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CHANGING WHAT'S POSSIBLE

Multijunction GaInP/GaAs Solar Cells Grown by Hydride Vapor Phase Epitaxy

Kevin L. Schulte, John Simon, and Aaron J. Ptak
National Renewable Energy Laboratory
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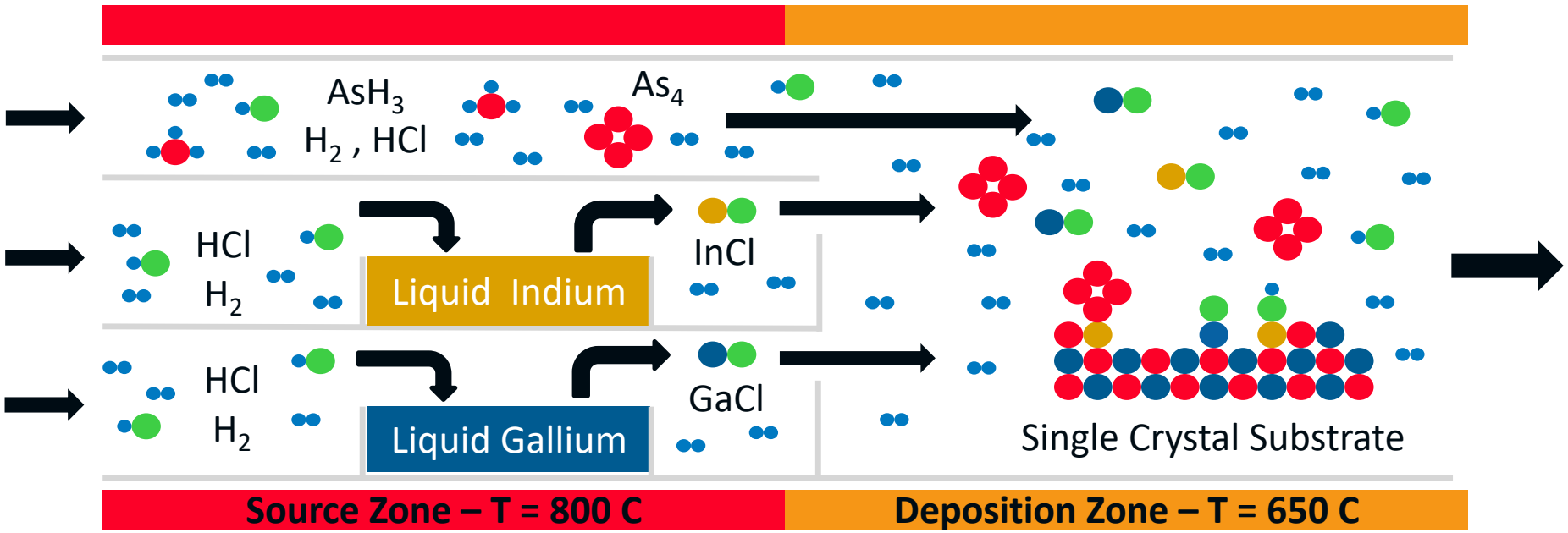
Reducing the Cost



Hydride Vapor Phase Epitaxy (HVPE)

HVPE advantages:

- Low cost precursors
- Proven high deposition rate (~300 µm/h for GaAs)
- High material utilization (V/III < 4, potential metals recycling & lower grade metals)

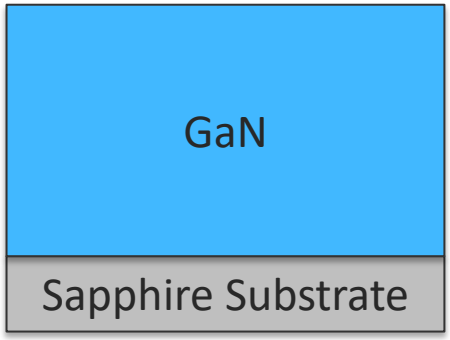
But:

- Applications limited to bulk applications due to difficulty forming hetero-interfaces

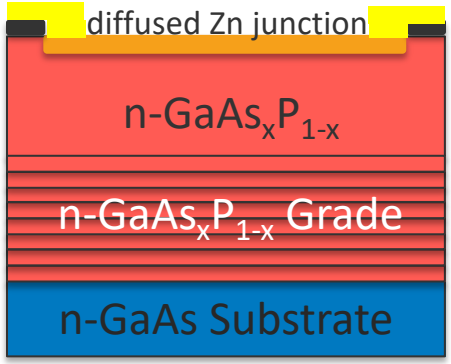
Pushing the Limits

Traditional HVPE Products

GaN Substrates

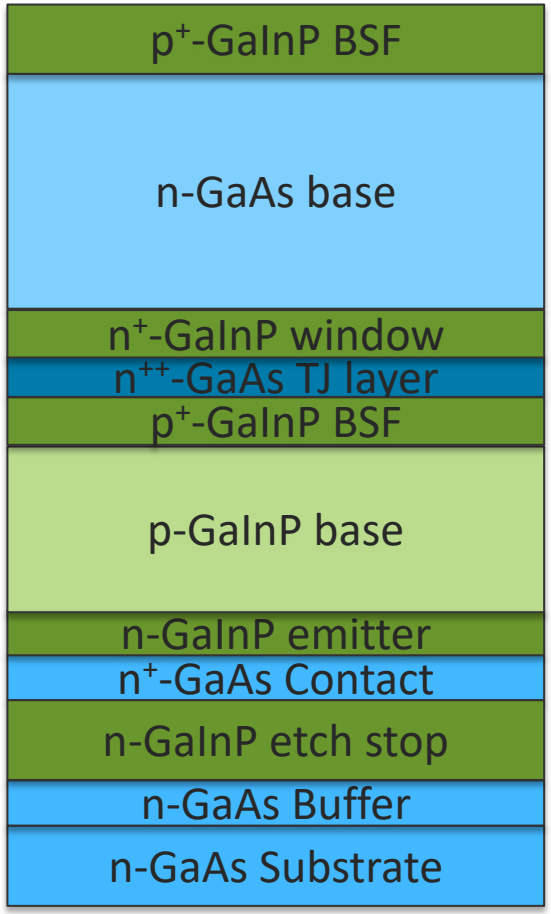


Visible LEDs



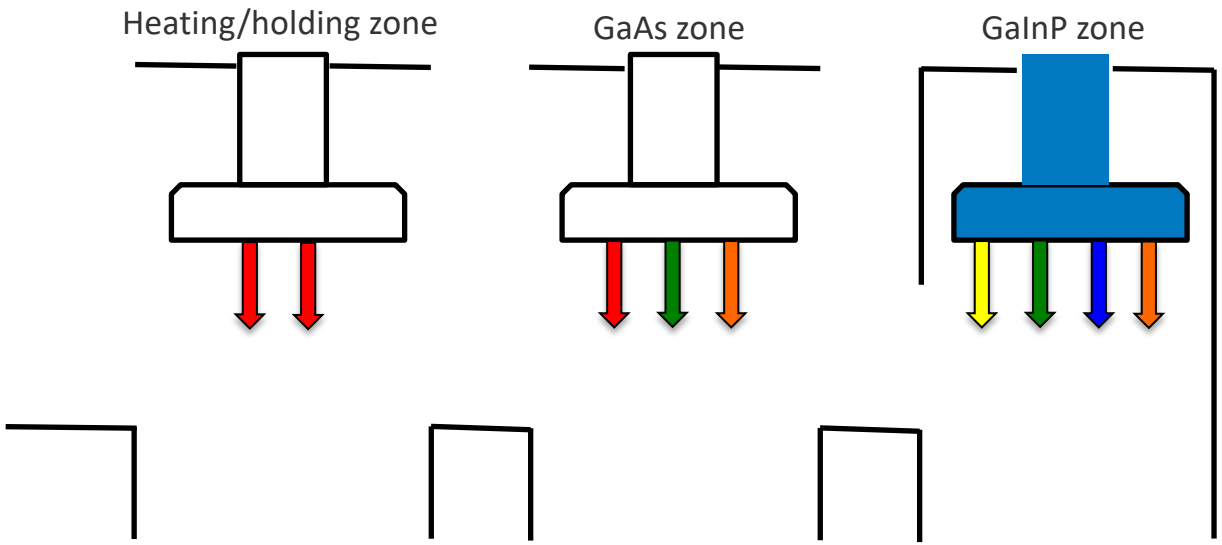
M.G. Craford, IEEE Trans. Elec. Dev. **24**(7) 1977

Inverted Tandem GaInP/GaAs Cell



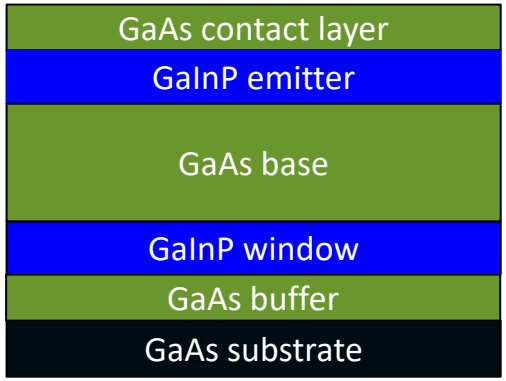
3 doping type switches 7 hetero-interfaces

Dynamic HVPE



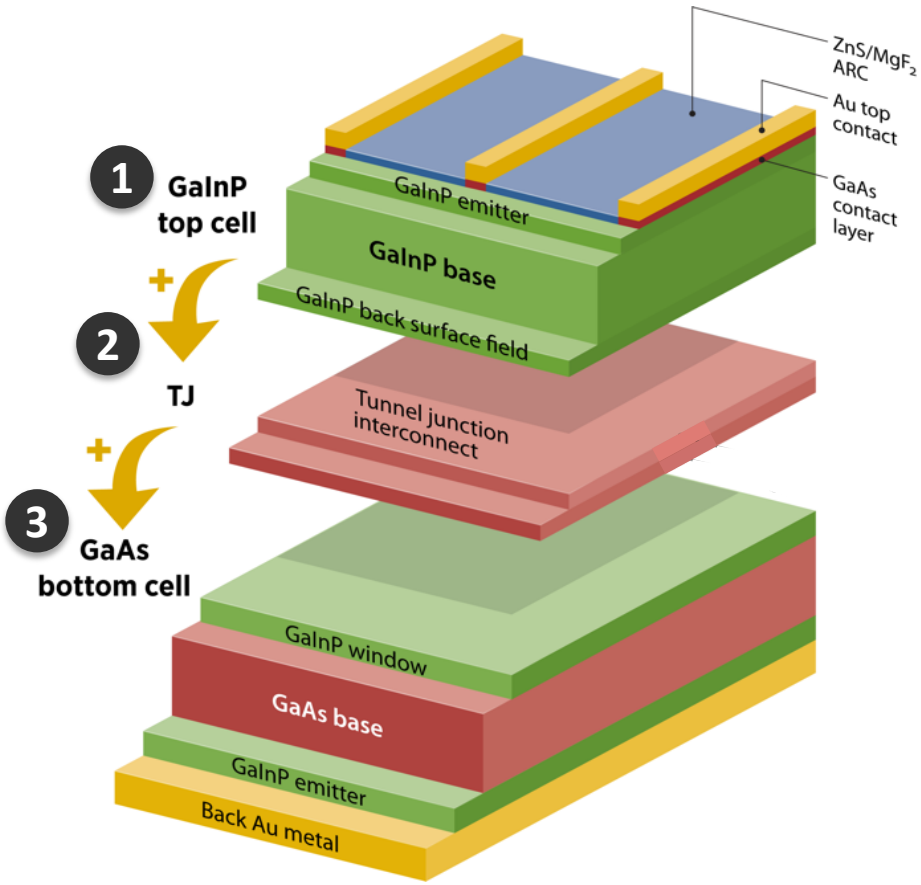
Inverted rear heterojunction GaAs cell

1. Heat substrate/remove oxide
2. Nucleate p-GaAs buffer
3. n-GaInP Window
4. n-GaAs base layer
5. p-GaInP emitter layer
6. p+-GaAs contact layer
7. Remove from system

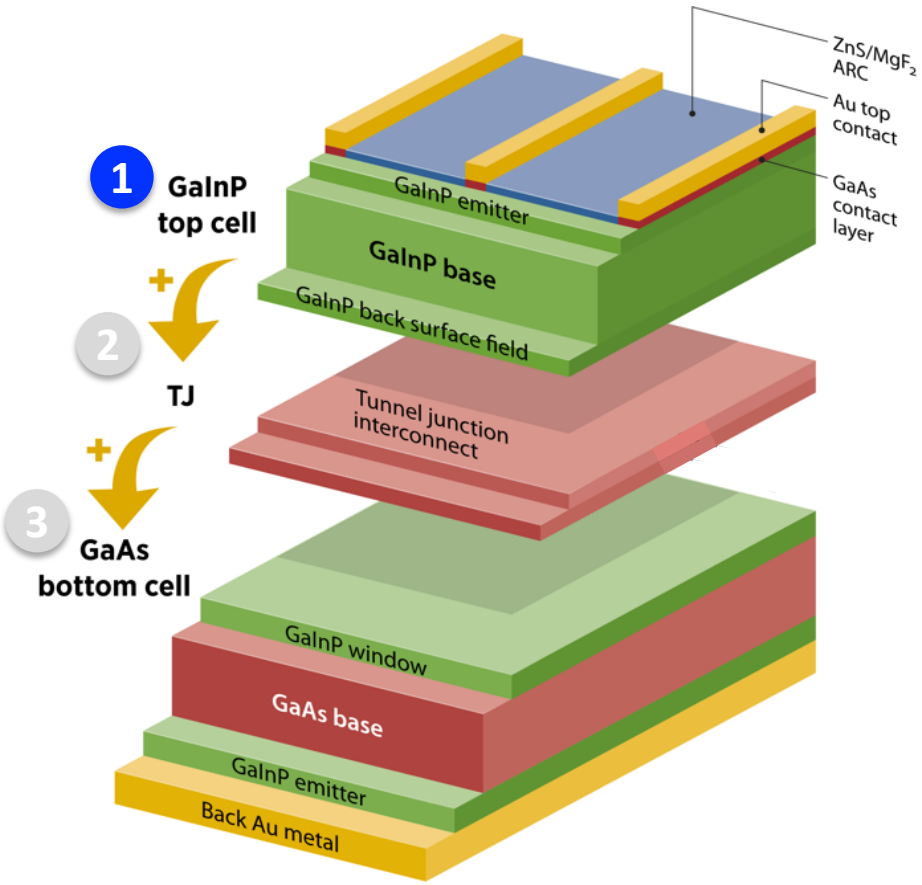


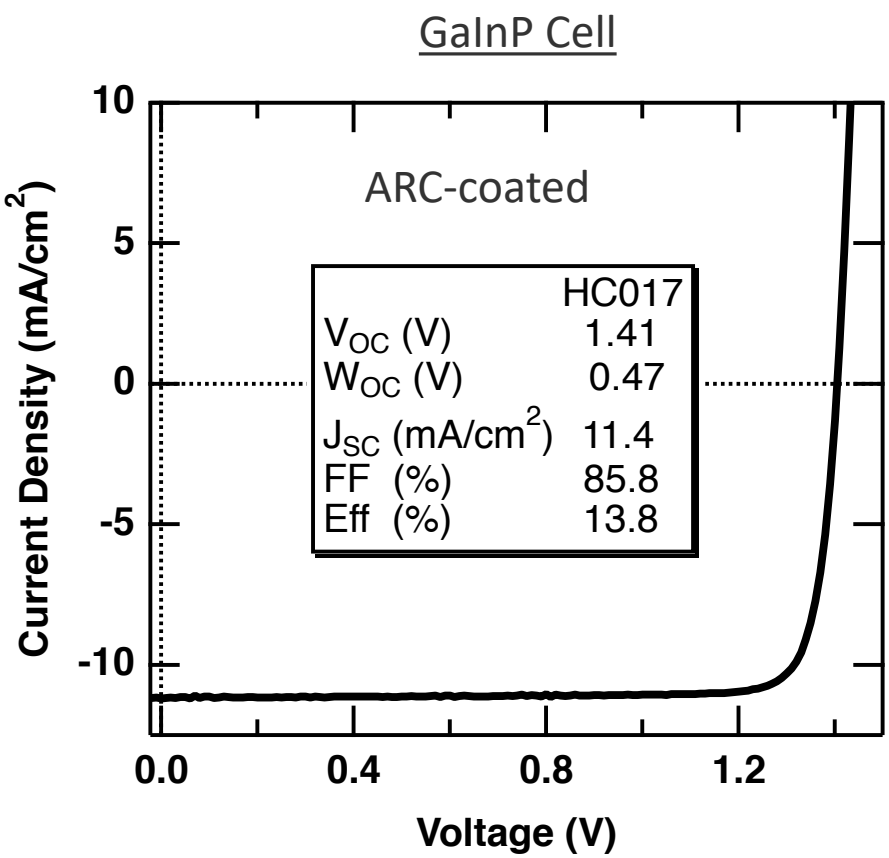
Simulates possible industrial in-line process

Tandem Component Development



Tandem Component Development





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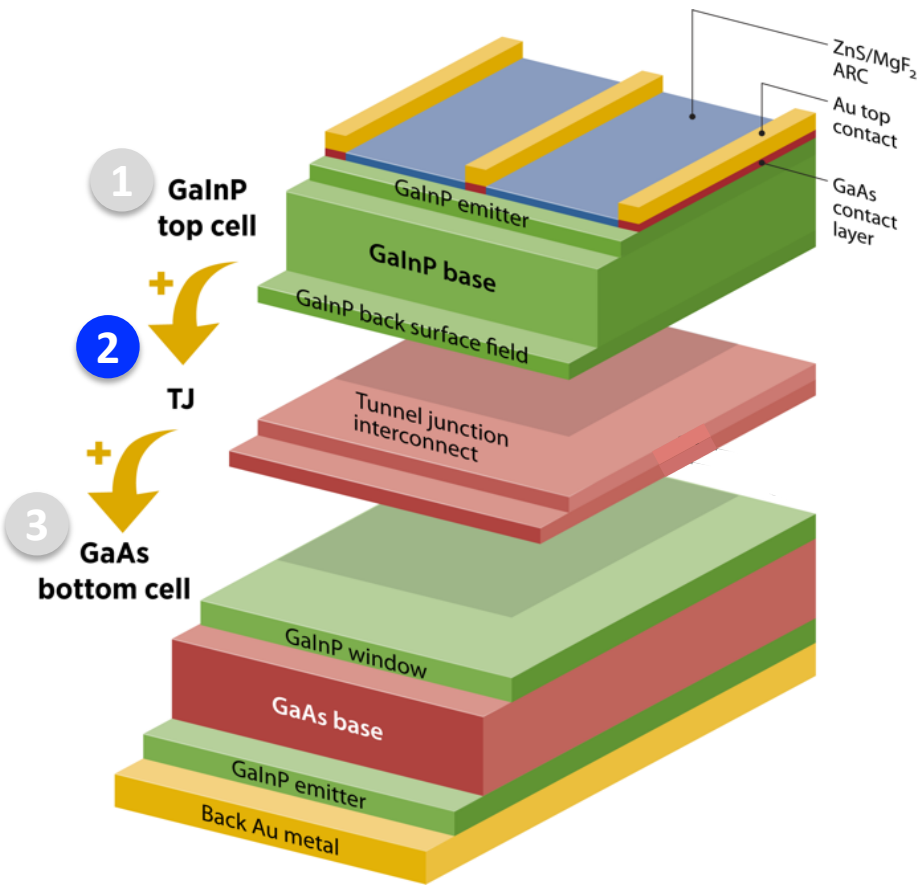
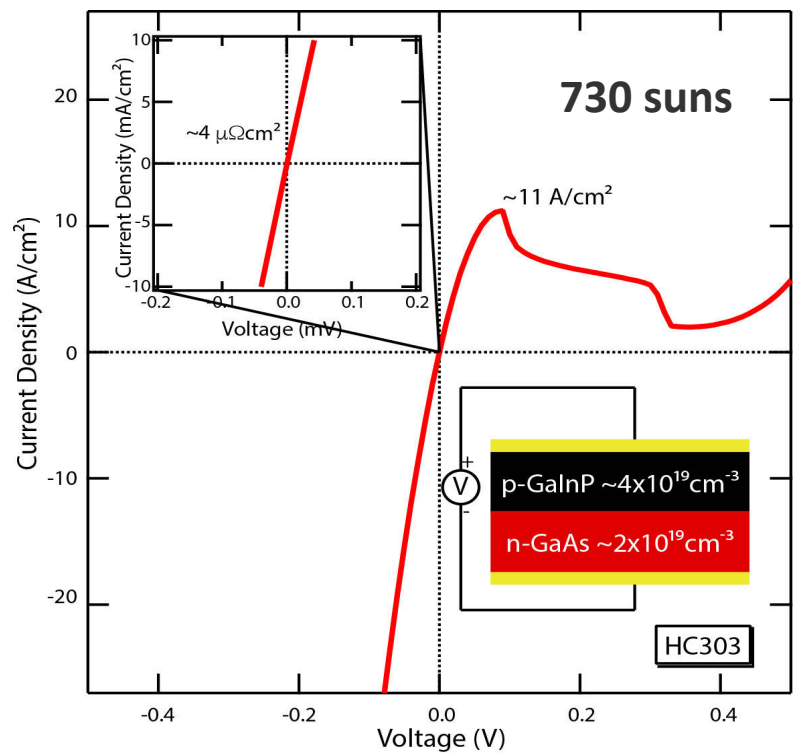
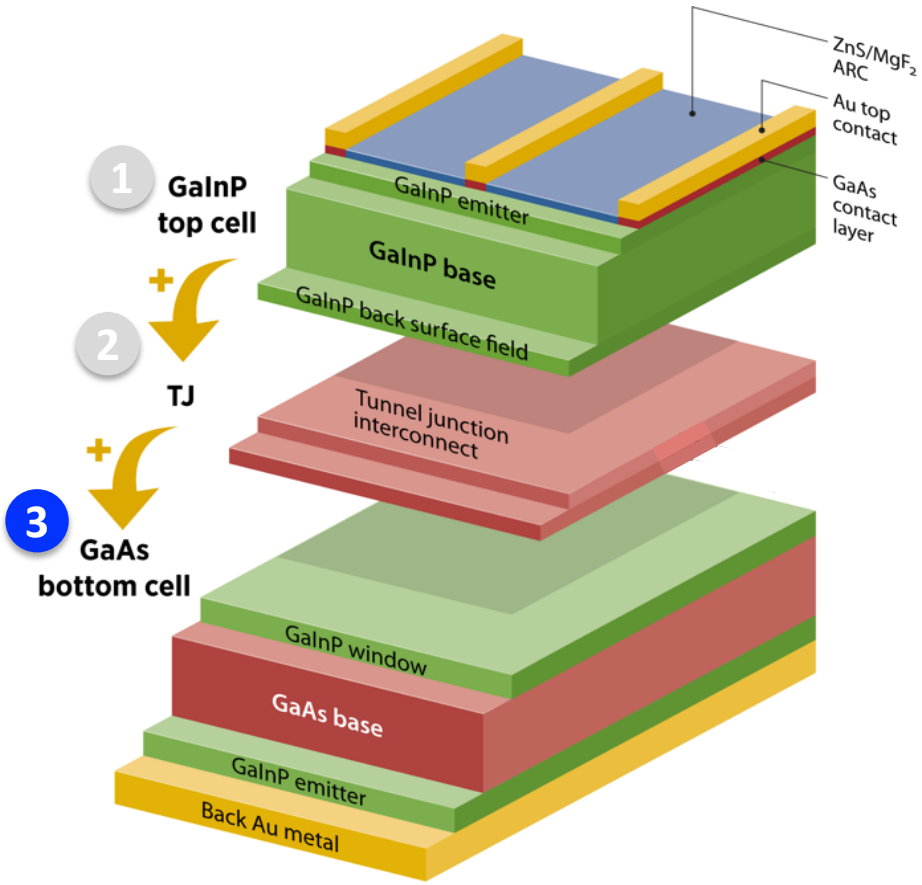
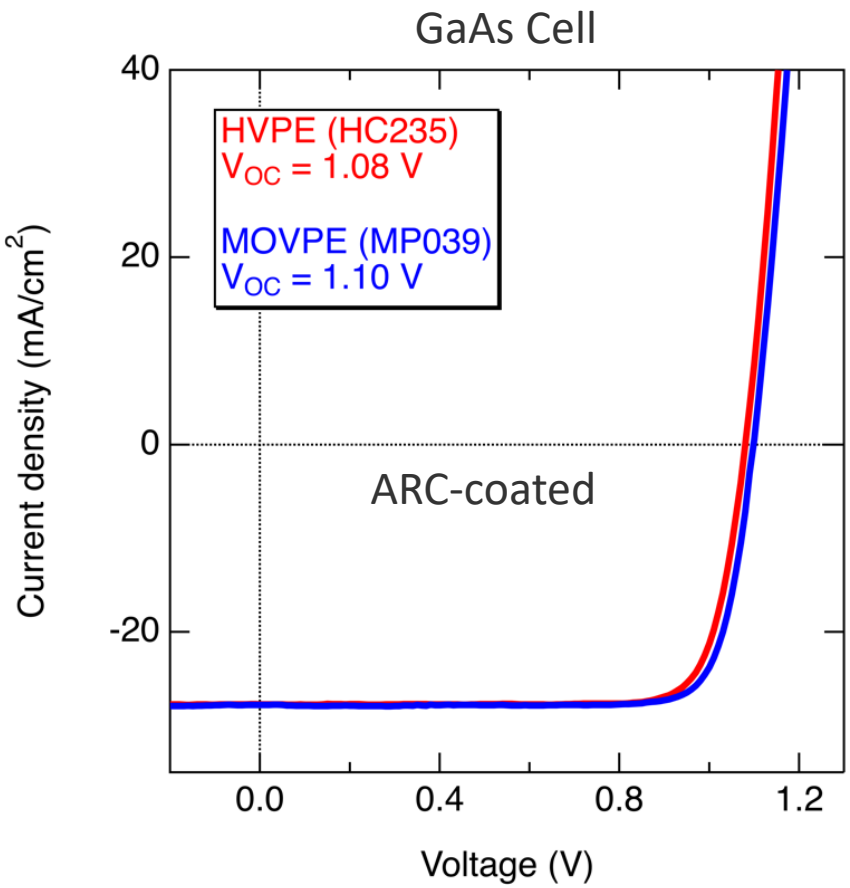


Tunnel Junction



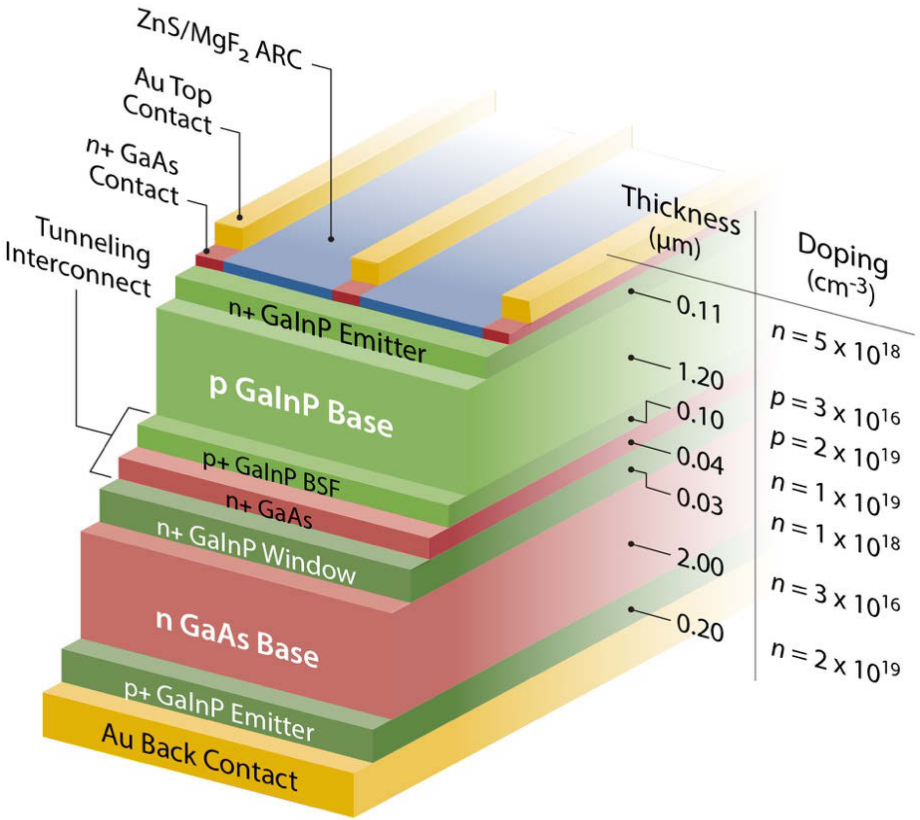
Tandem Component Development





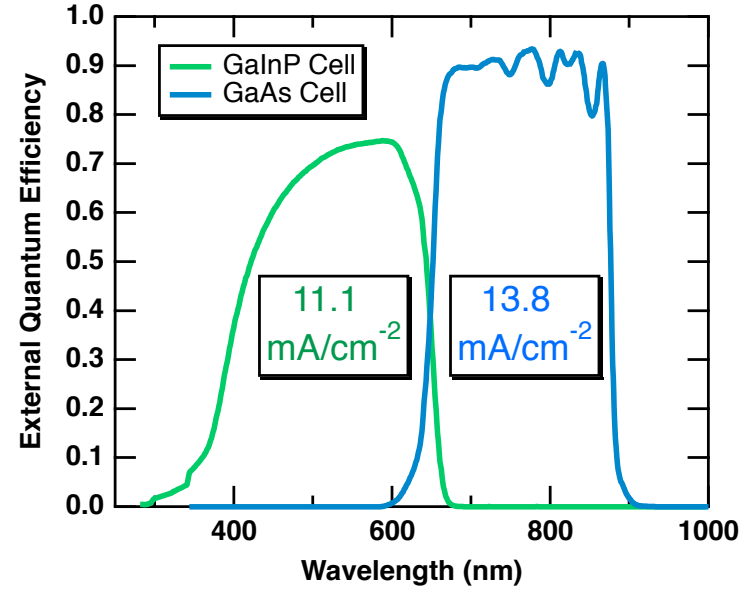
HVPE Growth Rate: 1.0 µm/min
MOVPE Growth Rate: 0.1 µm/min

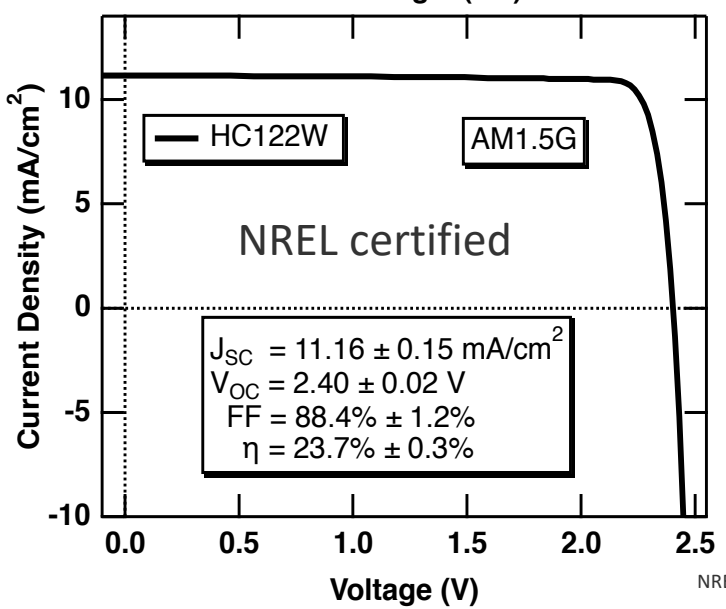
Putting it All Together



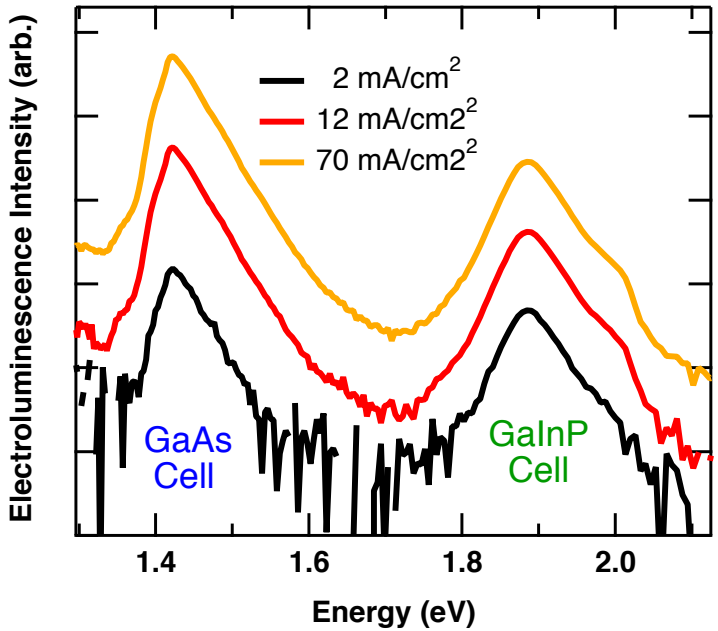
GaInP Base: 0.9 µm/min
GaAs Base: 1.0 µm/min

T_{Dep} = 650 °C

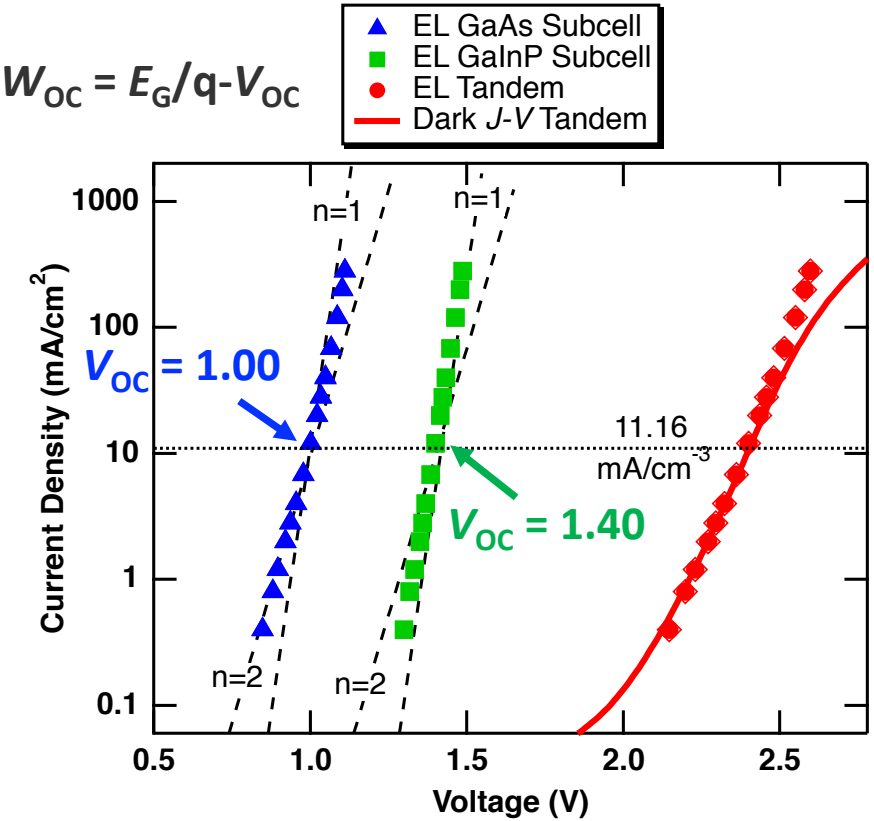




Radiative Efficiency



$W_{OC} = E_G/q - V_{OC}$

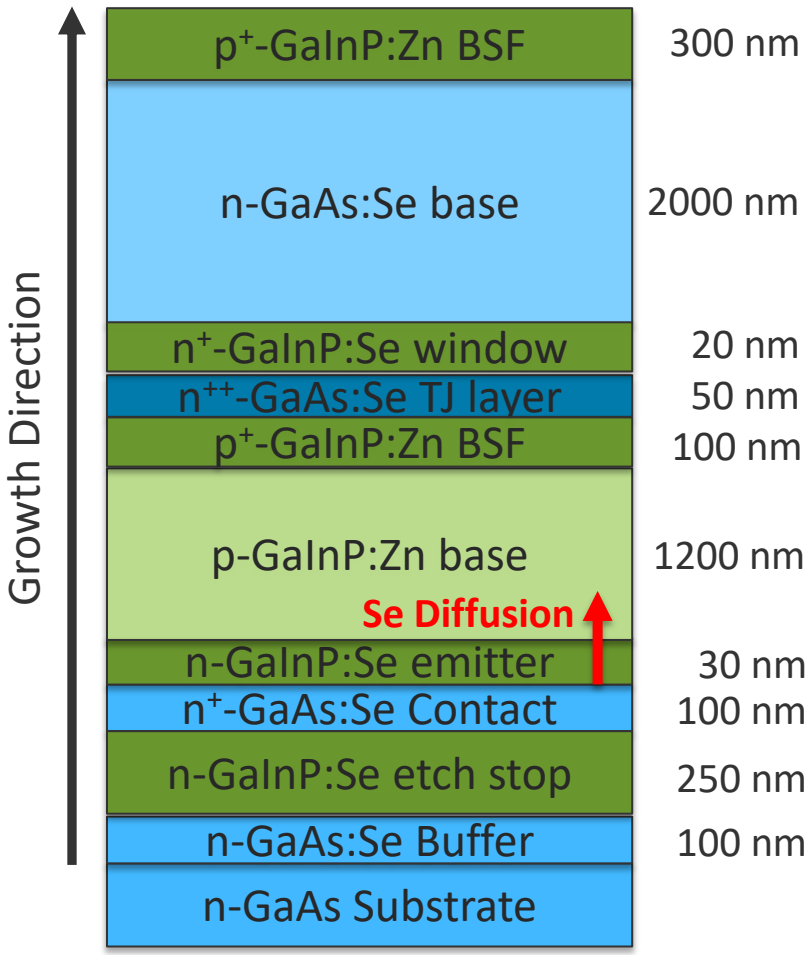


$$\eta_{ext} = \frac{J_{em}}{J_{inj}} \qquad V_{OC} = V_{OC}^{rad} + \frac{kT}{q}\ln(\eta_{ext})$$

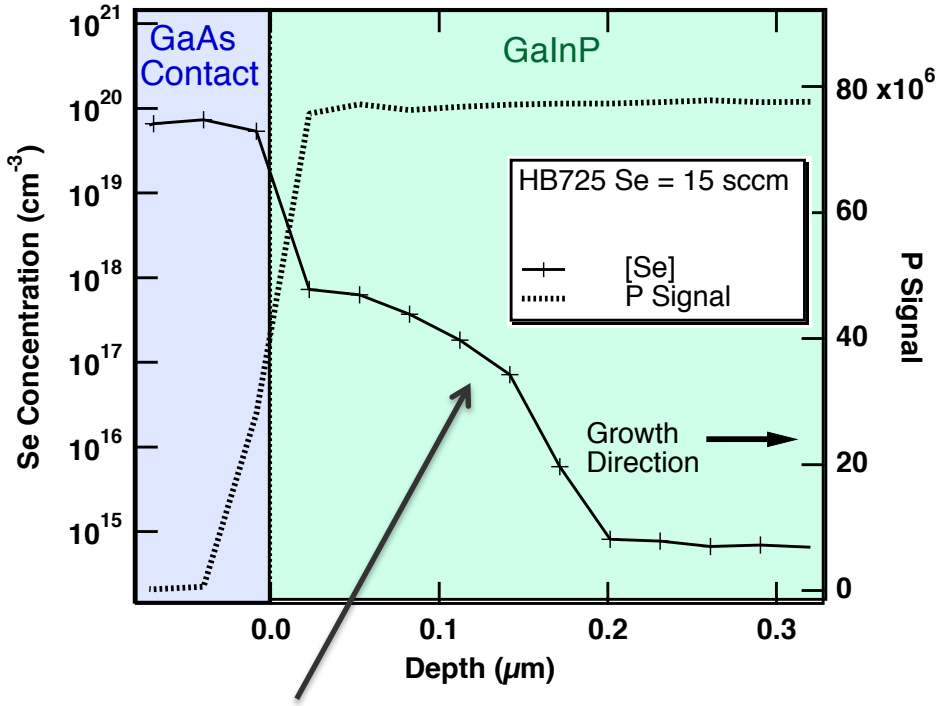
$$W_{OC}^{GaAs} = 0.41 \qquad W_{OC}^{GaInP} = 0.48$$

- Electroluminescence of the tandem device reveals subcell V_{OC}'s of 1.40 and 1.00 V for GaInP and GaAs, respectively
- n~1 diode ideality at J_{SC} for both cells, implying good material quality

Boosting Top Cell Current

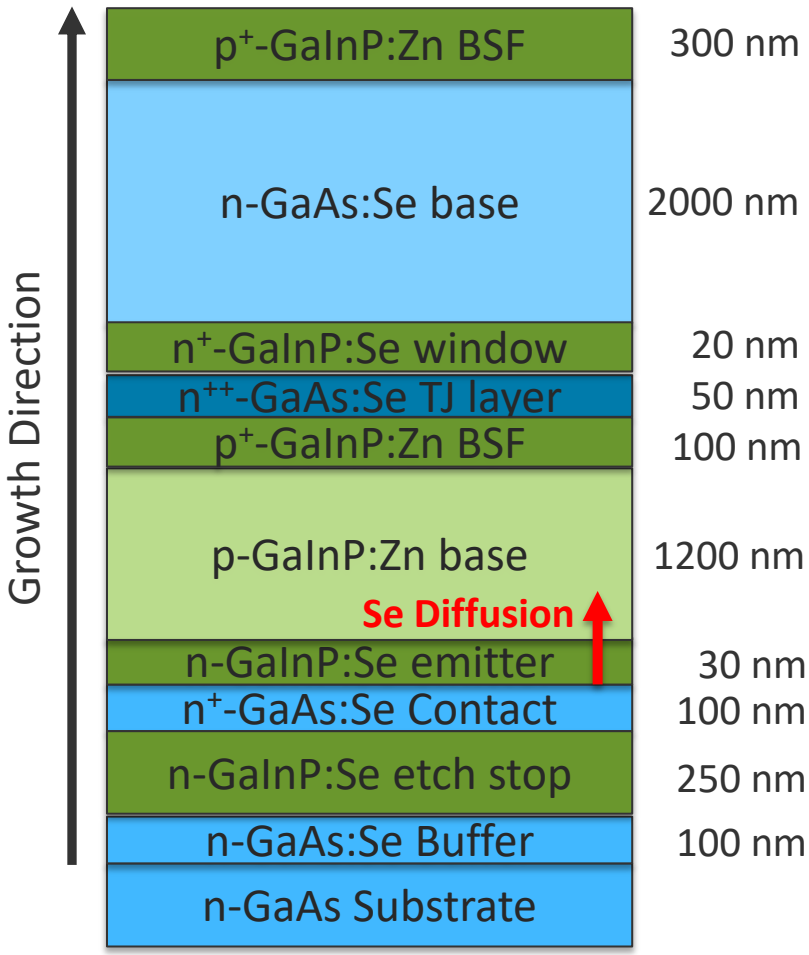


SIMS Data



Se Diffusing into GaInP Base

Boosting Top Cell Current



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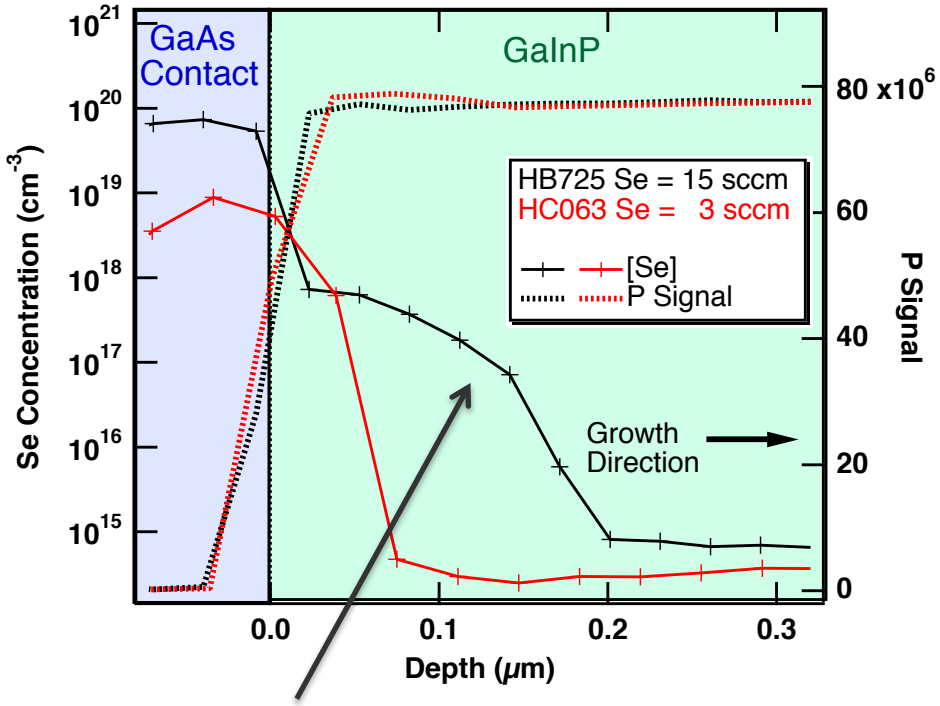
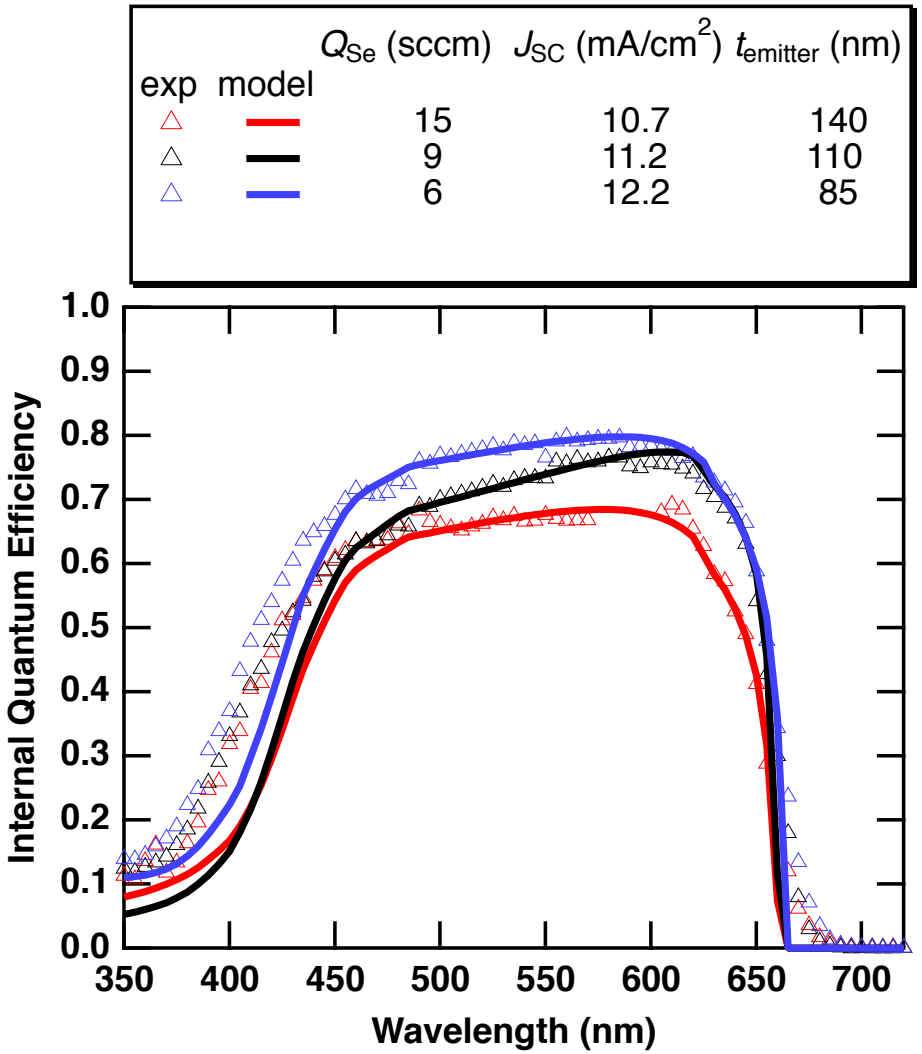


Se Diffusing into GaInP Base

Increasing Top Cell Current

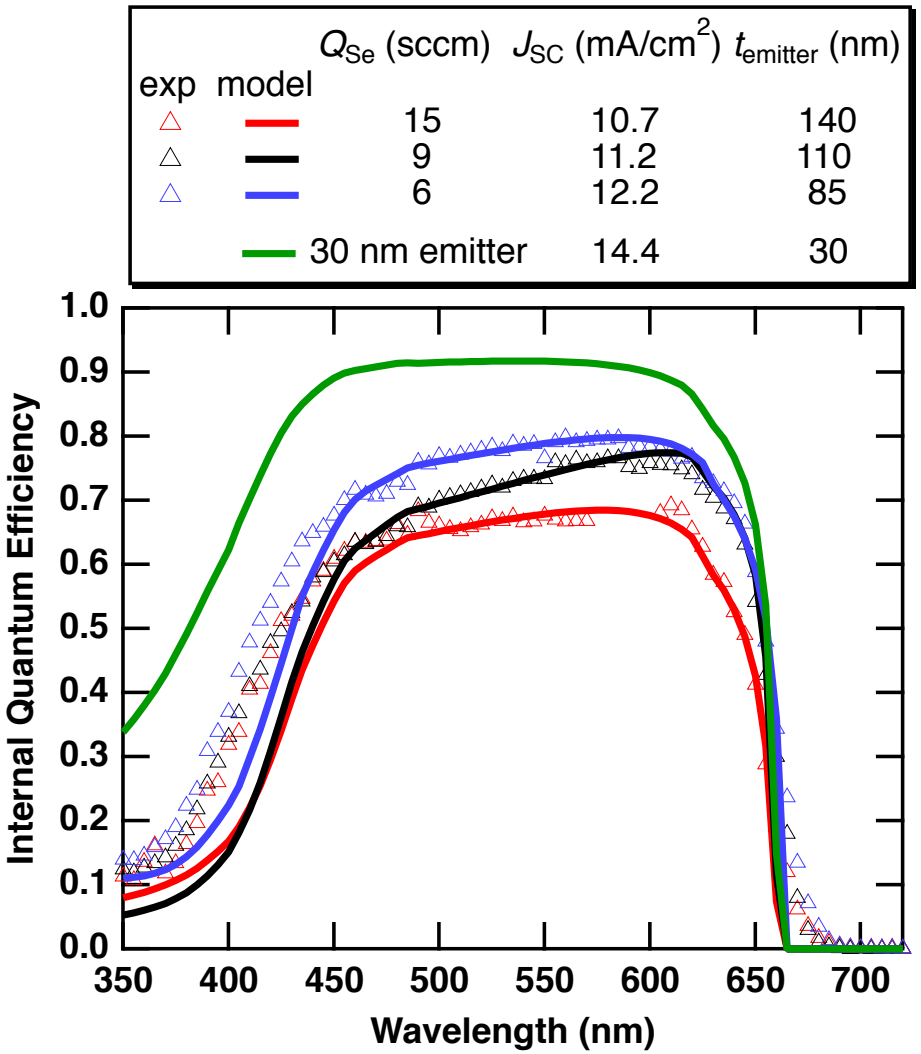
IQE as a function of Se Flow (Q_{Se}) during contact growth



Simply reducing GaAs contact doping boosts GaInP IQE -> limit is structure rather than material quality

Increasing Top Cell Current

IQE as a function of Se Flow (Q_{Se}) during contact growth



30 nm emitter would yield 14.4 mA/cm^2 of current (before reflection losses)

$$\eta = 23.7\% * \frac{14.10\,\frac{mA}{cm^2}}{11.16\,\frac{mA}{cm^2}} * \frac{2.43\,V}{2.40\,V} = 30.3\%$$

Possible with current material quality!

Conclusions

- III-V Tandem Devices with significantly reduced deposition cost are possible via D-HVPE
- Bulk material quality is not limiting device performance
- >30% efficiency possible with current material quality and only structural improvements to device

Thank You

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