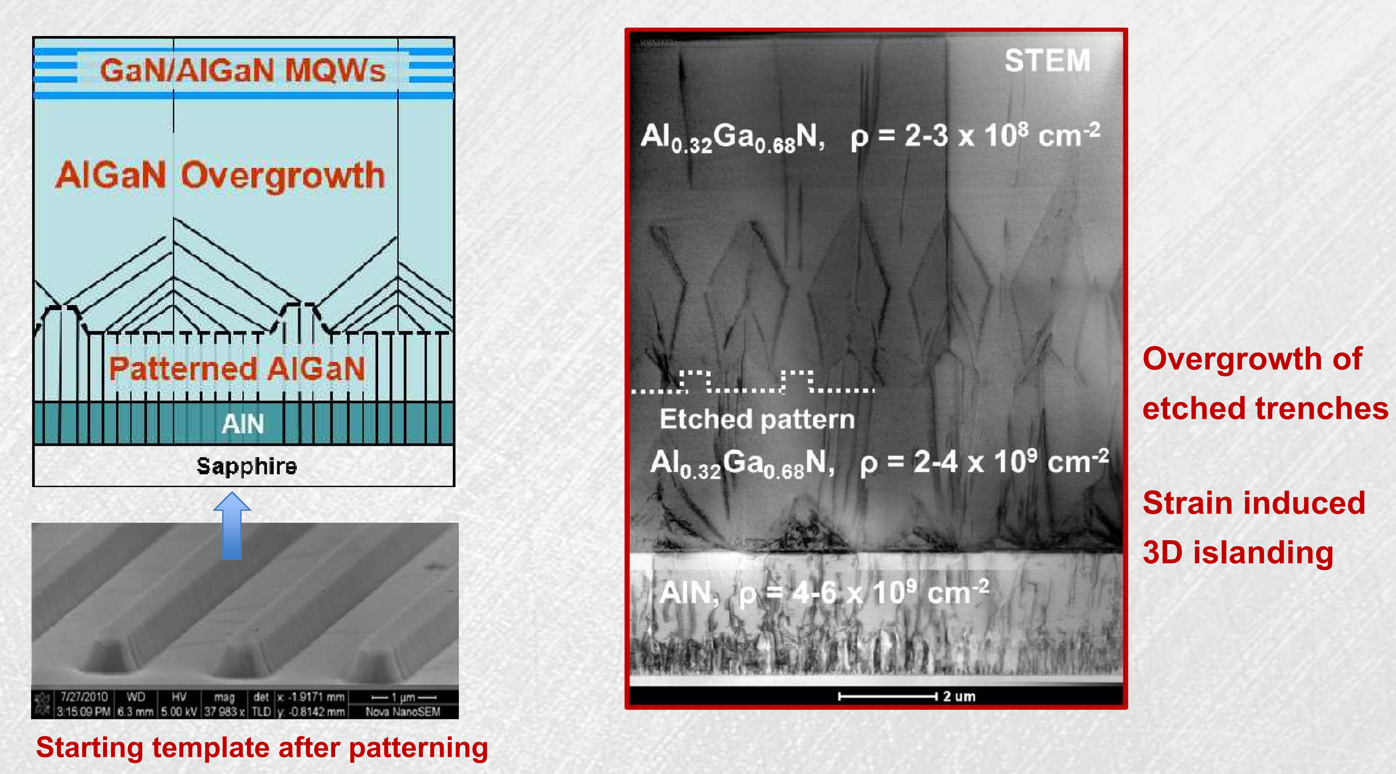
- Mg acceptor level is > 200 meV above the valence band. Thermal activation of holes at room temperature (kT ~ 26 meV) is ineffective
- Internal polarization fields in AlGaN/AlN multilayer structure modify band profiles and lead to enhanced acceptor ionization and hole accumulation

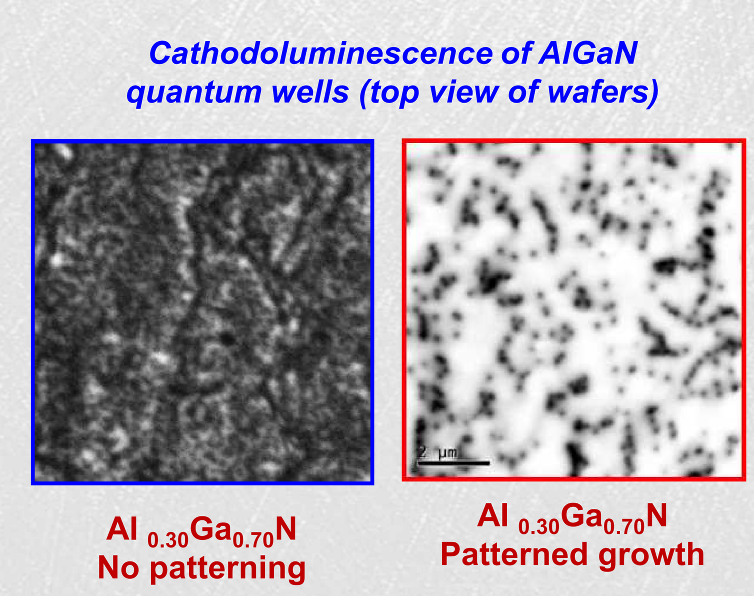
(2) Deep Level Optical Spectroscopy (DLOS) to quantify and mitigate point defects

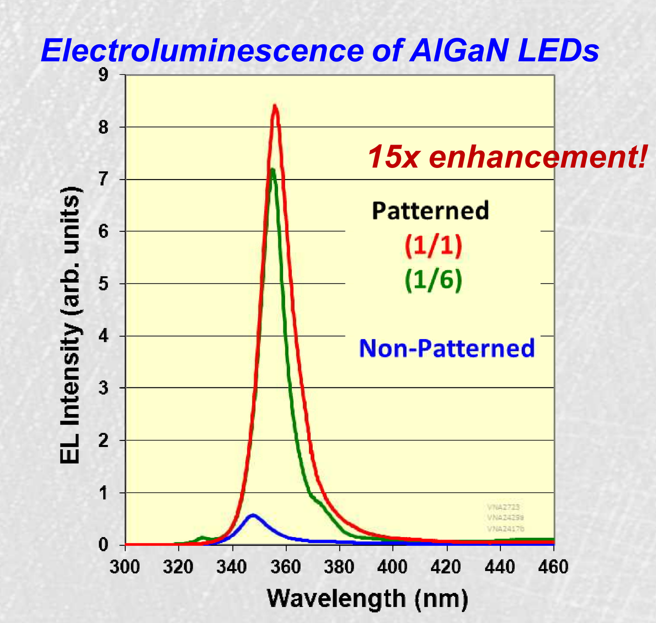


- DLOS technique employs *optical ionization* of defect levels to probe defects throughout the bandgap, including mid-gap non-radiative centers
- Anticipate *unprecedented quantitative information* on defect properties and their correlation with growth conditions and radiative efficiency/optical gain

(3) Patterned regrowth strategies to mitigate extended defects



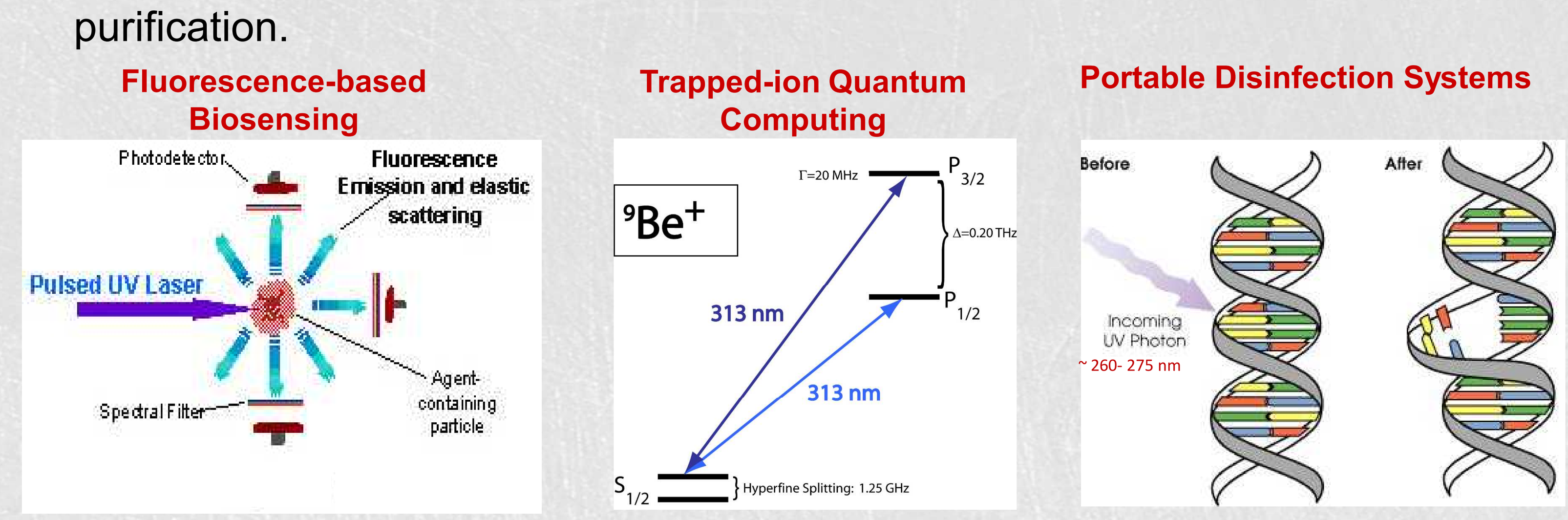




- Advance *innovative approaches* to reduce threading dislocations for high luminescence efficiency and optical gain
- New work will focus on more challenging alloys and strategies for greater defect reduction

Significance

- **Success would be a *major technological breakthrough*, achieving the shortest wavelength laser diodes to date with custom properties for NW applications**
- Enables entirely new approaches for numerous other applications including fluorescence-based biosensing, trapped-ion quantum computing, water and air purification.



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