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Epitaxial AlAsSb for Spectroscopic Gamma Detectors

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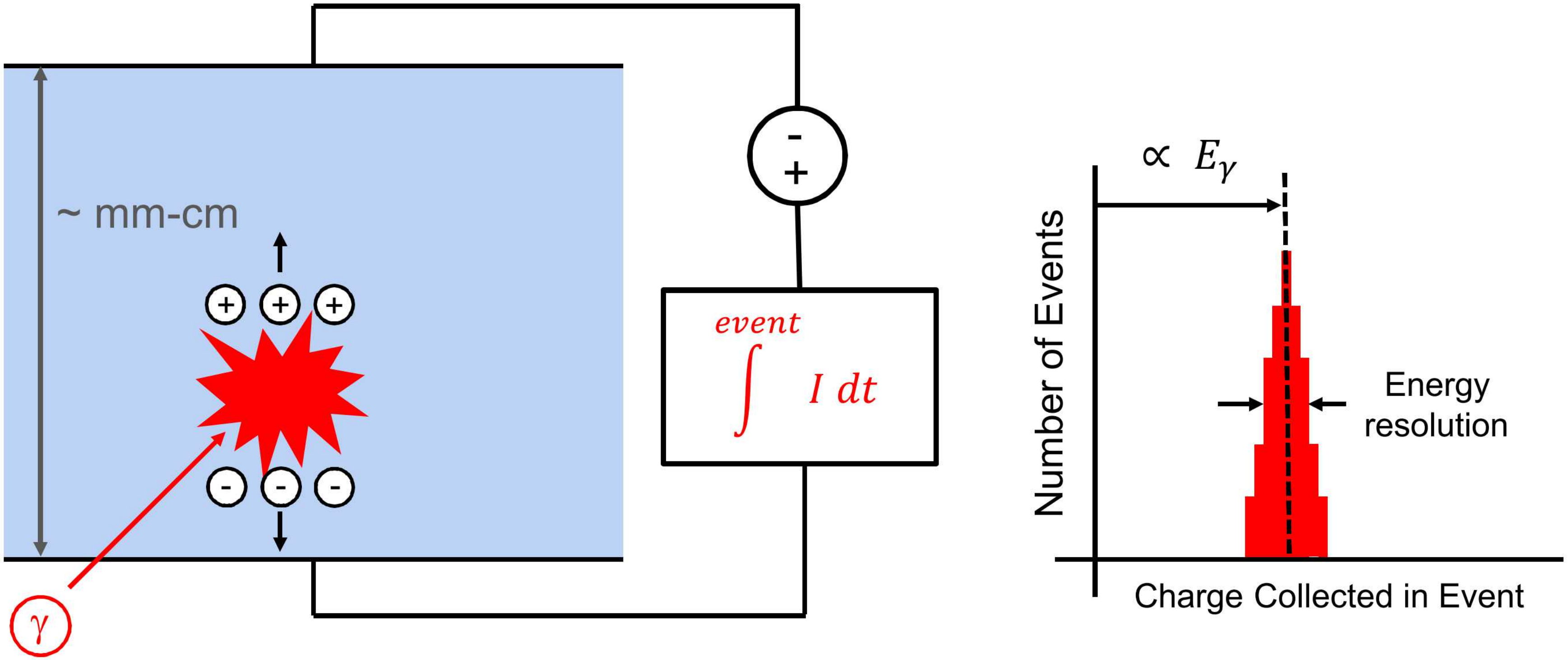
Spectroscopic Semiconductor Gamma Radiation Detectors



Desirable material properties

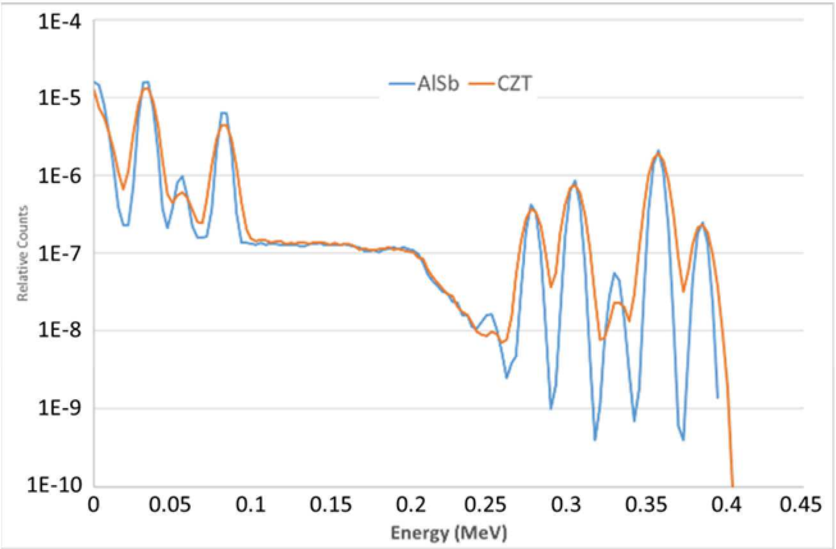
- High atomic number – improves gamma absorption
- Large mobility-lifetime products for both electrons and holes – reduces position dependence
- Low residual doping – allows large collection volume
- Large bandgap – reduces leakage current

Commonly bulk-grown HPGe (77 K), CdTe, CdZnTe

Epitaxial AlAsSb as a Gamma Detector Material

For Compact Sensor Applications

Simulated Ba-133 gamma ray spectra for 1 cm^3 CdZnTe and AlSb devices



AlSb offers potential resolution improvement of 40%

Expected advantages over existing materials

- CdZnTe
  - Improved hole transport (hole mobility similar to electron mobility)
  - Improved Fano factor (reduced charge generation variability)
- HPGe
  - Improved gamma absorption
  - Higher-temperature operation
- Availability of heterostructure options (AlGaAsSb and InGaAsSb alloys)

Challenges

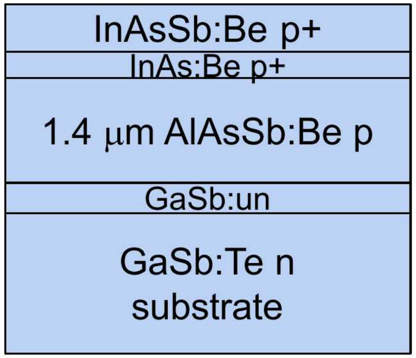
- Oxidation of exposed surface/edges
- Background doping concentration and trap density
- Lattice matching / compositional control of very thick layers
- Surface defect density
- Surface conductance

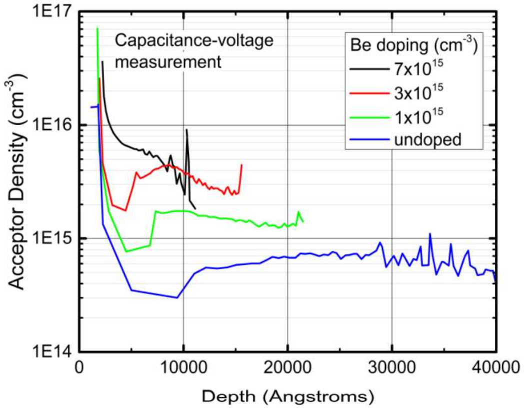
History

- Use in mid-IR lasers, microelectronics (FETs), and infrared detector (barrier diodes)
- Calculations suggest that Te-compensated material could have high resistivity
- AlSb bulk crystals have been grown

MBE Growth of AlAsSb on GaSb

C-V diode structures



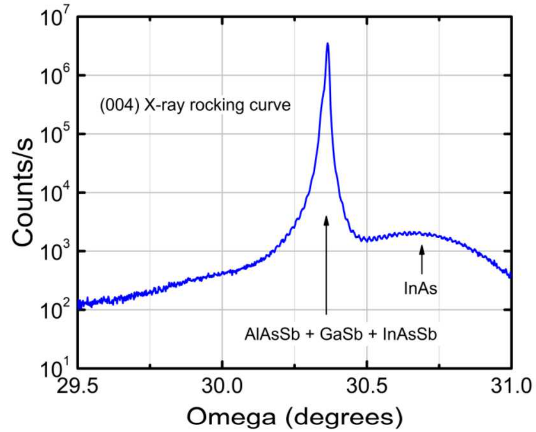


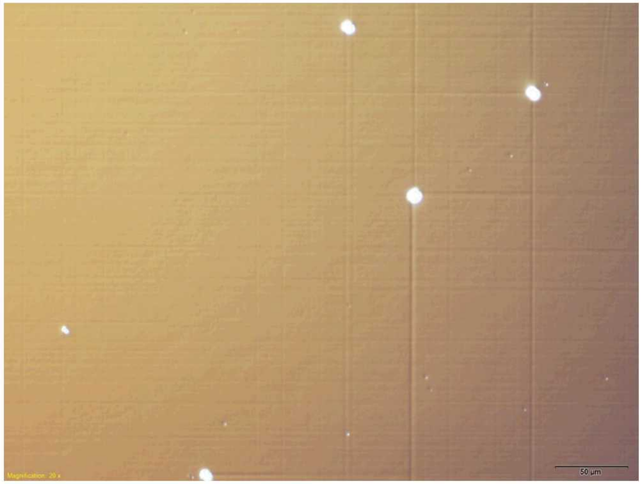
AlAsSb growth conditions

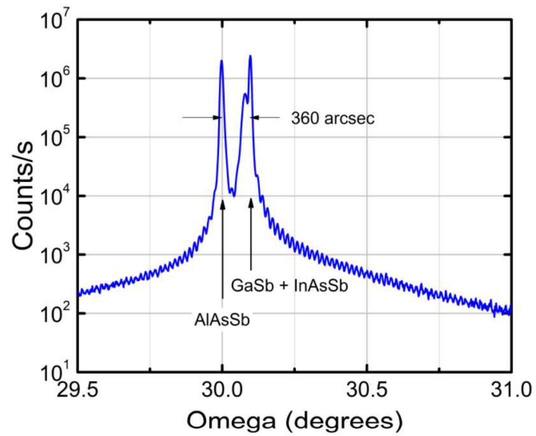
- 0.75 um/hr
- T_s 520 °C
- ~ 1.3:1 Sb:Al
- Sb cracker 800 °C

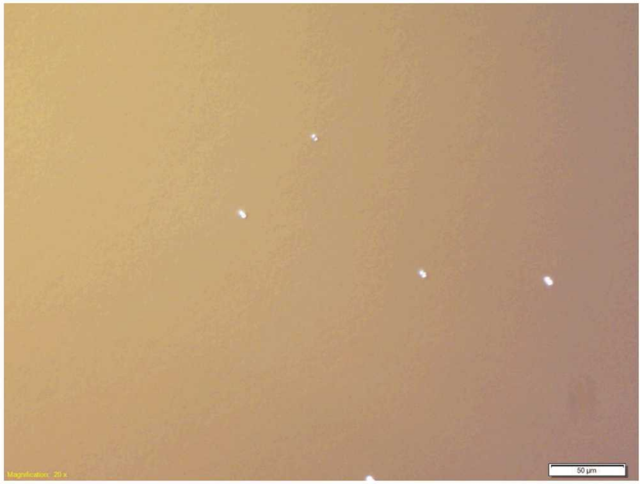
Undoped material p-type ~5x10^{14} cm^{-3}

CTE_{GaSb} > CTE_{AlAsSb}
300K-lattice-matched films exhibit cracking



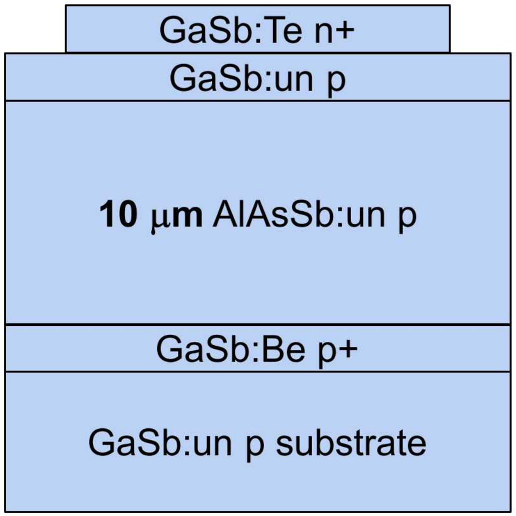




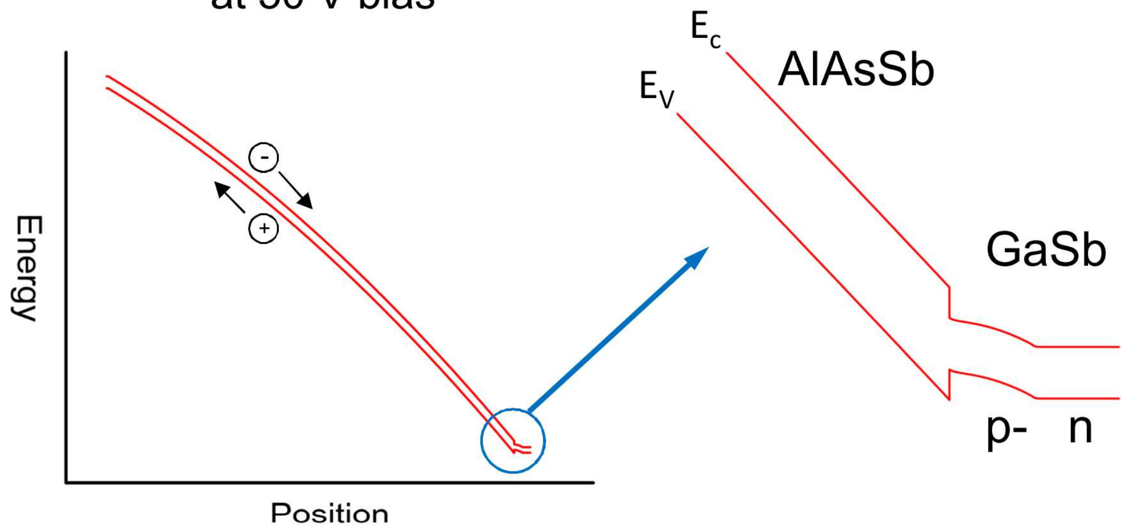


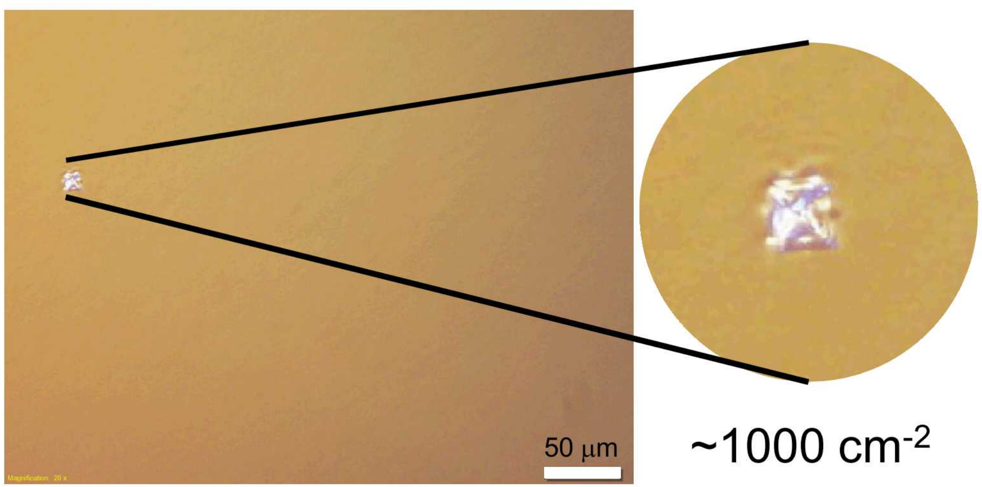
AlAsSb Diodes with Epitaxial Surface Passivation

- Heterojunction p-n diode
- No exposed AlAsSb

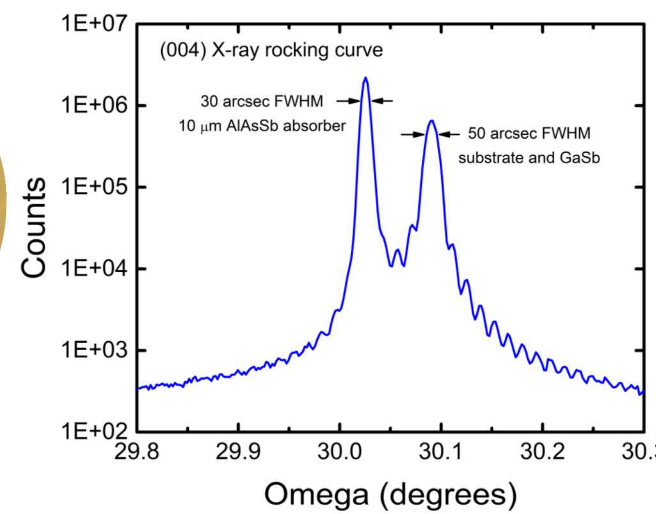


Band diagram at 50 V bias



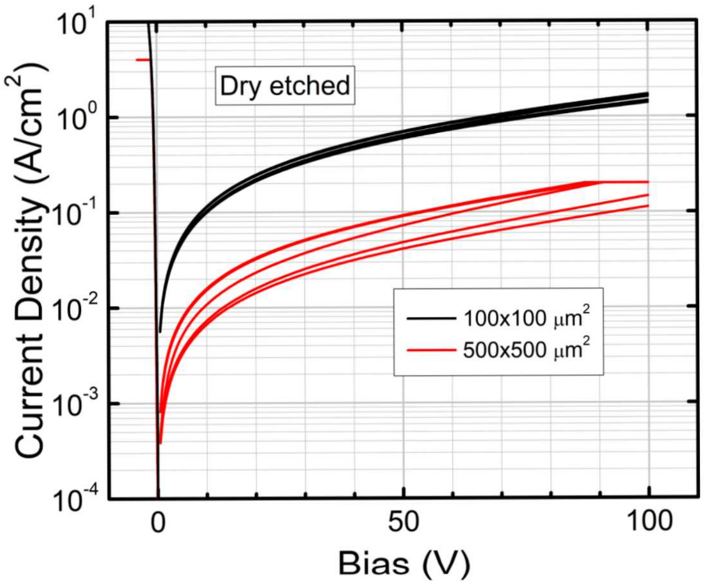


~1000 cm^{-2}



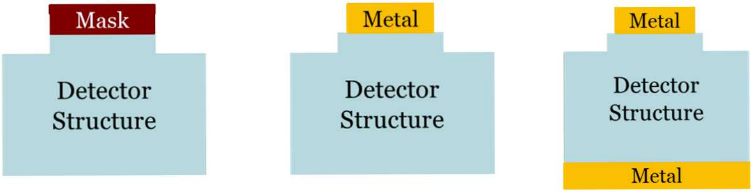
Diode Characteristics

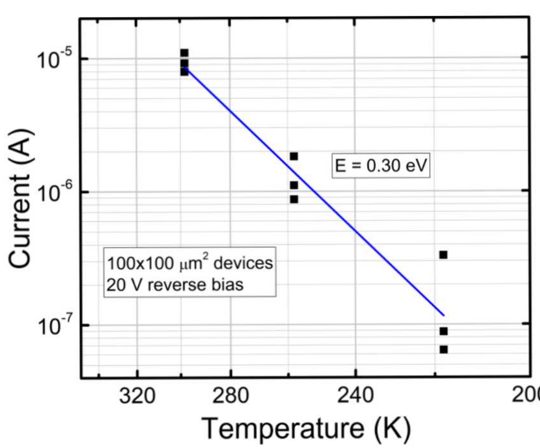
Unintentionally doped AlAsSb

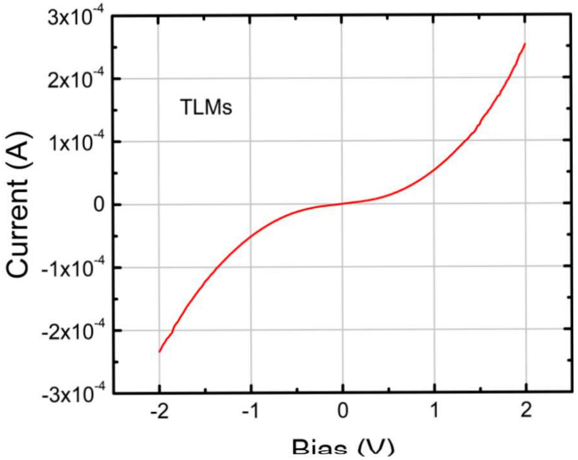


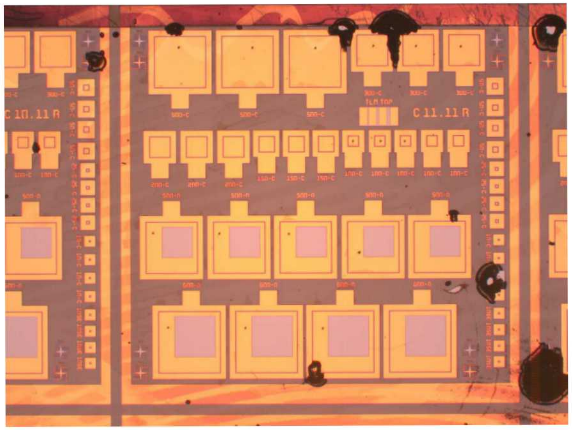
Diode processing

- Wet: HCl/H_2O_2 (non-uniform, lower leakage)
- Dry: Cl_2/Ar (uniform)
- Metal: Ta 20 nm/Au 700 nm, top and bottom







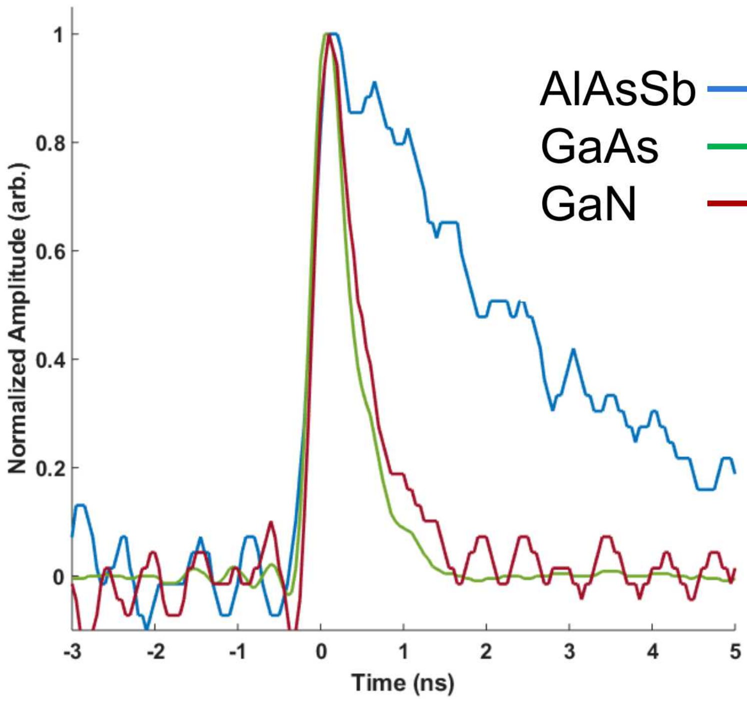


Diode X-ray AlAsSb Diode Photoresponse

"White" 1-100 keV beam

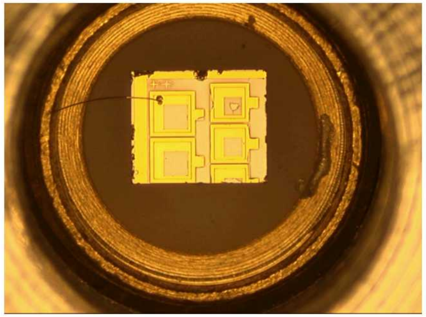
Time-resolved response
AlAsSb diode bias 2 V

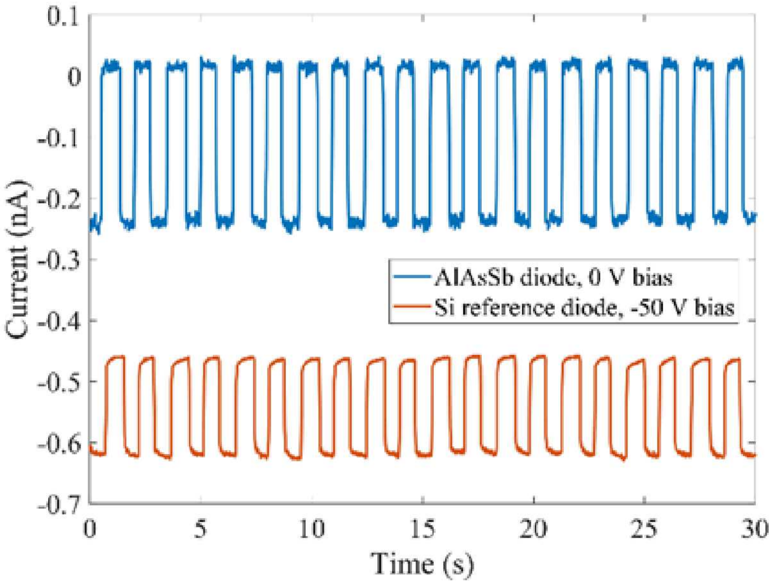
Low electric field limits speed



Mo K_α + K_β chopped source

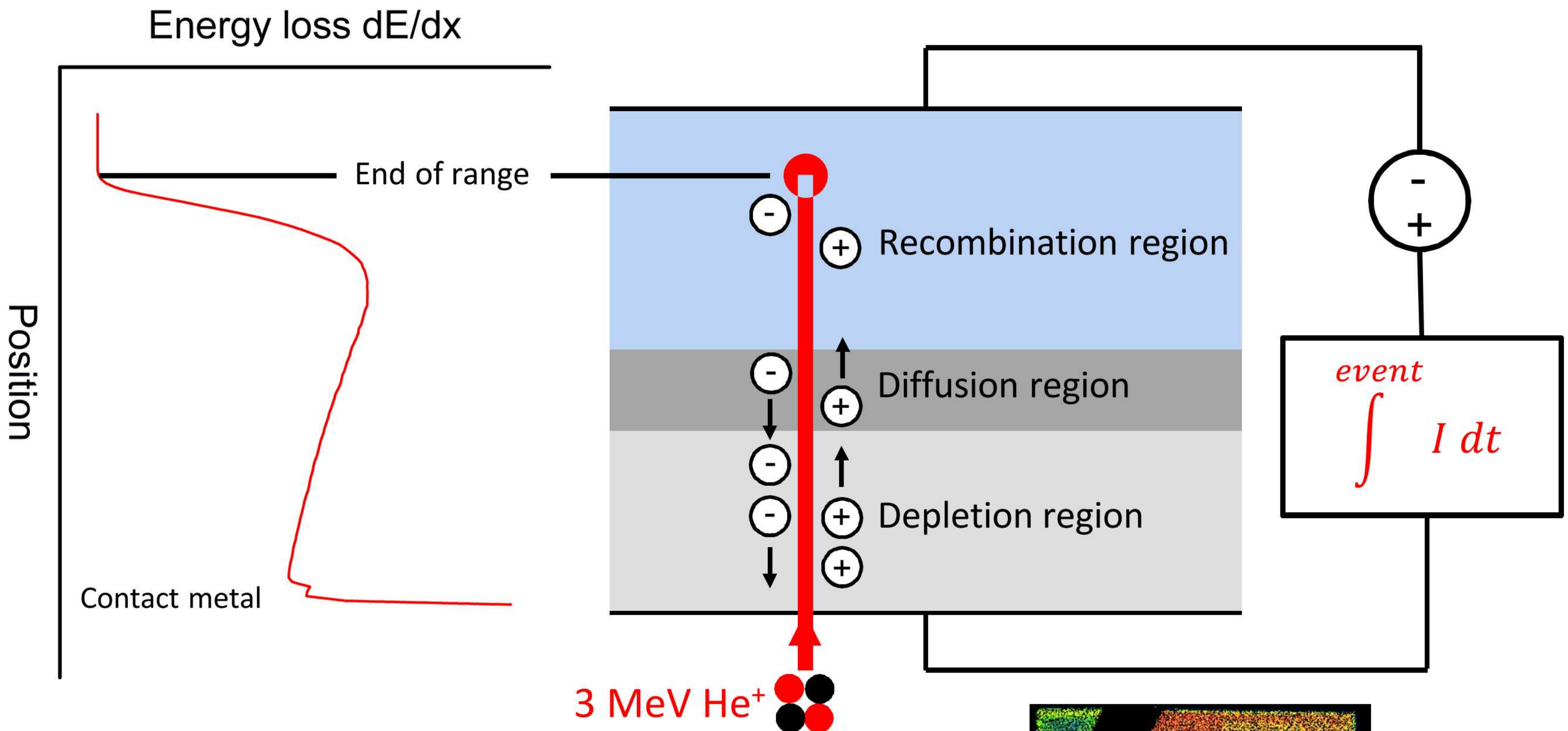
Zero-bias responsivity
similar to full depleted 25 μm Si diode



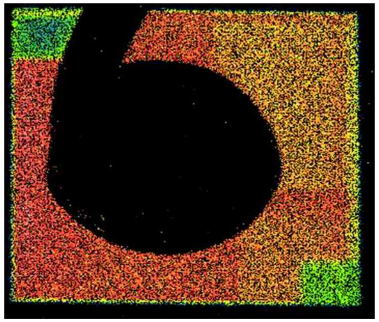


Ion Beam Induced Current Measurements

Charge Collection Efficiency Determination



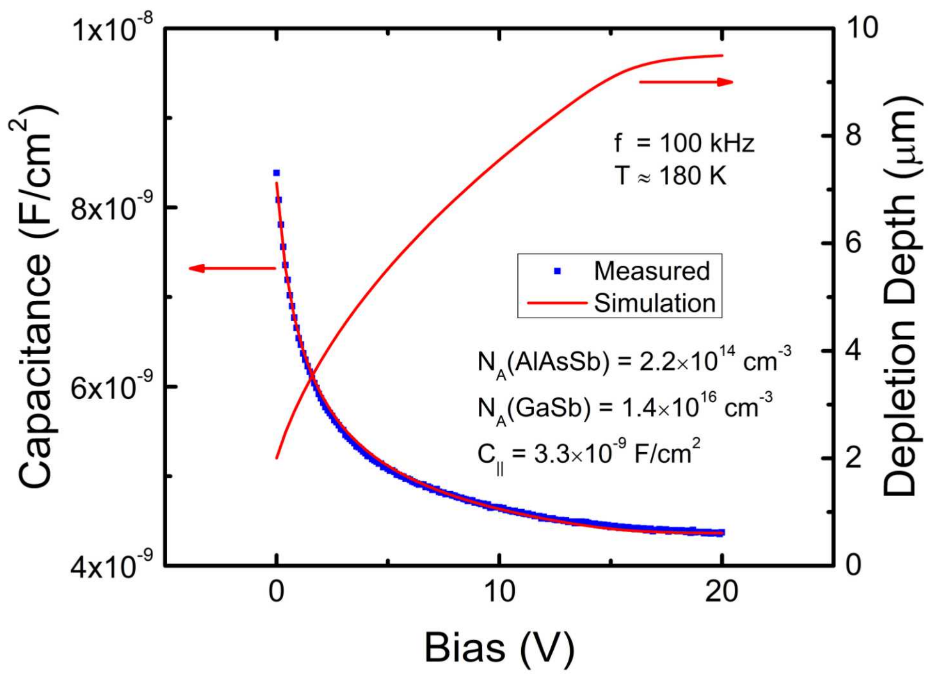
- Measures charge collected from a single ion track
- Charge is collected only from depletion and diffusion regions
- Depletion region depth can be varied by changing bias
- Relationship between collection efficiency and bias provides information about electronic transport

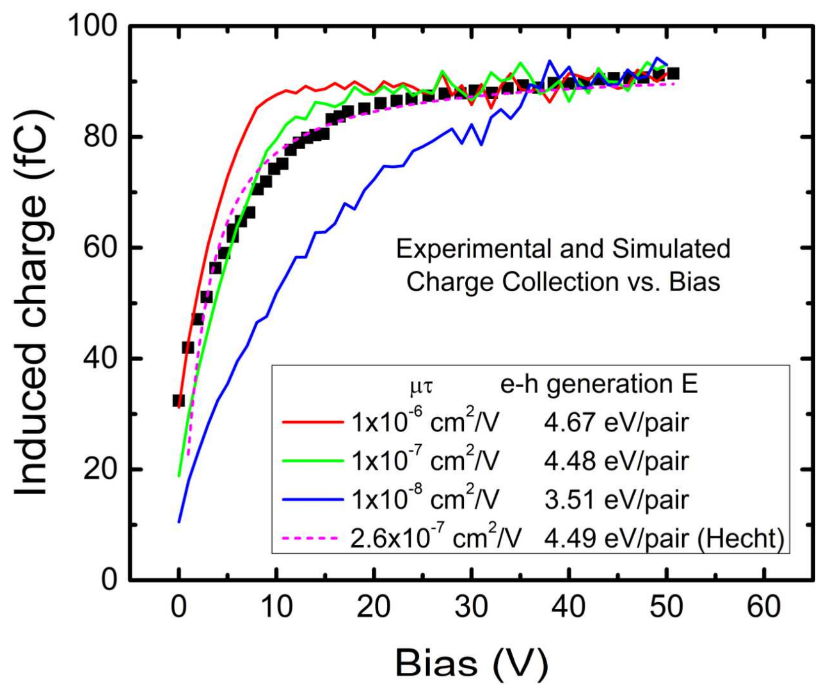


IBIC image

Determination of AlAsSb Electronic Mobility-Lifetime Product

$\mu\tau$ is estimated from ion-generated charge collection / bias relation at ~180 K





Capacitance-voltage fit determines

- AlAsSb background doping
- GaSb background doping
- Depletion depth vs. bias

Drift-diffusion simulation provides estimates of

- $\mu\tau$ ~ 10^{-7} cm^2/V (assumed equal for electrons and holes)
  - Diffusion length ~ 0.4 μm
- Electron-hole pair generation energy ~ 4.5 eV
  - 5.1 eV expected based on AlAsSb bandgap of 1.68 eV

Hecht equation fit yields similar results

- But condition of uniform electric field not satisfied

Perspectives on AlAsSb characteristics

Ballpark requirements for a good, thin spectroscopic gamma detector

- Energy resolution < 1%
- Bias < 100 V
- γ detection efficiency > 1 %

AlAsSb layer thickness d = 120 μm

- $1-\exp(-\alpha d) = 10^{-2}$

$\mu\tau$ ~10^{-4} cm^2/V (need ~500x improvement)

- $E = V/d = 8.3 \times 10^3$ V/cm
- Want collection length $\mu\tau E$ ~ 100x AlAsSb thickness → 1.2 cm

Background carrier concentration $N_A \sim 1 \times 10^{13}$ cm^{-3} (need 20x reduction)

- Depletion depth 120 μm at 100 V

Leakage current ?

- Related to detector area

Conclusions

We have grown thick (10 μm) AlAsSb by MBE with

- Excellent compositional control ($\frac{dx_{AlAs}}{x_{AlAs}} \approx 0.01$)
- Defect density ~ 1000 cm^{-2}
- Background carrier concentration ~2×10^{14} cm^{-3}

A novel heterostructure provided surface passivation for the AlAsSb

- Enabled simple processing
- Good diode characteristics
- Leakage currents need to be further reduced

Diodes exhibited good x-ray response

- Reduction in leakage current needed to enable measurements at high bias

$\mu\tau$ estimated with ion beam induced current measurements

- ~ 2×10^{-7} cm^2/V

Further improvements needed for desired detector characteristics

- 10x lower doping
- Much higher $\mu\tau$