ENGINEERING AT ILLINOIS

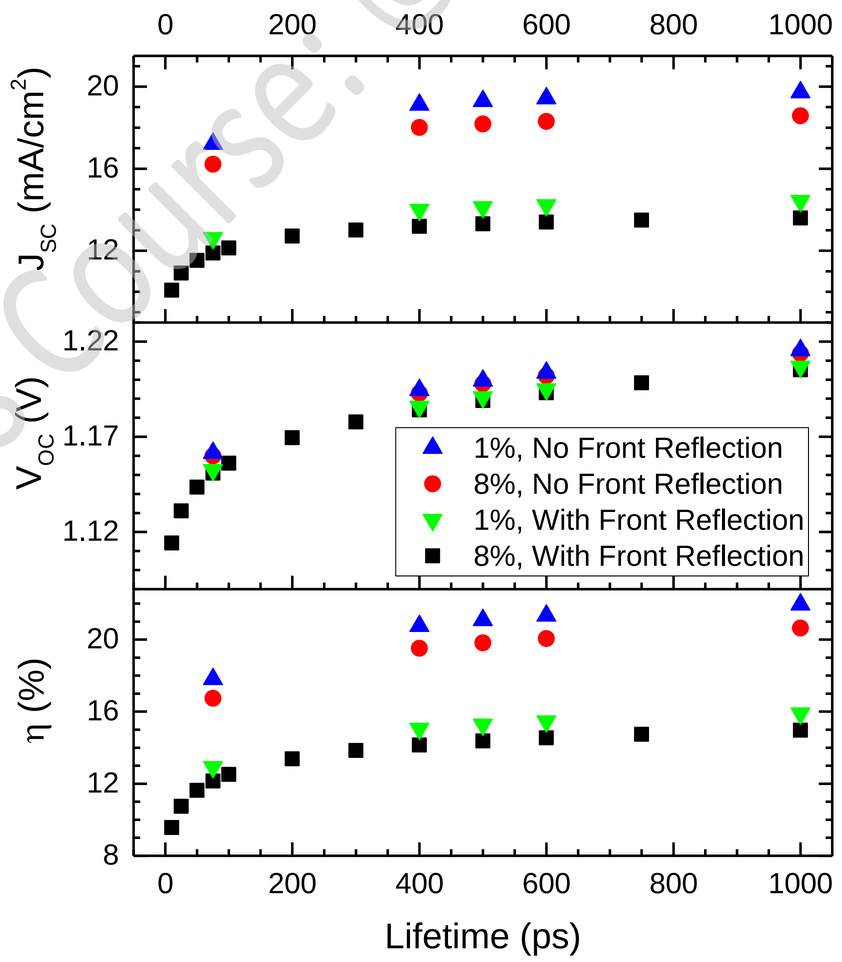
Integration of GaAsP on Si for High Efficiency Tandem Solar Cells

Ryan Hool | ECE 498CB Term Project
April 28, 2017

MNTL
micro+nanotechnology lab

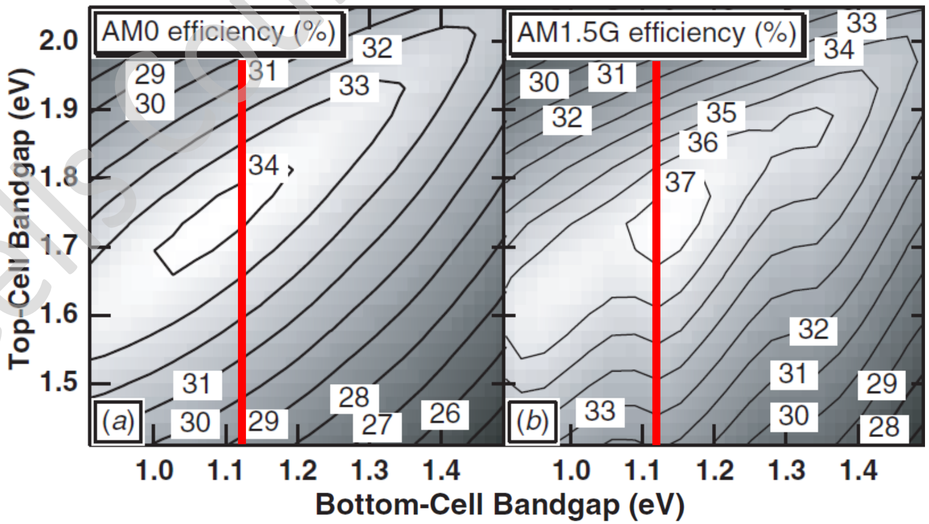
Outline

- Motivation
- Technical Background
- Simulation Results
- Conclusions



Outline

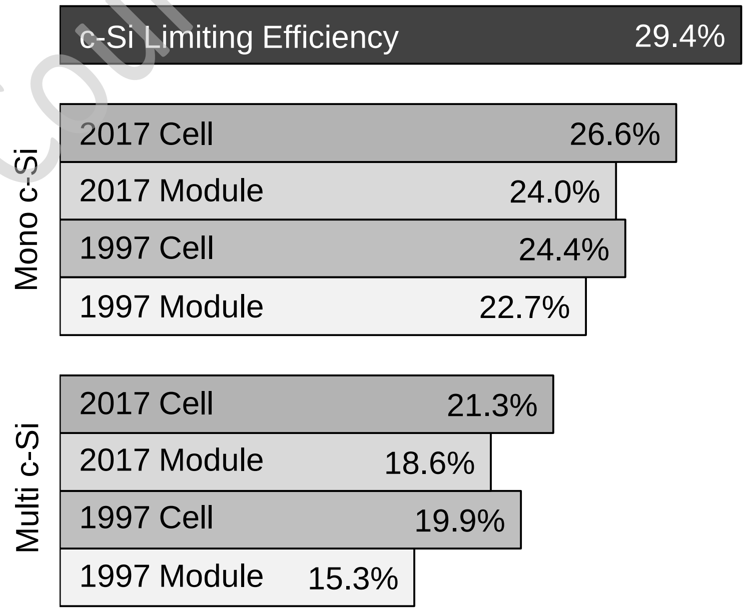
- **Motivation**
- Technical Background
- Simulation Results
- Conclusions



Motivation for Solar Cells Past Si

- To compete with fossil fuels ↓ *cost per watt*
  - ↓ module cost
  - ↑ **module efficiency**
  - ~50% of *cost per watt* is non-module cost
- With ↑ module efficiency
  - Can ↑ specific power
  - Aerospace and military applications

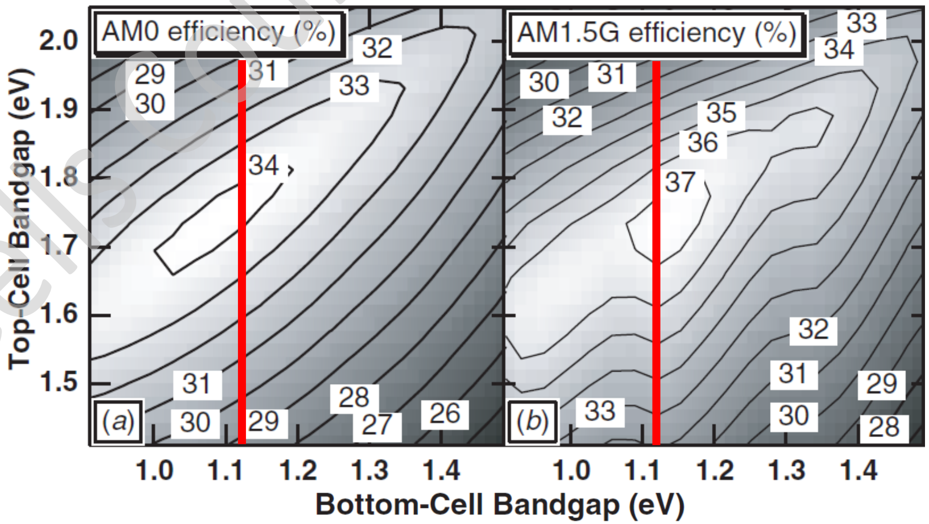
c-Si Record Single Junction Efficiencies 2017 vs 1997 and Limiting



Green,, "Solar Cell Efficiency Tables" (Version 10, 49, and Corrigendum to 49).
Richter, *IEEE J. Photovolt.* (2013).
Polman, *Science* (2016).

Motivation for Integration of III-V on Si

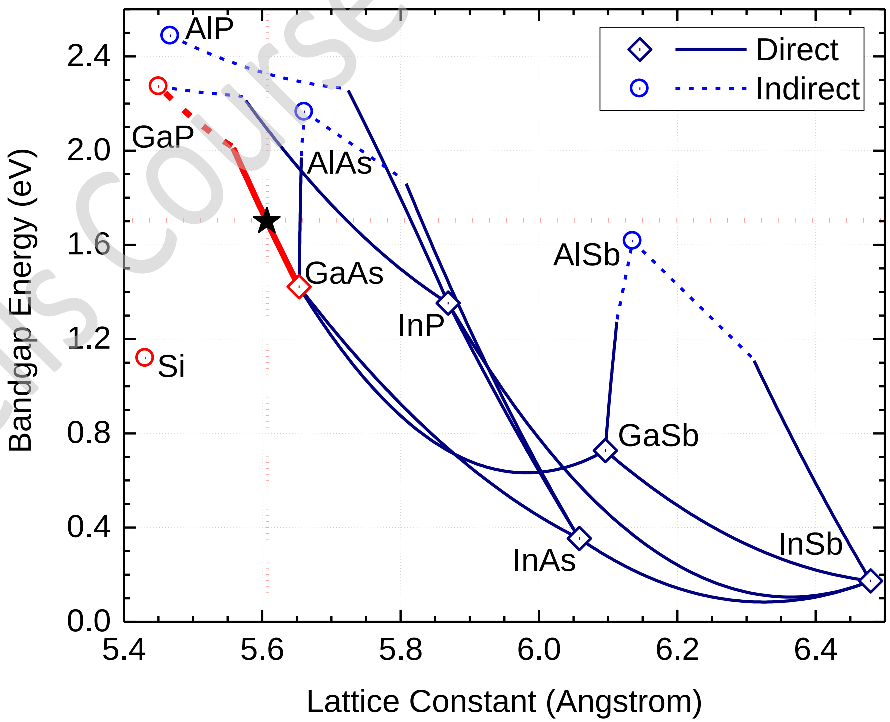
- Combine in tandem cell to leverage benefits from both
  - Si bottom cell: Low-cost, efficient, and established
  - III-V top cell: Potential for bandgap control, high efficiency, and durability



Geisz, *Semicond. Sci. Tech* (2002).

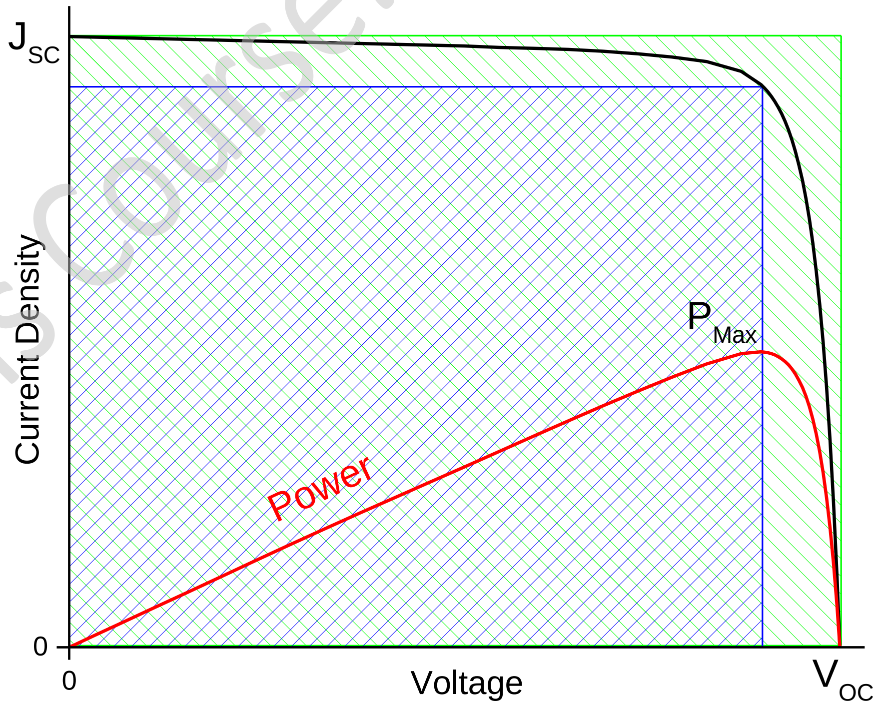
Motivation for GaAsP on Si

- Top cell choice: $GaAs_xP_{1-x}$
  - Direct and tunable bandgap (x ~0.77 for E_g ~1.7 eV)
  - Smallest lattice mismatch for ~1.7 eV
  - Compositionally grade from GaP



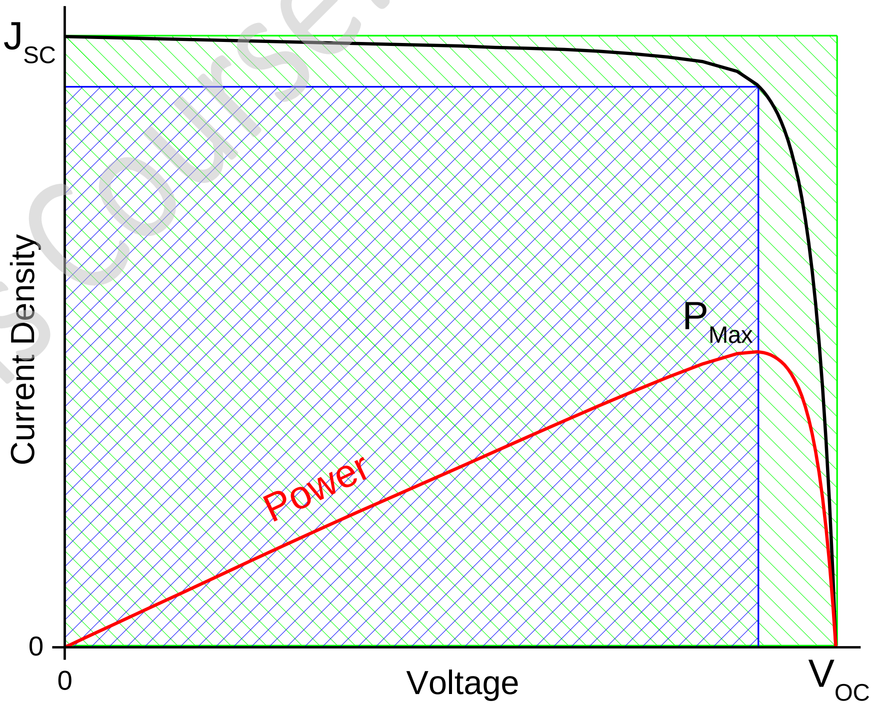
Outline

- Motivation
- **Technical Background**
- Simulation Results
- Conclusions



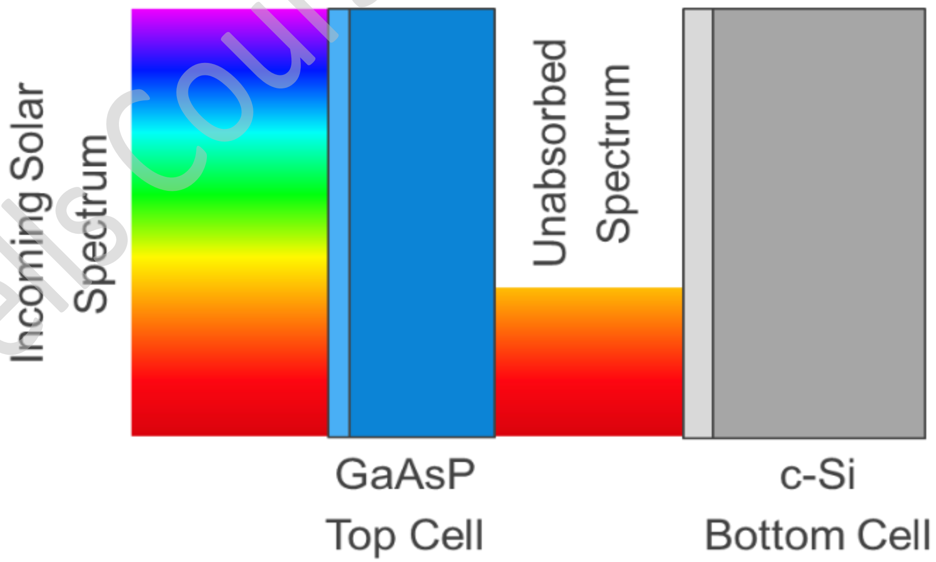
Solar Cell Performance Characterization

- Determined through LIV at standard spectrum
- Figures of Merit include:
  - J_{SC}
  - V_{OC}
  - P_{max}
  - FF
  - η



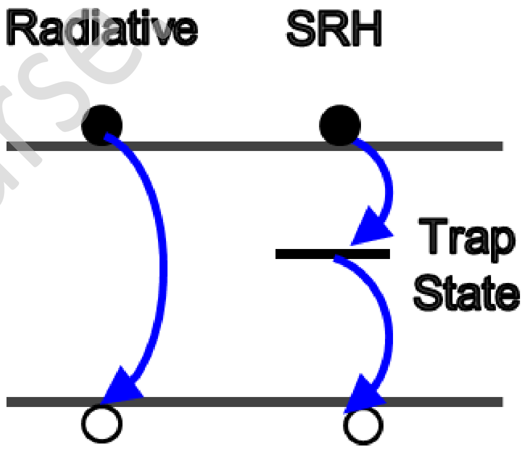
Tandem Solar Cell Operation

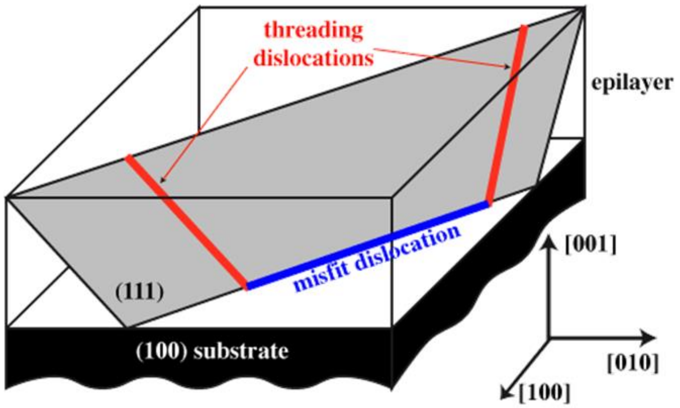
- High energy photons cause thermalization losses
- Higher bandgap top cell suffers less thermalization losses
- Bottom cell utilizes remaining spectrum



Lattice Mismatch Causes Performance-Limiting Dislocations

- Lattice mismatch for growth on c-Si relaxed through dislocations
- ↑ local trap states → ↑ SRH recombination
- ↓ minority carrier lifetime

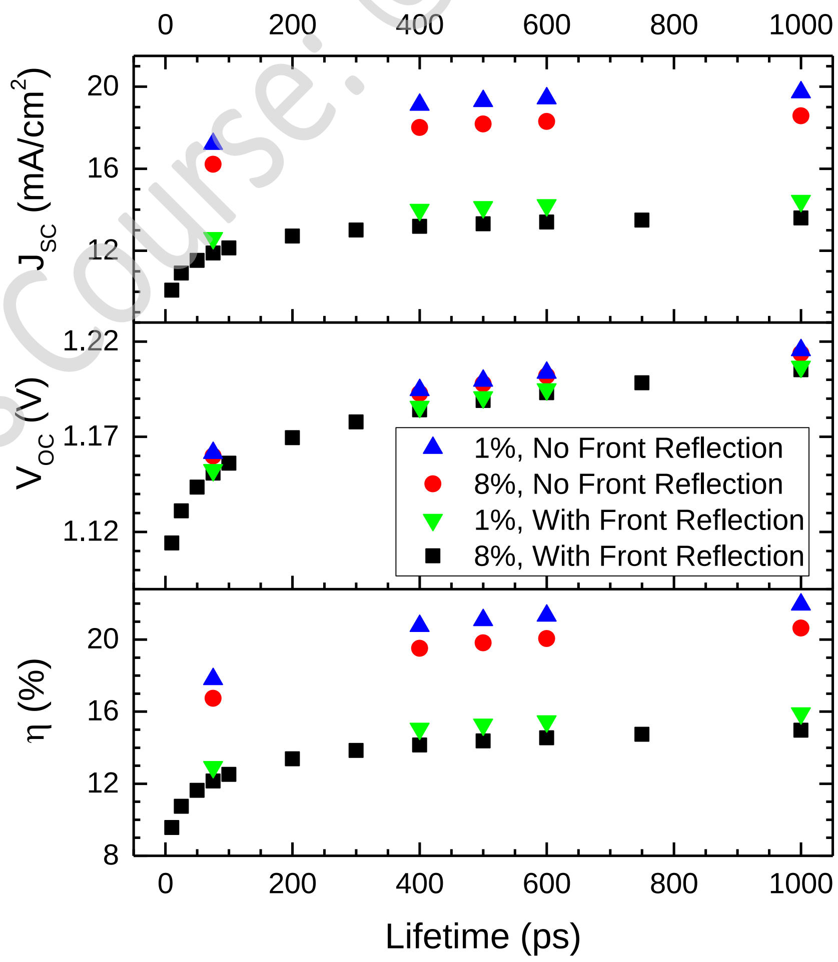




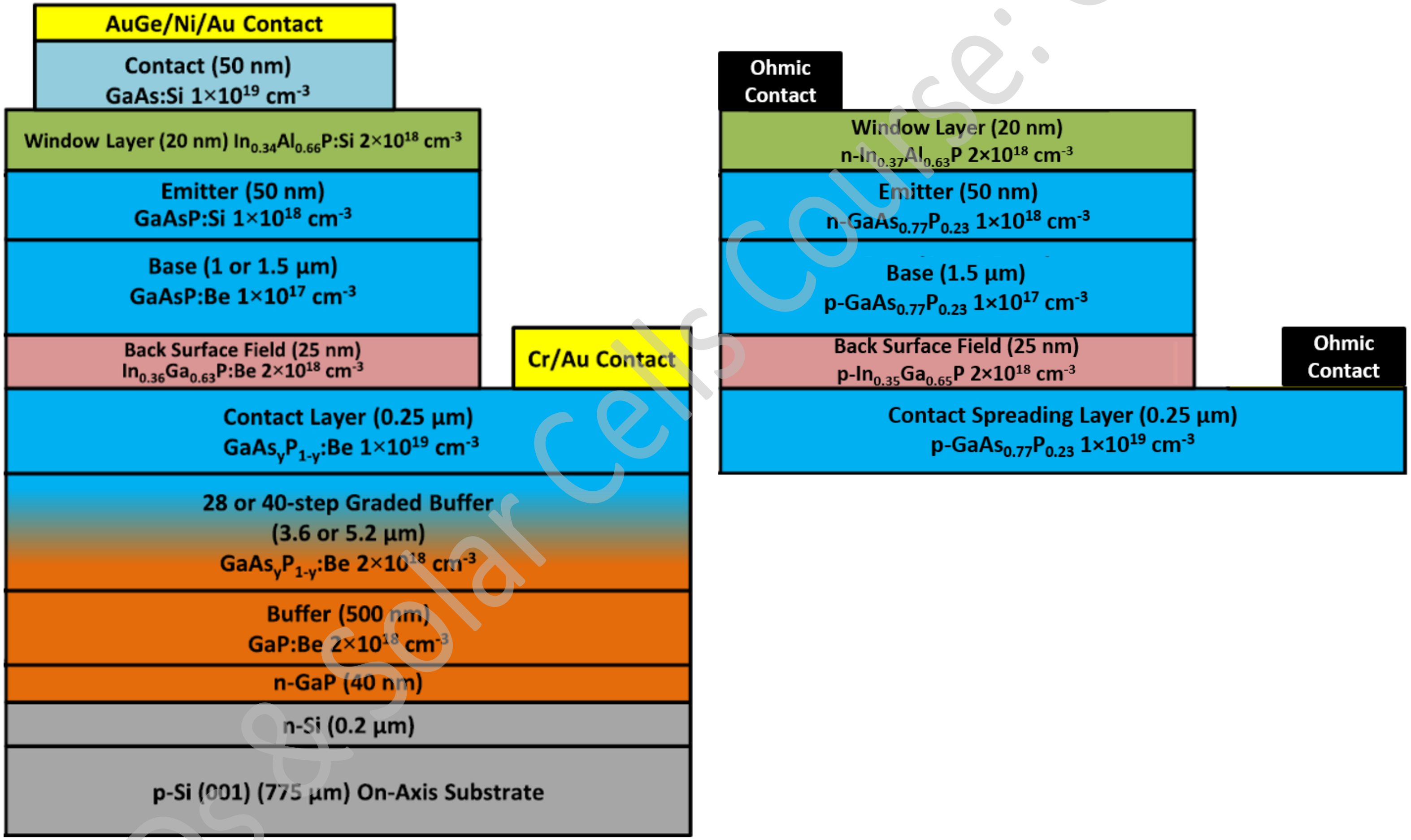
http://userweb.eng.gla.ac.uk/douglas.paul/SiGe/misfit.html

Outline

- Motivation
- Technical Background
- **Simulation Results**
- Conclusions



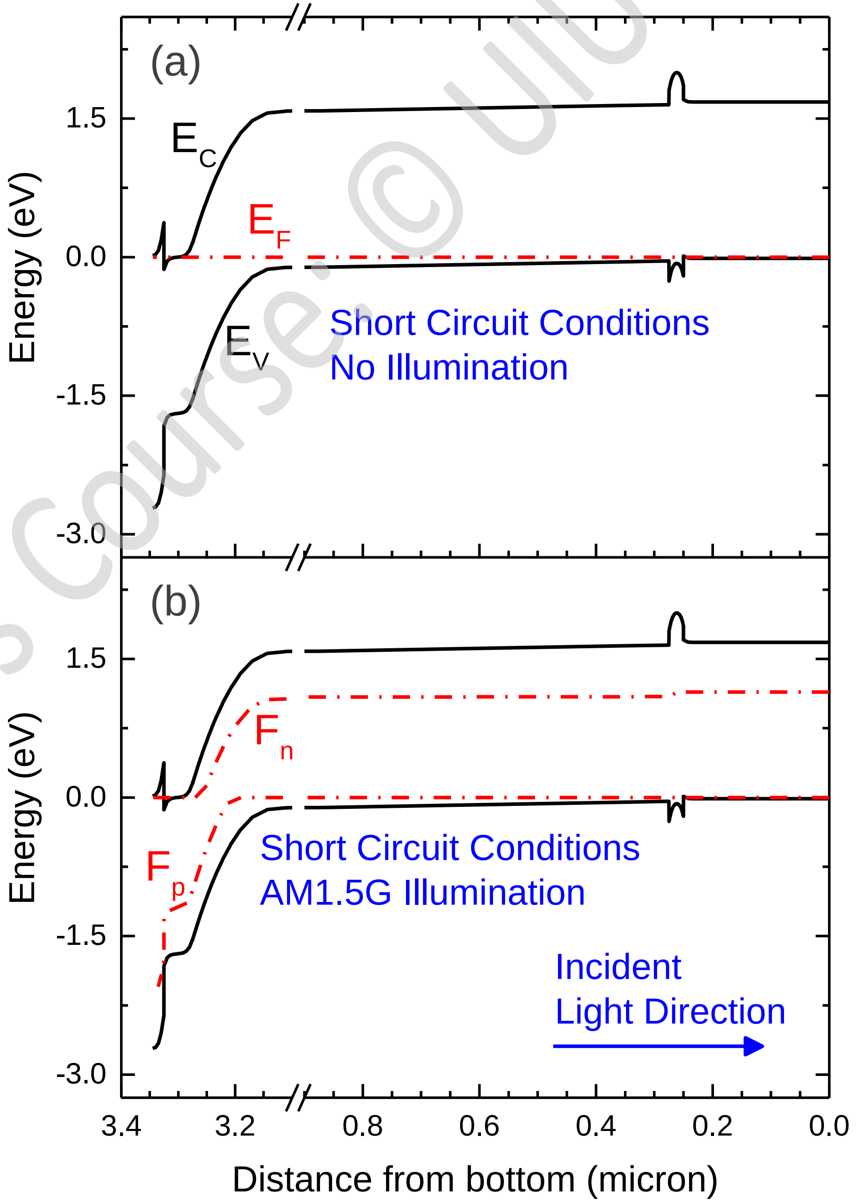
Experimental and Simulated Structures



Yaung, *Appl. Phys. Lett.* (2016).

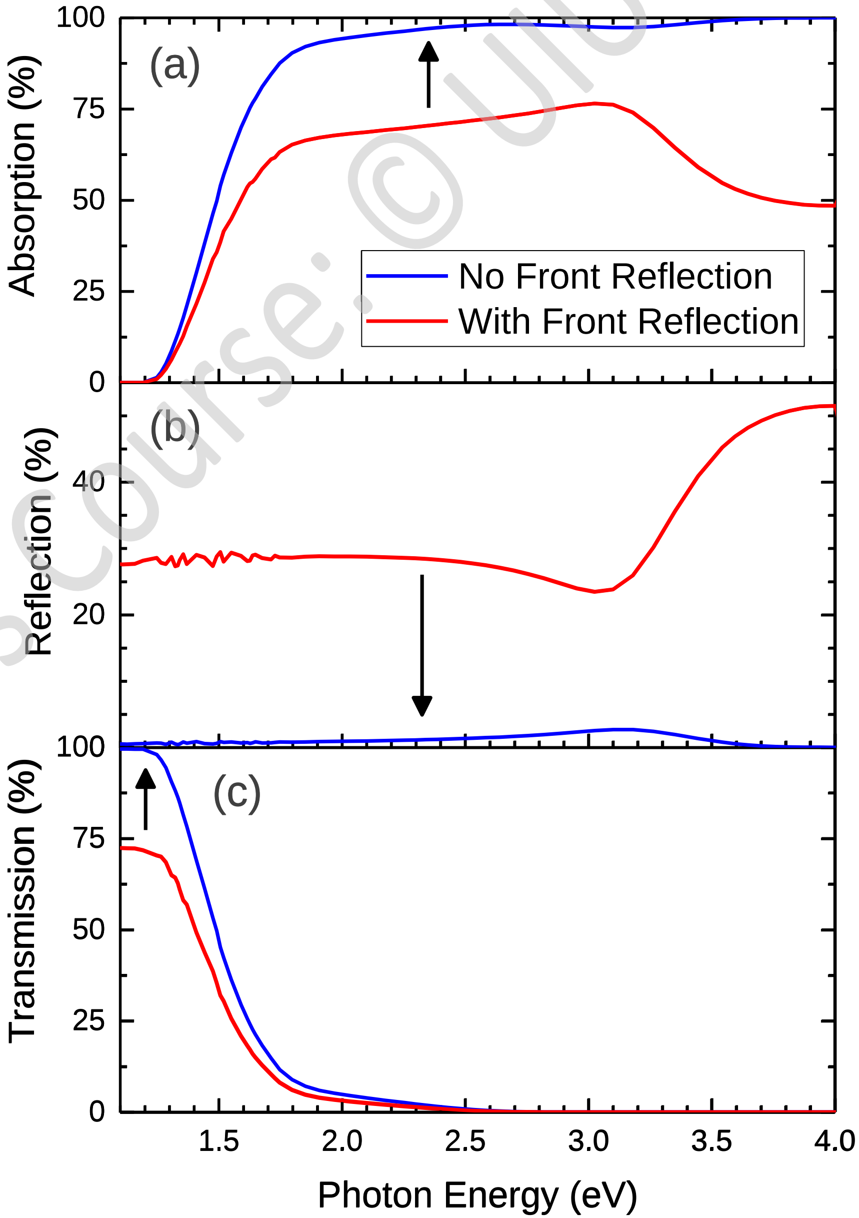
Simulated Band Structure

- Simulated band structure is similar to expected
- Although surprising that n-emitter is degenerately doped



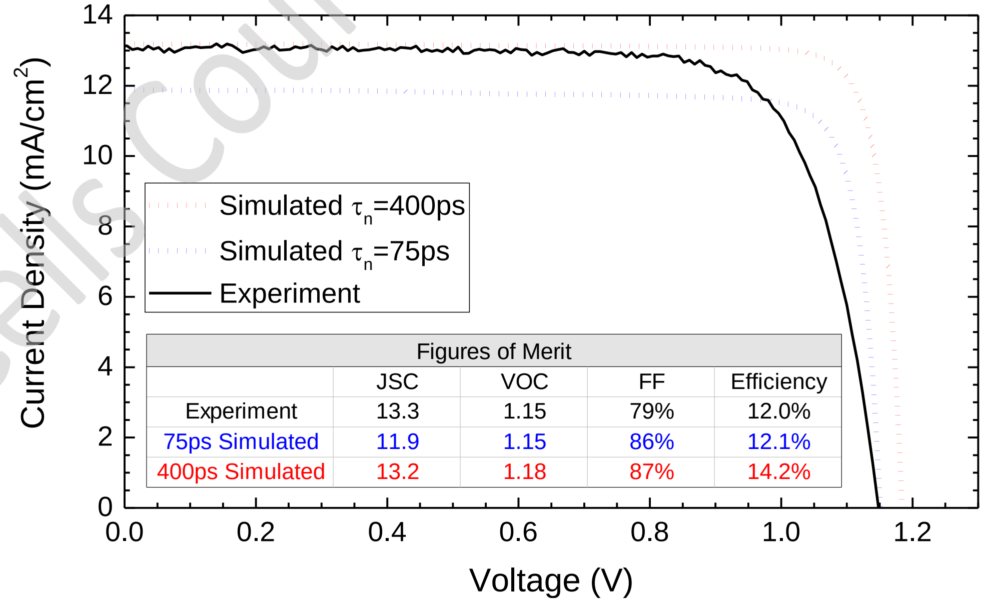
Simulated Optical Properties

- ~30% reduction in reflection results from turning off front reflection
- Shows great potential for anti-reflection coating



Attempt to Simulate Experimental Performance

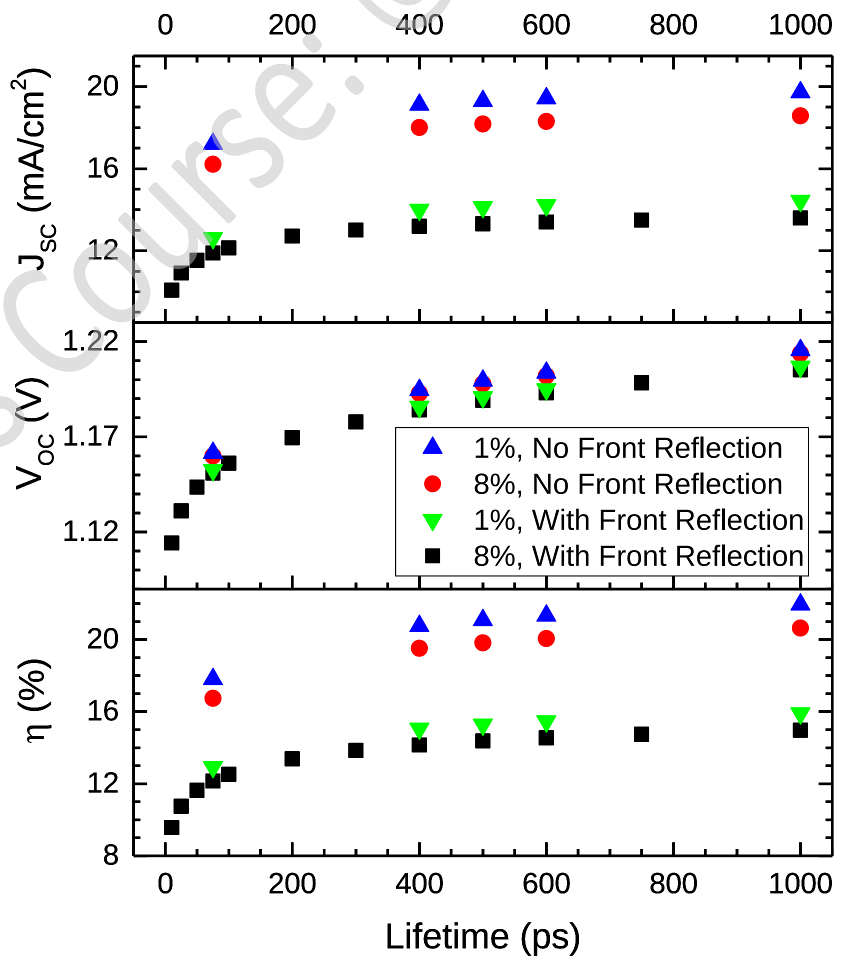
- Varying τ_n did not match both V_{OC} and J_{SC}
- ↑ shunt resistance for experiment decreased *FF*
- Double diode model applied for simulations?



	JSC	VOC	FF	Efficiency
Experiment	13.3	1.15	79%	12.0%
75ps Simulated	11.9	1.15	86%	12.1%
400ps Simulated	13.2	1.18	87%	14.2%

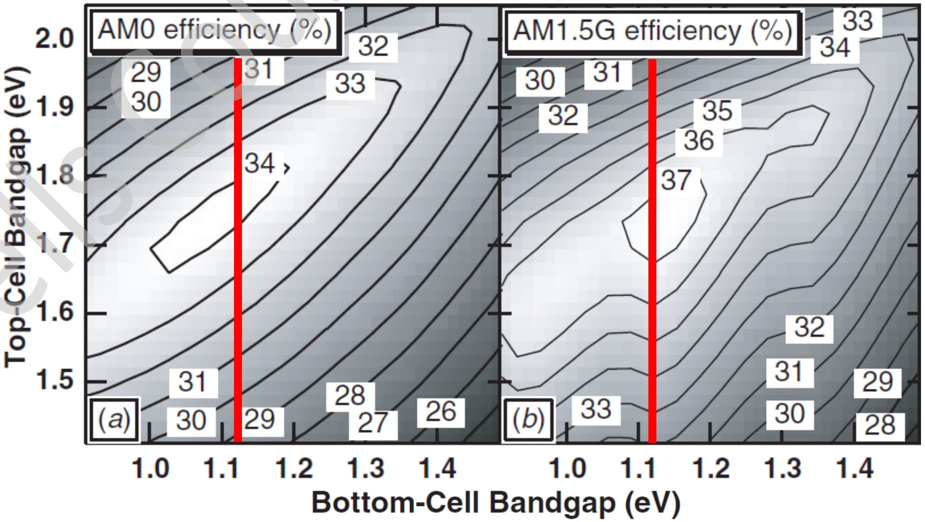
Performance Improvement through Design

- Improved top cell performance for:
  - ↑ minority carrier lifetime in base
  - ↓ top contact mesa coverage
  - ↓ front reflection
    - Greatest improvement



Outline

- Motivation
- Technical Background
- Simulation Results
- **Conclusions**



Conclusions

- Simulations indicate a that a 20% ~1.7eV GaAsP top cell is achievable through improvements in:
  - Design of an anti-reflection coating to reduce reflection losses
  - Material quality by lengthening the minority carrier lifetime in the p-GaAsP base to ~1ns
  - Design of a n-type top contact with 1% mesa coverage
  - Reducing parasitic shunting