SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

PORTFOLIO REVIEW
2018

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2018 SETO Portfolio Review

Silicon-Based Tandem Photovoltaic Cells

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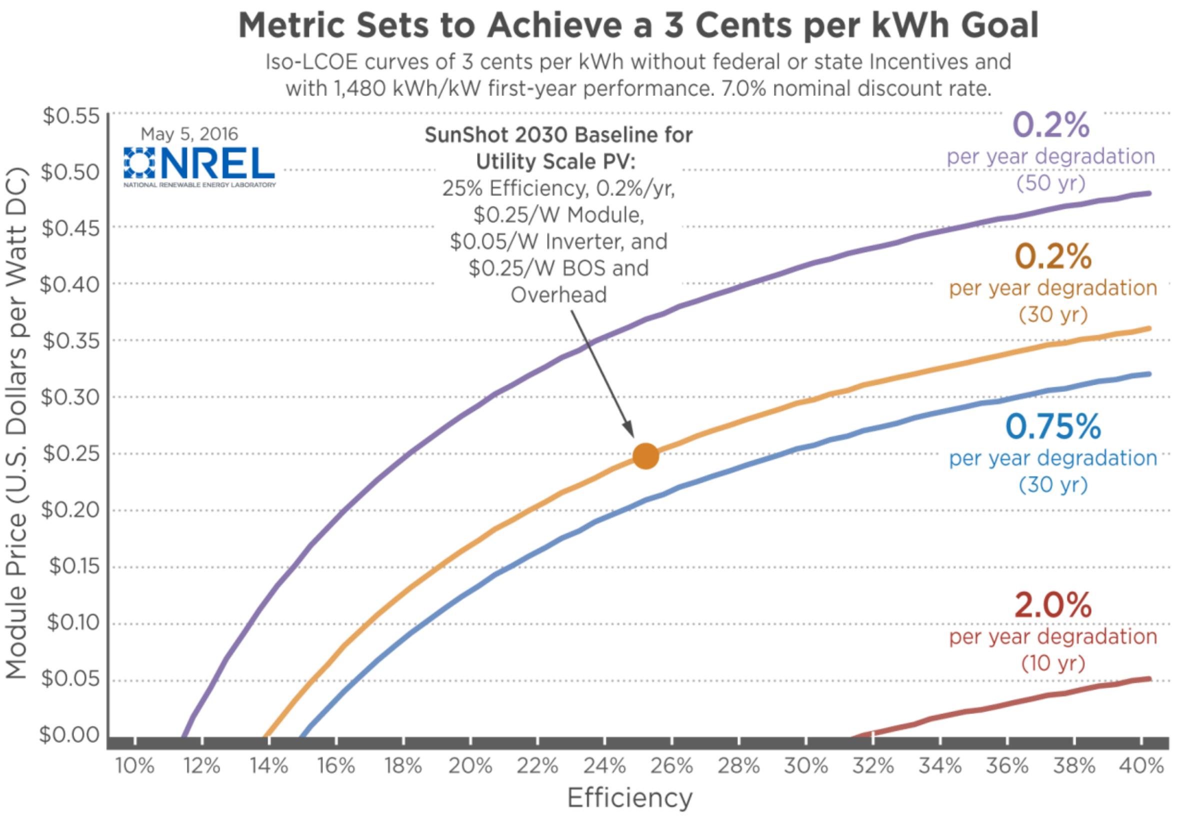
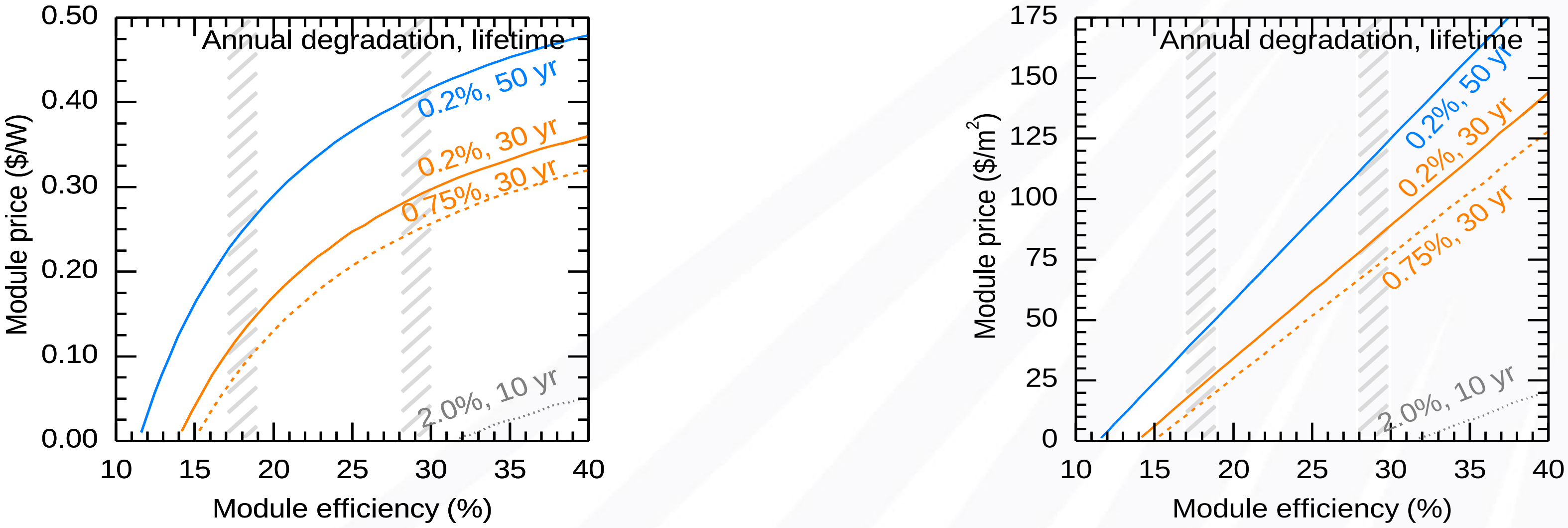
SETO Mantra: Efficiency, Reliability, Cost



SETO Mantra: Efficiency, Reliability, Cost



➢ Doubling efficiency more than doubles module selling price

Holman Research Group

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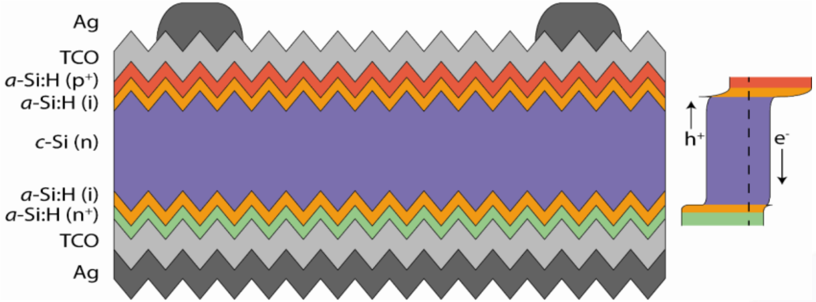
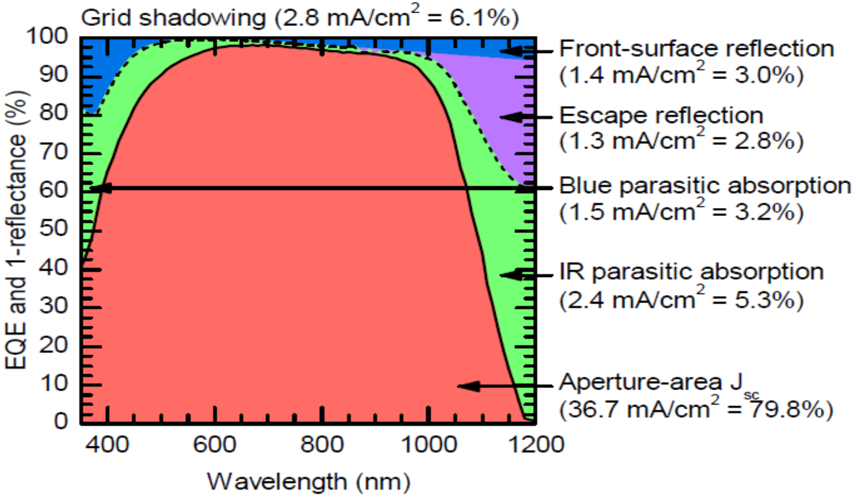
What Will the Silicon Bottom Cell Look Like?



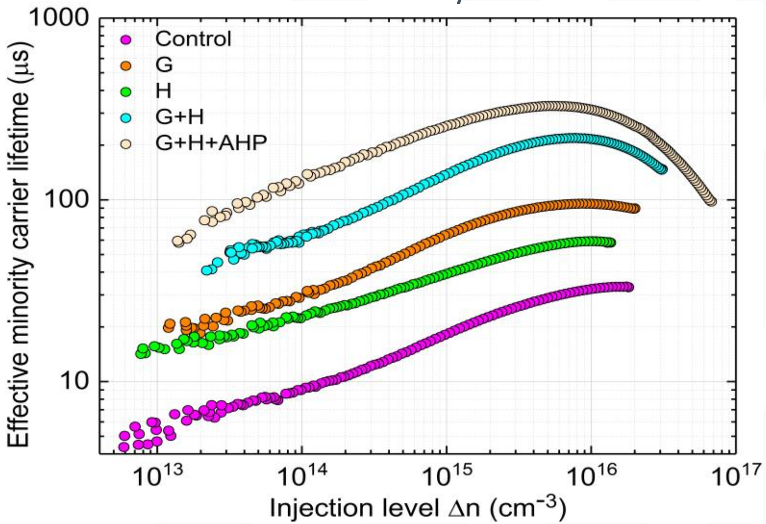


- Silicon heterojunction (SHJ) cells have highest V_{oc}s
- Blue parasitic absorption is non-issue in tandems
- Front TCO is a natural recombination junction
- Expensive low-temperature silver paste not needed for two-terminal tandems
- Benefits from a high-lifetime (n-type wafer)
- TCOs and rear metallization can be pricey

Silicon Heterojunction Bottom Cell: Solar-Grade *p*-Type Wafers

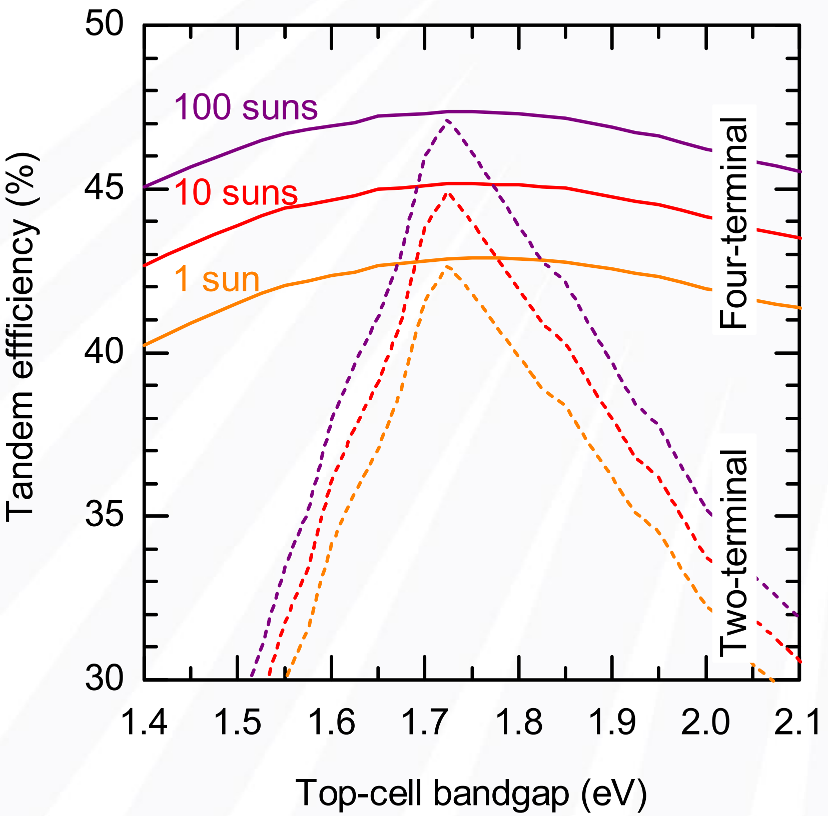
- Gettering (G), hydrogenation (H), and advanced hydrogenation (AHP) improves *p*-type SHJ lifetime from 30 μs to 300 μs
- Certified V_{oc} of 707 mV on *p*-type CZ, 702 mV on *p*-type multi

CZ monocrystalline



What Will the Top Cell Look Like?

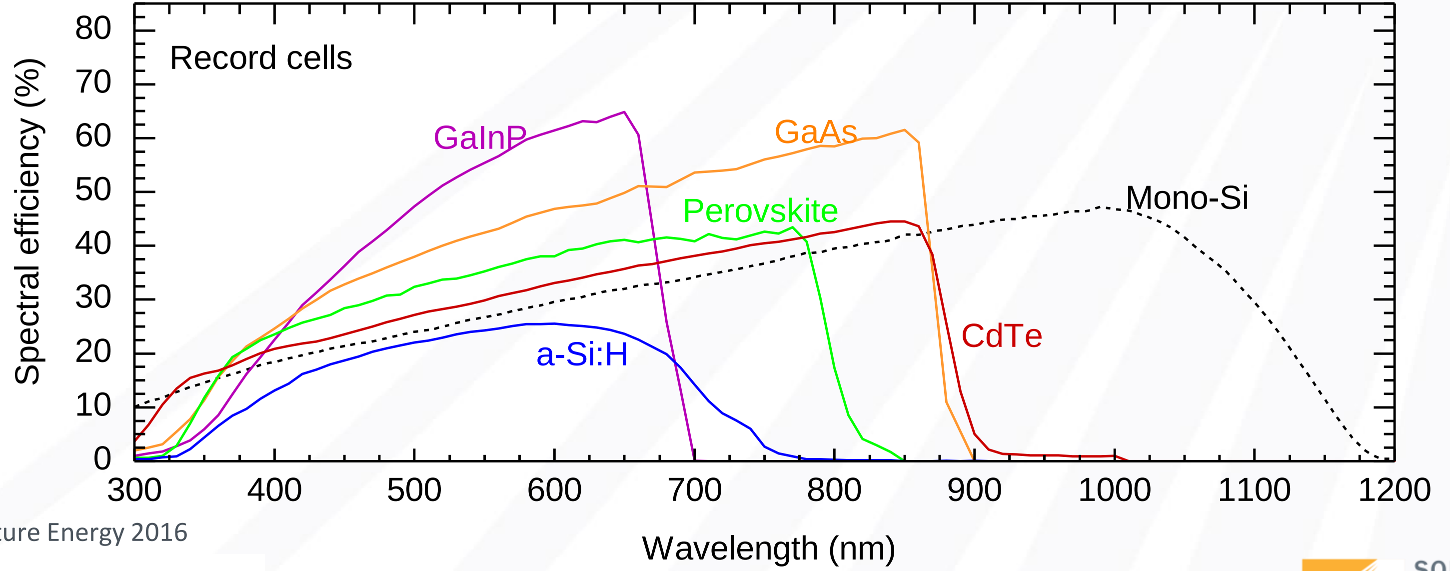
- Limiting-efficiency calculations including Auger recombination give 43%
- 1.72 eV top cell is best for two-terminal tandem; 1.6–1.9 eV for four-terminal
- But we don't make sub-cells that operate at their limiting efficiency!



Spectral Efficiency Shows the Way

$$\eta(\lambda) = \frac{J_{SC}(\lambda) \cdot V_{OC} \cdot FF}{I(\lambda)} \quad \text{with} \quad J_{SC}(\lambda) = q\frac{\lambda}{hc}EQE(\lambda) \cdot I(\lambda)$$

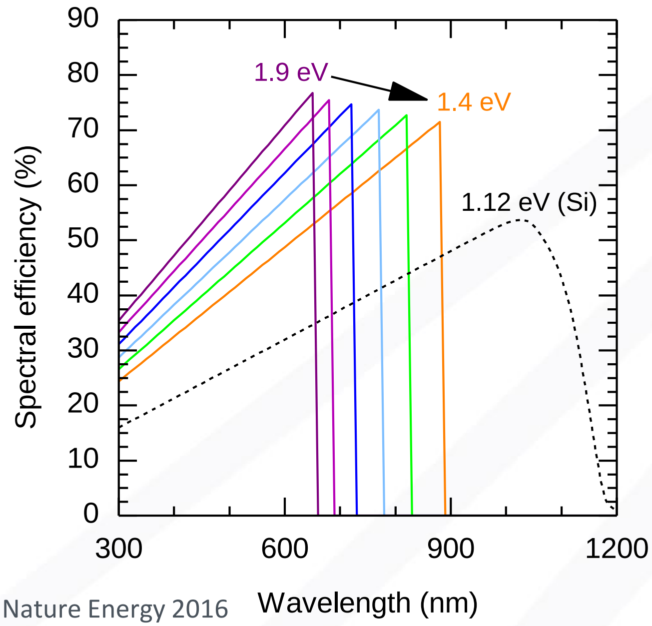
- Efficiency resolved by wavelength
- Allows direct evaluation of cell pairs—only bother considering a tandem if top cell is considerably better than silicon for λ < 700 nm



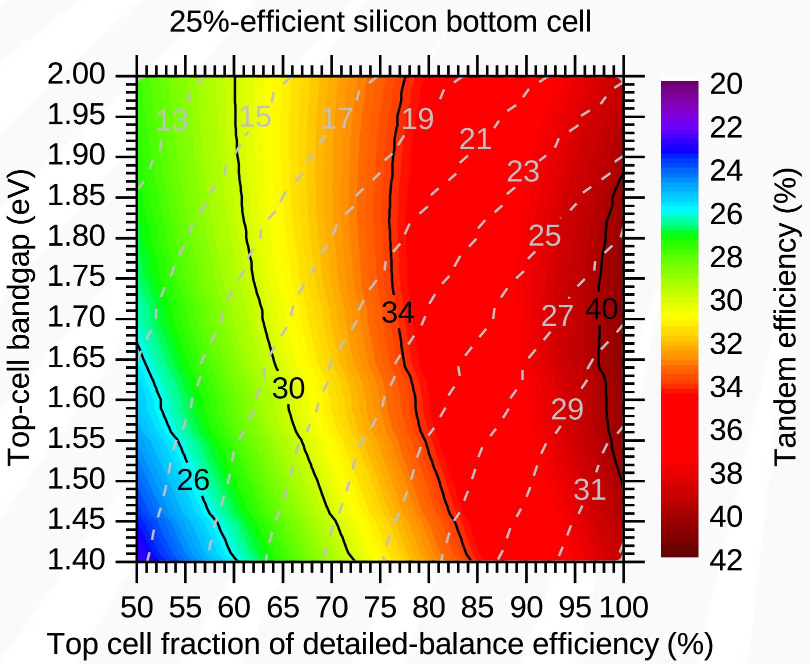
Yu *et al*, Nature Energy 2016

Spectral Efficiency Shows the Way

- ➢ Predicts the maximum possible tandem efficiency for any two sub-cells

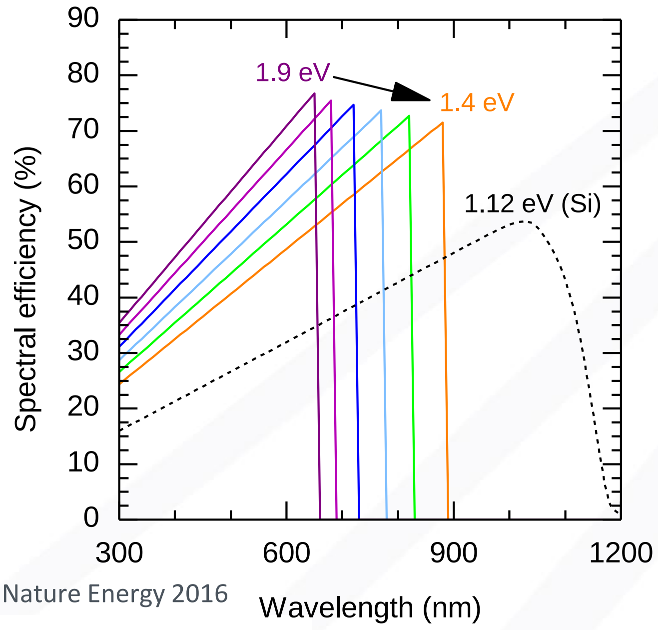


Yu *et al*, Nature Energy 2016

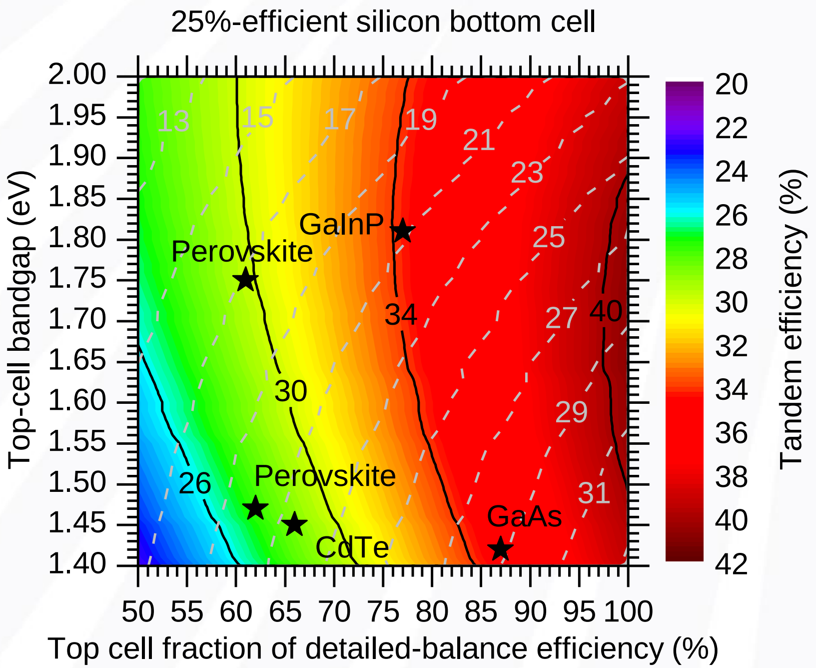


Spectral Efficiency Shows the Way

- Predicts the maximum possible tandem efficiency for any two sub-cells
- Of existing cells, GaAs gives highest tandem efficiency despite wrong bandgap!



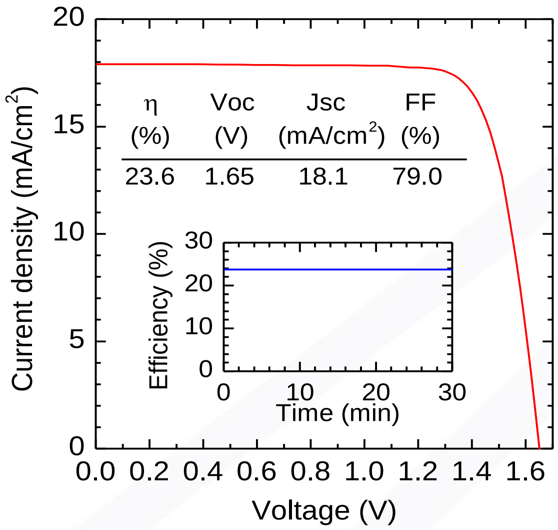
Yu *et al*, Nature Energy 2016

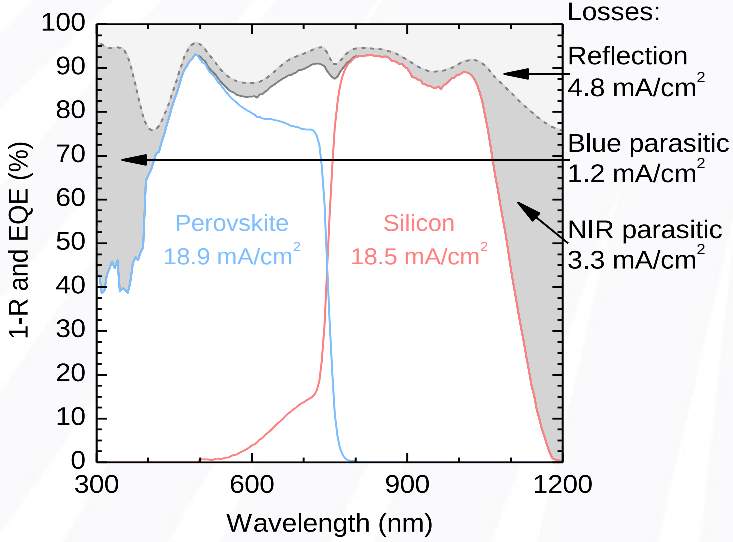


Perovskite Top Cells

+ Amazing lifetime and V_{oc} for polycrystalline material, potentially inexpensive

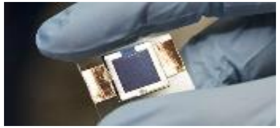
– Stability, scaling, depositing on textured surfaces

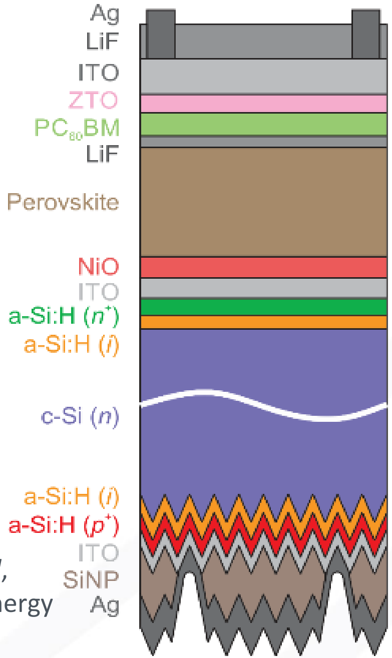




Bush *et al*, Nature Energy 2017

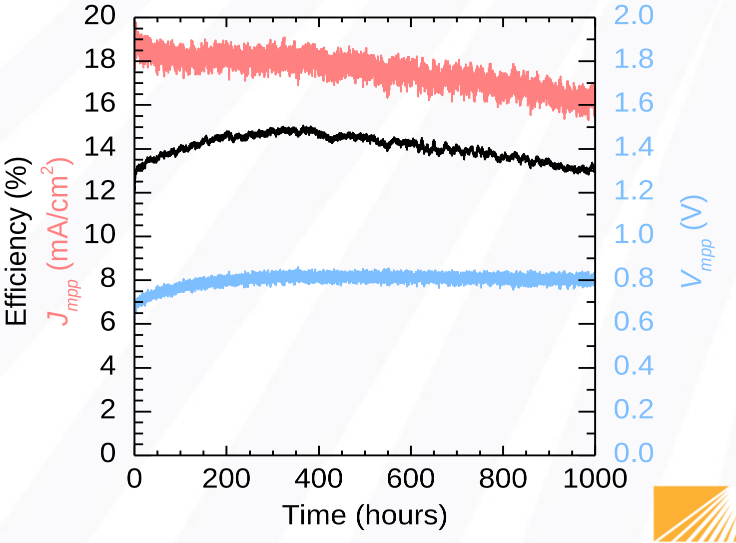
Perovskite Top Cells



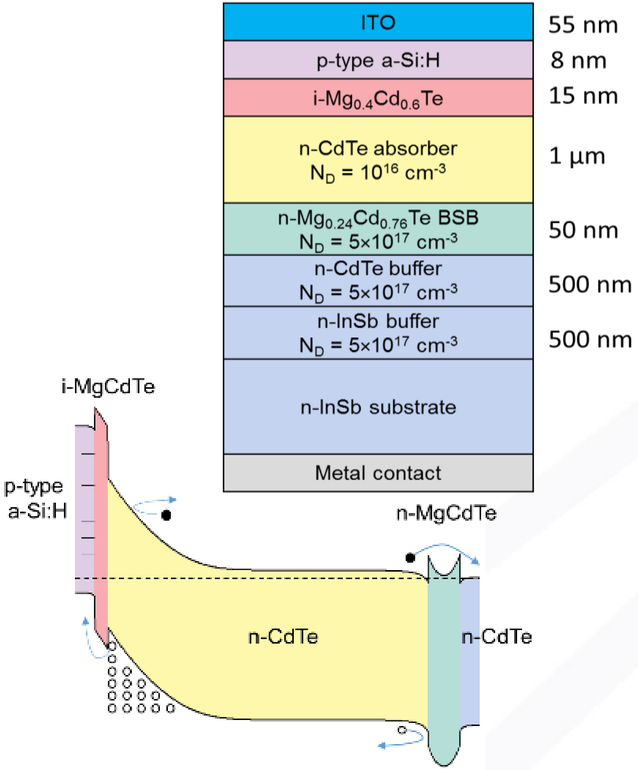


Bush *et al*, Nature Energy 2017

- Thermally stable absorber: $Cs_{0.17}FA_{0.83}Pb(Br_{0.17}I_{0.83})_3$ (CsFA) perovskite
- Thermally evaporated PCBM (electron contact)
- ALD-deposited SnO_2/ZTO buffer layer prevents sputter damage

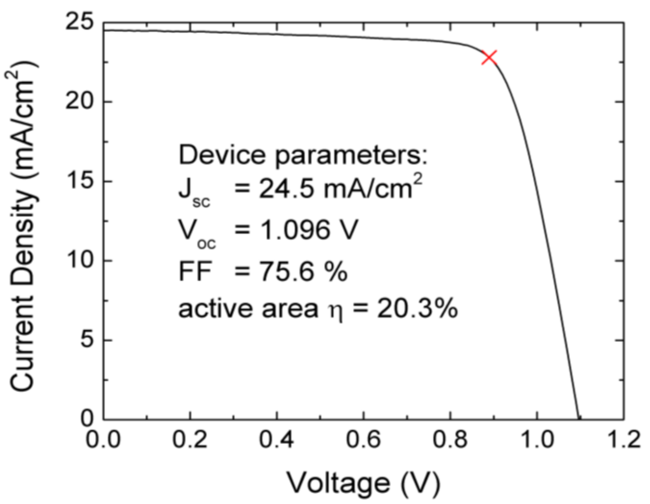


CdMgTe and CdZnTe Top Cells



+ CdTe cells at 22%, Mg or Zn to get to 1.7 eV, GW-scale manufacturing in place

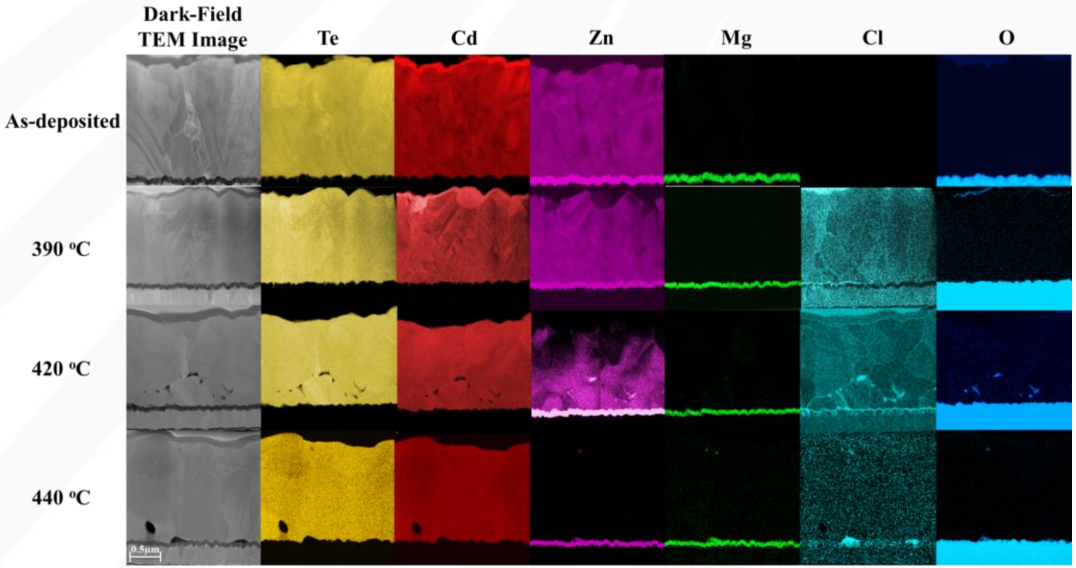
– Ternary alloys are complicated, V_{oc} of II-VI cells low due in part to back contact



Zhao *et al*, Nature Energy 2016; Becker *et al*, IEEE JPV 2017

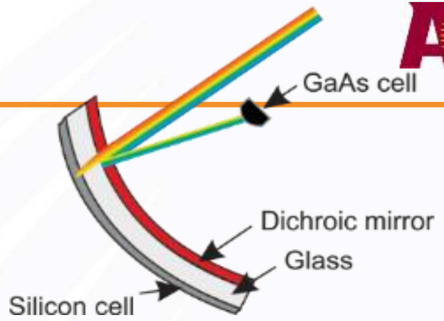
CdMgTe and CdZnTe Top Cells

- Best 1.7 eV monocrystalline CdMgTe cell at 15.2%; reached V_{oc} = 1.18 V and FF = 82% separately
- Polycrystalline CdMgTe and CdZnTe lose Mg and Zn upon $CdCl_2$ treatment
- Best 1.65 eV polycrystalline CdMgTe cell at 10.2%; lifetime of 7 ns with double heterostructure



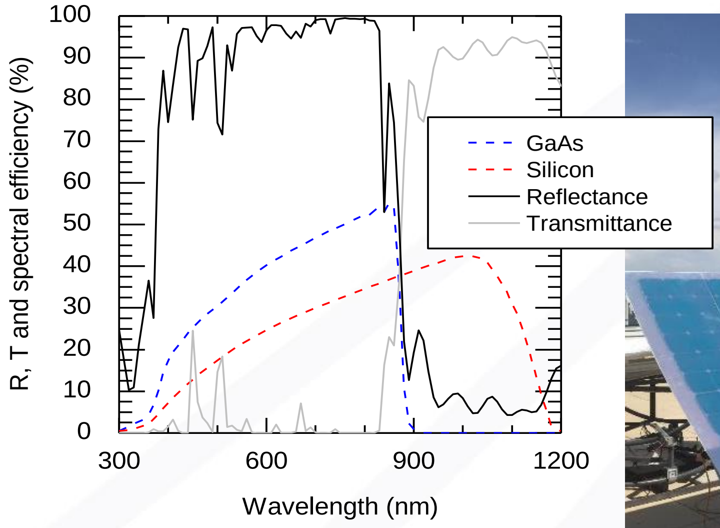
Swanson *et al*, submitted; Becker *et al*, IEEE JPV 2018

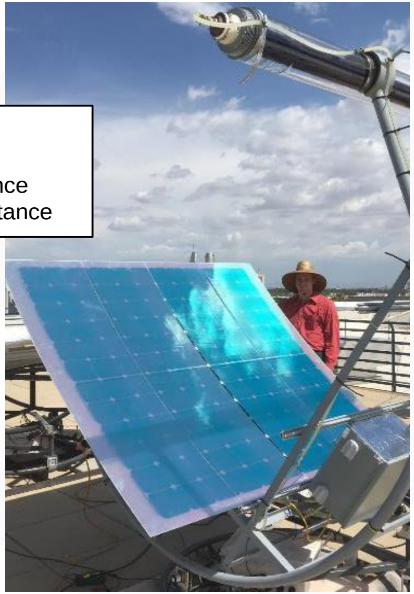
III-V Top Cells

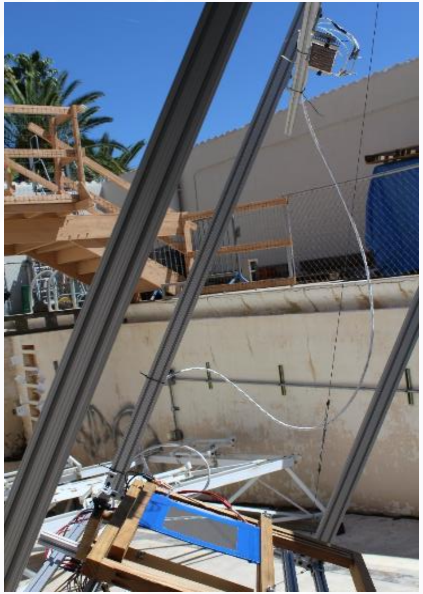


+ Monocrystalline cells are very efficient, stable

– Cost, integration with silicon







Yu *et al*, in preparation

Acknowledgements

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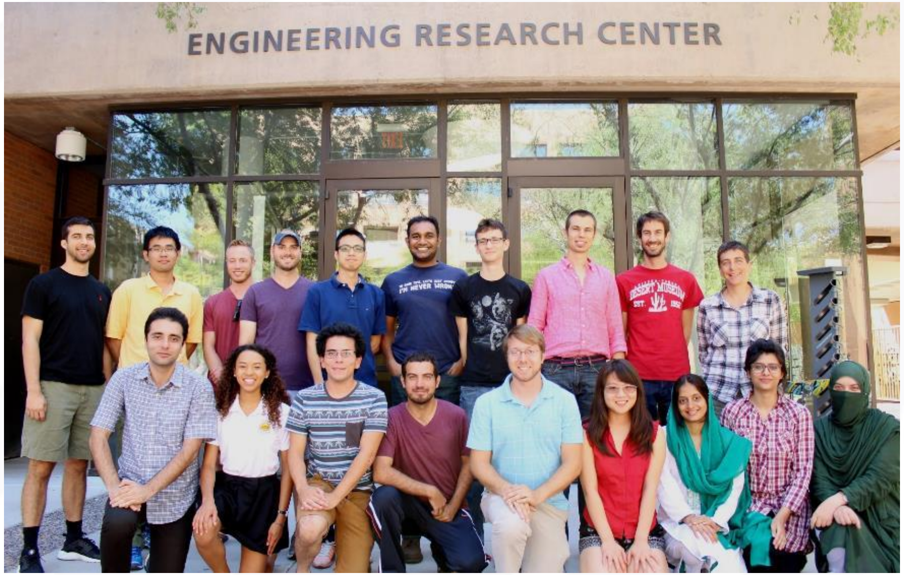
UA (Angel)

UIUC (Lee)



What's next?

- *Long-lifetime, cheap, stable polycrystalline absorbers*
  - Perovskite: Degradation mechanisms? Conformal deposition on 156 mm textured wafers?
  - II-VI: Maintain alloy stoichiometry during Cl treatment? Surface passivation?
  - III-V: Any plausible way to get these to < $100/m^2? Passivation of grain boundaries in polycrystalline III-V materials?
  - Other absorbers that we're not yet exploring?

- *Heterojunction contacts with high or low work function*
  - Measurement of implied voltage, comparison to extracted voltage?
  - New, transparent high- and low-work-function materials?
  - Deposition methods that don't damage absorbers?

- *Integration with silicon*
  - Process compatibility (temperature, chemistry)?
  - Two, three, or four terminals? Realistic energy yield calculations?
  - Metallization when combining a thin-film solar cell with a wafer-based solar cell?