A Summary of my Research at ASU

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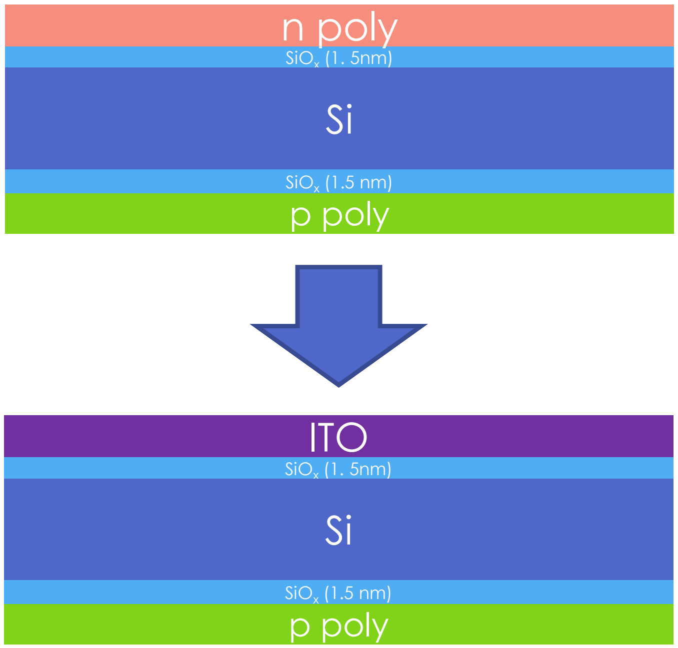
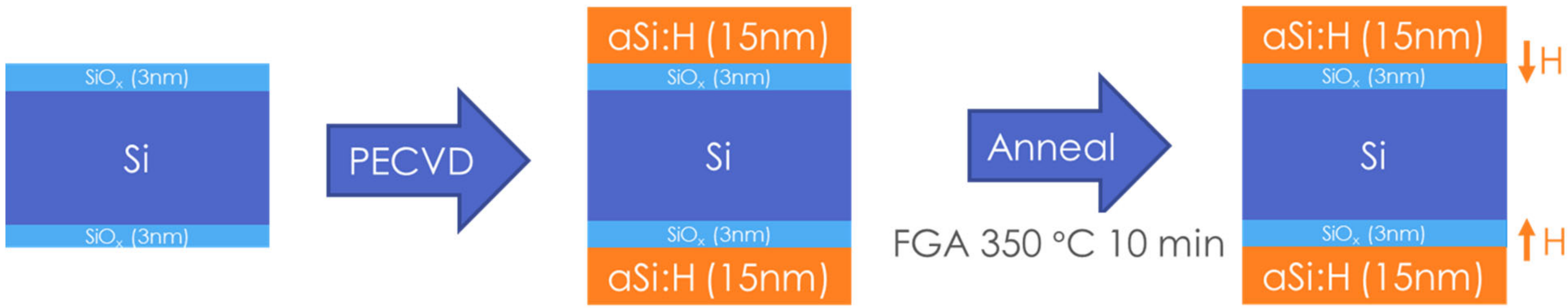
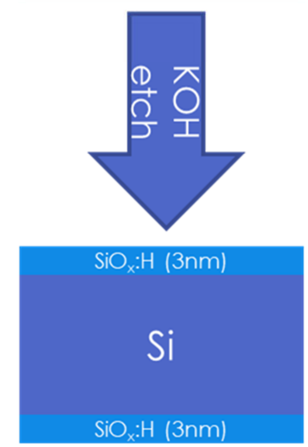
Transparent, passivating, and carrier-selective contacts to silicon solar cells

- Carrier selective contacts on tunnel oxide
  - SiO_2/Poly-Si – NREL Baseline
  - SiO_2/ITO – Young et. al, PVSC-2014
    - 50Å SiO_2
    - $\rho_c \approx$ **11.5mΩcm²**
    - $J_0 \approx$ **55–95 fAcm⁻²**
- **Two Key Challenges:**
  - Passivation
  - Contact resistivity

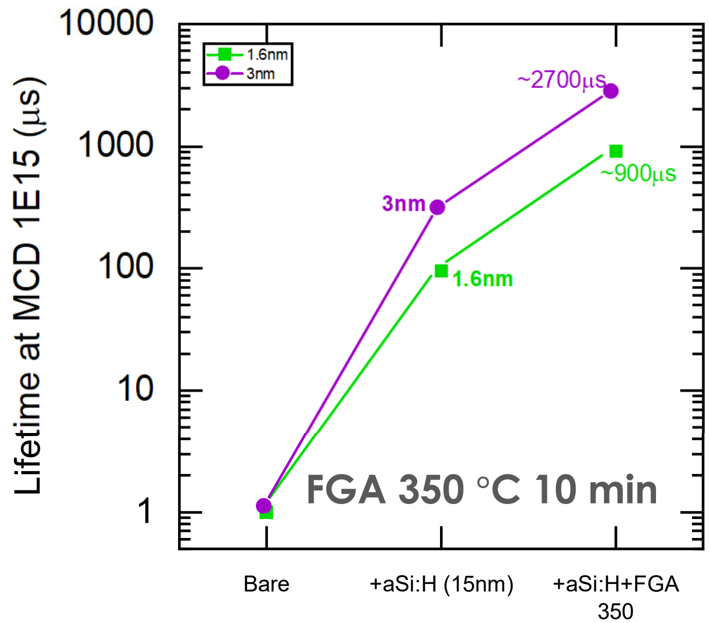


Challenges in Experimental realization - Passivation





- SiO_2 is the passivation layer
- 2 necessities for effective passivation*
  - Hydrogen radicals for dangling bonds
  - Capping layer on oxide
- PECVD aSi:H **capping** layer and **hydrogen** source
- Hydrogen overpressure in forming gas promotes **diffusion** into SiO_2 layer
- aSi:H **stripped** by dilute KOH etch

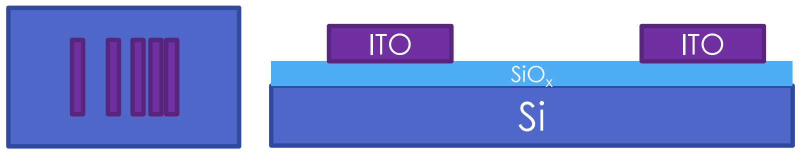


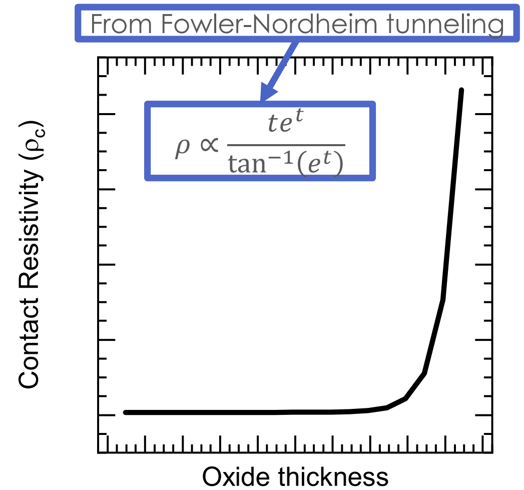
*Mazzarella, L. *et al.* Optimization of PECVD process for ultra-thin tunnel SiO x film as passivation layer for silicon heterojunction solar cells. *2017 IEEE 44th Photovolt. Spec. Conf. PVSC 2017* 1–5 (2017). doi:10.1109/PVSC.2017.8366698

Challenges in Experimental realization – Contact Resistivity

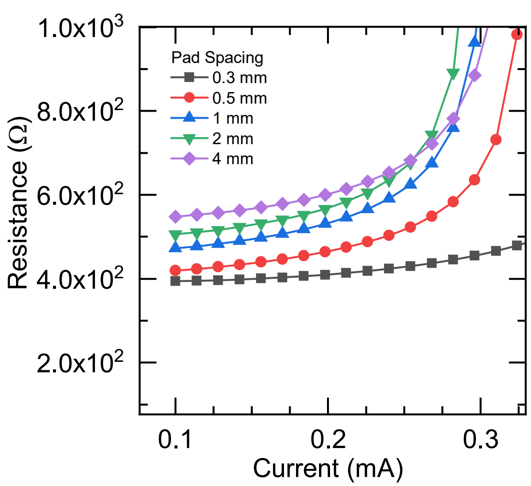
- Thicker oxides → Better passivation → Exponentially worse ρ_c
- NREL demonstrated with 5 nm SiO_2 → Too thick for tunneling?

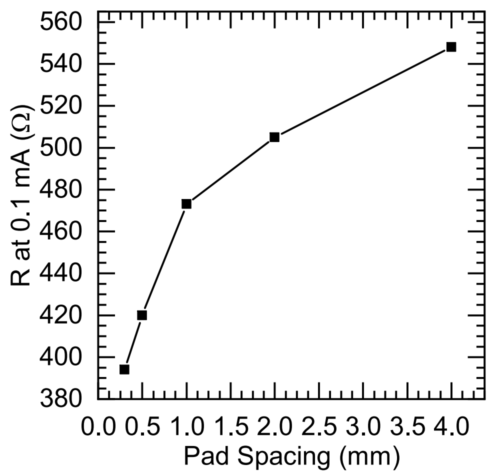
- TLM test structures
  - 2 nm SiO_2 + 30 nm ITO

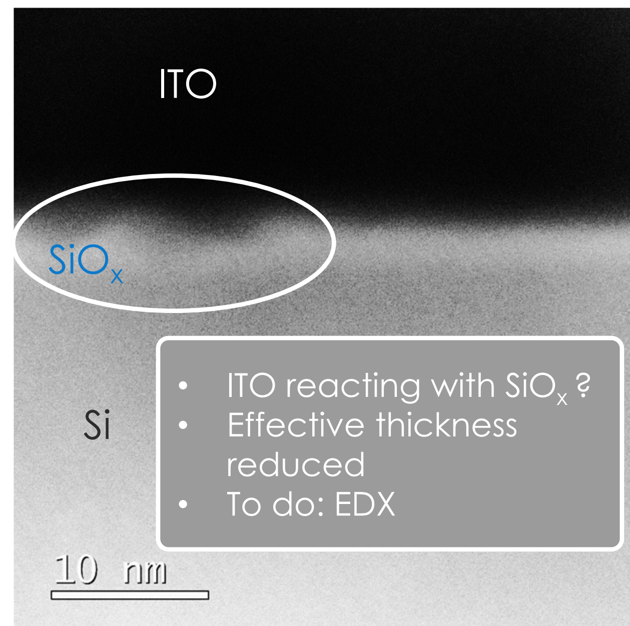




- As is → ρ_c too high for measurement
- 600 °C Anneal → Measurable resistance, but not **ohmic**







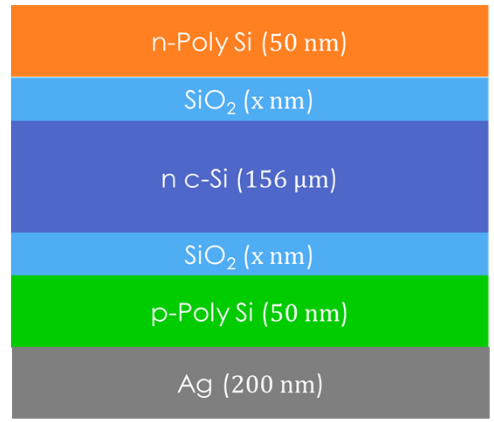
Simulation of TOPCON cells in AFORS-HET

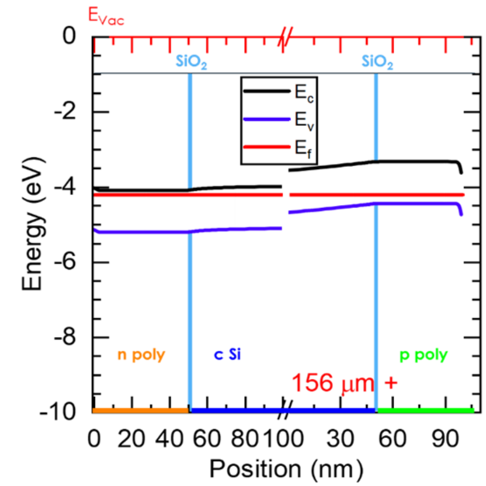
- Reference TOPCON model in AFORS-HET v2.5[1]
- **Goal**: Model device similar to NREL baseline

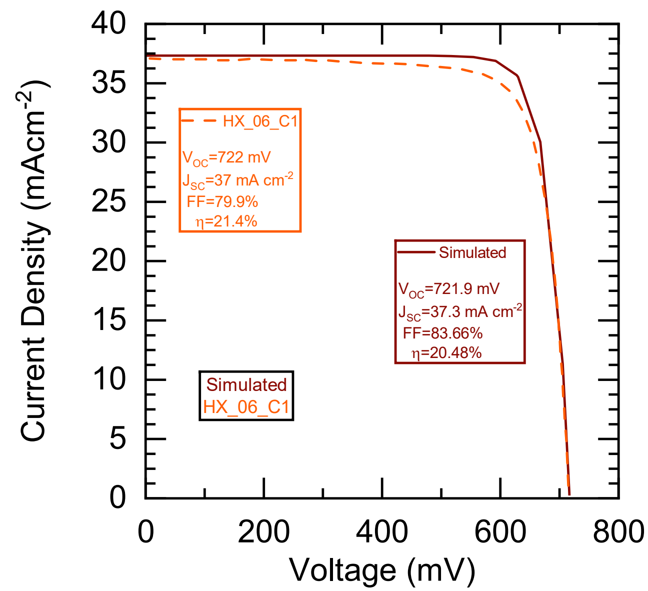
- **Defects** in cSi/SiO_x interface
  - 1 Å transition layer
  - $10^{17}\ \mathrm{cm}^{-3}\ \mathrm{eV}^{-1}$ defect density at midgap[2]
- Tunneling **Barrier Height** of Oxide
  - Lower than expected from band alignment[3]
  - Adjusted χ and E_g to get barrier height 2.5 eV

- **Results** (1.2 nm oxide):
  - $V_{OC} = 721.9\ \mathrm{mV}$
  - $J_{SC} = 37.3\ \mathrm{mA\ cm^{-2}}$
  - $\eta = 20.48\ \%; \mathrm{FF} = 83.66\ \%$

- **Conclusions**:
  - Fairly realistic representation of NREL's baseline
  - Reference for comparing to devices with novel contacts





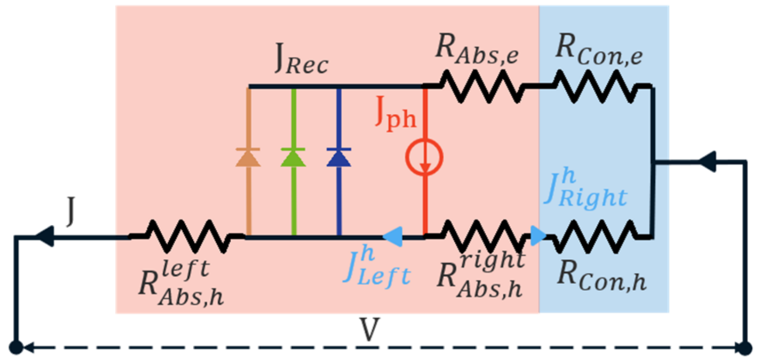


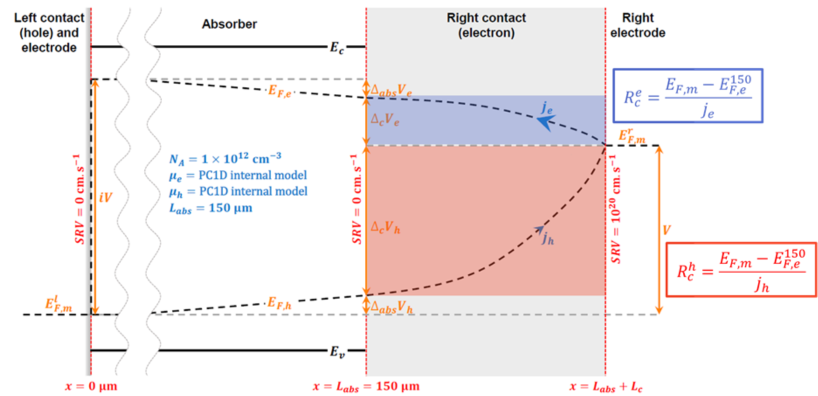
1. Varache, R. *et al.* Investigation of selective junctions using a newly developed tunnel current model for solar cell applications. *Sol. Energy Mater. Sol. Cells* **141**, 14–23 (2015).
2. King, T. J., Hack, M. G. & Wu, I. W. Effective density-of-states distributions for accurate modeling of polycrystalline-silicon thin-film transistors. *J. Appl. Phys.* **75**, 908–913 (1994).
3. Gan, J.-Y. Polysilicon emitters for silicon concentrator solar cells. (Stanford University, 1990).

Partial Specific Contact Resistances as a Proxy for Device performance

- Simulations in PC1D, Analyzed in MATLAB
- Goal:
  - Obtain electron and hole partial contact resistances
  - Function of iV
  - From iJV and JV

- Simulation assumptions
  - Ideal electron contact
  - Uniform generation in the absorber





PC1D data (J-iV; J-V) → **Solve for $R_{Tot,h}$ & $R_{Tot,e}$ (2e-2v)** → **Compare with calculated resistances**

Calculating the partial Specific Contact resistances

Generation current

$$J\left(\frac{R^{\mathrm{Right}}_{\mathrm{Tot,h}}}{R_{Tot,e}+R_{Tot,h}}\right)=J_{\mathrm{ph}}+J_{0,\mathrm{rad}}\left(1-e^{\frac{q\cdot iV}{k_BT}}\right)+J_{0,Auger}\left(1-e^{\frac{3q\cdot iV}{2k_BT}}\right)+J_{0,SRH}\left(1-e^{\frac{q\cdot iV}{2k_BT}}\right)-\frac{iV}{R_{Tot,e}+R_{Tot,h}}$$

Radiative recombination | Auger recombination | Shockley-Read-Hall recombination

$$V=\left(J_{\mathrm{ph}}+J_{0,\mathrm{rad}}\left(1-e^{\frac{q\cdot iV}{k_BT}}\right)+J_{0,Auger}\left(1-e^{\frac{3q\cdot iV}{2k_BT}}\right)+J_{0,SRH}\left(1-e^{\frac{q\cdot iV}{2k_BT}}\right)\right)\times R^{Right}_{Tot,h}-J\left(R^{Left}_{Abs,h}+R^{Right}_{Tot,h}\right)$$