Four-wire thin-film silicon devices: Towards high efficiency

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Motivation

- Micromorph (a-Si:H/μc-Si:H) devices have 12.34% stabilized efficiency for full size modules (1.4m^2)*.
- Low η devices (<12%) face tougher market due to high installation cost (even for low $/W).
- To reach higher η requires either huge material quality improvements, or **novel cell designs**.

- Here we study the "4-wire" configuration concept.

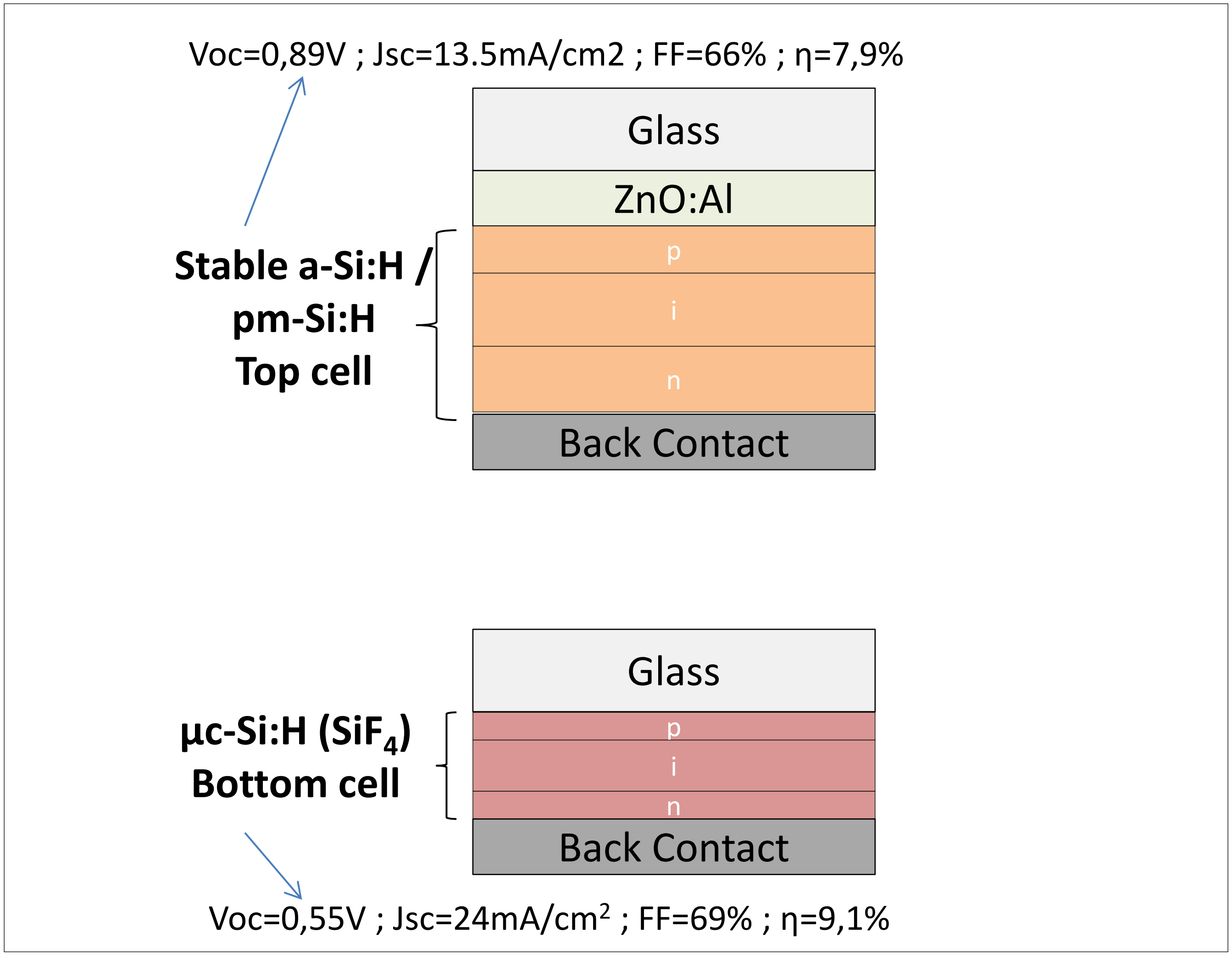
* J. Cashmore / TEL Solar AG / 12.24% Record Module WCPEC-6 Paper Rev. 1 / 25th November 2014

why a “4-wire” configuration??

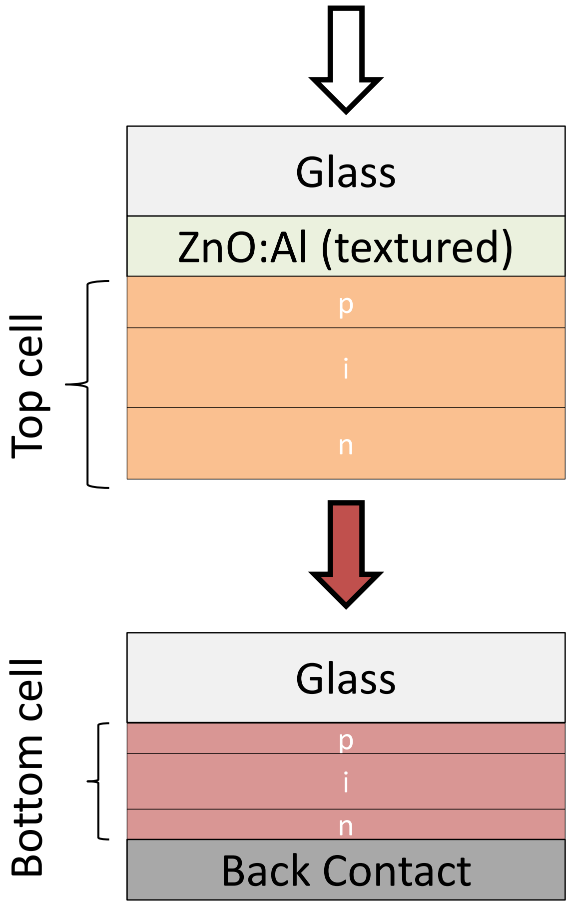
- Previous studies (simulations) showed 4-15% higher output power
- bottom μc-Si:H cell not current-limited by the top cell due to electrical decoupling
- the use of more stable top-cell configurations
- more advanced optical elements between the two cells, such as high bandgap material and Bragg reflectors.

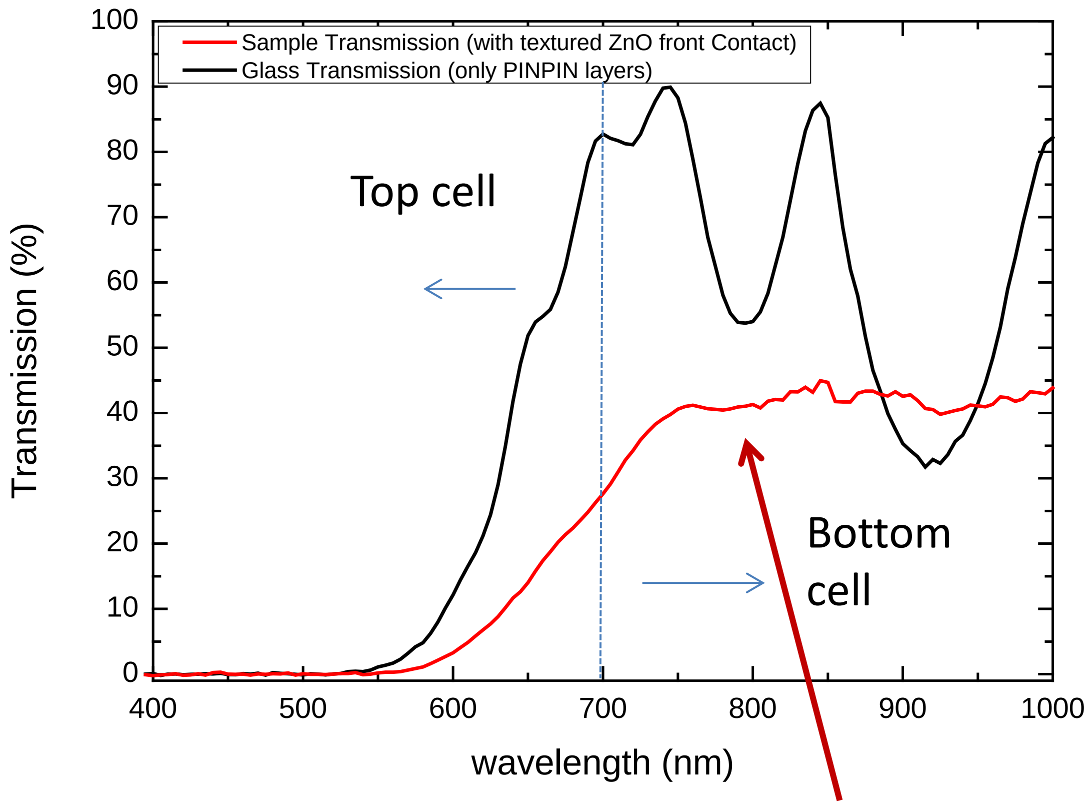
-F. Dadouche, O. Béthoux, M. E. Gueunier-Farret, E. V. Johnson, P. Roca i Cabarrocas, C. Marchand, J. P. Kleider, **EPJ Photovolt. 2** 20301 (2011).
-S. Reynolds and V. Smirnov, **J. Phys. Conf. Series. 398** (2012) 012006.

from 2W -> 4W device: building blocks



2W -> 4W : the challenge

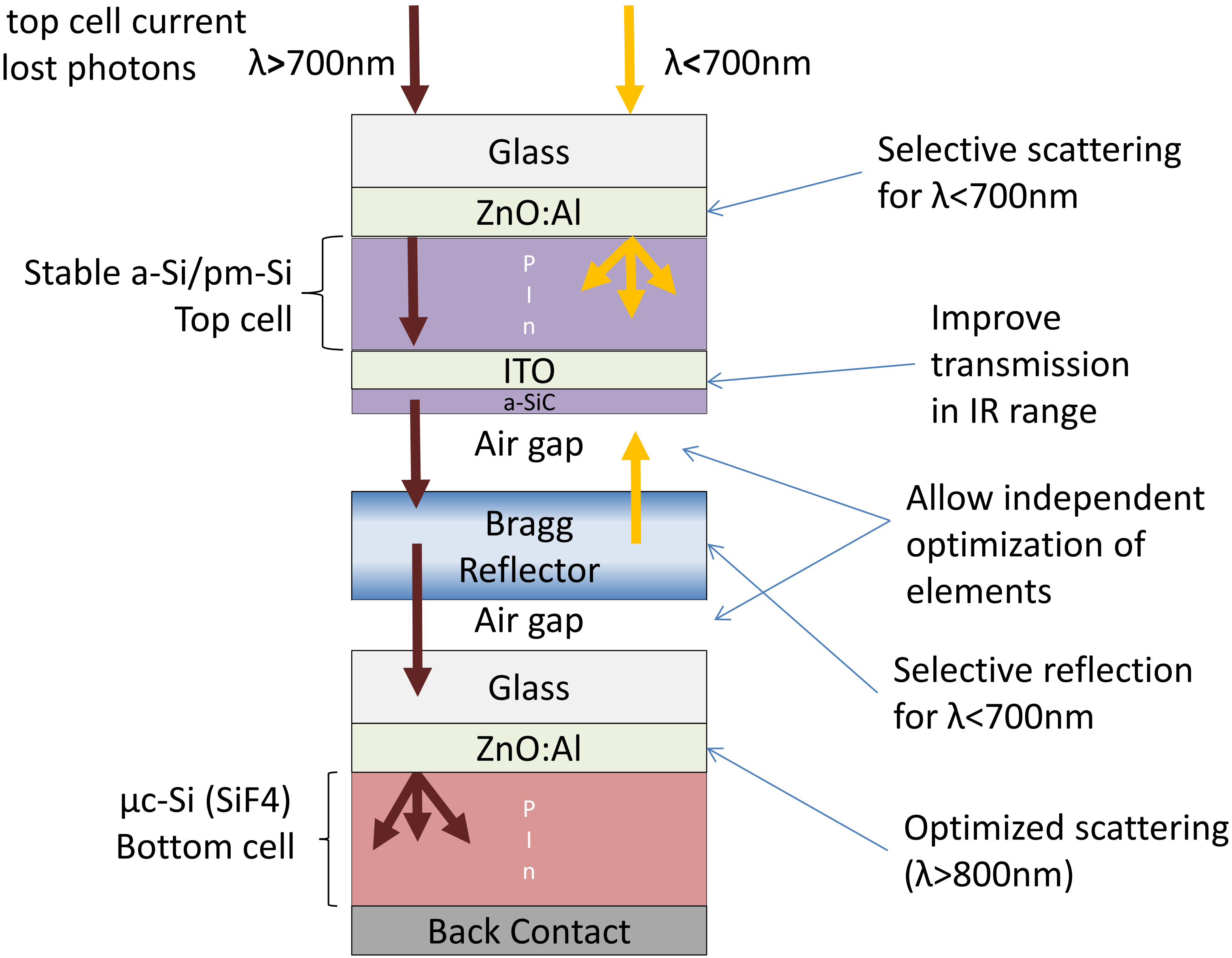




Light meant for bottom cell is scattered and trapped in top cell → **need to improve transmission towards the bottom cell**

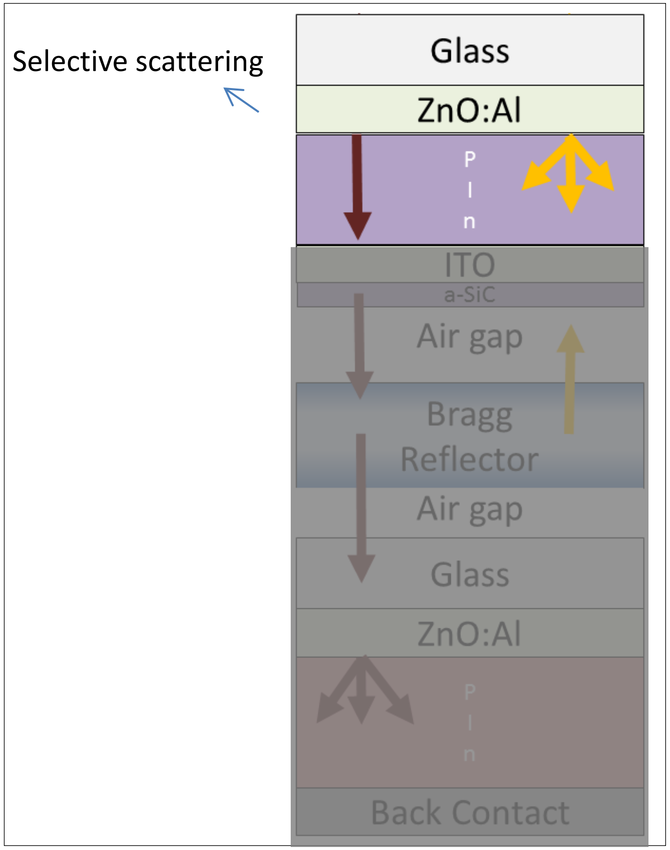
our 4W device: goals

Maximize top cell current
Minimize lost photons

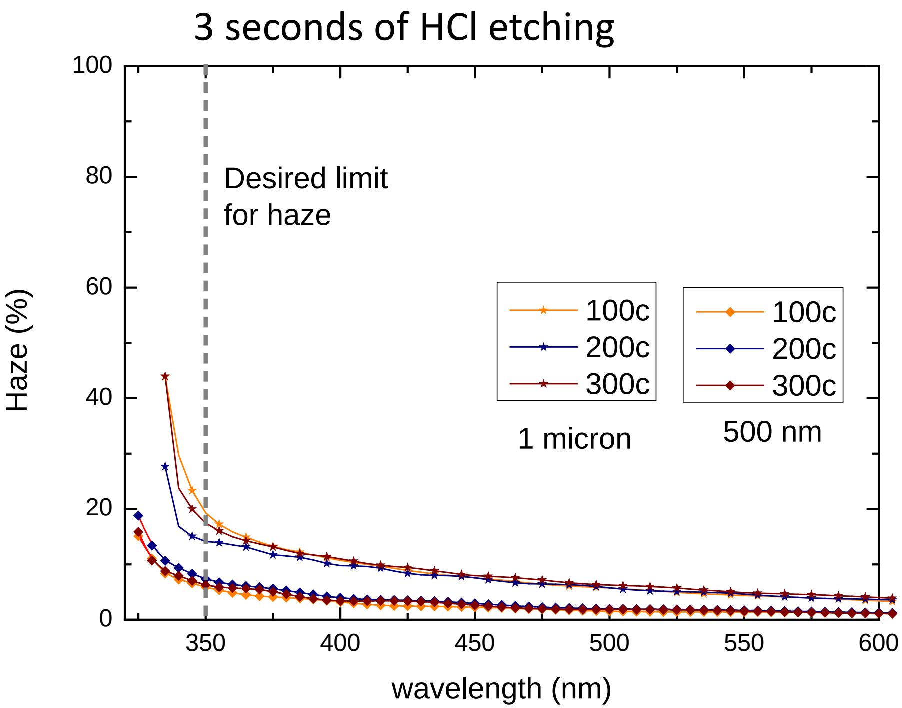


ZnO:Al front contact: selective light trapping

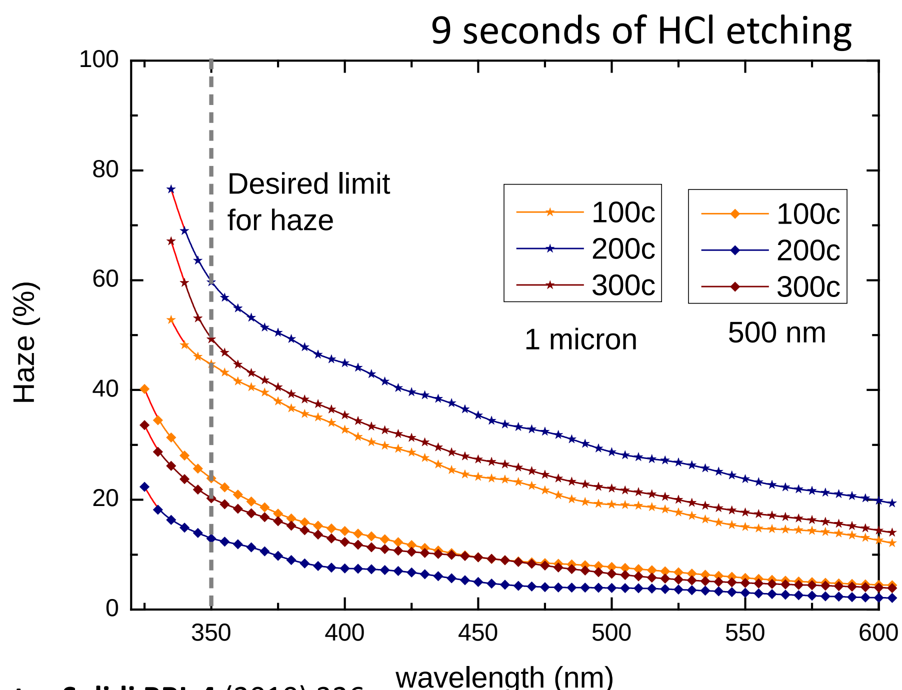
- Scatter short wavelengths (<700 nm) while leaving higher wavelengths unscattered
- Sputter ZnO:Al varying conditions:
  - Temperatures (100 ˚C /200 ˚C / 300˚C)
  - Thickness (500nm / 1000nm)
  - Etching times (0.5% HCl bath, 3s / 9s)
- Measure the transmission and the haze factor



ZnO front Contact: selective light trapping



- Haze limit is chosen at 700 nm
  - Strong scattering < 700nm (top cell)
  - No scattering > 700 nm (bottom cell)
- Due to *n* of silicon (vs air) we have to look at haze value at 350 nm *

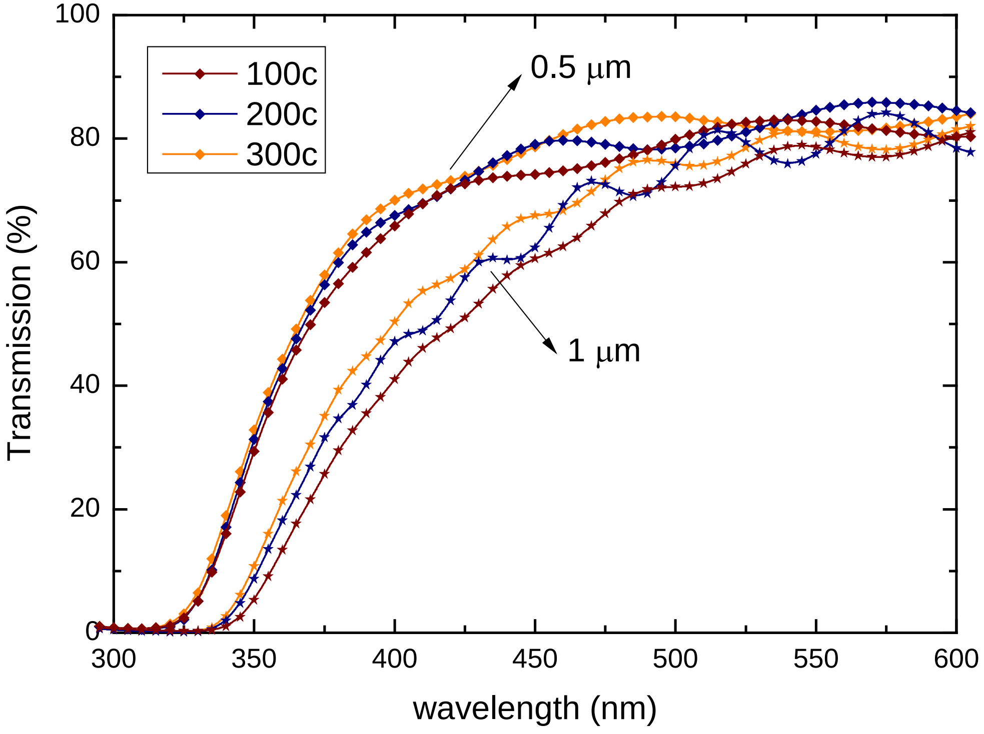


- Temperature dependency of haze less obvious
- 9s of etching shows better haze properties
- Samples with 1 µm thickness are closer to desired haze limit

* M. Boccard, P. Cuony, C. Battaglia, M. Despeisse, and C. Ballif, **Phys. Status Solidi RRL 4** (2010) 326

ZnO front Contact: selective light trapping

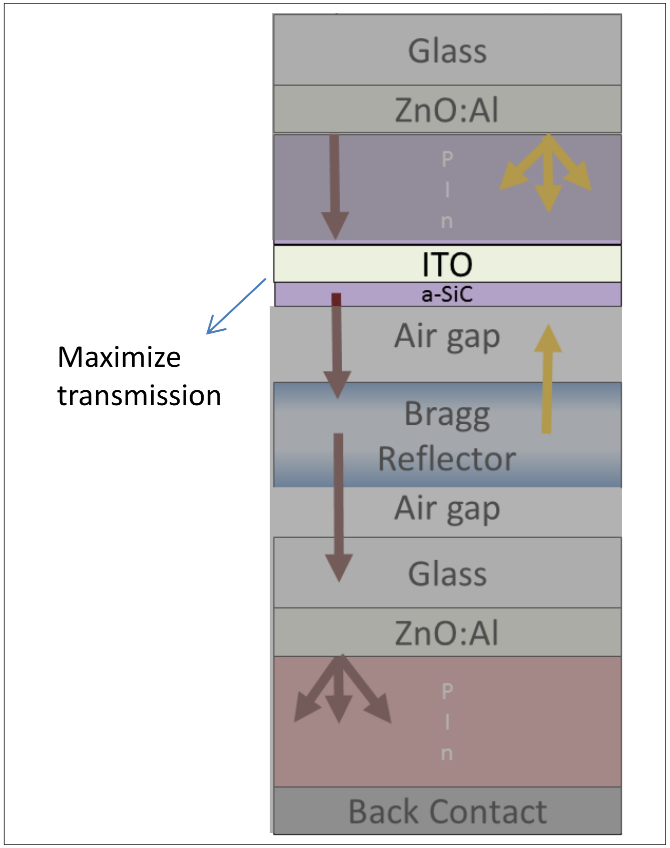
9 seconds etching



- Transmission is better for higher temperature sputtering conditions
- 9s etching improves Jsc by 0.5mA/cm^2
- Best conditions: **0.5µm, 9s etch**
- Optimal etching times probably between 3s and 9s → finer optimization to be done

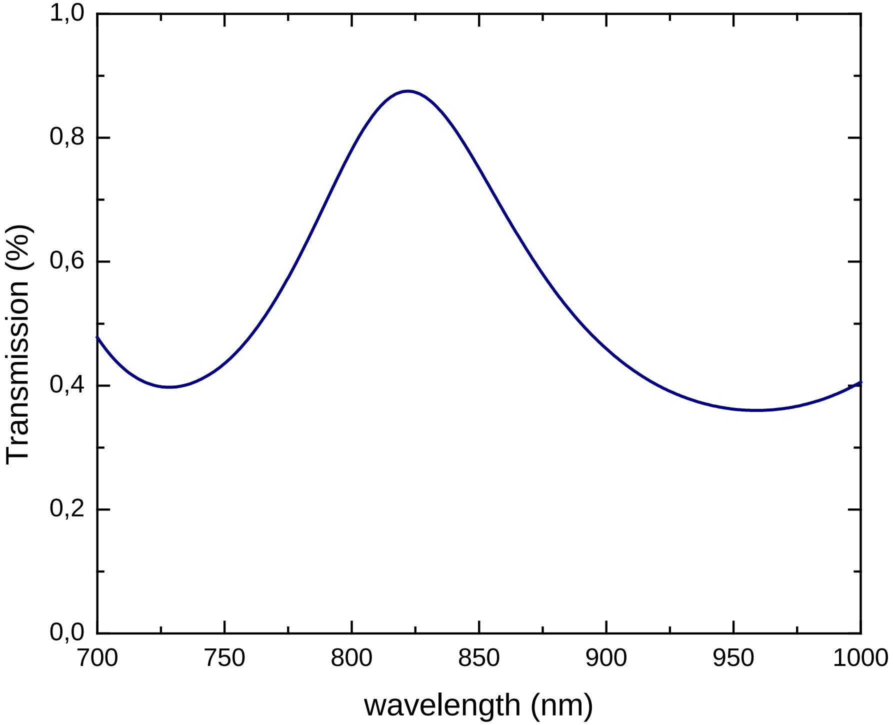
ITO & a-SiC back contact: Maximize Transmission

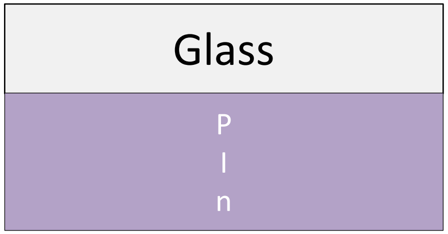
- Using (n,k) parameters from ellipsometry we model the materials
- We use a computer code to find the optimal thickness of ITO and another high band gap material, such as a-SiC
- Compare the simulation to actual measurements on PIN a-Si cell



ITO & a-SiC:H back contact: Maximize Transmission

Simulations

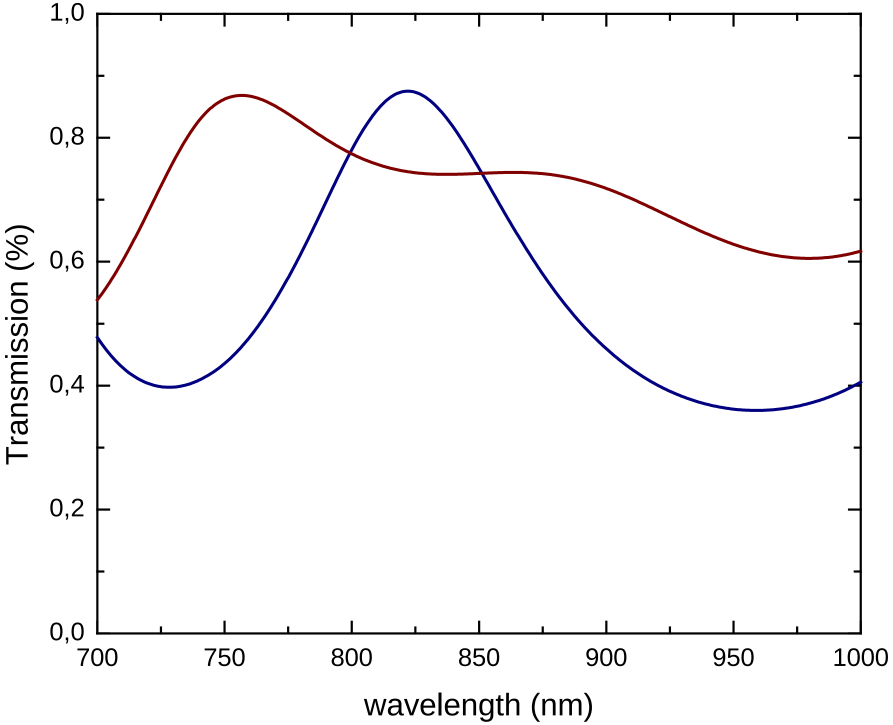


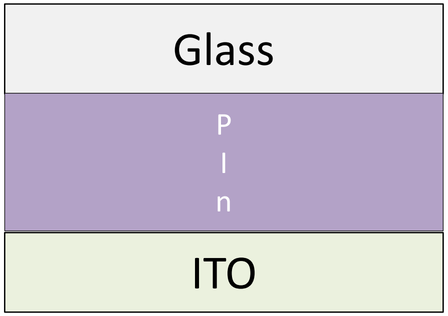


- a-Si:H PIN on glass

ITO & a-SiC:H back contact: Maximize Transmission

Simulations

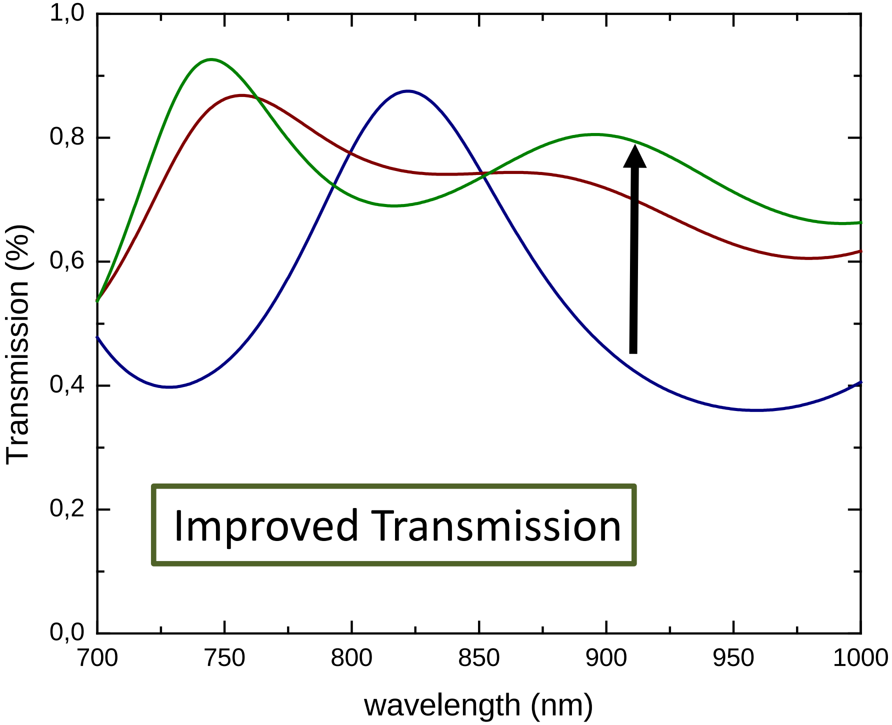


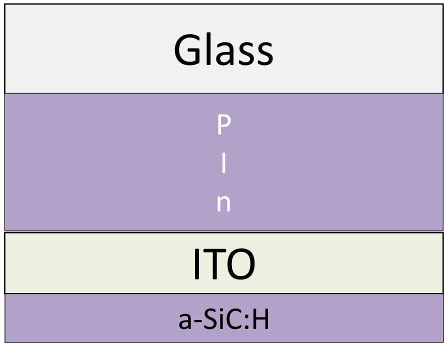


- a-Si:H PIN on glass
- a-Si:H PIN + ITO (70nm) on glass

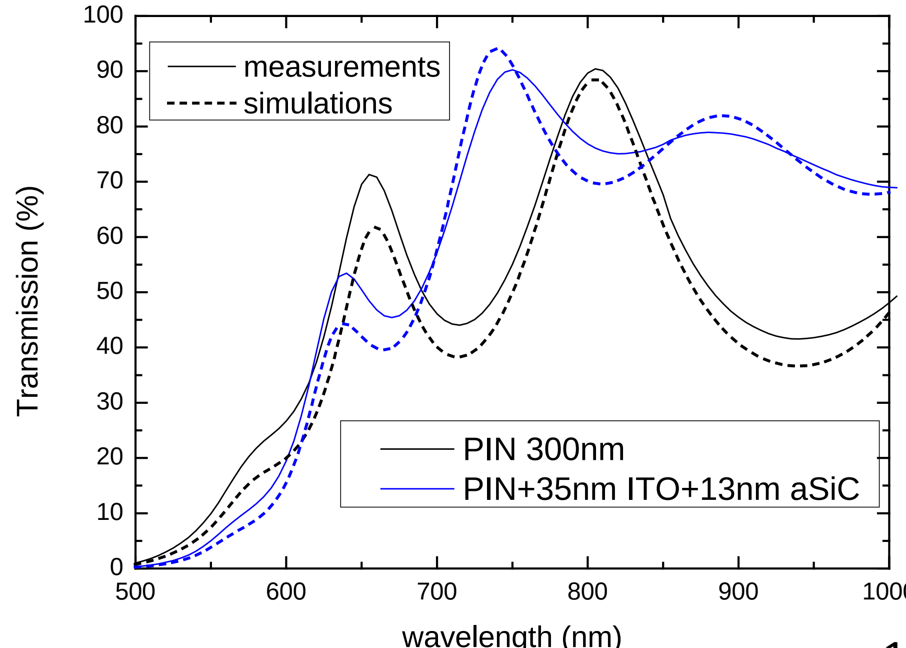
ITO & a-SiC:H back contact: Maximize Transmission

Simulations





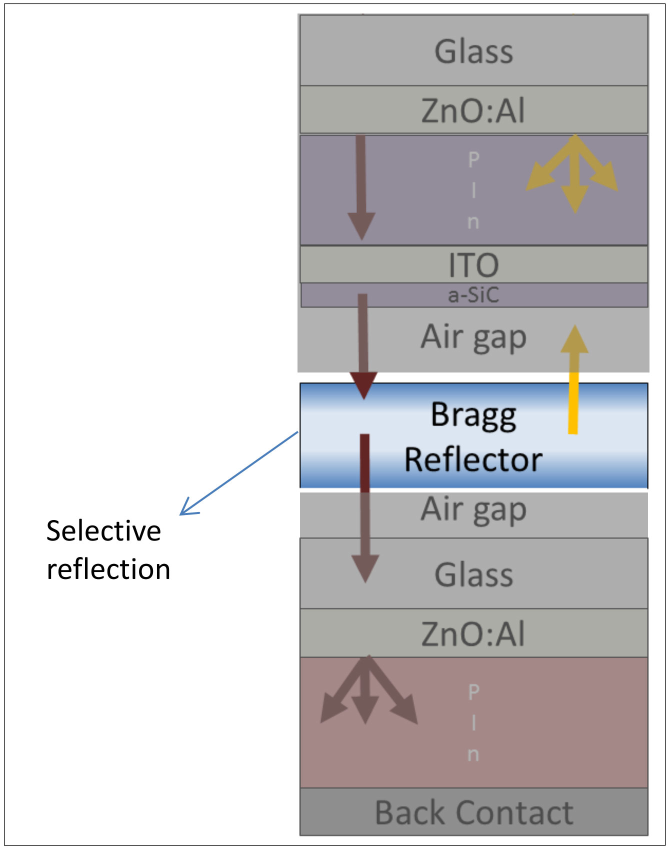
- a-Si:H PIN on glass
- a-Si:H PIN + ITO (70nm) on glass
- a-Si:H PIN + ITO (34nm)+a-SiC:H (13nm) on glass



- A stack of PIN a-Si:H was deposited following the recipe given by the optimization program
- Very good agreement found between simulations and measurements

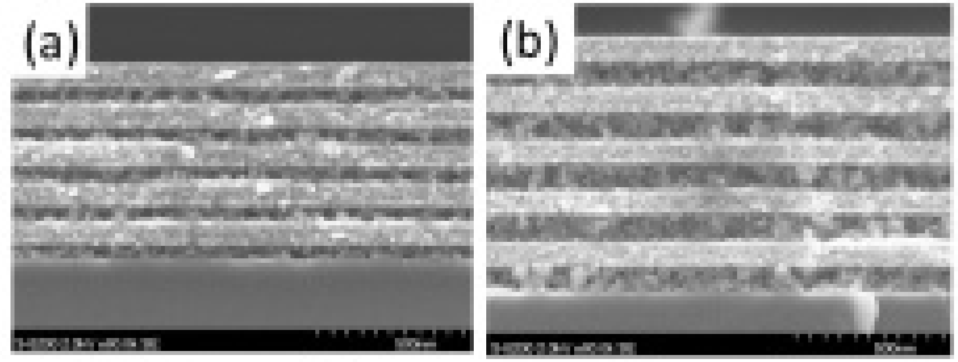
Bragg Reflectors: A selective reflection

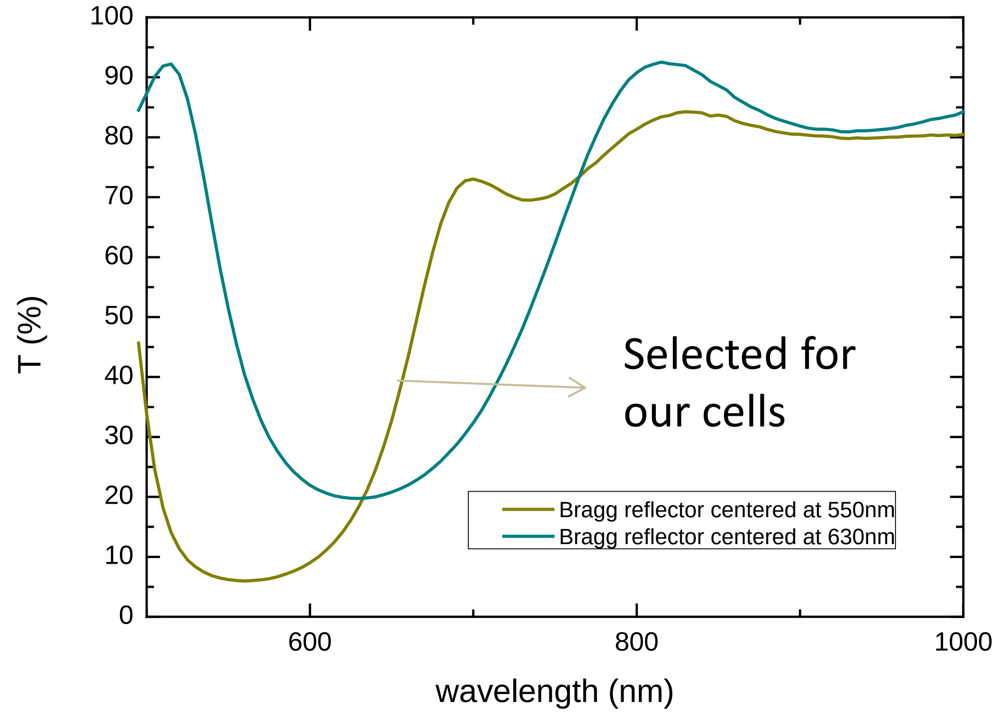
- Selectively transparent and conducting photonic crystals are use to reflect only part of the spectrum
- Maximise the current in the a-Si:H top cell (Voc higher)



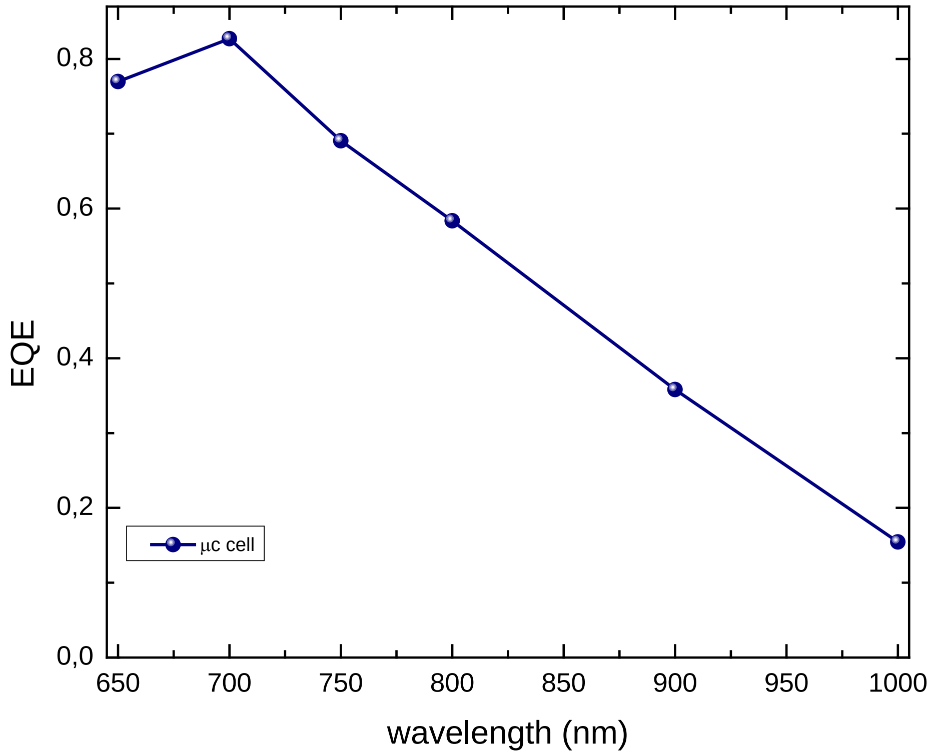
Bragg Reflectors: A selective reflection

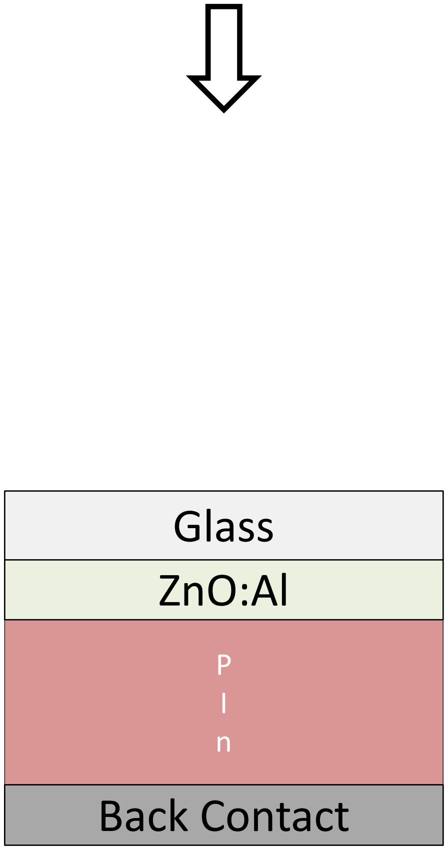
- They are composed of alternating layers of nano-silica particles and ITO
- The shorter the inter-distance the shorter the wavelength at which the window is centered.
- Allows ~90% of transmission towards µc-Si:H cell





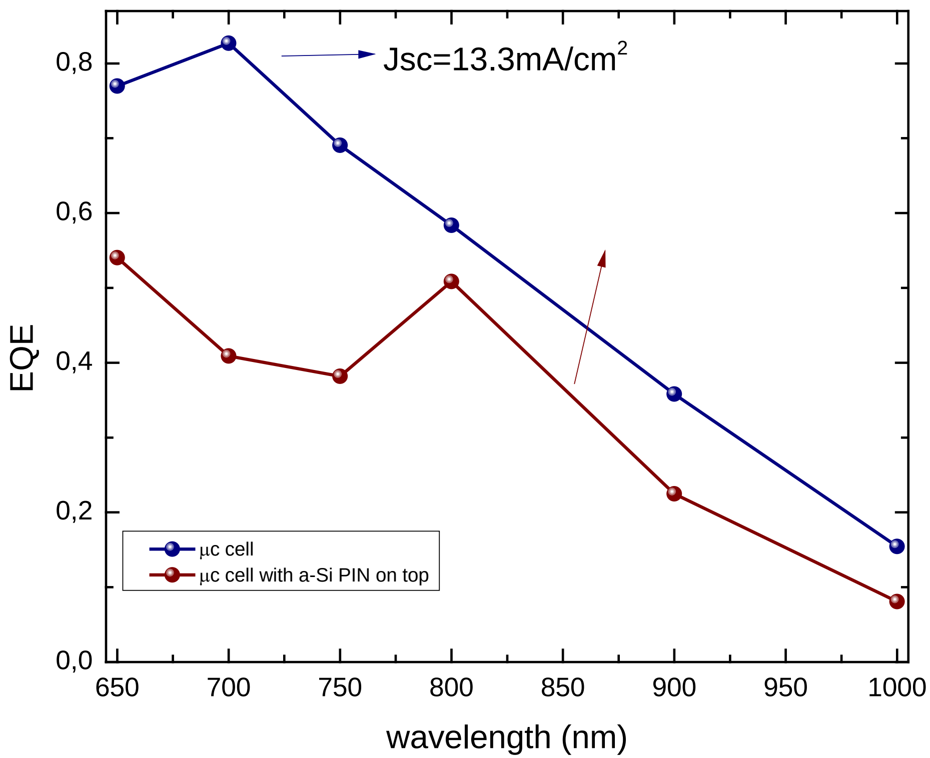
The Whole Stack: Preliminary Results

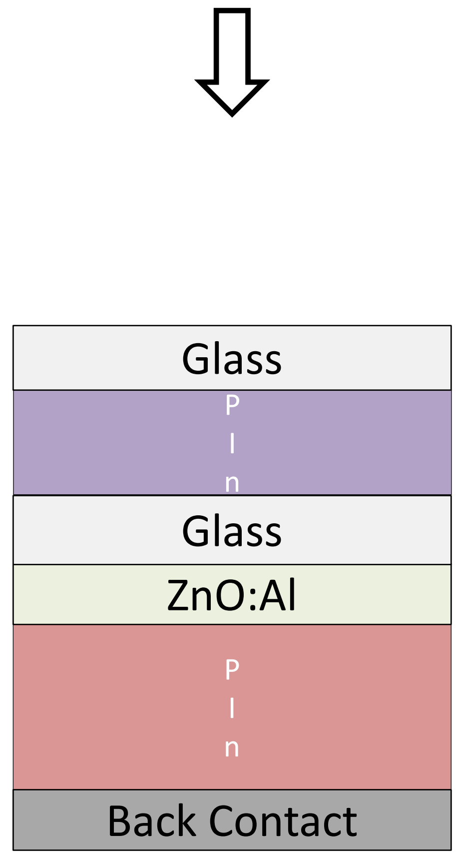




- μc-Si cell

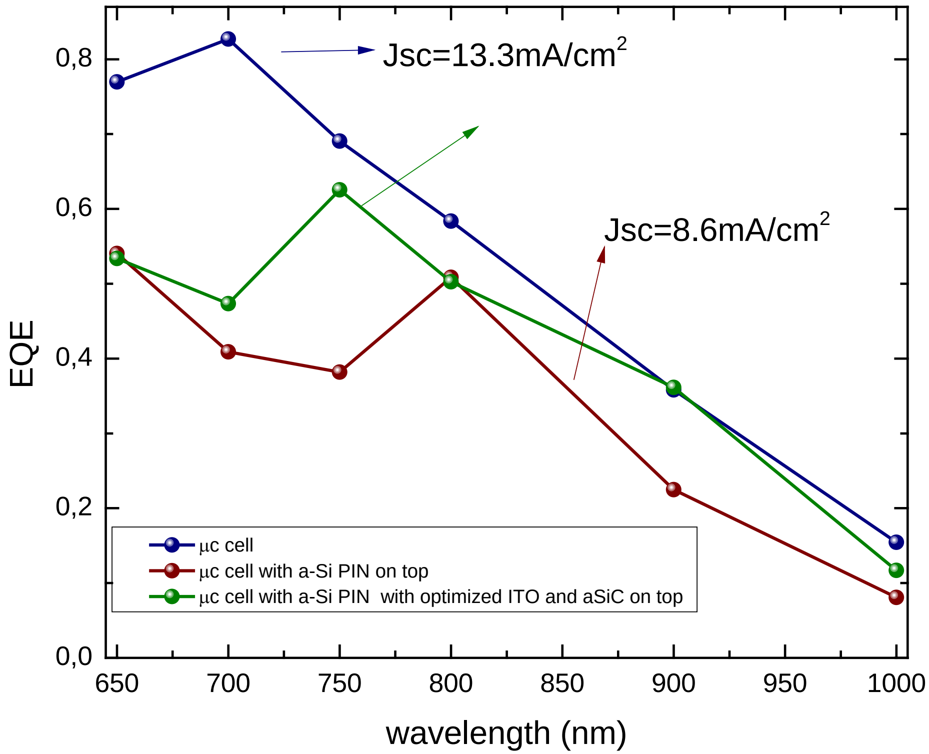
The Whole Stack: Preliminary Results

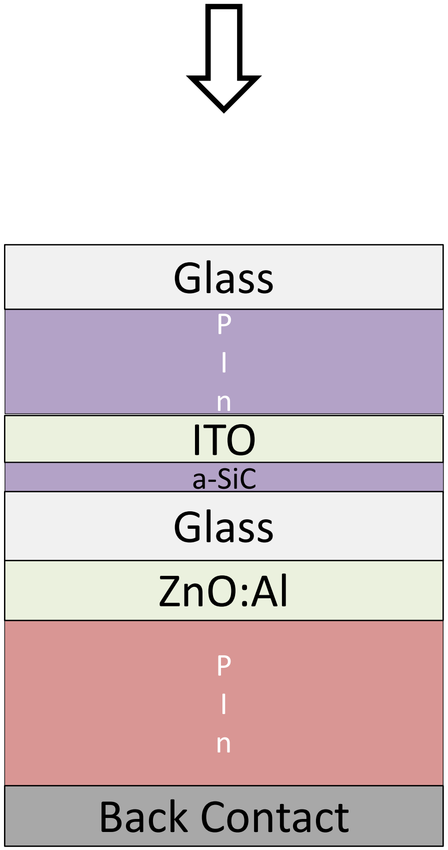




- µc-Si cell + a-Si:H PIN

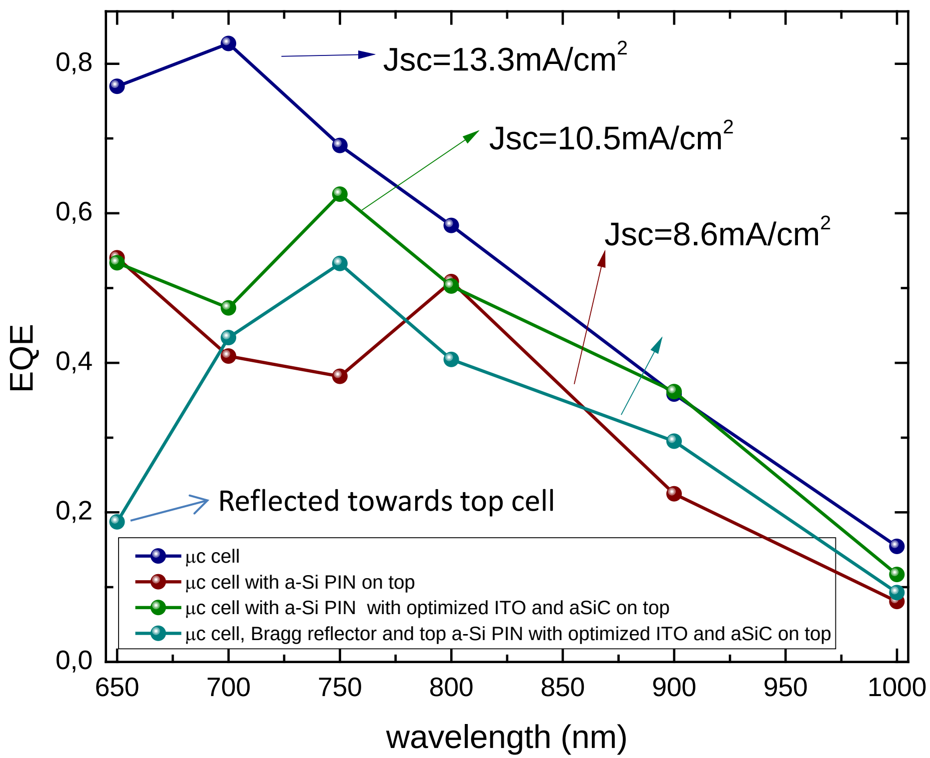
The Whole Stack: Preliminary Results

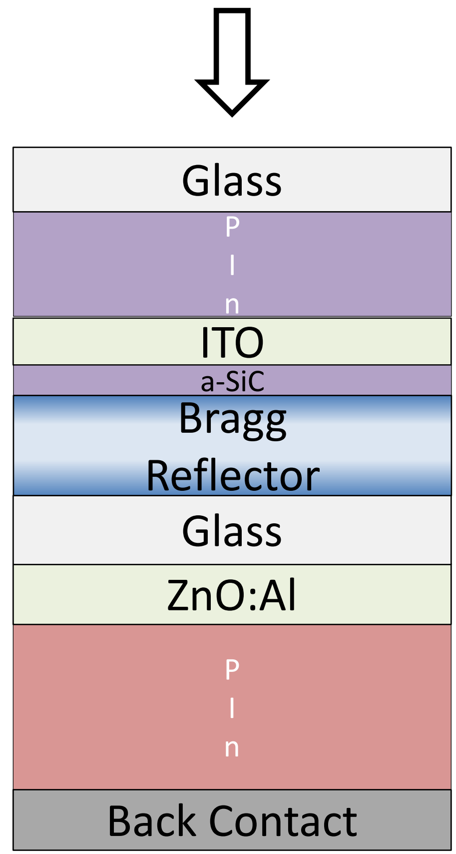




- μc-Si cell + a-Si:H PIN + ITO+a-SiC:H

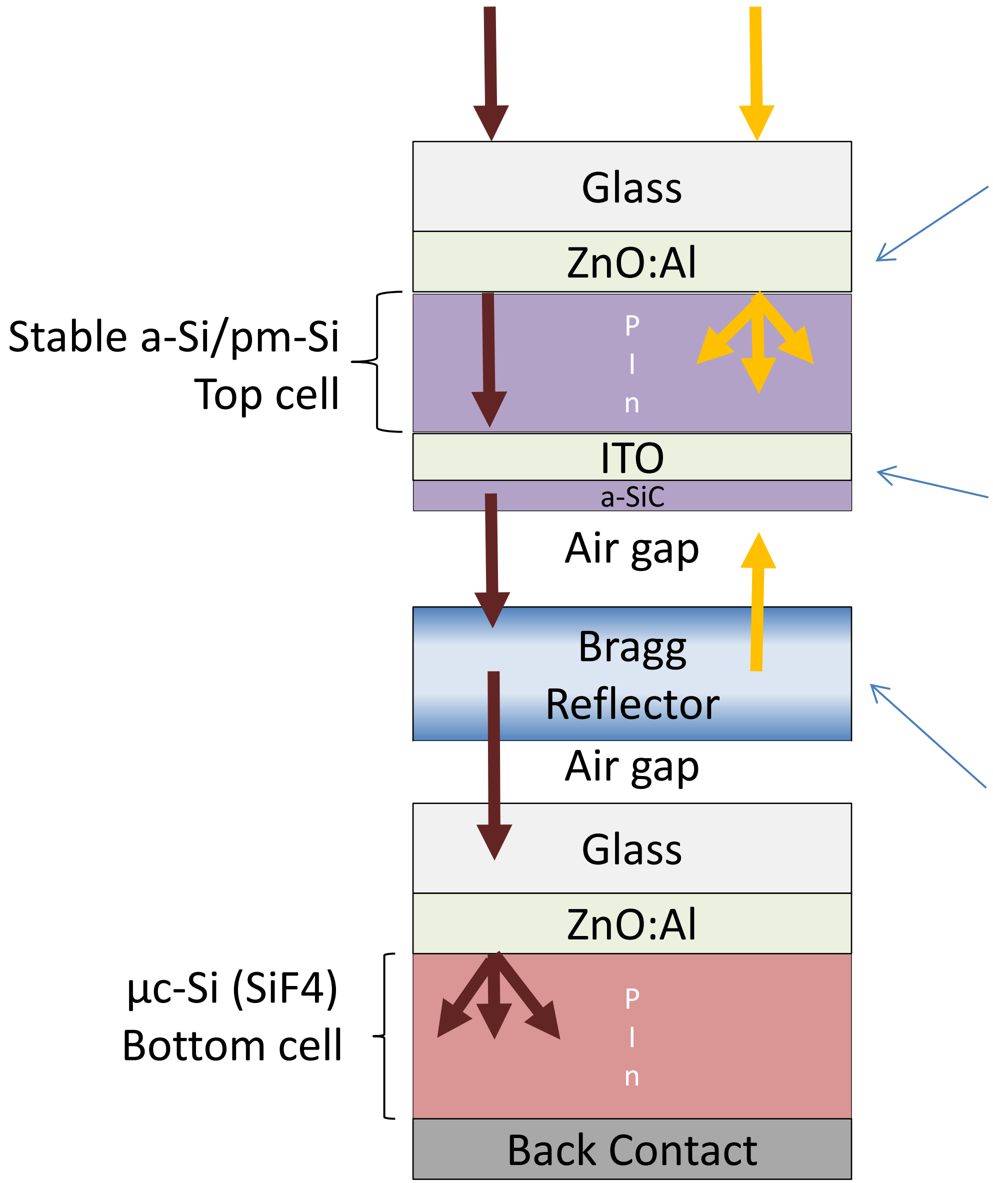
The Whole Stack: Preliminary Results





- μc-Si cell + a-Si:H PIN + ITO+a-SiC:H + Bragg reflector (centered at 550nm)

Conclusion



Selective scattering λ<700nm:
40% to 25% haze in the 600-700 nm range, less than 15% haze from 800nm.
ΔJsc>0.5mA/cm^2 in the top cell

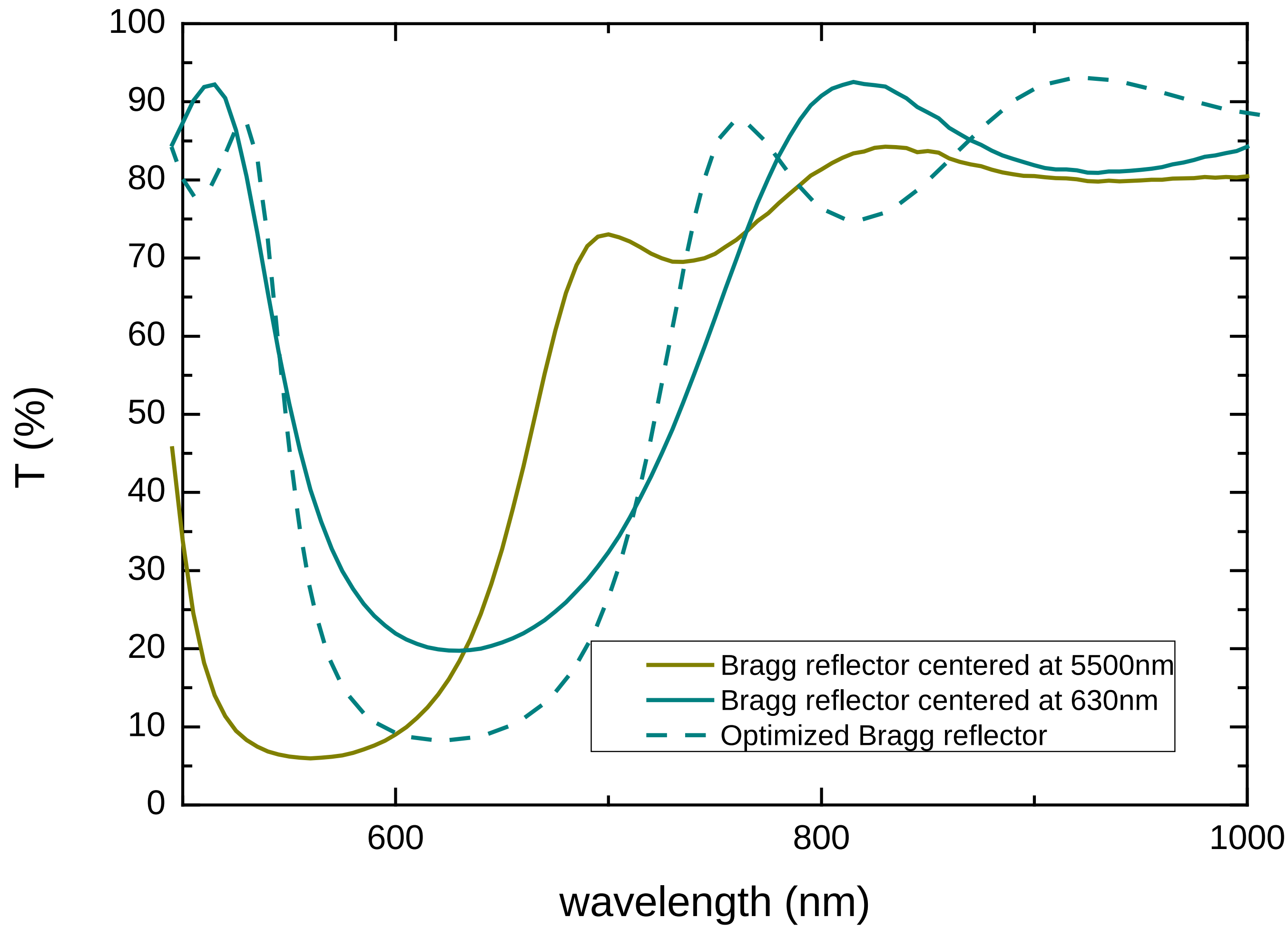
Improve transmission in IR:
From 40% to 90% at 730nm
From 40% to 75% after 900 nm
Up to 2mA/cm^2 recovered in the bottom cell

Selective reflection (λ<700nm):
>90% reflection in a 100nm window
~85% transmission outside reflection window, ΔJsc>0.5mA/cm^2 in the top cell

Some Perspectives

- Find the maximum amount of etching to improve light trapping in the top cell without loosing the optical properties of the Bragg reflector
- Include etched ZnO in the simulations
- Use more optimized Bragg reflectors to improve transmission

Bragg Reflectors: optimized for the 4W device



Some Perspectives

- Find the maximum amount of etching to improve light trapping in the top cell without loosing the optical properties of the Bragg reflector
- Include etched ZnO in the simulations
- Use more optimized Bragg reflectors to improve transmission
- For a stable 9% top cell , 90% transmission in the IR towards a 9.2% μc silicon Cell values of almost 14% efficiency can be foreseen.

Thanks for your attention!!!