Effect of Sb on the Properties of GaInP Top Cells

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- Background
  - Efficiency of GaInP/GaAs tandem cells: effect of top cell band gap
  - Why Sb?
- Result
  - Properties of Sb:GaInP
  - Sb:GaInP top cells
  - Sb:GaInP/GaAs tandem cells
- Summary

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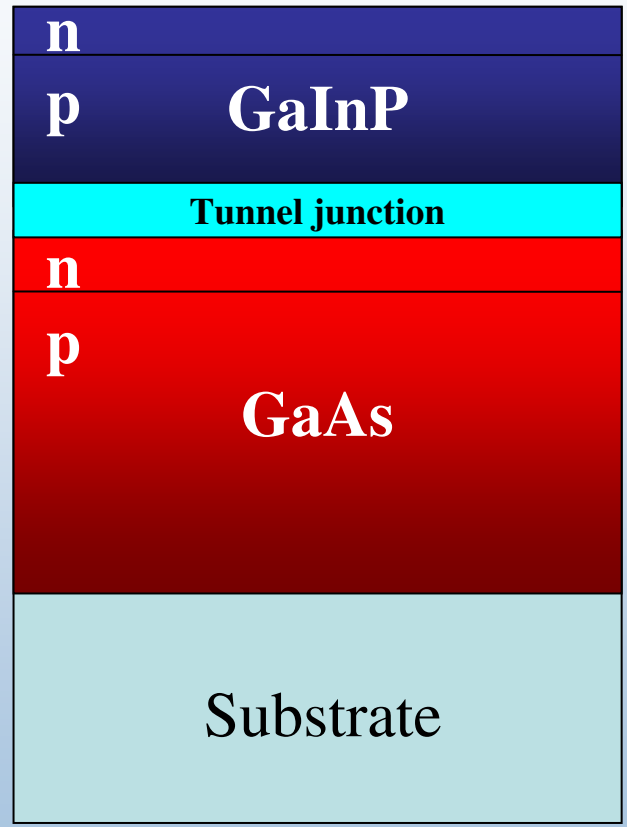
A Bit of History

- In 1984 - invention of GaInP/GaAs tandem cell. (Olson)
- In 1989 - 27.3% (Olson et al.)
- In 1993 - 29.5% (Bertness et al.)

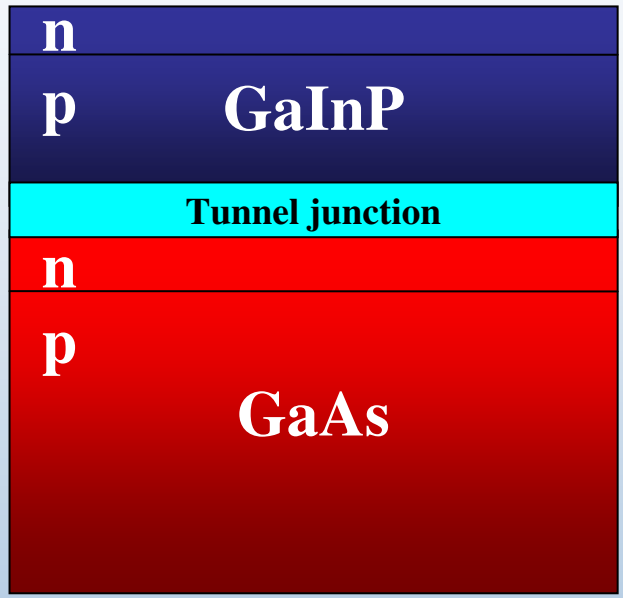
- In 1996 - production of first commercial GaInP/GaAs cell (Spectrolab, et al.)
  - Space applications, Mars rovers
  - Terrestrial concentrator applications

- In 1997 - 30.3% AM1.5G (Takamoto et al.)



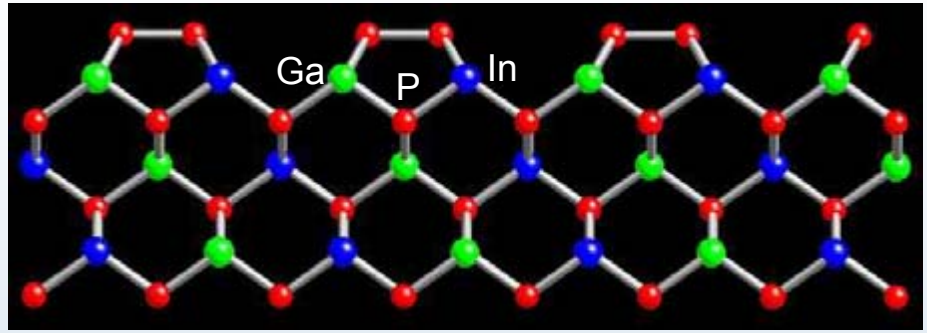
GaInP/GaAs tandem cell

- Ideal top cell band gap for a GaAs bottom cell is ~1.9eV (~2eV AM0).
- Typical band gap of GaInP is ~1.8eV which reduces the ultimate efficiency by about 1 point.



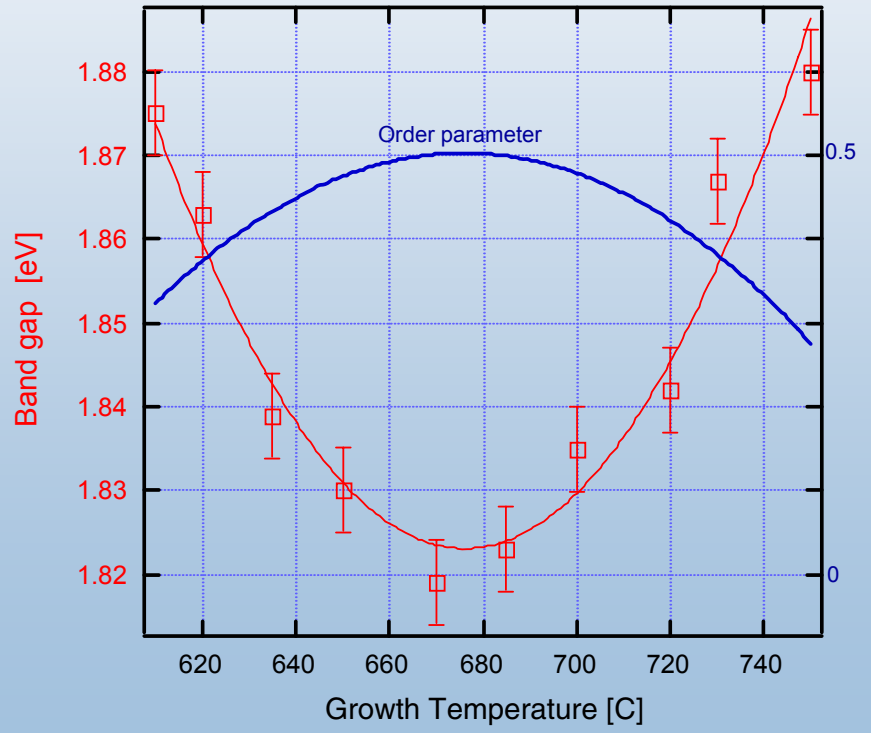
Ordering in GaInP

- Band gap shift
  - caused by CuPt ordering of Ga and In on the Group III sublattice.



- Order parameter and band gap energy varies with
  - growth temperature
  - growth rate,
  - PH_3 partial pressure,
  - substrate orientation
  - Type and concentration of shallow dopants.

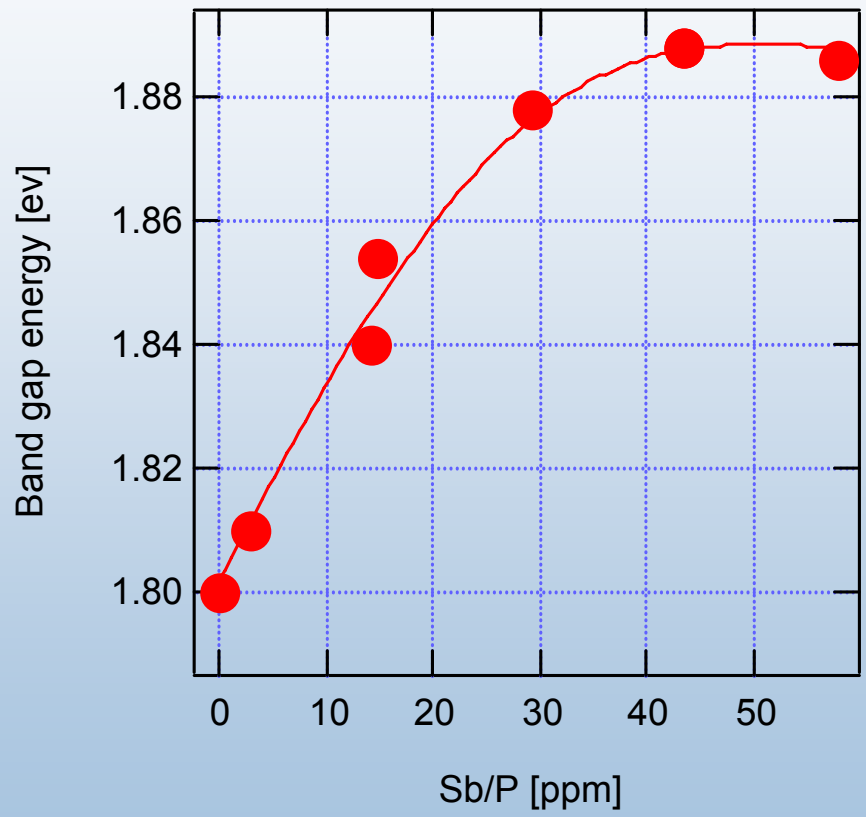
(Kurtz el al. JEM 1994)



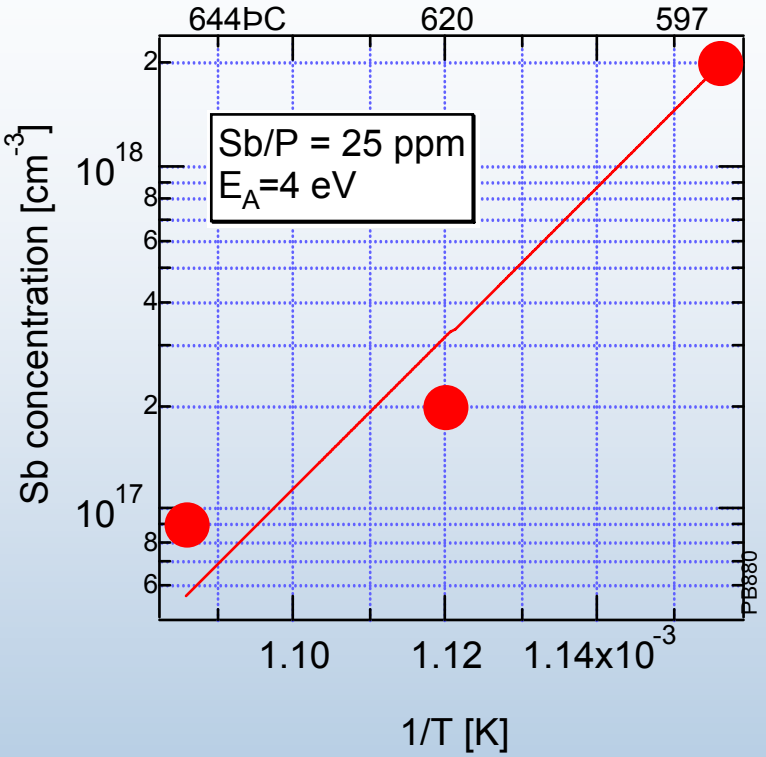
Effect of Sb on the Bandgap of GaInP

- Addition of Sb (TESb) during growth can hinder the ordering process and increase the band gap*
- Effect controlled by ratio of TESb to PH_3 (Sb/P)
- Effect is largest for
  - B-miscut substrates
  - Tg ~ 625˚C

*Shurtleff et al. APL (1999)

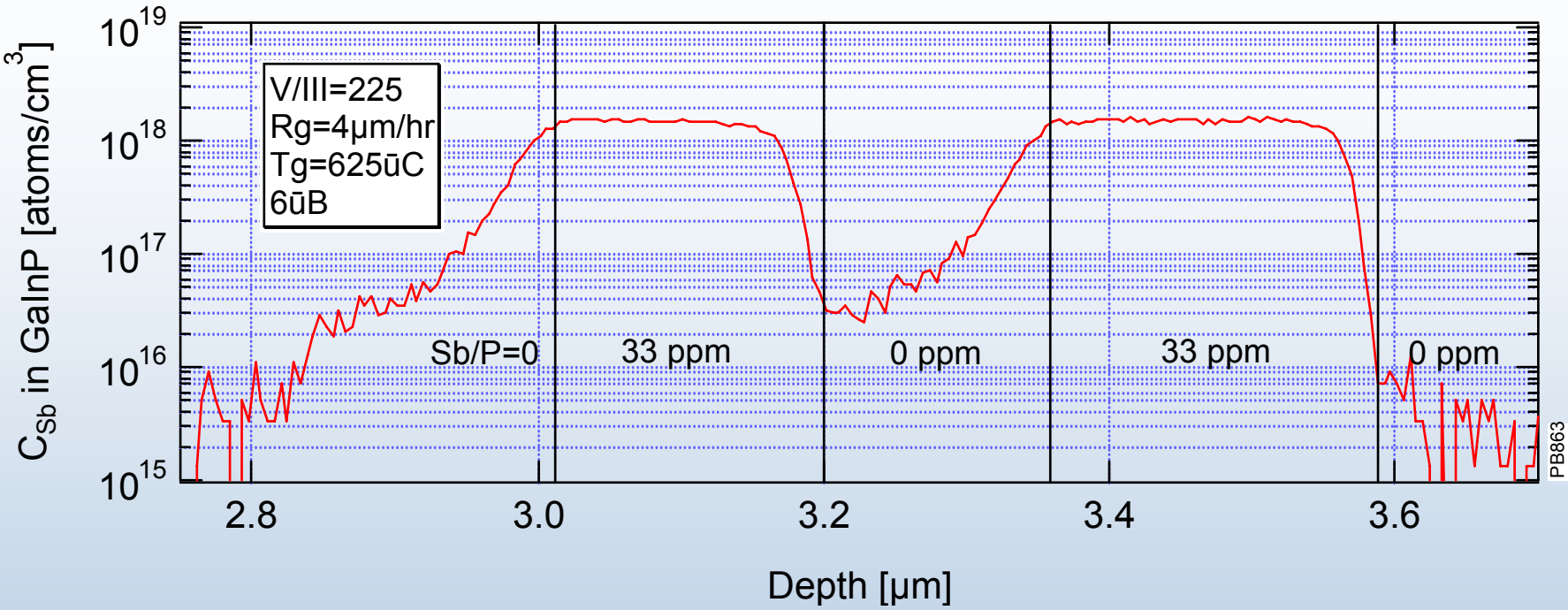


Sb incorporation vs Tg



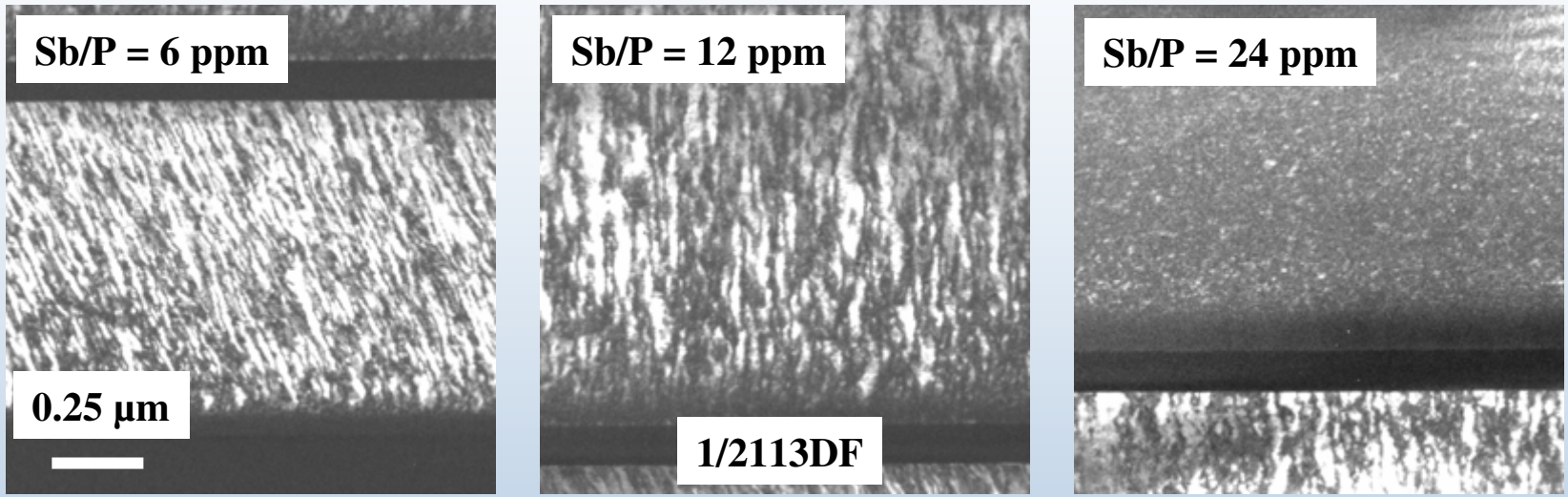
- Under conditions used for top cell, C_{Sb} = ~2e17cm^{-3}
- Activation energy ~4eV, comparable to that of the 1/P_{Sb}.

Surface Concentration Θ_{Sb} on GaInP



- The 1/e decay length L=23nm
- Surface segregation coefficient R = exp(-a_0/L) = 0.988
- Sb surface concentration $\theta_{Sb} \propto C_{Sb}/(1\text{-}R)$, θ_{Sb} = 0.006
- Implies (001) terrace not occupied with Sb-Sb dimers
- Theoretical work - preferred Sb attachment at B-type steps, (Batyrev, PRL 2005)

Ordered domain structure



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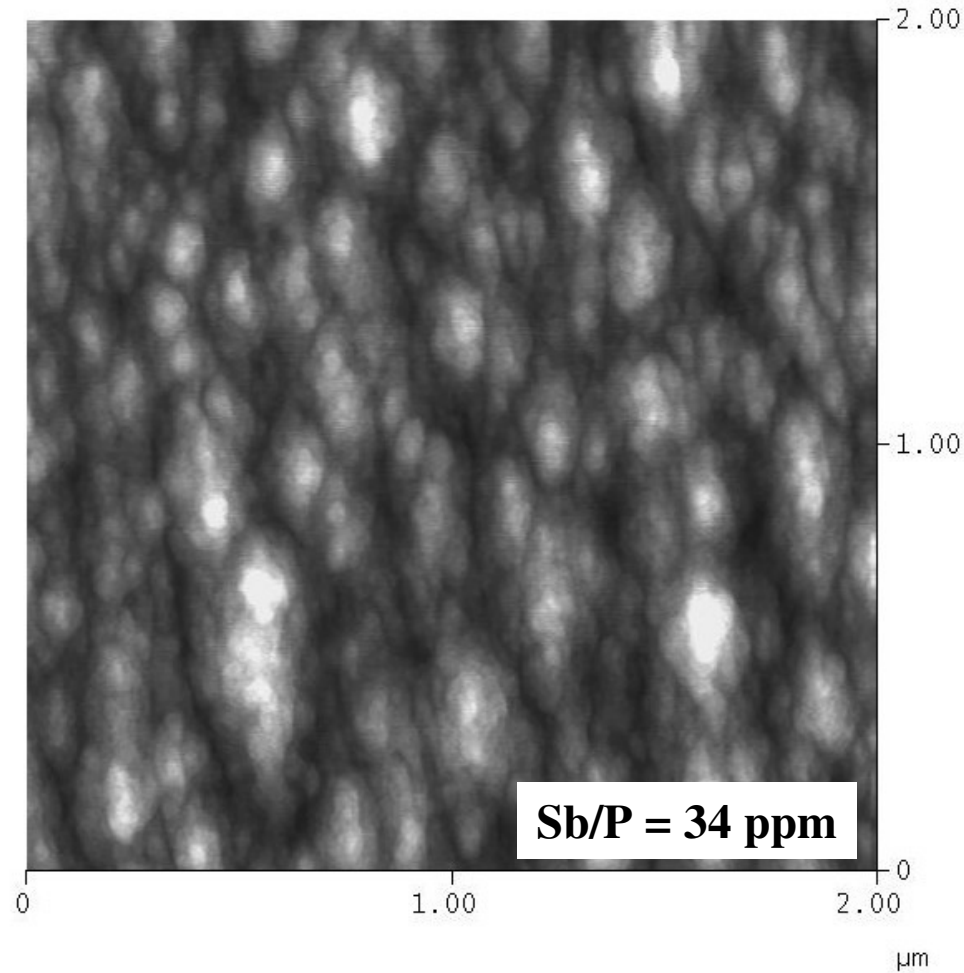
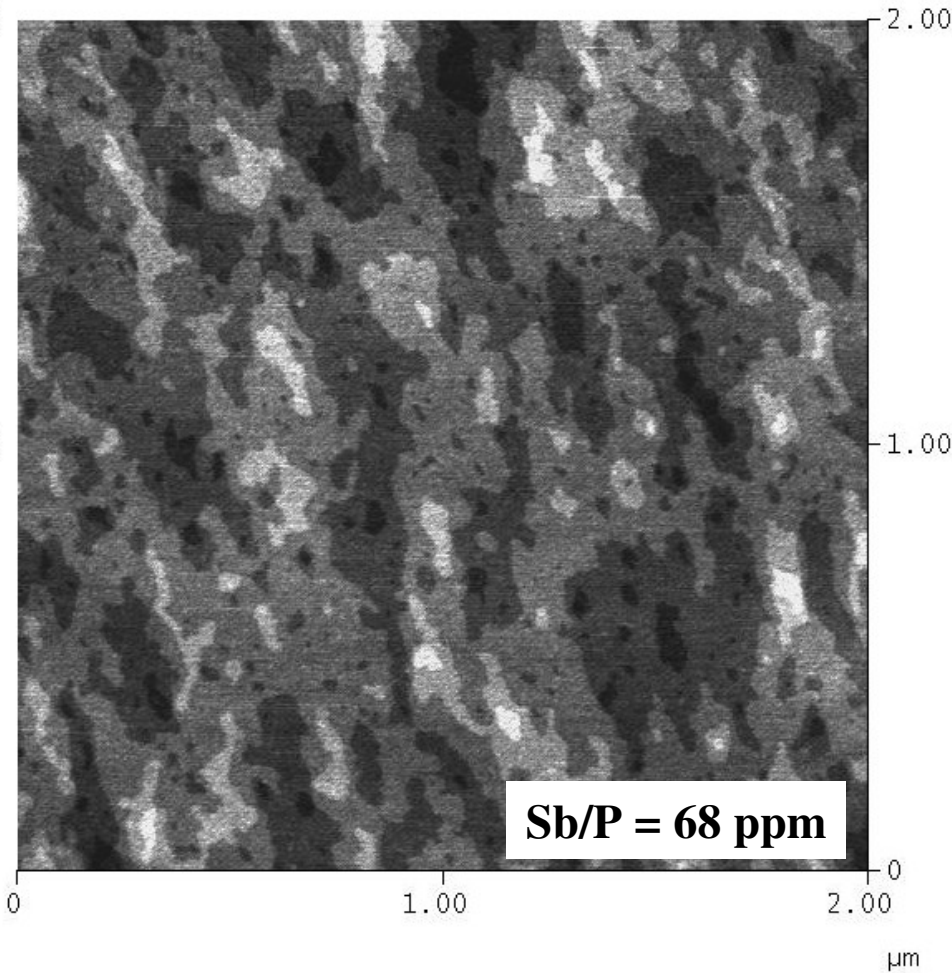
- Tilted domain boundaries result from step flow (Ishimura, et al PRB 51 p9707)

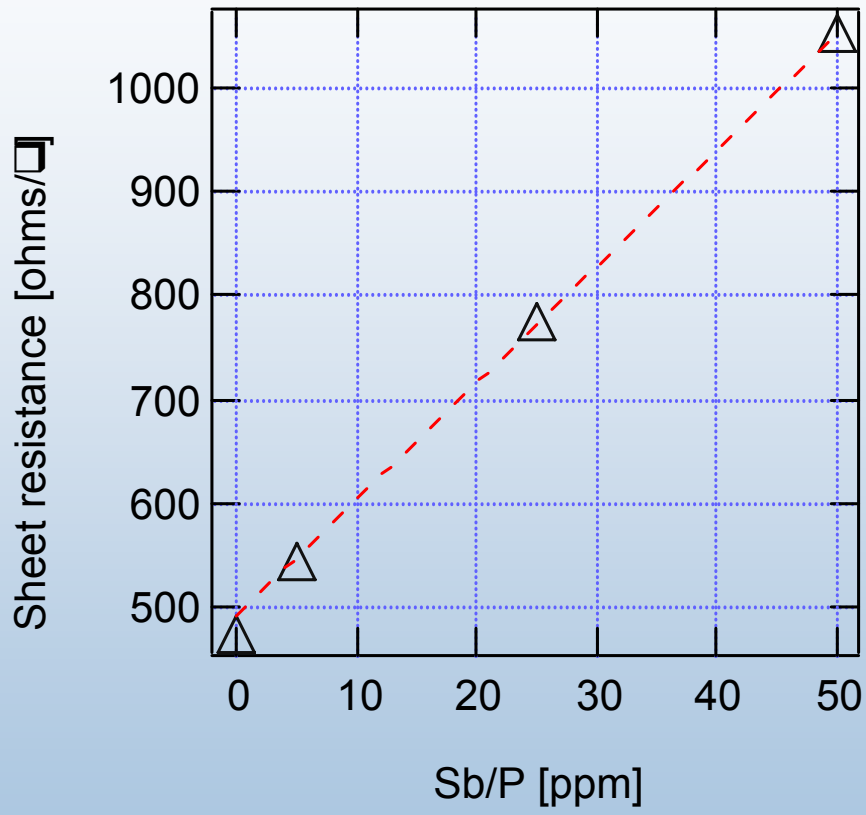
Surface morphologies of Sb:GaInP on singular GaAs(100)

- For intermediate Sb, surface composed of asymmetric hillocks, 5 to 7nm high, bounded by low angle B-type facets, Friedman et al APL (1993).
- For higher Sb, surface composed of large terraces separated by ML steps (0.28nm).
- This implies that Sb raises the energy of B-type steps on GaInP(100).



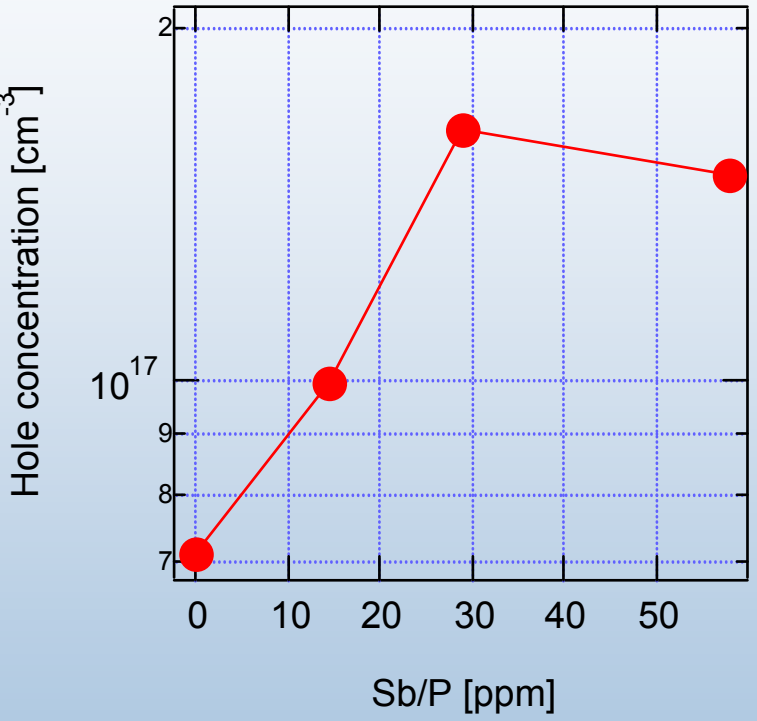


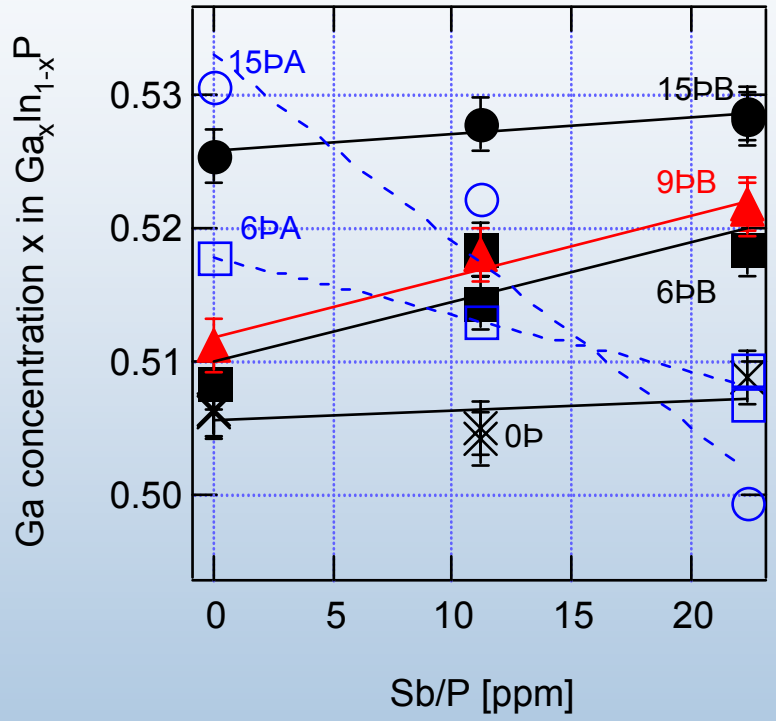
Effect of Sb on Se incorporation



- Sb, P and Se compete for group V lattice sites
- $C_{Se} \propto \alpha F_{Se}/(1+\alpha F_{Se}+\beta F_{Sb}+\gamma F_P)$

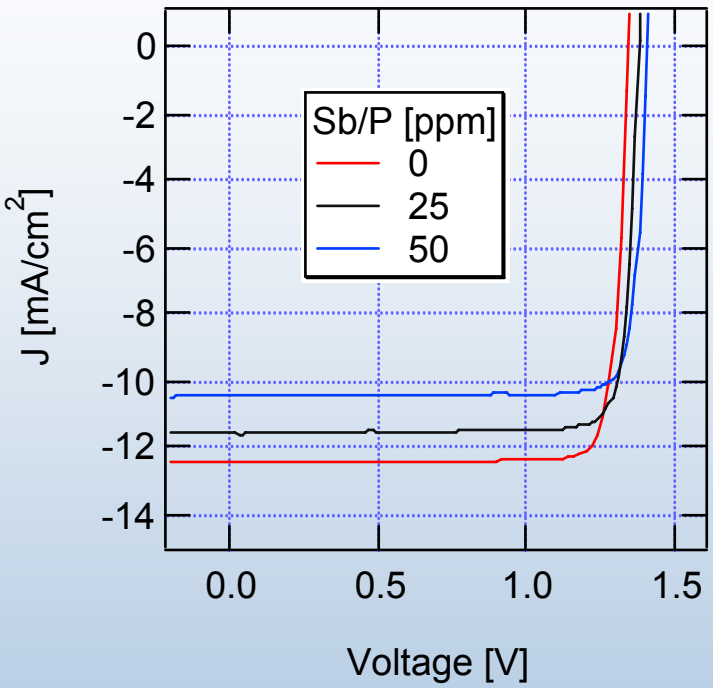
Effect of Sb on Group III Site Occupations

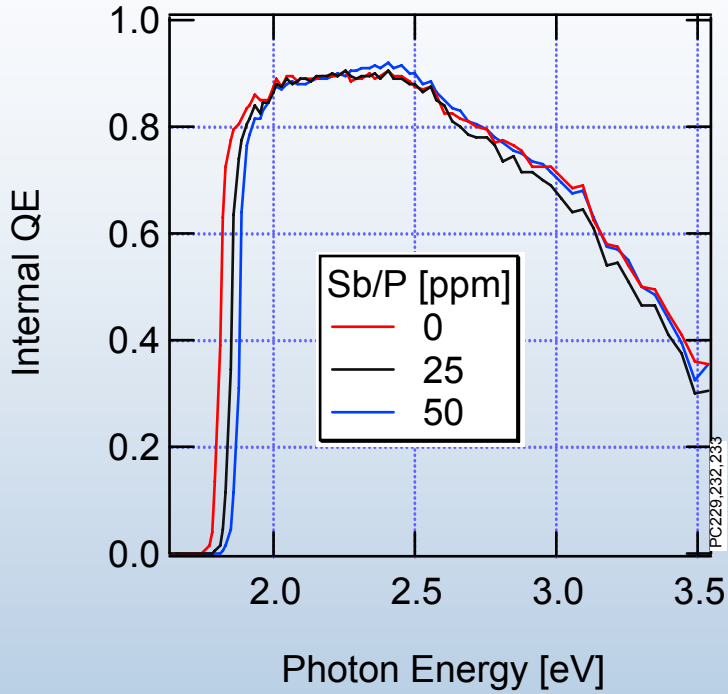




Mechanism?

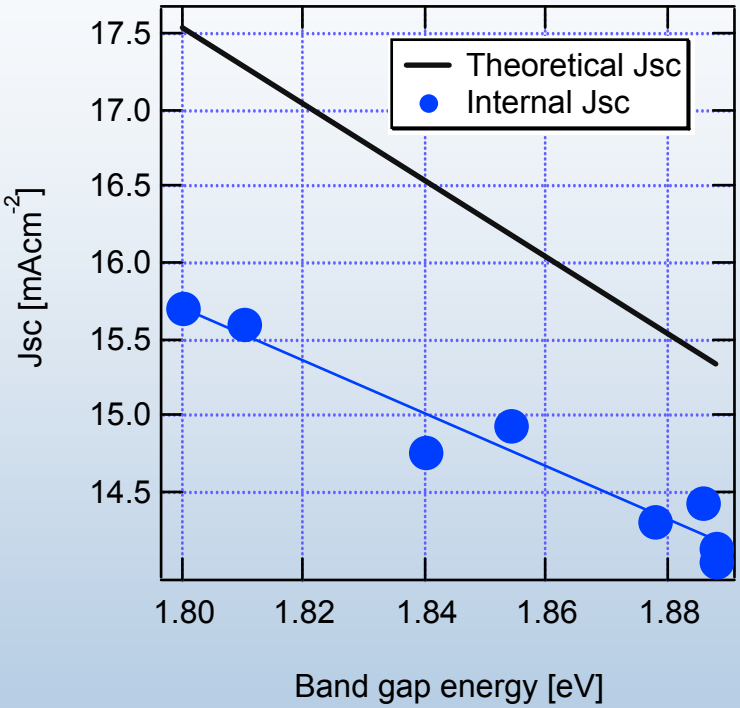
Sb-doped GaInP top cells

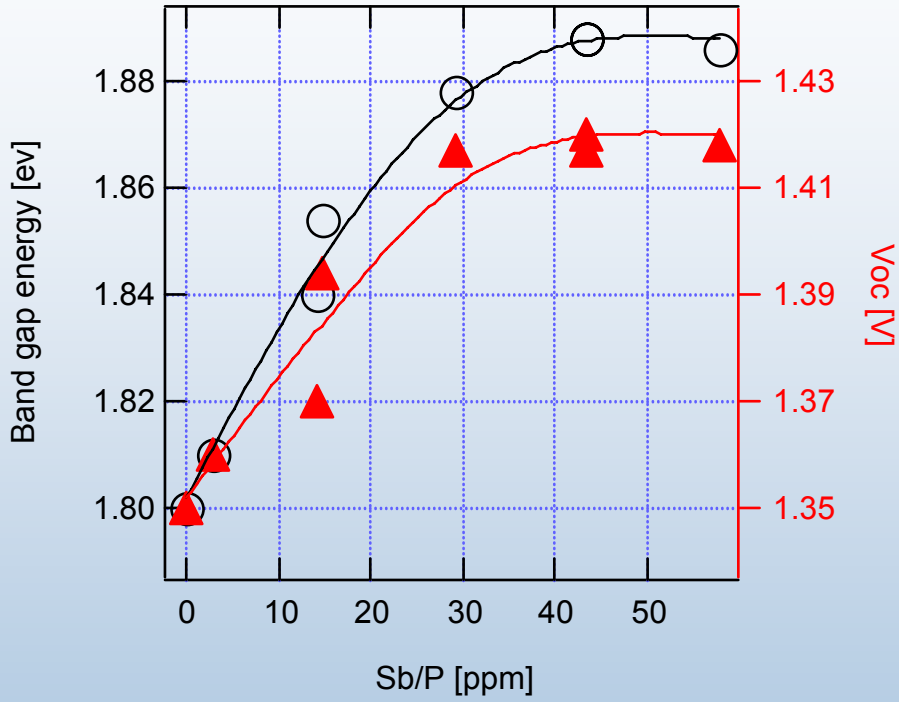




- The base/emitter/window thicknesses are 2μm, 0.1μm and 0.025μm, respectively
- The base p varies from 7e16 to ~2e17 cm^{-3}
- The emitter sheet resistance varies from 500 to 1000 Ω/□.

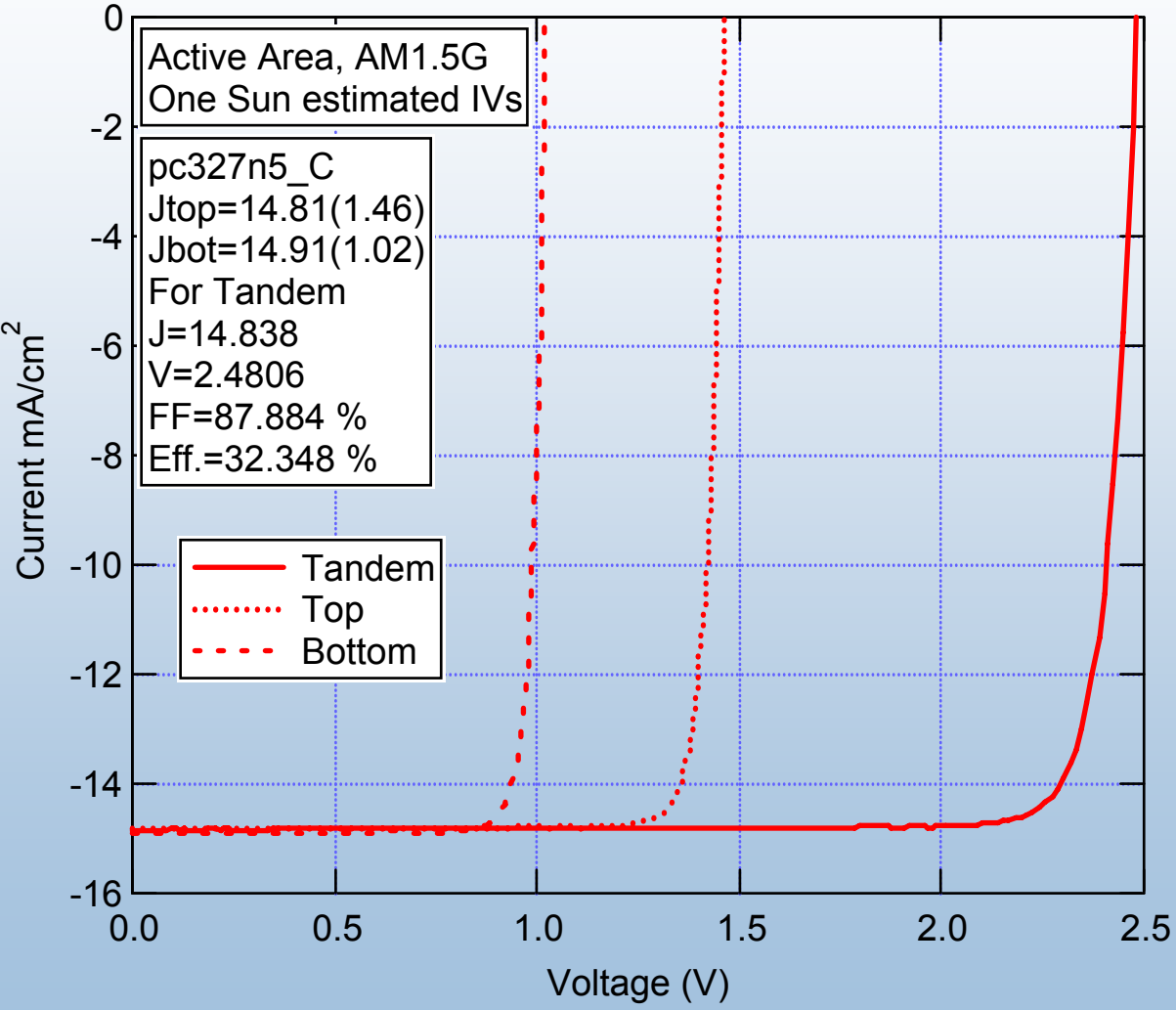
Top cell device parameters vs Sb





- Internal J_{sc} decreases with E_g slower than expected.
- V_{oc} increases more slowly than E_g.

Sb-doped GaInP/GaAs tandem cells



Total Area 15% metal
J_{sc} = 12.388 mAcm^{-2}
V_{oc} = 2.476 V
Ff = 86.95%
Eff = 26.67%

- Top cell base
  - Thickness = 2μm
  - E_g = 1.89 eV,

Summary

- Sb can be used to increase V_{oc} of a GaInP top cell.
- The photovoltaic quality of GaInP is relatively unaffected by the presence of Sb.
- Sb-doped GaInP/GaAs tandem cells show promise for achieving efficiencies over 32%.

Acknowledgements

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