# Contact resistance of the p-type amorphous silicon hole contact in silicon heterojunction solar cells

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## Motivation

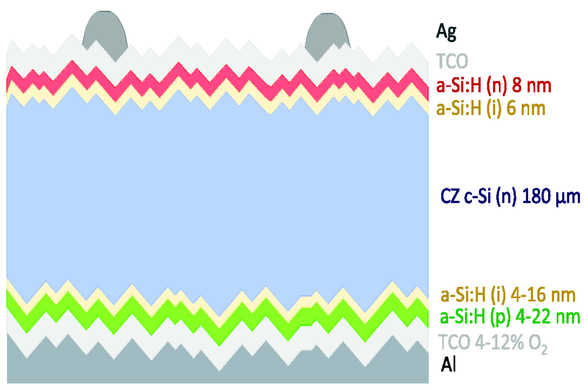
- Silicon heterojunction solar (SHJ) cells produce the ***highest efficiencies***[1] and have open circuit voltages greater than 720 mV.
- SHJ cells tend to suffer from ***low fill factor*** limiting maximum power output.
- This low fill factor is heavily influenced by the ***high series resistance***[2] present in this device architecture.
- One of the main contributors to the high series resistance come from the ***hole collector*** made up of an a-Si:H(i)/a-Si:H(p)/TCO stack.
- We investigate the ***contact resistivity*** ($\rho_c$) of this stack and its effects on cell results.

## Investigated parameters

*Contact resistance in SHJ solar cells is affected by:*

❑ **Interface:**
- Crystalline Si and intrinsic a-Si layer
- Intrinsic a-Si layer and doped (p or n) a-Si layer.
- Doped (p or n) a-Si layer and TCO interface.

❑ **Thickness:**
- Intrinsic a-Si layer thickness
- Doped (p or n) a-Si layer.
- TCO layer thickness.




In practice we vary:

✓ p-doped a-Si layer thickness

✓ Intrinsic a-Si layer thickness

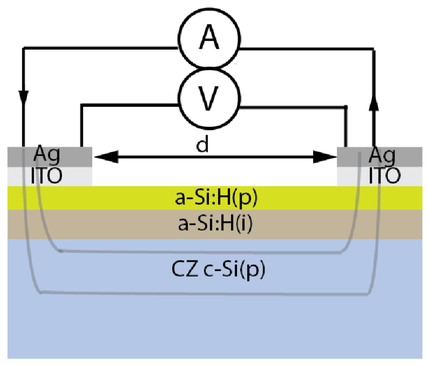
✓ p-doped a-Si layer doping density

✓ TCO $O_2$ concentration

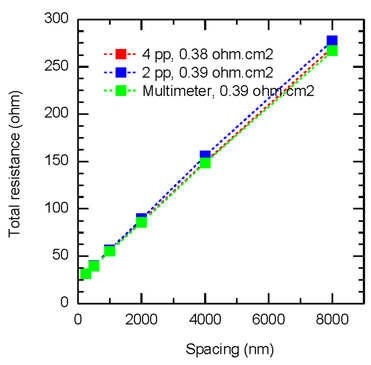
## Methodology

*Contact resistivity measured using transfer length method (TLM).*

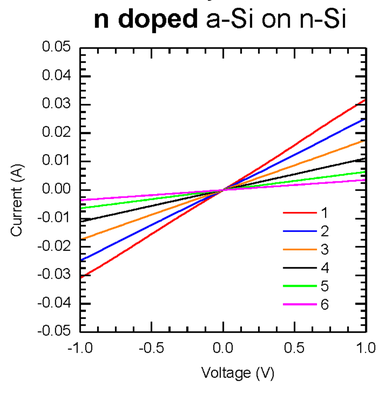
- The TLM pad length is 2mm (larger than the transfer length, $L_t$< 300 µm)
- The spacing varied between 250 µm and 8 mm.



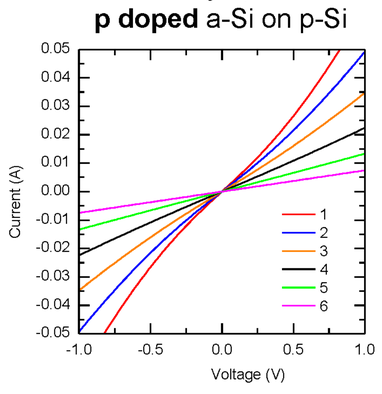

## Accuracy of the measurement




**6nm** i-layer, 5% O2
**n doped** a-Si on n-Si




**6nm** i-layer, 5% O2
**p doped** a-Si on p-Si



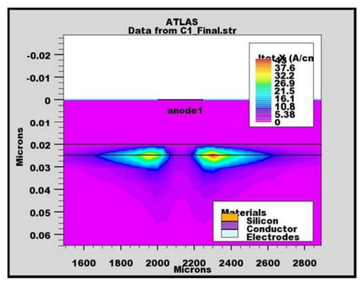

Rsh = **235** Ω/sq, ρc= **0.38** Ω.cm2

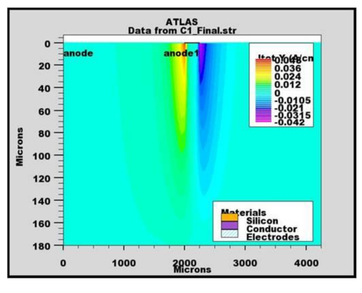
Rsh = **140** Ω/sq, ρc= **0.32** Ω.cm2

## Simulation structure

- Recreated TLM structure using Silavco Atlas simulator.
- Studied the behavior of the ITO as a Schottky contact and as semiconductor.
- Included non local band to band tunneling to simulate electrical characteristics.

*X and Y components of current density in the cell*




## References

[1] U. Wurfeland et. al, IEEE Journal of Photovoltaics, vol 5, pp. 461-169, 2015.
[2] J. Bullock and et. al, Applied Physics Letters, vol 105, 2014.
[3] G. Nogay and et. al, *IEEE Journal of Photovoltaics*, vol 6, pp 1652-1662, 2016
[4] "SILVACO, Atlas User's Manual," 2015..

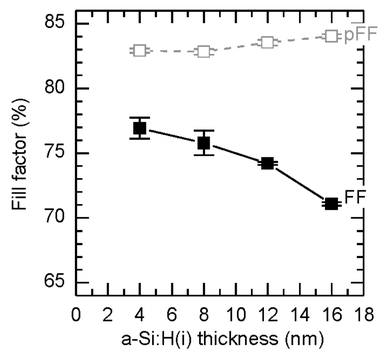
## Intrinsic a-Si:H thickness variation

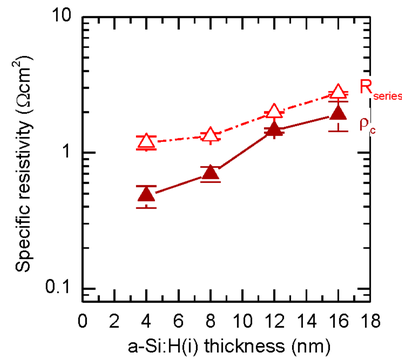
❑ p-FF is not affected by series resistance.

❑ FF, however, drops from 76.1% for the thinnest layer to 71.1%

❑ The series resistivity exponentially increases from 1.2 to 2.7 Ωcm2.

❑ The contact resistivity follows a similar trend increasing from 0.48 to 1.9 Ωcm2.



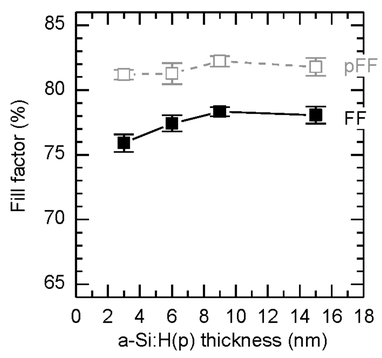



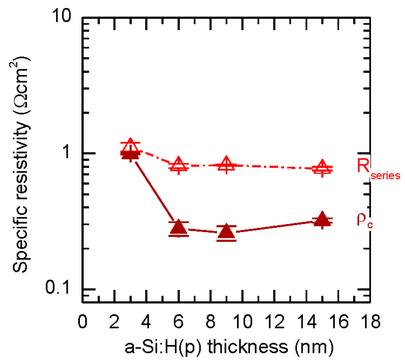

## Doped a-Si:H thickness variation

❑ FF increases from 76% for the thinnest layer then remains relatively constant at 78%

❑ The series resistivity initially decreases from 1.1 Ωcm² then maintains a constant value for thicker layers

❑ The contact resistivity follows a similar trend decreasing from nearly 1 Ωcm² and remaining constant for thicker layers

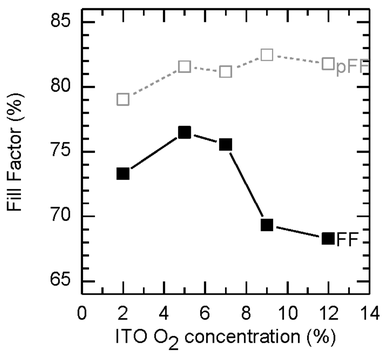


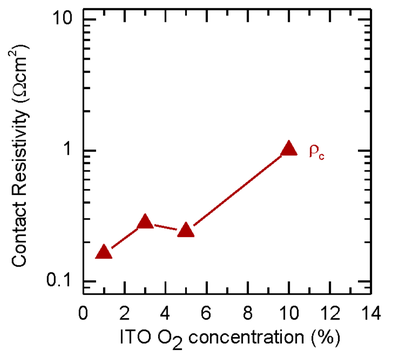




## ITO layer Oxygen concentration variation

❑ pFF remains constant for all oxygen concentrations but FF initial initially increases then decreases for higher oxygen concentations.

❑ The contact resistivity increases from 0.2 Ωcm² for an oxygen concentration of 1% and reaches 1 Ωcm² for an oxygen concentration of 10%



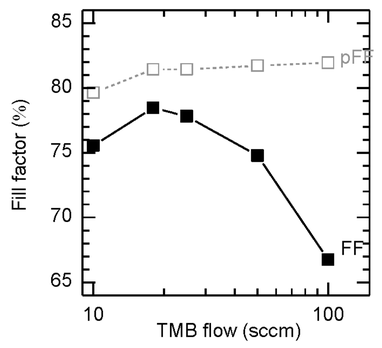



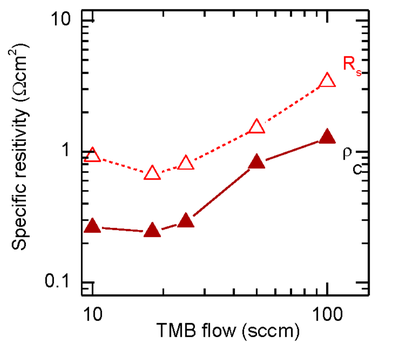

## a-Si:H doping density variation

❑ FF reaches a maximum for a TMB flow of 18 sccm with a FF of 78.45%

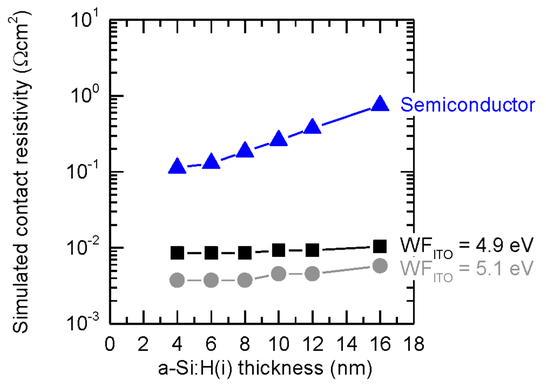
❑ The series resistivity reaches a minimum of .67 Ωcm² at 18 sccm of TMB and increases exponentially or higher flow rates

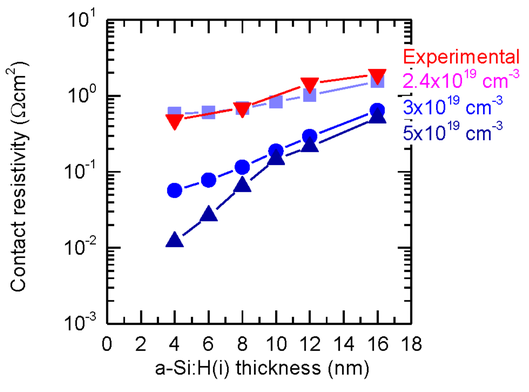
❑ The contact resistivity follows a similar trend with a minimum of 0.24 Ωcm² at 18 sccm of TMB.




## Simulation: A comparison with experiment




## Conclusion

✓ Intrinsic a-Si layer thickness affects contact resistant and corresponding FF, significantly.
✓ p-layer doping and ITO $O_2$ concentration determine the band offset in the interface.
✓ p-layer thickness won't affect FF as far as it's thick enough (>6nm) and is not depleted.
✓ Simulations can reproduce the experimental results if ITO is treated as a semiconductor.