$Al_xIn_{1-x}P$ Amber LEDs for Solid-State Lighting

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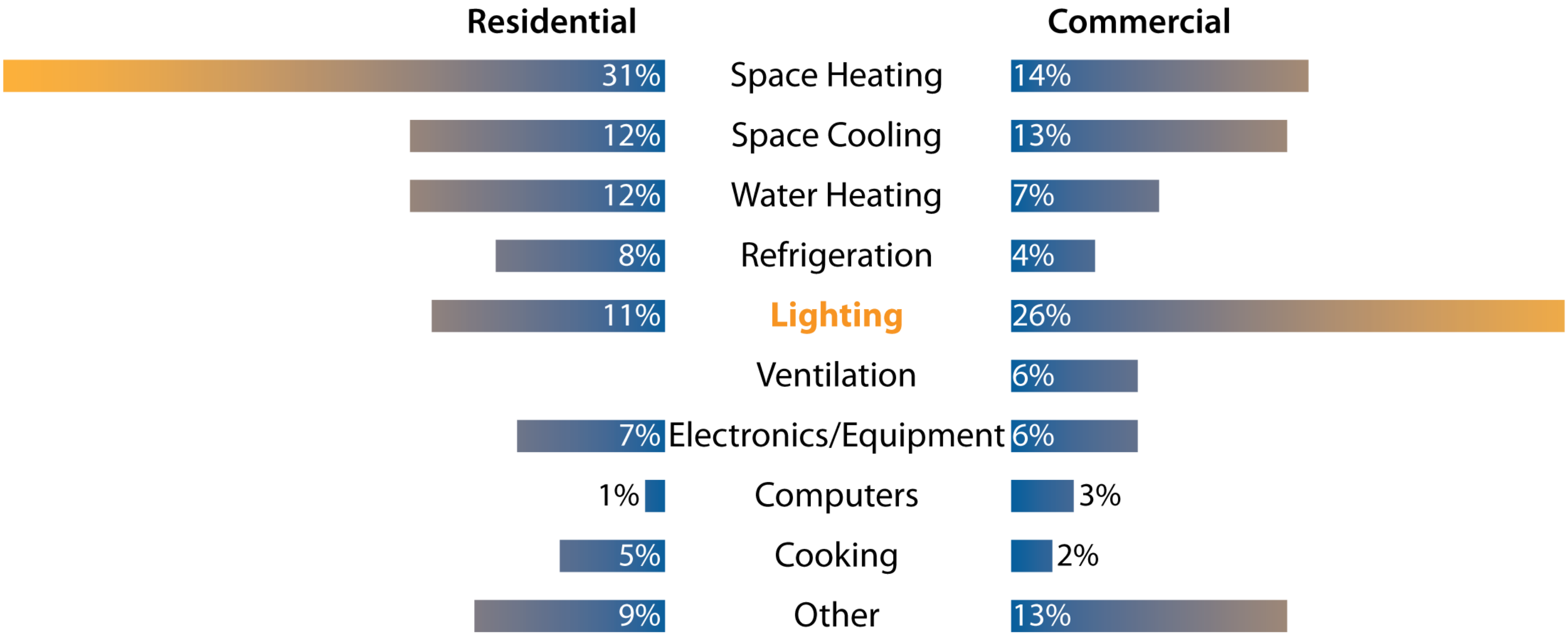
Breakdown of Buildings Energy Use



Source: *Energy Efficiency Trends in Residential and Commercial Buildings*, DOE Energy Efficiency and Renewable Energy Report, 2008

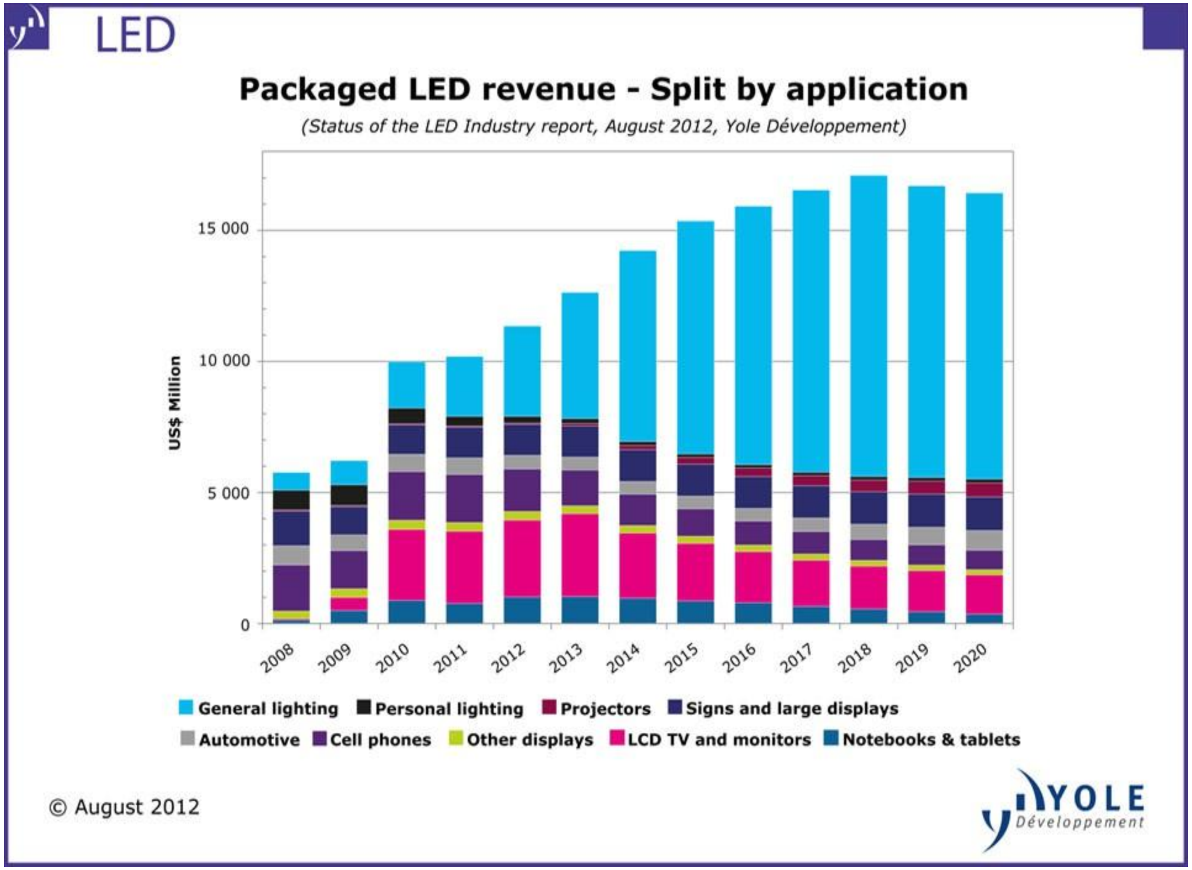
Switching to solid-state lamps is forecast to result in a 46% reduction in lighting energy consumption by 2030.

- Cumulative energy savings 2010-2030: 2,700 TWh
- Cumulative cost savings 2010-2030: $250B

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, DOE Energy Efficiency and Renewable Energy Buildings Report, 2012

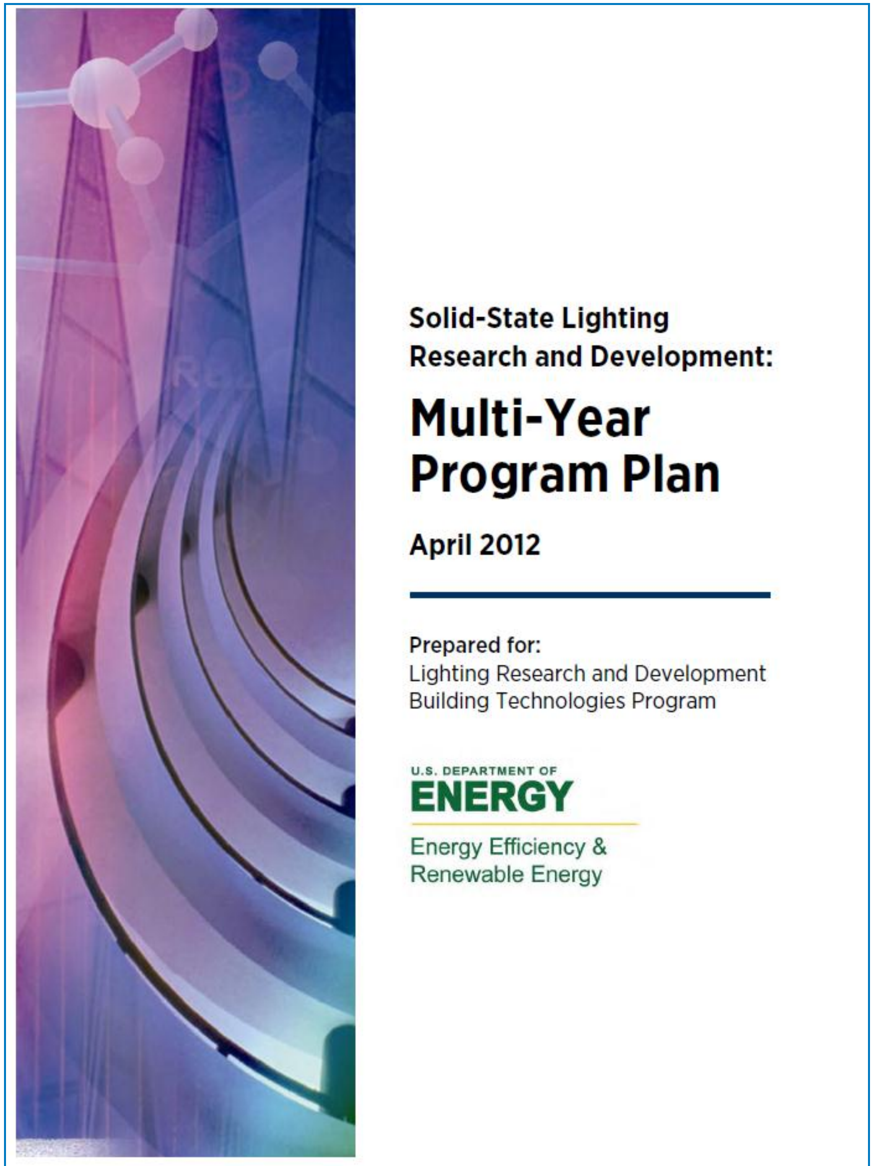
Packaged LED Market and Revenues

Packaged LED revenue is projected to reach $17.1 billion by 2018



Source: *Status of the LED Industry*, Yole Développement and EPIC, 2012

DOE – EERE Mandate



Solid-State Lighting
Research and Development:

Multi-Year
Program Plan

April 2012

Prepared for:
Lighting Research and Development
Building Technologies Program

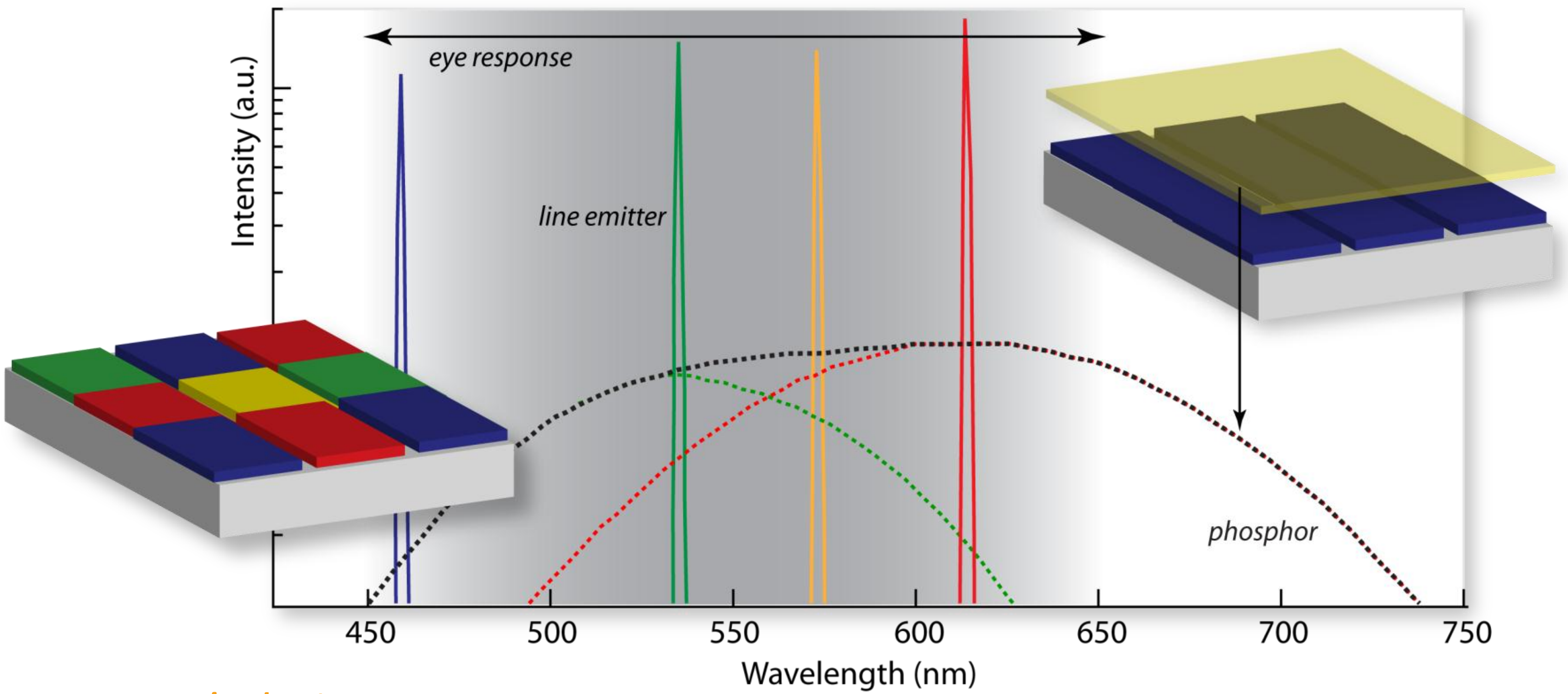
U.S. DEPARTMENT OF
ENERGY
Energy Efficiency &
Renewable Energy

"By 2025, develop advanced solid-state lighting technologies that…are much more energy efficient, longer lasting, and cost-competitive by targeting a product system efficiency of 50 percent with lighting that **closely reproduces the visible portions of the sunlight spectrum**."

- US Department of Energy

Solid-State Lamp Designs

Today's design:
Blue LED + phosphors



Tomorrow's design:
Combination of individual LEDs

This approach requires each of the LEDs also be highly efficient!

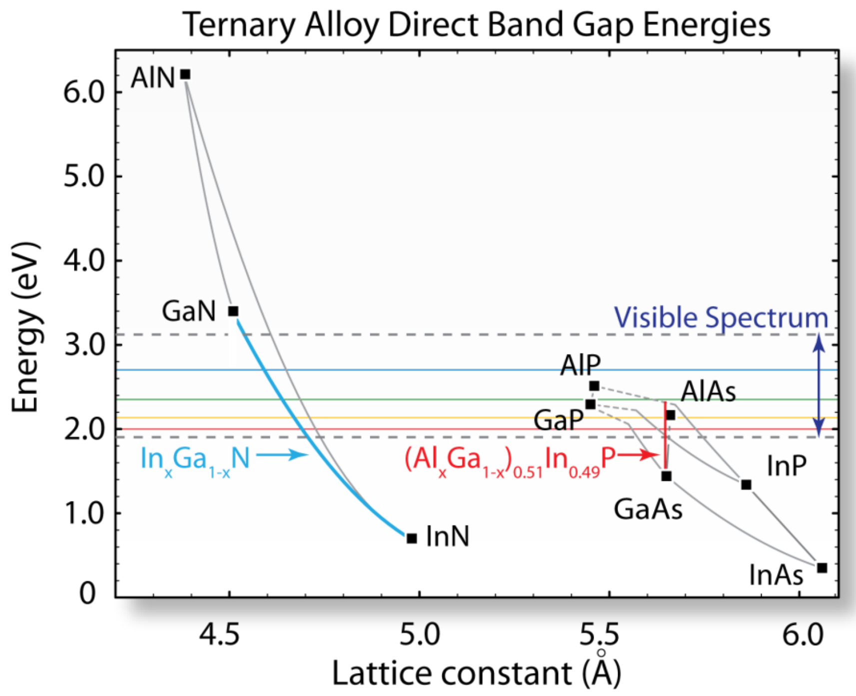
Conventional Materials for Visible LEDs

$In_xGa_{1-x}N$

- Suitable for short λ emission
- Addition of In reduces EQE

$(Al_xGa_{1-x})_{0.51}In_{0.49}P$

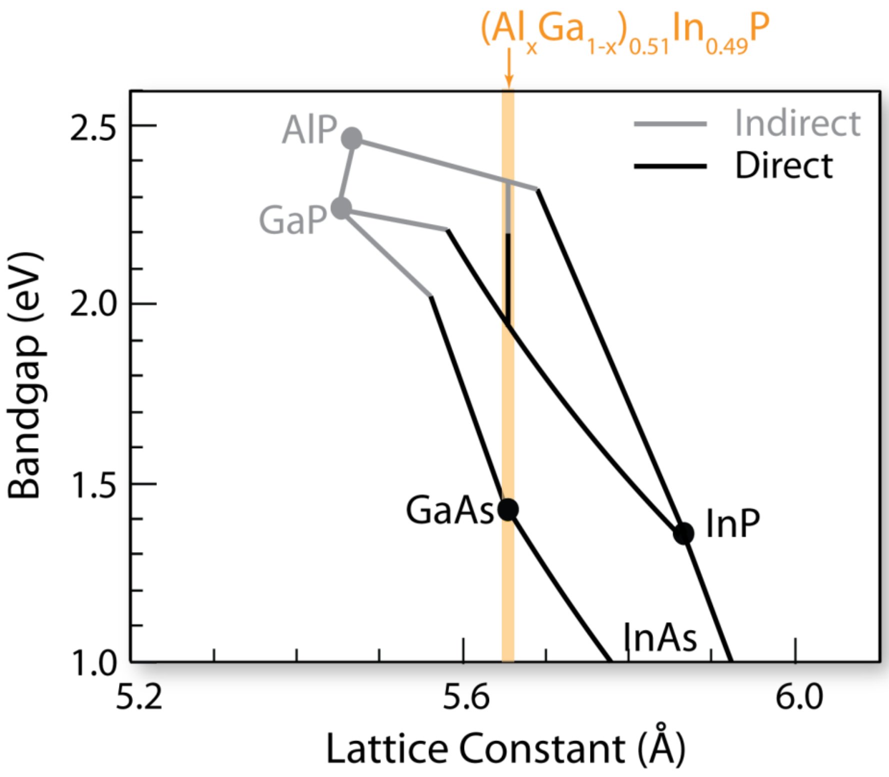
- Lattice-matched to GaAs
- Cannot reach high efficiencies at amber/green λ due to fundamental material issues.

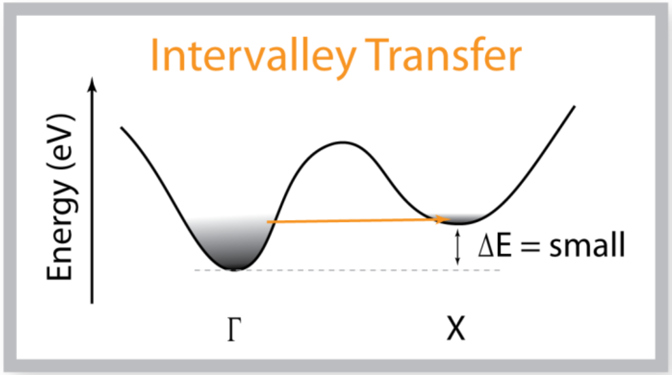


Wavelength (nm)	Material	Current EQE @ 35 A/cm^2	2020 Target EQE
440-460	InGaN	75%	81%
520-540	InGaN	30%	
580-595	AlGaInP	10%	
610-620	AlGaInP	52%	

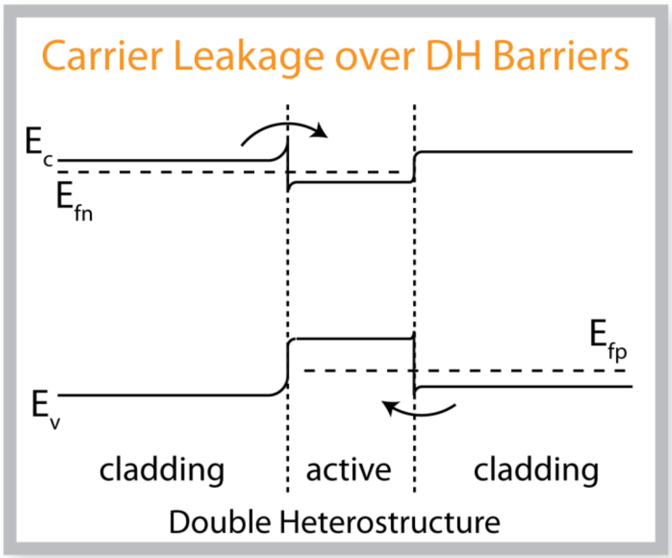
Fundamental Material Properties Limit $(Al_xGa_{1-x})_{0.51}In_{0.49}P$ LEDs

Light emission at shorter wavelengths is limited by two mechanisms.





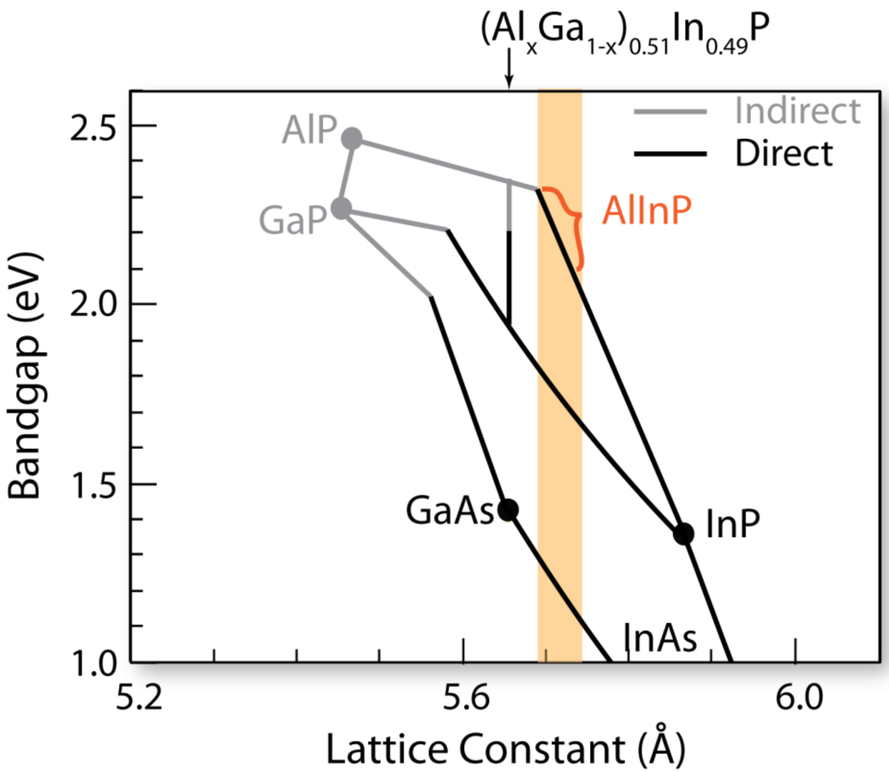
Electrons move to the X conduction band when the composition is near the direct-indirect crossover.



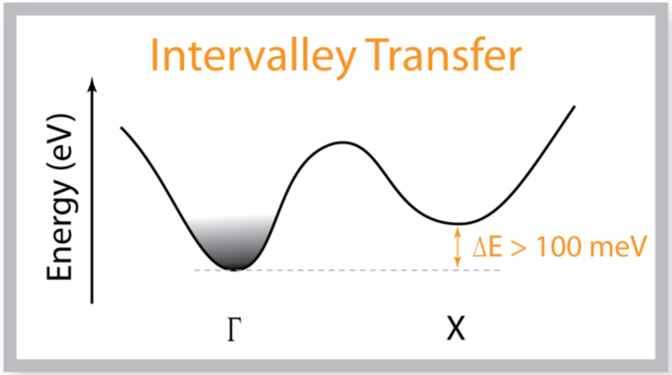
Carrier confinement potentials are important

$Al_xIn_{1-x}P$ for Amber LEDs

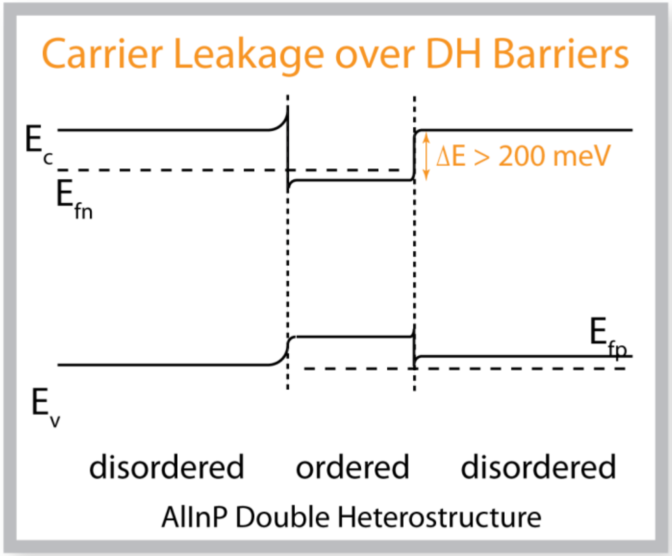
The properties of $Al_xIn_{1-x}P$ offer a way to reduce the impact of these loss mechanisms.



Material	Crossover	Emission λ Limit
$(Al_xGa_{1-x})_{0.51}In_{0.49}P$	2.23 eV	582 nm
$Al_xIn_{1-x}P$	2.32 eV	558 nm



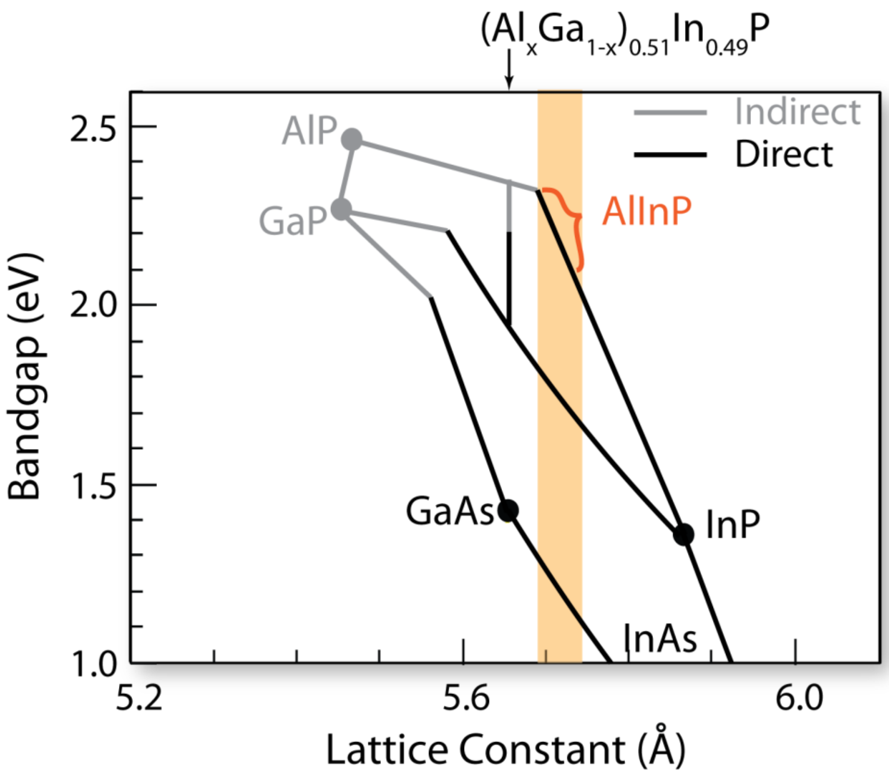
$Al_xIn_{1-x}P$ has the highest Γ-X crossover of any non-nitride III-V alloy (2.3 eV)



Disordered/ordered/disordered double heterostructures provide electron

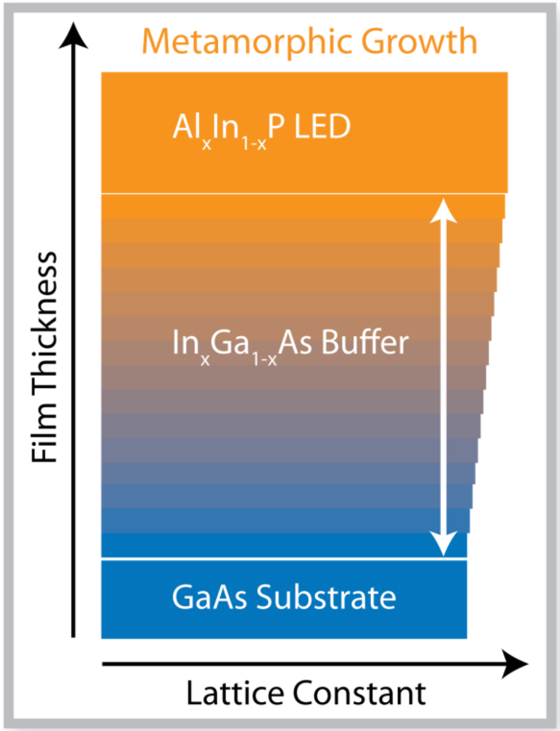
Past Barriers for $Al_xIn_{1-x}P$ LEDs

A number of problems have until now prevented the use of $Al_xIn_{1-x}P$ as the light-emitting material in LEDs



Oxygen contamination

Modern improvements in reactor design and precursor purity have reduced this problem.

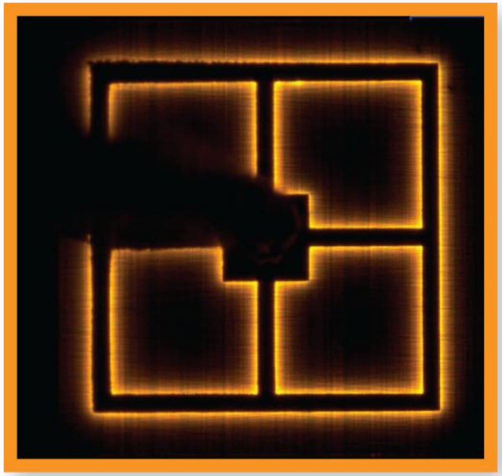


The lattice-mismatch with the substrate can be accommodated with a metamorphic buffer.

$Al_xIn_{1-x}P$ LED Performance

$Al_xIn_{1-x}P$ LEDs were compared to red-emitting lattice-matched $Ga_{0.5}In_{0.5}P$ LED standards of the same structure in order to gauge relative efficiency.

- This approach is used to understand the efficiency potential without having to optimized the structure for current spreading and light extraction.
- Extrapolation to optimized efficiencies:
  - Lattice-matched $Ga_{0.5}In_{0.5}P$ LED = 50% EQE
  - Our best $Al_xIn_{1-x}P$ LED (595 nm) is 39% as efficient as the $Ga_{0.5}In_{0.5}P$ standard.
  - These results suggest that these $Al_xIn_{1-x}P$ LEDs could have absolute EQEs as high as 20%.



AlInP LED (595 nm emission)

Work is ongoing to optimize the material and structure for LED applications.

Current NREL IP Status

- **Record of Invention (ROI) 09-36: Patent application pending in US**
- **ROI 09-59: Patent application pending in US and Canada**
- **ROI 10-64: Patent application pending in US, Canada, Japan, and Europe**

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(54) Title: LATTICE-MISMATCHED GaInP LED DEVICES AND METHODS OF FABRICATING SAME

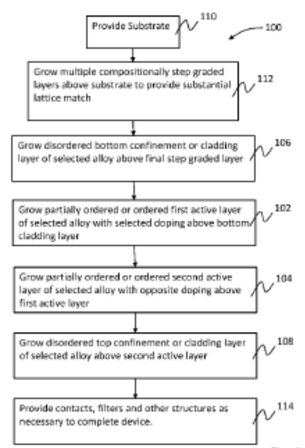

Fig. 1

(57) Abstract: A method (100) of fabricating an LED or the active regions of an LED and an LED (200). The method includes growing, depositing or otherwise providing a bottom cladding layer (208) of a selected semiconductor alloy with an adjusted bandgap provided by intentionally disordering the structure of the cladding layer (208). A first active layer (202) may be grown above the bottom cladding layer (208) wherein the first active layer (202) is fabricated of the same semiconductor alloy, with however, a partially ordered structure. The first active layer (202) will also be fabricated to include a selected n or p type doping. The method further includes growing a second active layer (204) above the first active layer (202) where the second active layer (204) Is fabricated from the same semiconductor alloy.

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