Leveraging Capabilities for Improving Emitter Materials

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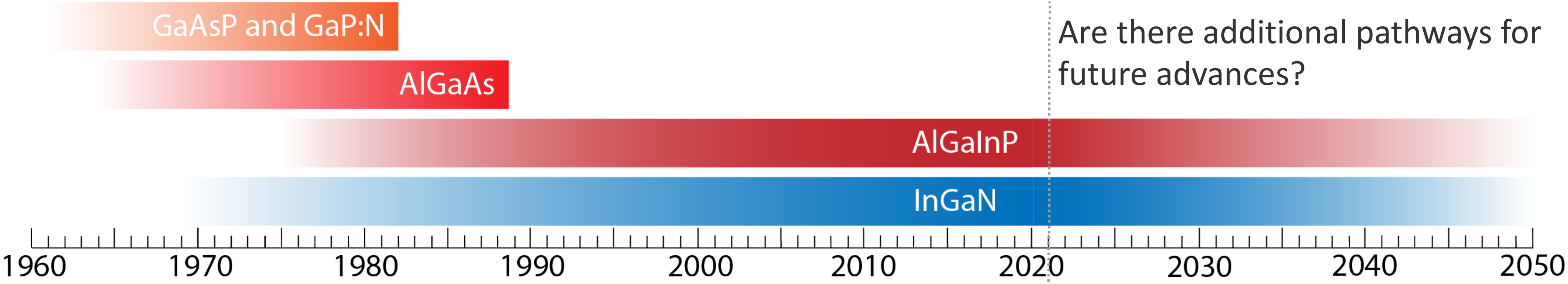
Pathways for Emitter Material Improvements



Access to existing materials

Development of new materials

Materials discovery

Implementation

Past advances in emitter materials were made possible by improvements in:

- Growth technology
- Doping and defects
- LED design

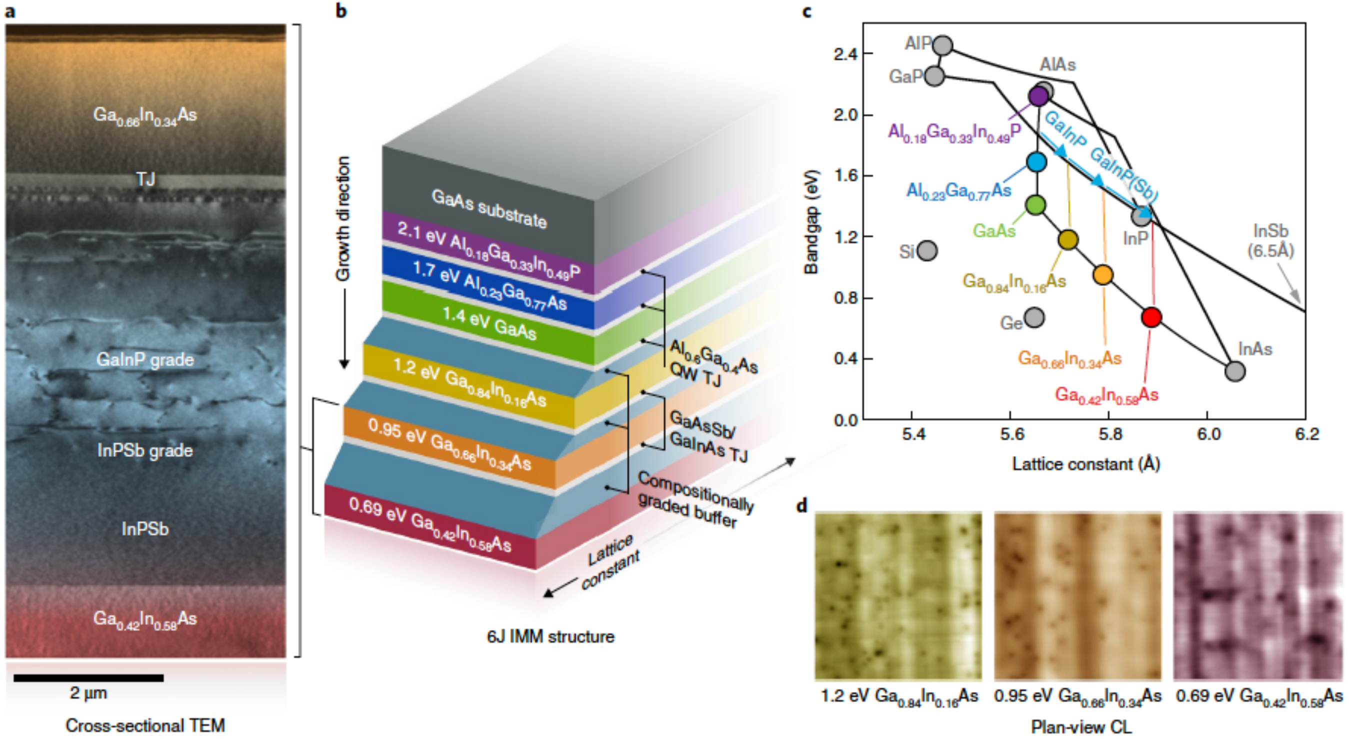
Historical emitter material timeline data adapted from:

R.D. Dupuis and M.R. Krames, History, Development and Applications of High-Brightness Visible Light-Emitting Diodes, *J. Lightwave Technology.*, **26**, 1154 (2008)

S. Nakamura and M.R. Krames, History of Gallium-Nitride-Based Light-Emitting Diodes for Illumination, *Proc. of the IEEE*, **101**, 2211 (2013)

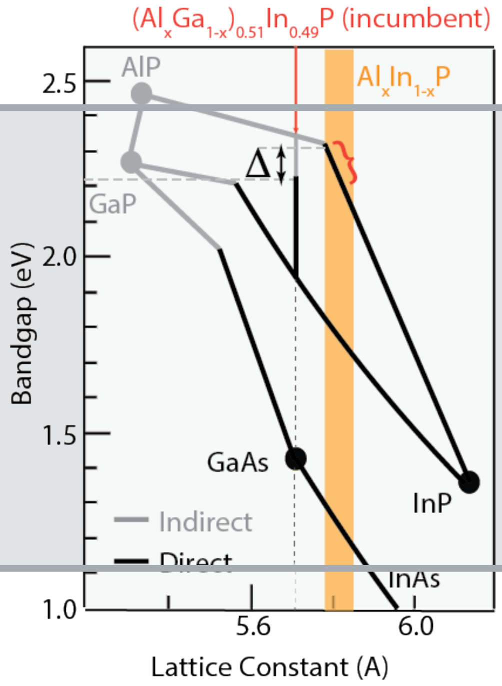
Accessing Existing Materials: High Efficiency Photovoltaics

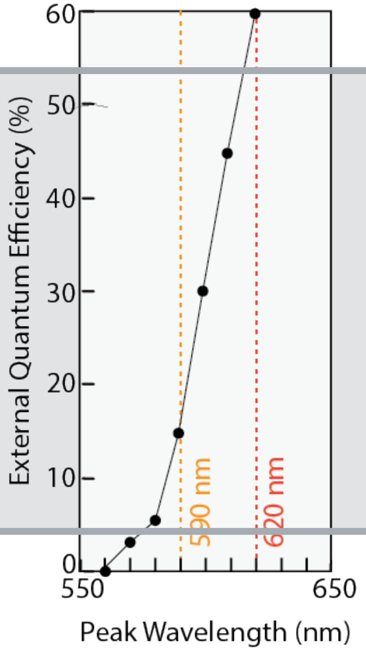
Multijunction solar cells have advanced on the ability to access and integrate III-V semiconductors through metamorphic growth.



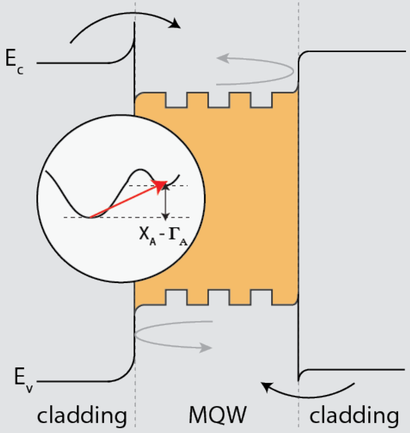
J.F. Geisz, *et al.*, Six-junction III-V solar cells with 47.1% conversion efficiency under 143 Suns concentration, *Nature Energy*, **5**, 326 (2020)

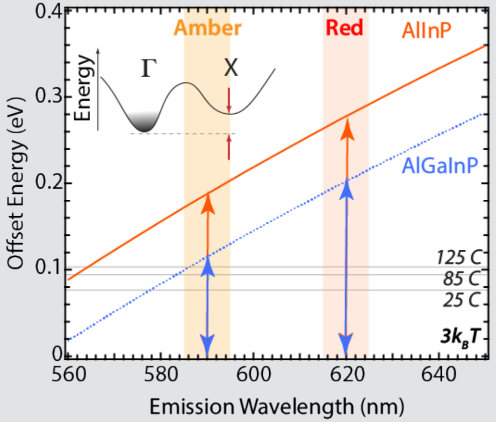
Example: Direct Bandgap AlInP for Red and Amber LEDs





AlInP has a higher direct-indirect bandgap crossover energy than AlGaInP



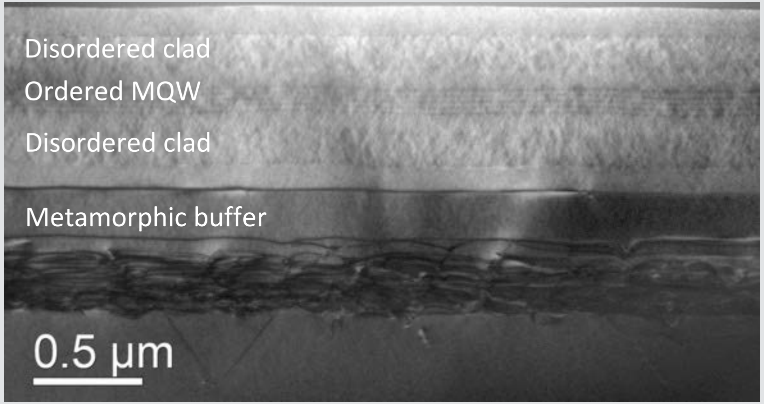


AlInP provides an additional energy barrier to electron loss to the indirect conduction band minima in the quantum wells

D.A. Beaton, *et al.*, Determination of the direct to indirect bandgap transition composition in $Al_xIn_{1-x}P$, *J. Appl. Phys.*, **114**, 203504 (2013)
LED EQE data adapted from: DOE 2019 Lighting R&D Opportunities Report

Example: Direct Bandgap AlInP for Red and Amber LEDs

Ordered/disordered AlInP LEDs can be grown on GaAs substrates with manageable dislocation densities.



TEM and diffraction images by N. Pokharel and P. Ahrenkiel (SDSMT)

LED growth by MicroLink Devices Inc.

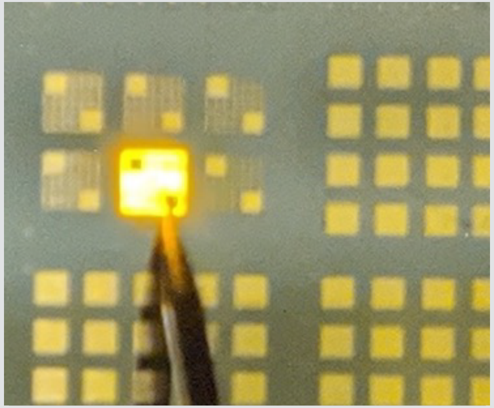
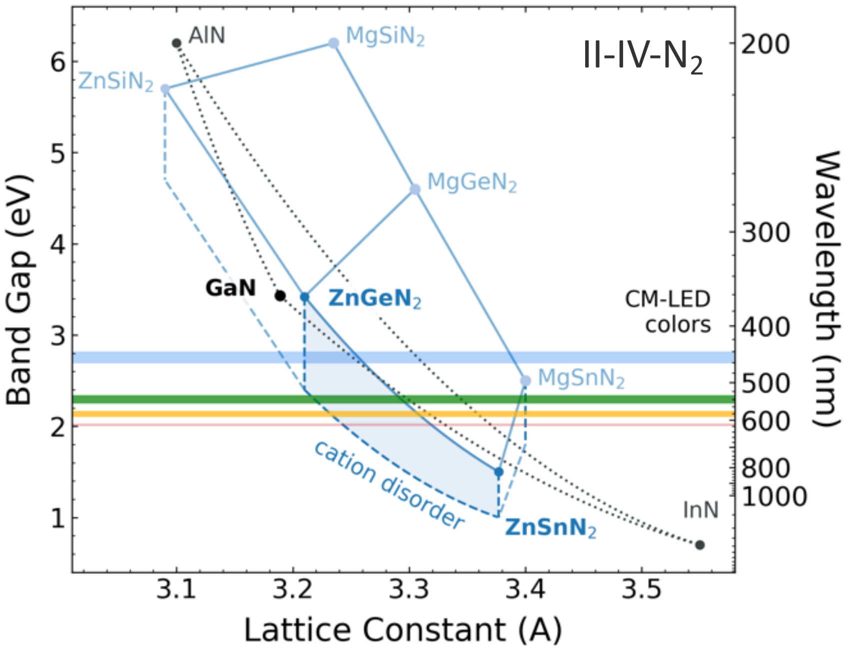


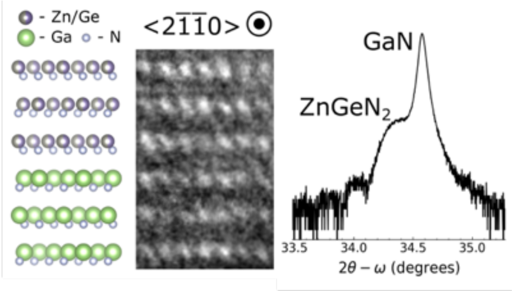
Photo by K. Alberi, NREL

LEDs have been demonstrated, but there is still a lot of room for improvement.

See our poster on “AlInP-based LEDs for efficient red and amber emission” for more information.

Developing Known "New" Materials: Ternary Nitrides





Many less-studied ternary nitrides have suitable bandgaps for visible light emission and can be integrated with GaN

- Disorder based tunability of band gap
- Non-polar options
- Alloying can fill in bandgap and lattice constant space

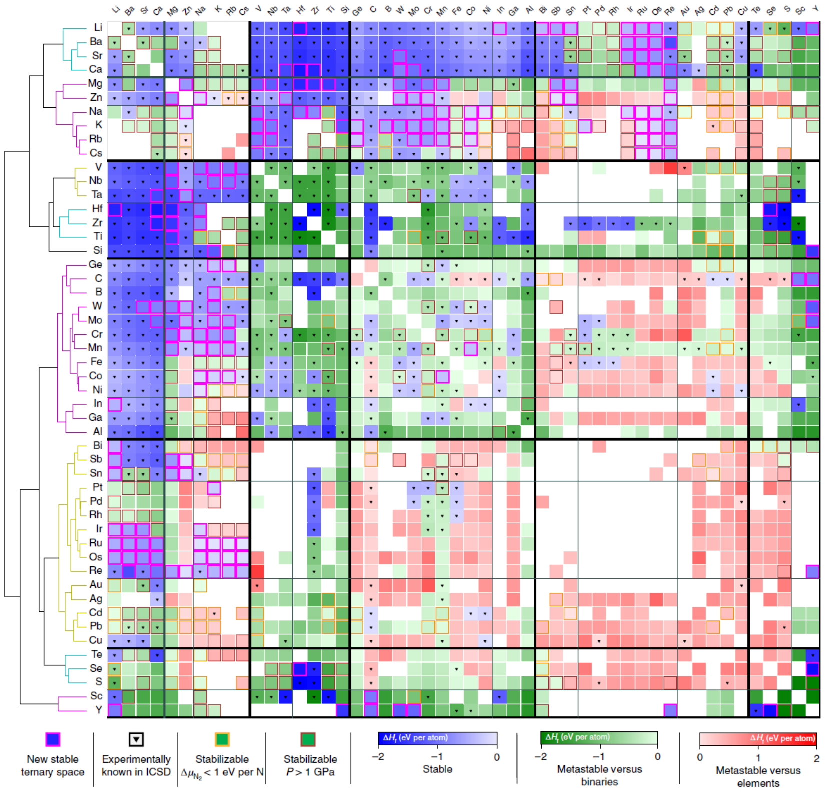
R.R. Schnepf, *et al.*, Utilizing site disorder in the development of new energy-relevant semiconductors, *ACS Energy Lett.*, **5**, 2027 (2020)

M. Brooks Tellekamp*, et al.,* Heteroepitaxial integration of $ZnGeN_2$ on GaN buffers using molecular beam epitaxy*, Crystal Growth and Design,* **20**, 1868 (2020)

Ternary Nitrides: Fundamentals and Emerging Device Applications, A. L. Greenaway et al., accepted (2020) – Annual Reviews of Materials Research

Computational Materials Discovery

Example: ternary nitrides



W. Sun, *et al.*, A map of the inorganic ternary metal nitrides, *Nature Materials*, **18**, 732 (2019)

Materials Discovery

- New compounds
  Composition and crystal structure, basic properties, synthesis
- Known compounds
  Identification of performance and application, how to make it work

Materials Design

- Fine tuning of properties, often by alloying
- Composition-gradient thin-film synthesis

Approaches and Considerations

Understand current limitations — *Improvement of existing material/device* — *Development of known new materials* — *Discovery and development of new materials*

near term → far term

Existing Materials Improvement

- Build on previous R&D
- Learn from work performed by other industries
- May not be able to overcome fundamental material property limitations

New Materials Development

- Expands materials selection
- Theory aids experimental materials optimization and hypothesis validation
- Longer development timeline

Computational Materials Discovery

- Opportunities to identify materials with “optimal” properties
- Requires a lot of development
- Success is not assured
- Theoretical methods are still evolving

Critical Questions for Implementation

When do we shift the focus of R&D on emitter materials?

- What timelines can the LED R&D community tolerate?
- What is an acceptable return on R&D investment?

How can we leverage R&D for other technologies?

- Build on breakthroughs in understanding and controlling material properties
- Collaboratively advance aspects that are beneficial to multiple technologies
- Engage a broader range of specialists

Thank you

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