R·I·T KATE GLEASON College of ENGINEERING
NPRL NanoPower Research Laboratory

Improvements in MOCVD Grown GaSb Homoepitaxial and IMF Solar Cells

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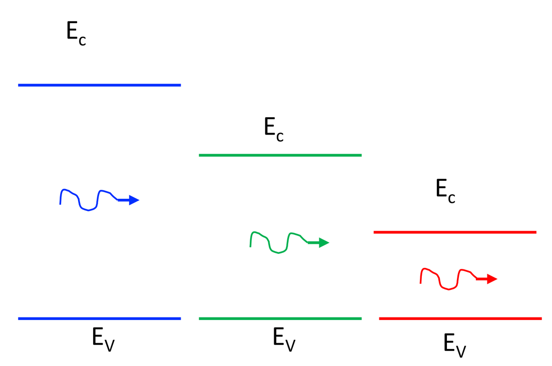
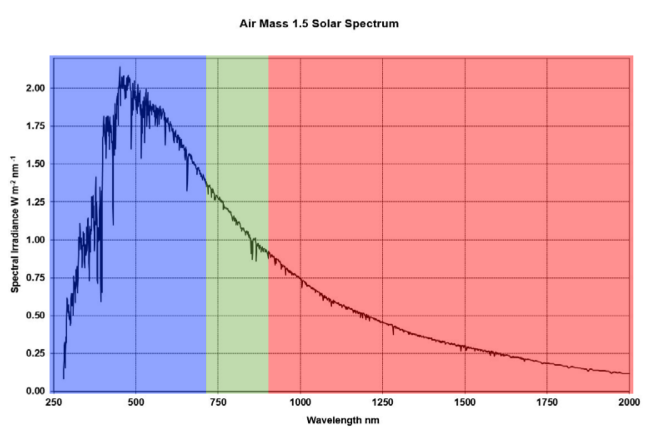
ASMC Advanced Semiconductor Manufacturing Conference
MicroE Microelectronic Engineering

I. Motivation-Multijunction Solar Cells

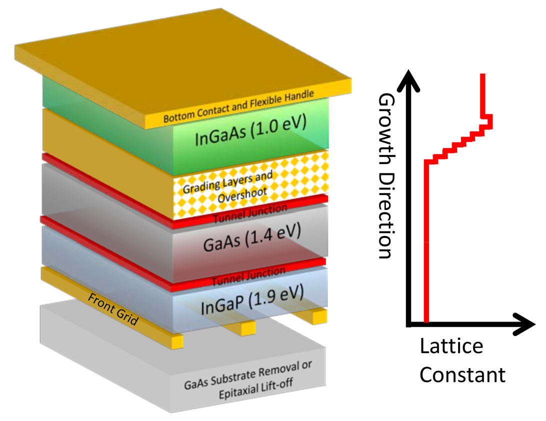
Single junction solar cells

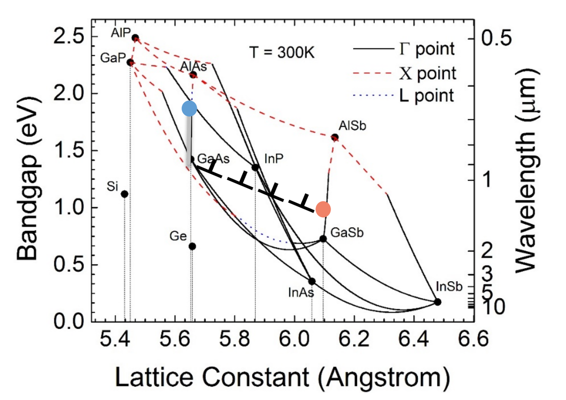
- Current record efficiency of 28.8% by Alta Devices using a GaAs (E_g=1.42 eV)
- Only collects a portion of the solar spectrum, loses due to thermalization and transmission below the bandgap
- Stacking multiple materials allows for collection of entire spectrum



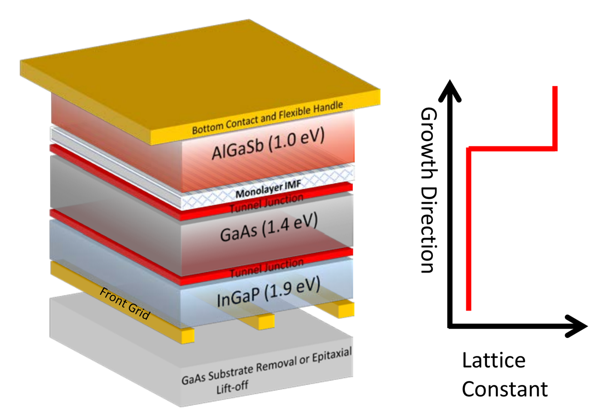


IMM Triple-Junction Cell





IMF Triple-Junction Cell



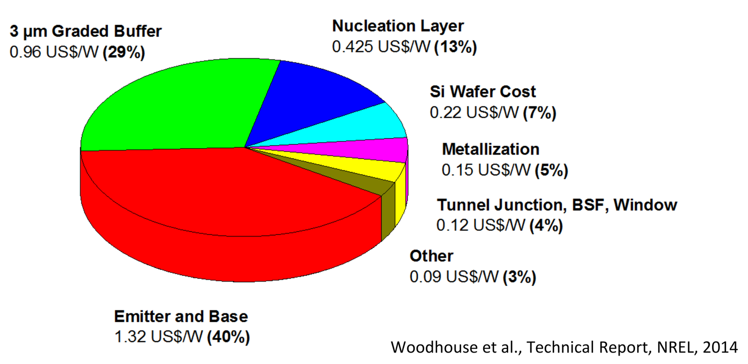
Inverted metamorphic (IMM) multijunction solar cell

- Proven technology, achieves high efficiency (<40%)
- Expensive and time consuming graded buffer required

Interfacial misfit (IMF) multijunction solar cell

- Not a proven technology, high threading dislocation density
- Theoretical efficiency rivals IMM
- Does not require graded buffer, cost reduction of **30%**

Metamorphic Cell Cost Analysis

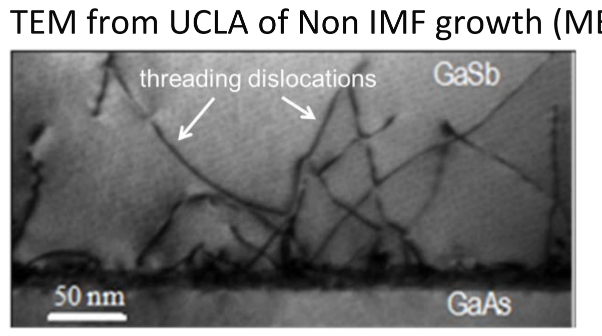


Woodhouse et al., Technical Report, NREL, 2014

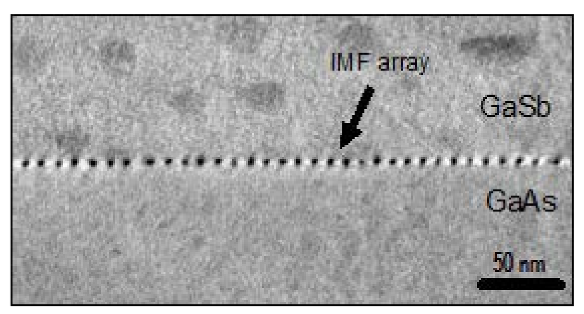
This work looks to better understand GaSb minority carrier lifetime and determine the best Ga precursor for both homoepitaxial and heteroepitaxial solar cells

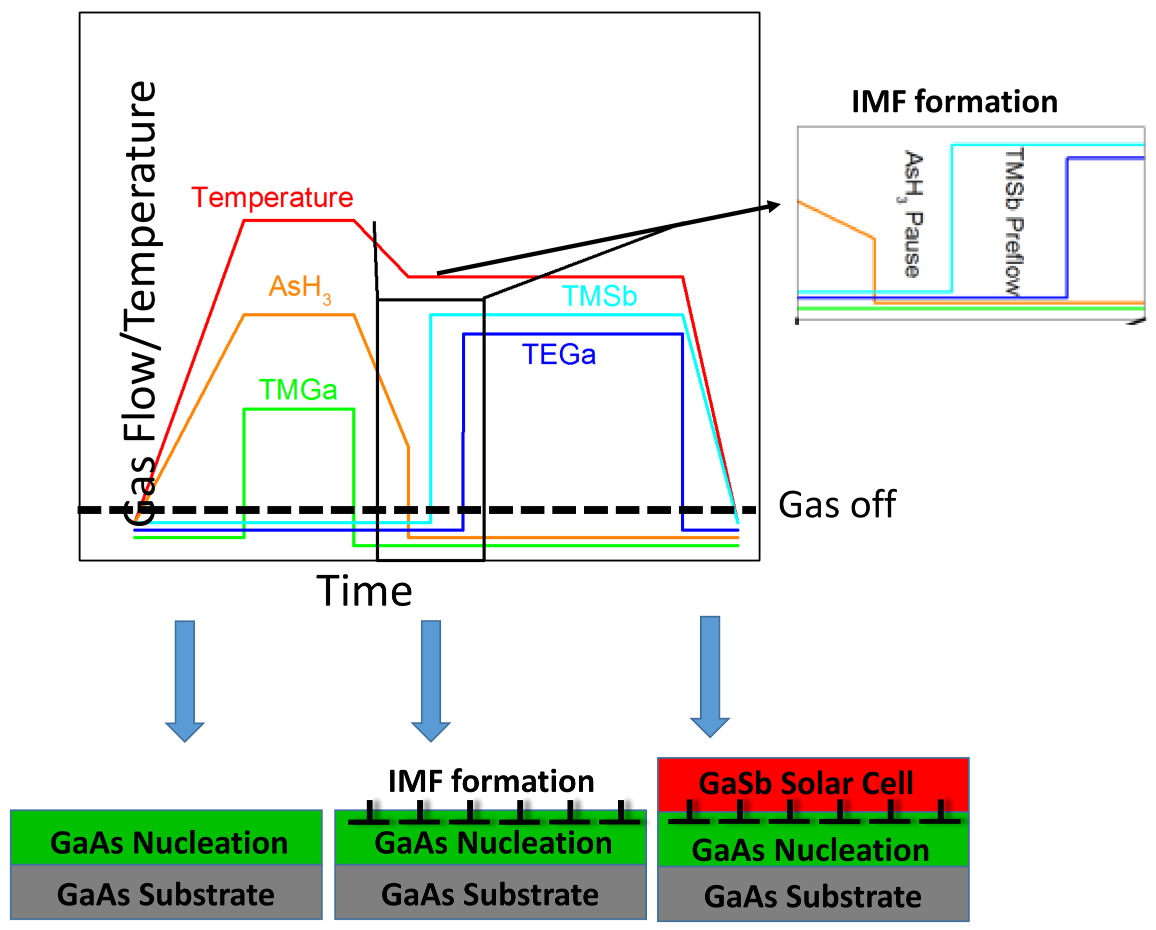
II. Interfacial Misfit and Metal-Organic Chemical Vapor Deposition

TEM from UCLA of Non IMF growth (MBE)

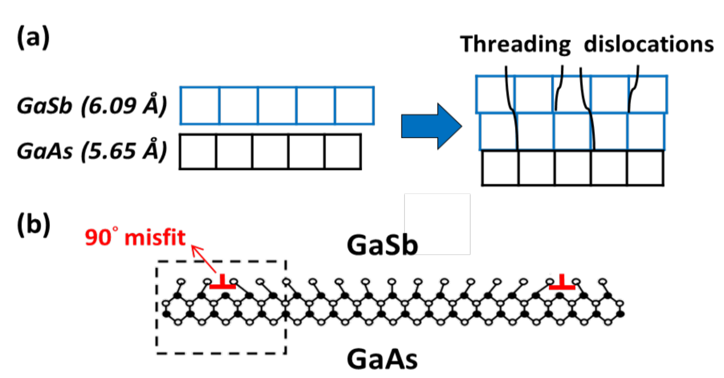


TEM from UCLA of IMF growth (MBE)



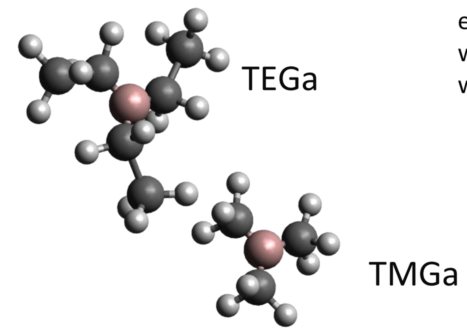


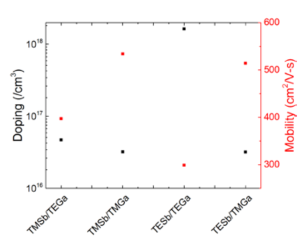
- Without IMF array, strain is relaxed through 60° dislocation, leading to threading dislocation along [111] plane
- Each black dot in the transmission electron microscope image (TEM) is a 90° misfit dislocation, arranged along [110] or [$\bar{1}$10] direction
- Target TDD <5x10^6 cm^{-2} in IMF GaSb/GaAs, not yet realized on a large scale

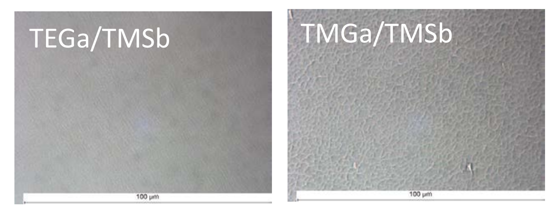


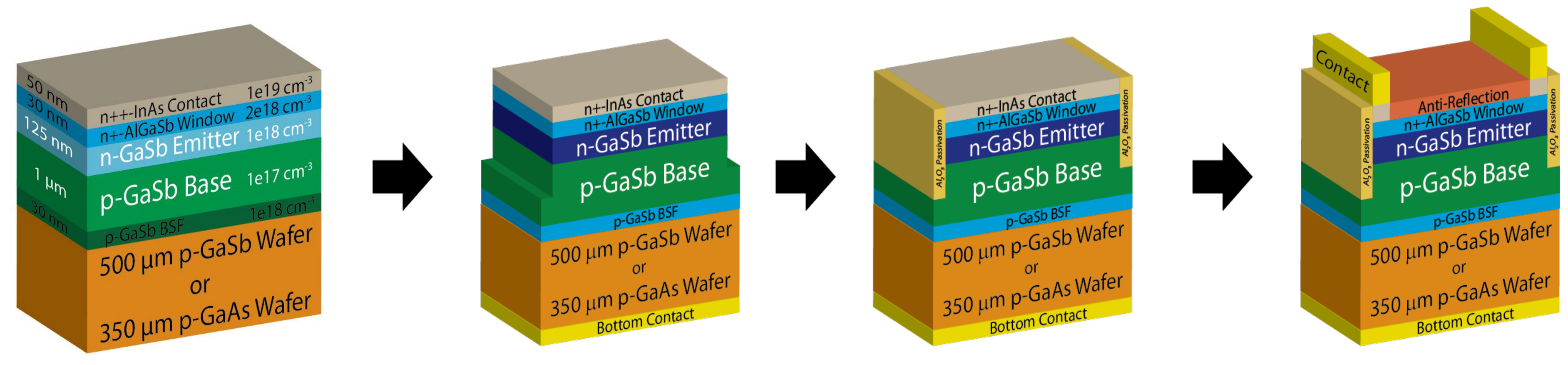
III. GaSb Solar Cell Growth and Fabrication

- Aixtron 3x2" Close-Coupled Showerhead Metal Organic Vapor Phase Epitaxy system
- GaSb Growth:
  - Growth temperature – 525°C
  - Sb precursor - TMSb
  - V/III Ratio– 1.2
  - N-type dopant – Te
  - P-type dopant – Zn
- Gallium precursors triethylgallium (TEGa) and trimethlgallium (TMGa) are compared
  - TEGa produces smoother film, but TMGa has better mobility and background doping







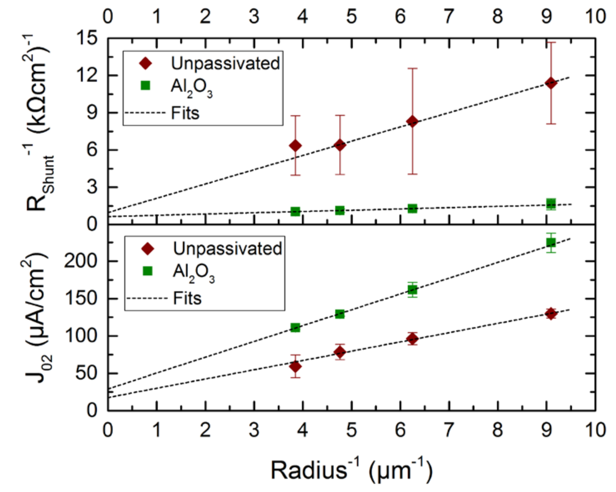


Growth of cell, 125nm emitter & 1µm base with $Al_{0.3}Ga_{0.7}Sb$ window

Mesa etch using citric:HF:H_2O_2:H_2O to improve R_{shunt}

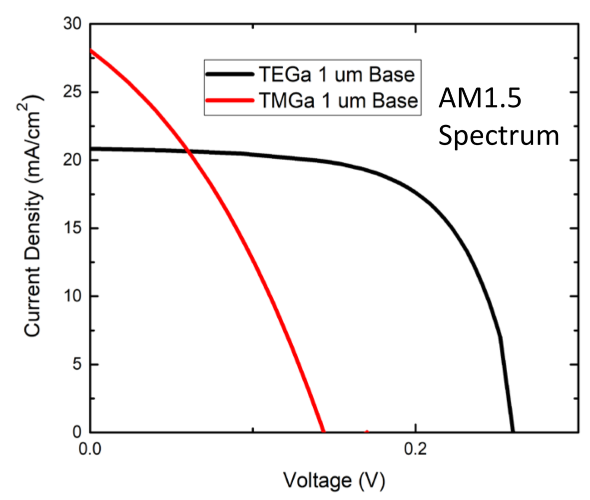
Al_2O_3 sidewall passivation by ALD to reduce leakage

Metal deposition, Ti/Au on front, Ti/Pt/Au for rear

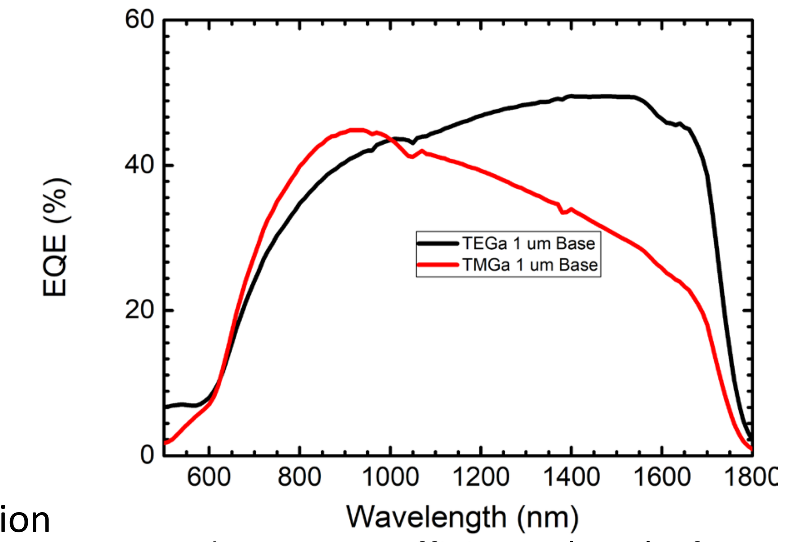


- Narrow bandgap materials are highly susceptible to sidewall shunts
- Al_2O_3 sidewall passivation is critical to device performance
- As devices scale up the impact of the sidewall is less pronounced

IV. Homoepitaxial Results



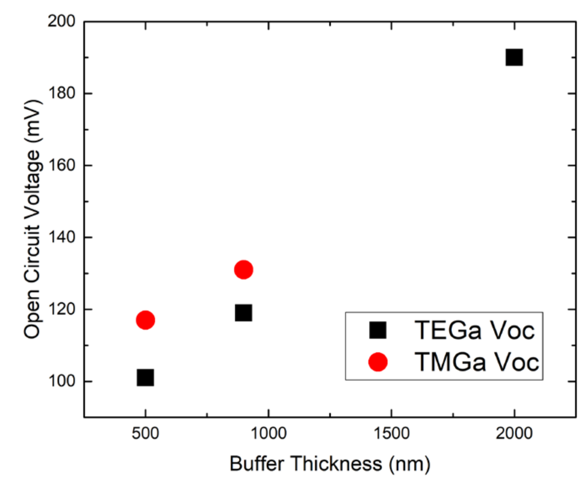
- Simulated 3J GaSb bottom junction V_{OC}=360 mV
- Light IV measurements show heavy shunting in TMGa device
  - Likely due to issues that occurred during fabrication



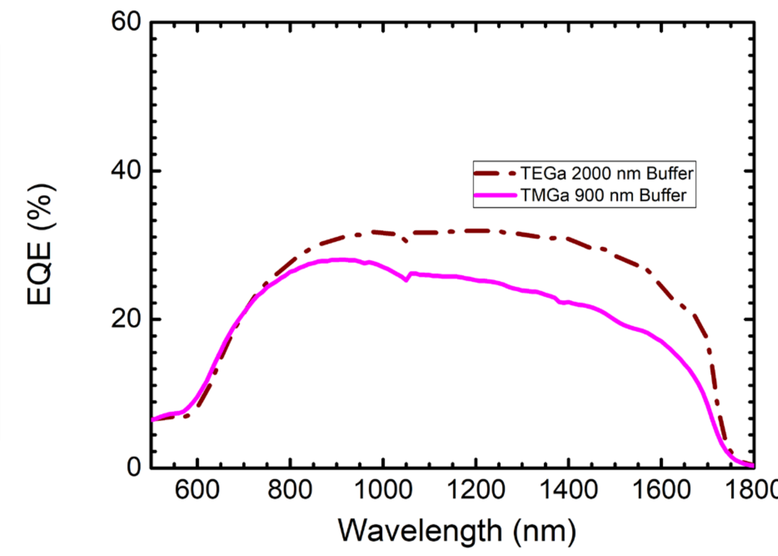
- External quantum efficiency (EQE) of TMGa cell is degraded compared to TEGa cell at λ > 1000 nm
- TMGa precursor may not have fully decomposed, causing defects and degraded lifetimes

	V_{OC} (mV)	FF (%)	Efficiency (%)	L_E (nm)	L_B (nm)	S_E (cm/s)	S_B (cm/s)
TEGa	269	53	3.34	75	>>3x base thickness	>>10^6	<<10^6
TMGa	145	34	1.37	196	600	>>10^6	<<10^6

V. IMF Results



- Light IV measurements show improved open circuit voltage (V_{OC}) in TMGa devices for equivalent buffer thickness



- EQE similar longer wavelength degradation as homoepitaxial cells
- All quantum efficiencies fit using Hovel Model

	L_E (nm)	L_B (nm)	S_E (cm/s)	S_B (cm/s)
TEGa 2000 nm Buffer	20	693	>>10^6	>>10^6
TMGa 900 nm Buffer	14	310	>>10^6	>>10^6

VI. Conclusions

- **GaSb solar cells were grown via MOCVD, fabricated, and tested all at RIT**
- **TEGa appears to be the optimal precursor for p-GaSb for both homoepitaxial and IMF devices**
- **TMGa may be a viable precursor for n-GaSb in homoepitaxial devices**
- **High S_B in IMF devices likely due to a graded defect density**

VII. Acknowledgments

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