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Extended-Short-Wavelength Infrared Detectors using Novel Quaternary III-V Alloys on InAs

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e-SWIR (1.7-3.0 μm) III-V Detector Absorber Materials

Type-II superlattices
- InGaAs/GaAsSb on InP
- InAs/GaSb on GaSb
- InAs/AlSb on GaSb

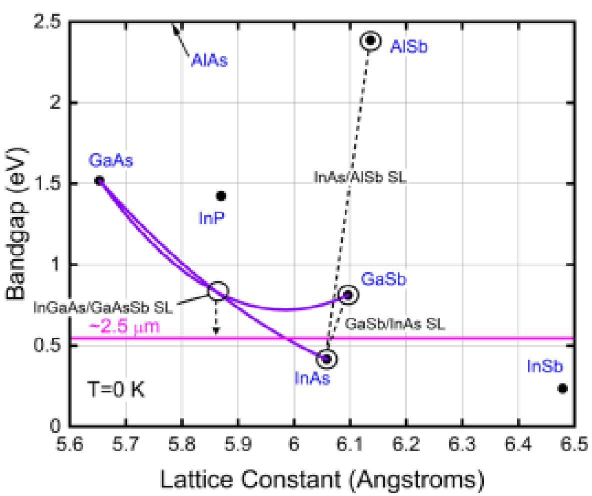
Issues:
- Carrier mobility
- Absorption coefficient
- Point defect density (G-R)

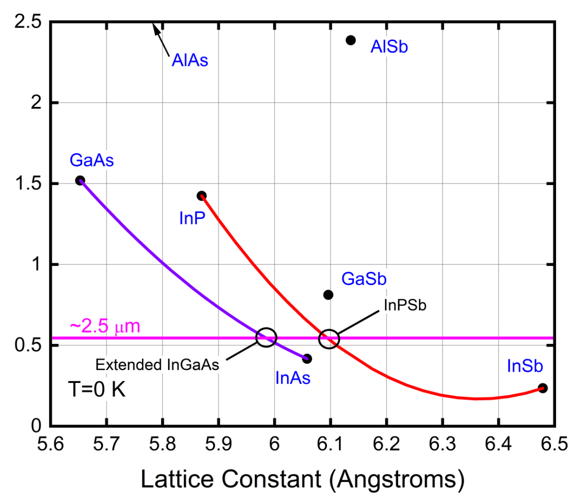
Ternary alloys
- Extended InGaAs on InP
- InPSb on GaSb

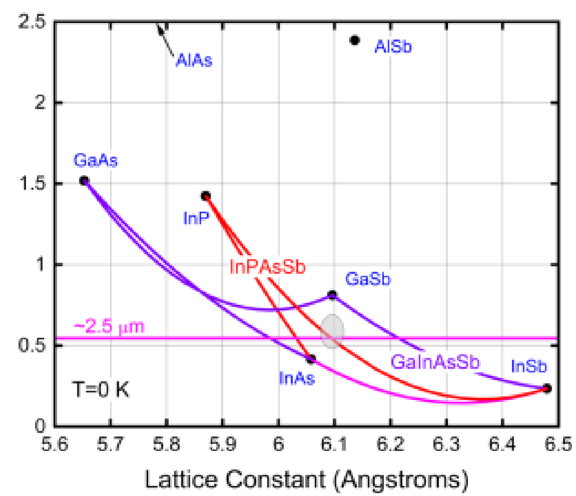
Issues:
- Mismatch defects
- Phase separation

Quaternary alloys
- GaInAsSb on GaSb
- InPAsSb on GaSb

Issues:
- Possible phase separation
- GaSb-related point defects







This work: Quaternary Alloys Lattice Matched to InAs

Start with InAs (rather than InAsSb)

- InAs is already almost in eSWIR

Add small amounts of AlAsSb or InPSb

AlInAsSb

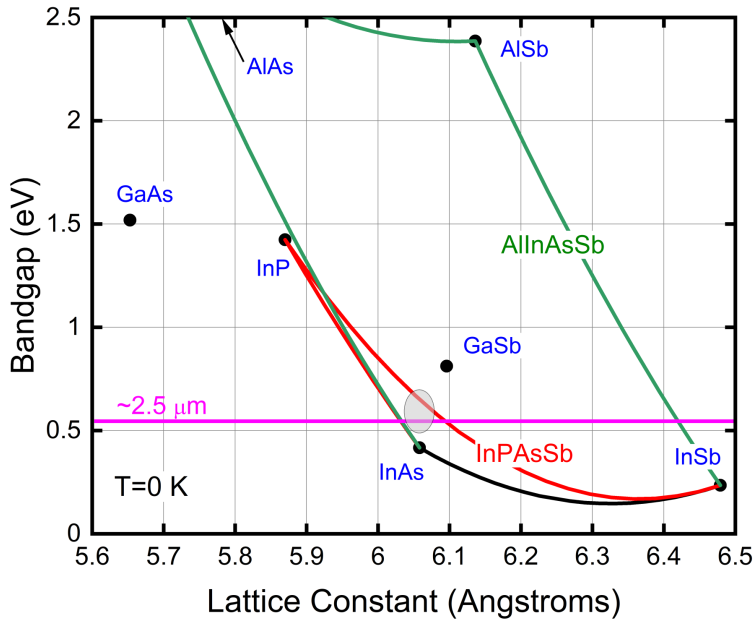
- Less Al or Sb than alloy with same bandgap on GaSb
- Reduces likelihood of phase separation

InPAsSb

- Less P or Sb than alloy with same bandgap on GaSb

The tradeoff: InAs substrate opaque in eSWIR

- Substrate removal required
- Even GaSb substrate removal required for SWIR



Experimental Details

Growth by molecular beam epitaxy

- Hybrid solid (As,Sb) / gas (PH_3) source system
- All epi lattice matched to InAs substrates

Etched-mesa nBn diodes

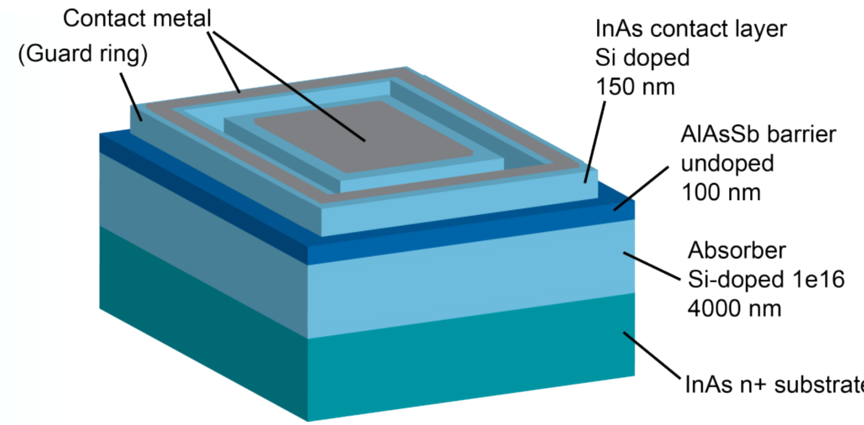
- 100×100 to 600×600 μm^2
- Shallow etch to AlAsSb barrier (left in place)
- No passivation

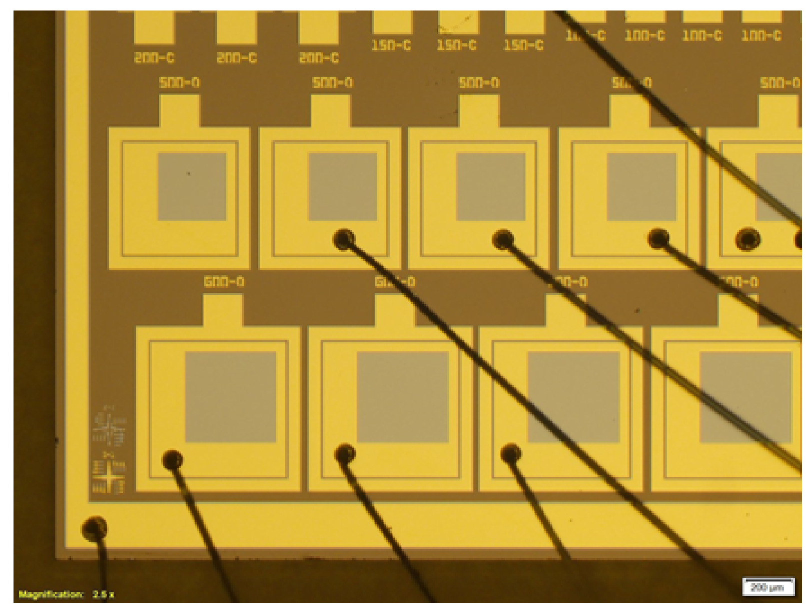
Material characterization

- X-ray diffraction
- Energy dispersive x-ray analysis (EDX)
- Electron channeling contrast imaging (ECCI)
- Photoluminescence (200 K)
- Time-resolved microwave reflectance (100 K)

Device characterization

- I-V, C-V
- QE: Front illumination, no AR coating





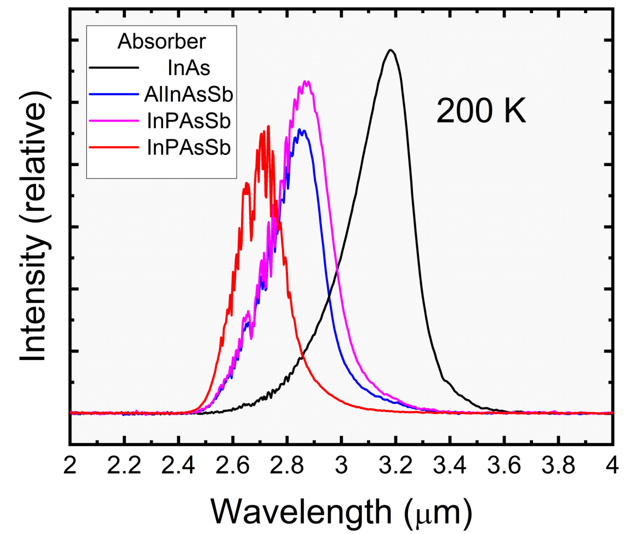
Epi Characteristics

X-ray linewidths typically ~50 arcsec FWHM

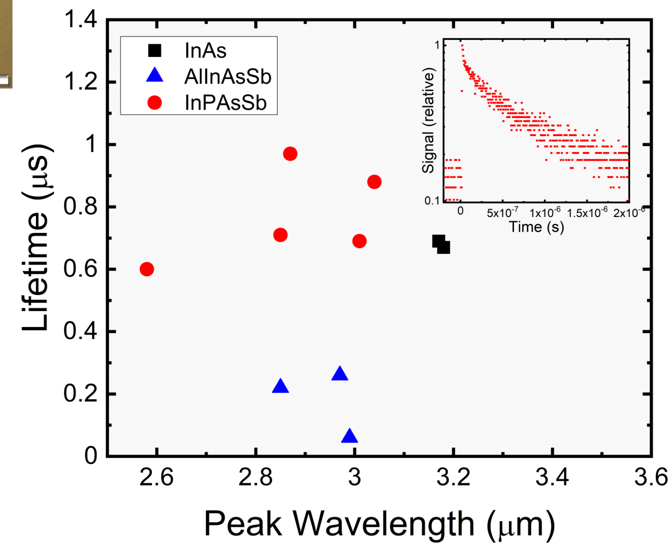
PL similar to InAs for wavelengths > 2.8 μm

Minority carrier lifetimes

- InPAsSb comparable to InAs
- AlInAsSb has shorter lifetimes

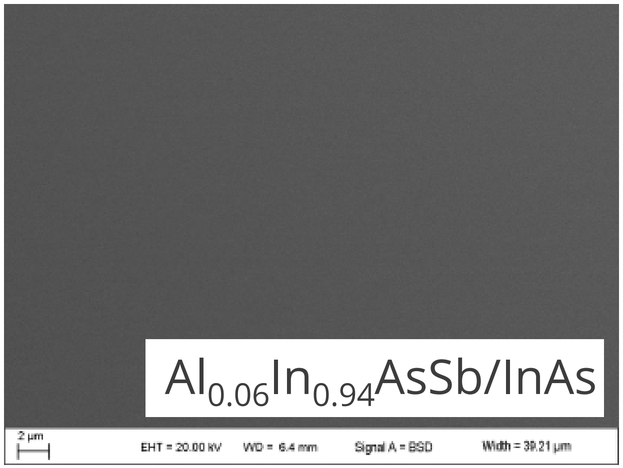


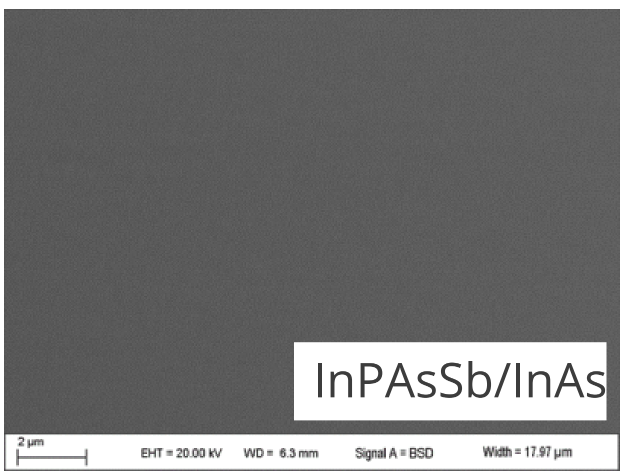
Nominal Composition	Measured by EDX	200 K PL Wavelength (μm)
InPAsSb	$InP_{0.12}As_{0.73}Sb_{0.15}$	2.85
InPAsSb	$InP_{0.18}As_{0.63}Sb_{0.19}$	2.58
$Al_{0.02}In_{0.98}As_{0.98}Sb_{0.02}$	--	2.99
$Al_{0.02}In_{0.98}As_{0.98}Sb_{0.02}$	--	2.97
$Al_{0.04}In_{0.96}As_{0.97}Sb_{0.03}$	$Al_{0.05}In_{0.95}As_{0.90}Sb_{0.10}$	2.85



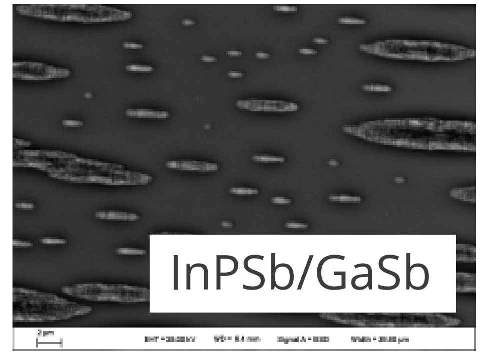
Phase separation not detectable with ECCI

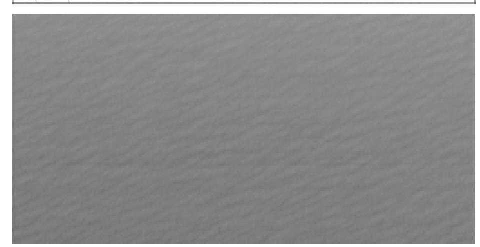
InPAsSb and AlInAsSb on InAs





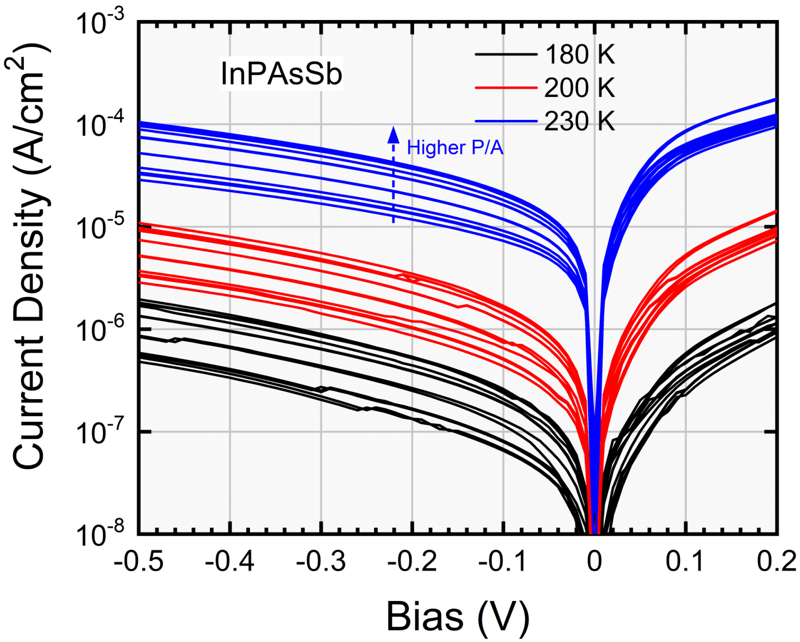
Other ~ 3 μm alloys

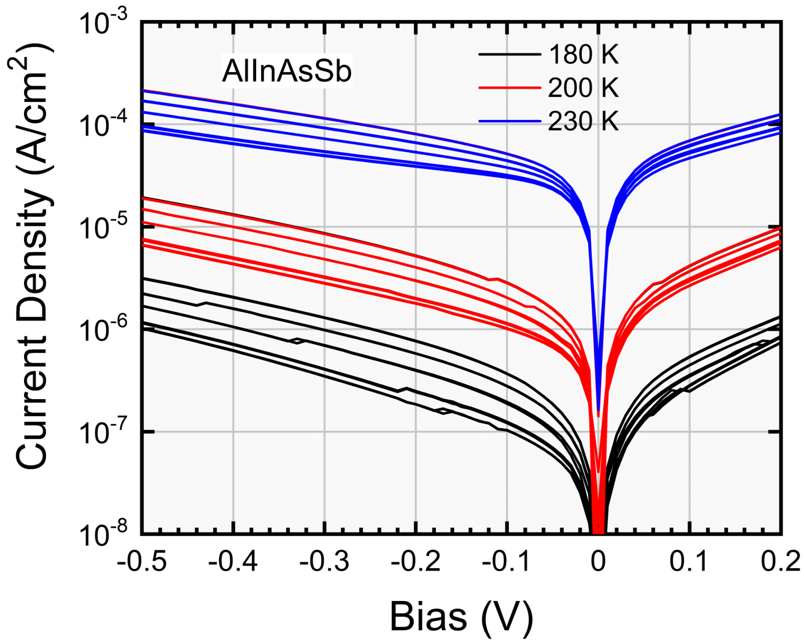




$Ga_{0.8}In_{0.2}AsSb/InAs$

Detector Dark Current Characteristics (λ_c ~ 2.85 μm)

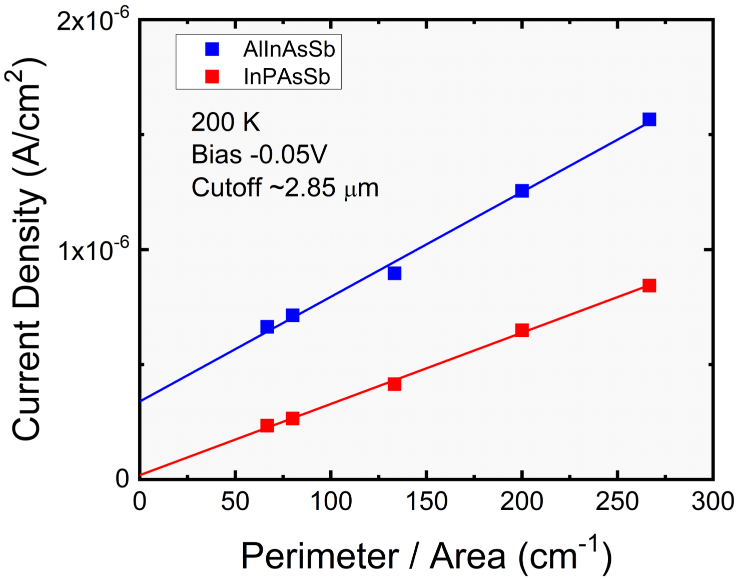




Current density is unusually dependent on device size

InPAsSb has lower current density than AlInAsSb (for same cutoff wavelength)

Dark Current Density Size Dependence

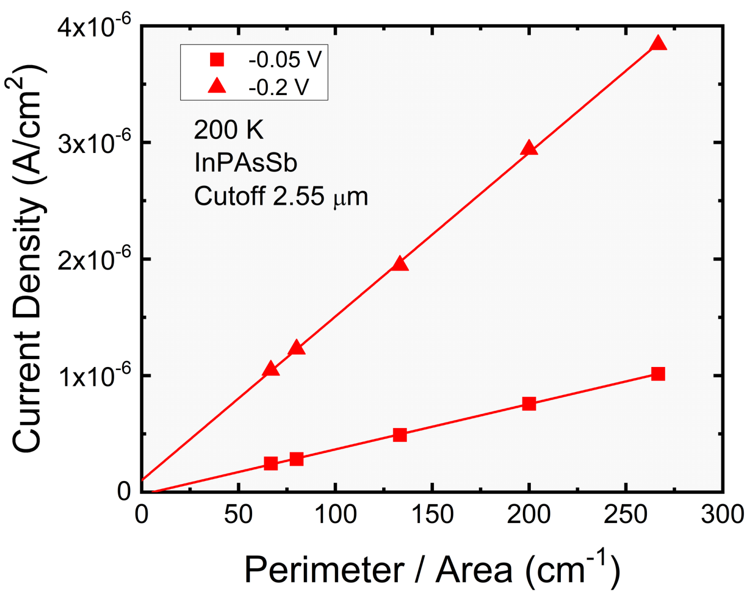


Even largest devices have significant perimeter current

Perimeter current fraction greater for

- InPAsSb
- Shorter cutoff

Extrapolation non-physical for some devices



Material	Cutoff (μm)	Largest Device (A/cm^2)	Areal (A/cm^2)	Perim. (A/cm)
AlInAsSb	2.89	6.6×10^{-7}	3.4×10^{-7}	4.6×10^{-9}
InPAsSb	2.87	2.3×10^{-7}	1.9×10^{-8}	3.1×10^{-9}
InPAsSb	2.55	2.5×10^{-7}	--	3.9×10^{-9}
InAs	3.25	1.1×10^{-6}	5.7×10^{-7}	5.3×10^{-9}

Isolation/passivation less effective than in MWIR nBn Devices

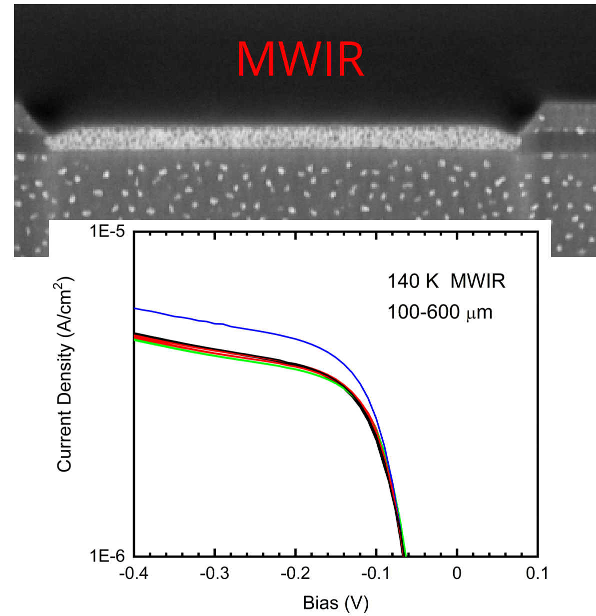
Shallow-etch isolation effective in MW devices
- Areal component dominates total current

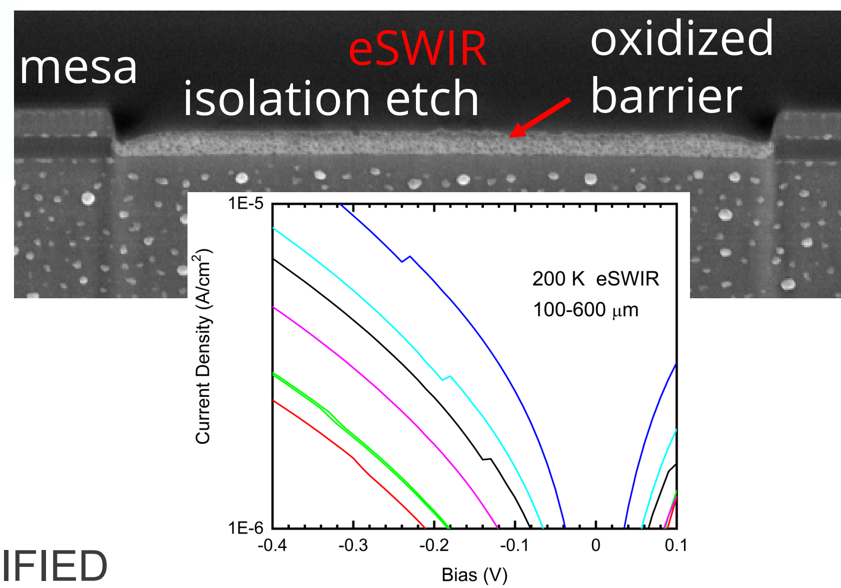
Barrier composition is only slightly different

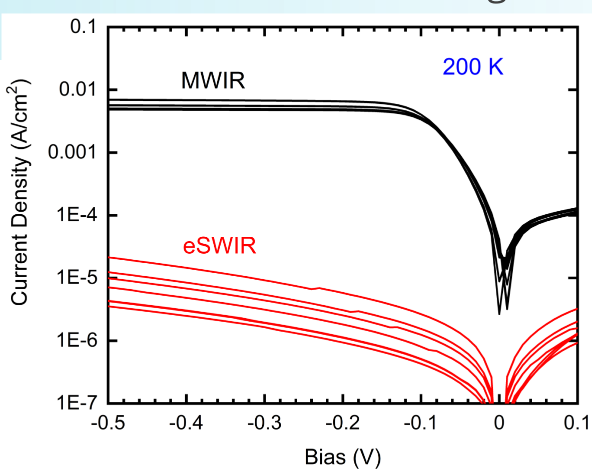
No gross differences in residual barrier oxide
- Further studies in progress

Through-barrier etch does not help

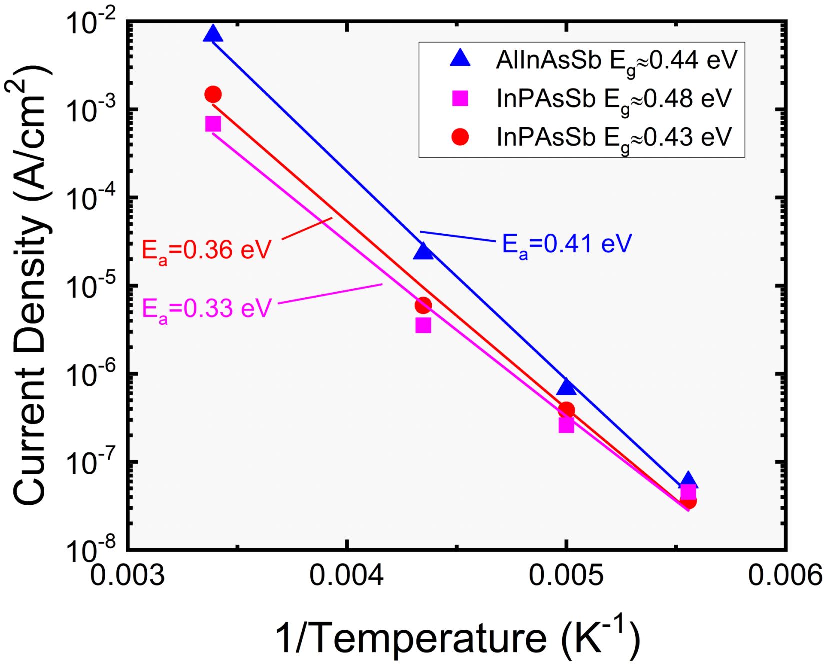
Possible causes
- Differences in surface/interface pinning
- Operating T higher for eSWIR devices
  - Isolation less effective at higher T?

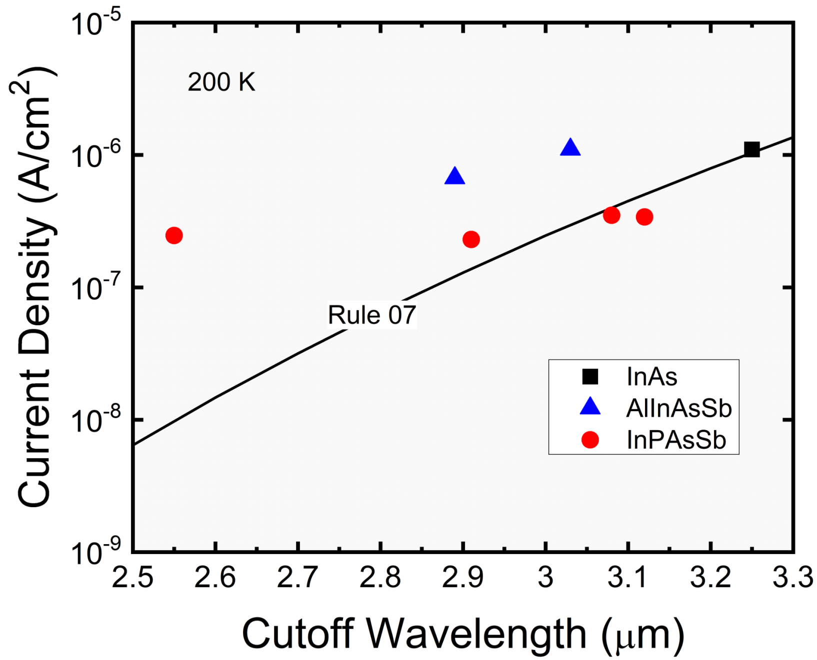






Dark Current Temperature Dependence and Benchmarking



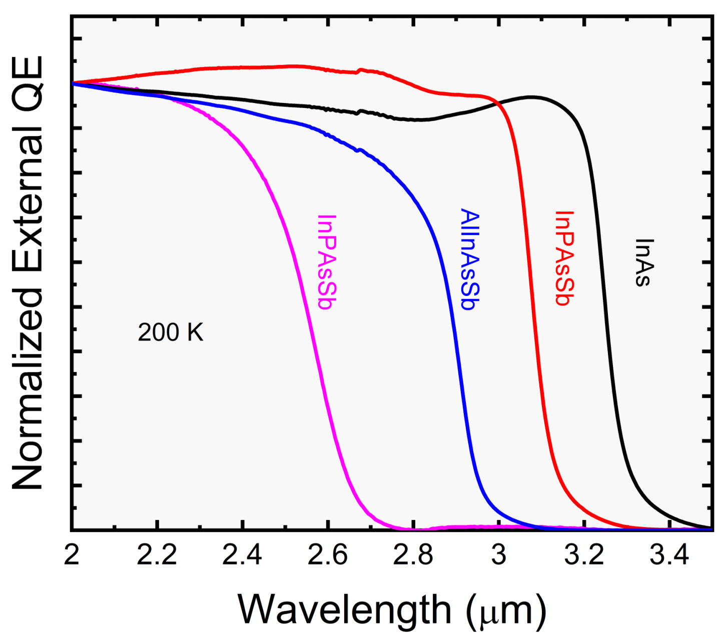


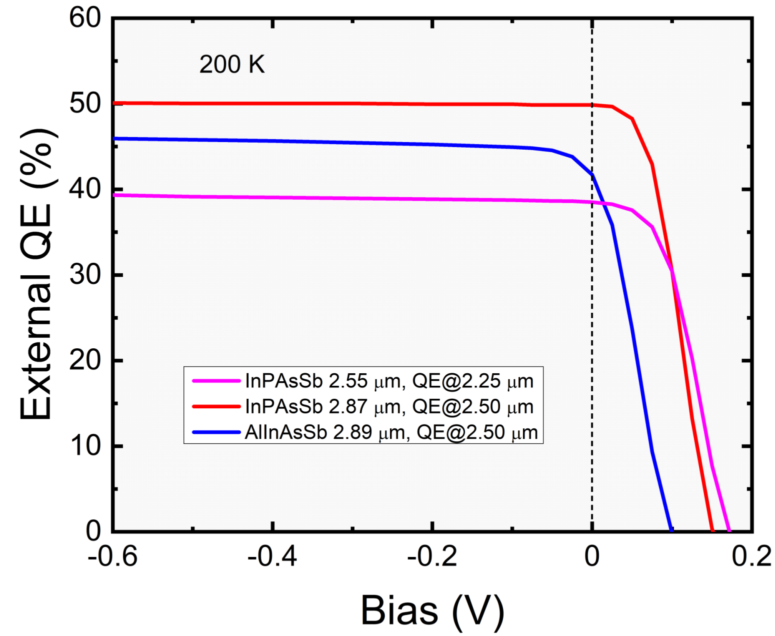
Dark current activation energies somewhat smaller than absorber bandgaps

InPAsSb dark current activation energy does not increase with absorber E_g (for E_g>0.43 eV)

InPAsSb dark currents within 2x Rule 07 for cutoffs of 2.9 μm or longer

Spectral Response and Quantum Efficiency





Sharp cutoff for longest-wavelength devices, softens for shorter wavelengths
- Cutoff at wavelength close to PL wavelength

External QEs 40-50% (at 0.35 μm shorter wavelength than cutoff)
- Should be improved by using larger-bandgap contact layers
- Very low turn-on bias
- Devices not AR-coated

Summary and Future Directions

Low dark current and high QE obtained in InAs-based AlInAsSb and InPAsSb detectors

- Improvements relative to GaSb-based materials
- Dark currents comparable to Rule07 values for cutoffs as short as 2.9 μm
- InPAsSb dark currents lower than AlInAsSb
- No indication of phase separation over range of alloys investigated
- Perimeter currents or incomplete device isolation dominate small-device dark current

Future directions

- Investigation of dark current saturation at shorter wavelengths
- Development of better device isolation/passivation process
- Flip-chip bonding and substrate removal