Application of TiO_x/metal bilayer as hole-selective passivating contact in crystalline silicon solar cells

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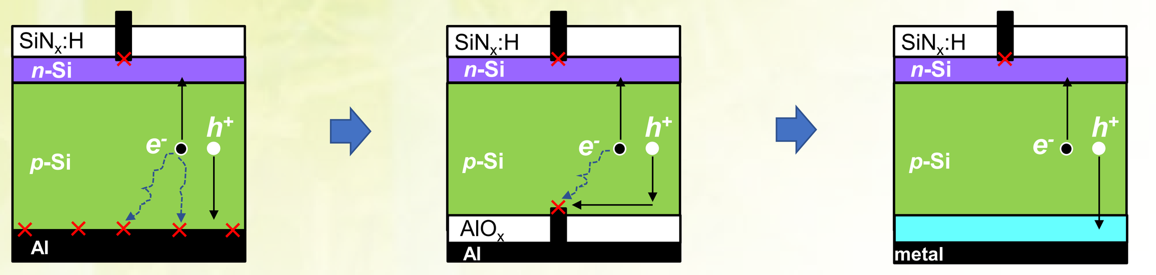
Introduction

Al-BSF (Back Surface Field) | **PERC** | **Passivating contact**



- Simplest process
- η<20%

- Rear passivation with partial Si/metal contact
- η~24%

- No direct Si/metal contact
- η>25%

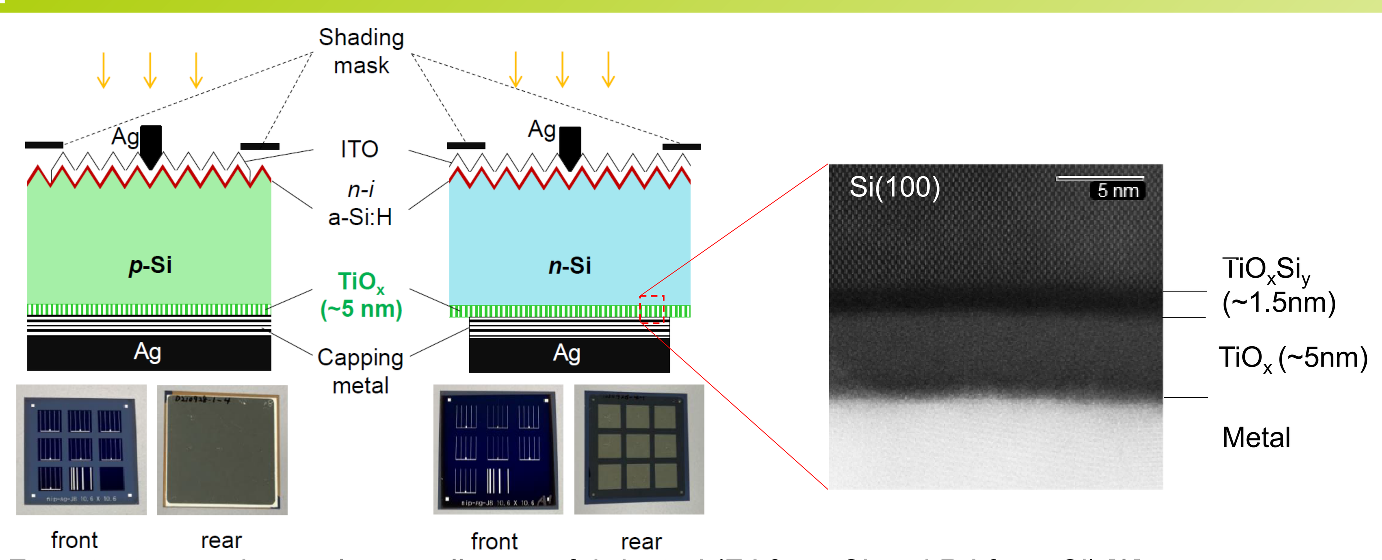
Requirements of passivating contact [1]

1. Surface passivation
2. Carrier selectivity
3. Low contact resistivity
4. Low optical loss

- Materials fulfilling these requirements are generally rare.
- Currently, Si-based contact materials are available (SHJ, TOPCon).
- Any non-Si material as good as Si-based contacts?

We have developed ALD-TiO_x nanolayer that uniquely functions as an efficient hole-selective passivating contact [2]

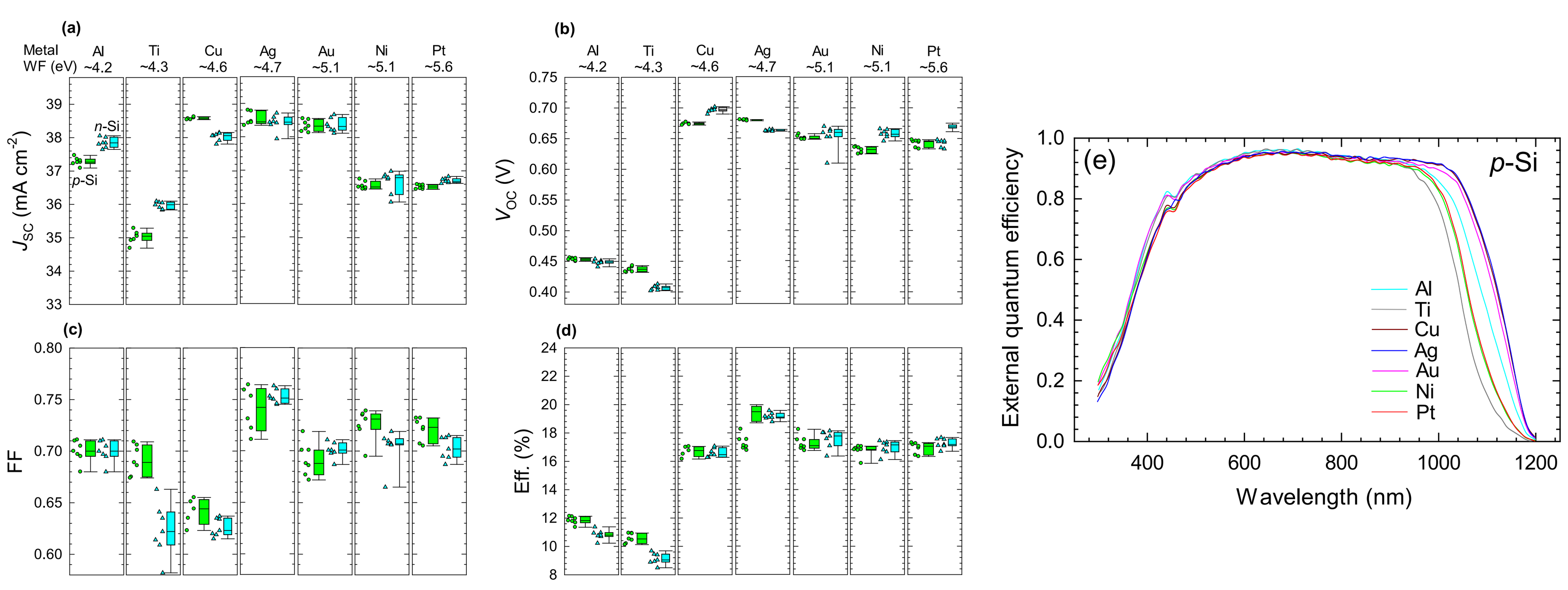
Experiment



- Front texture and rear planar cells were fabricated (FJ for *p*-Si and RJ for *n*-Si) [3].
- ALD-TiO_x hole contact layer (~5 nm) was deposited at the rear surface of *p*- and *n*-Si.
- TiO_x was capped with 7 different metals (Al, Ti, Cu, Ag, Au, Ni, Pt) having a range of work functions (WF: ~4.2-5.6) , by DC sputtering or e-beam evaporation.
- No metal penetration through TiO_x layer is observed.

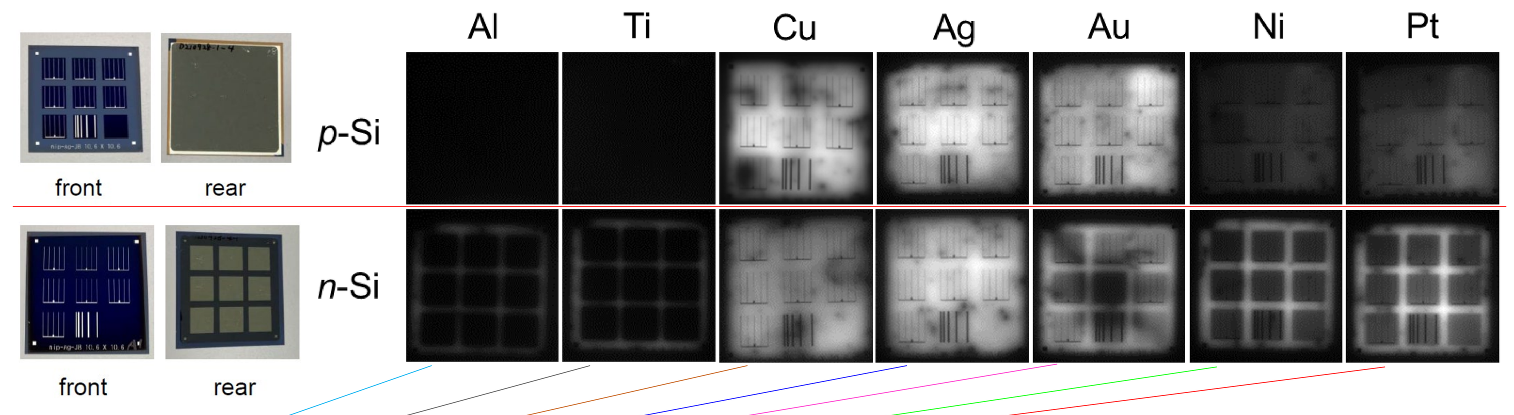
Results and discussion I

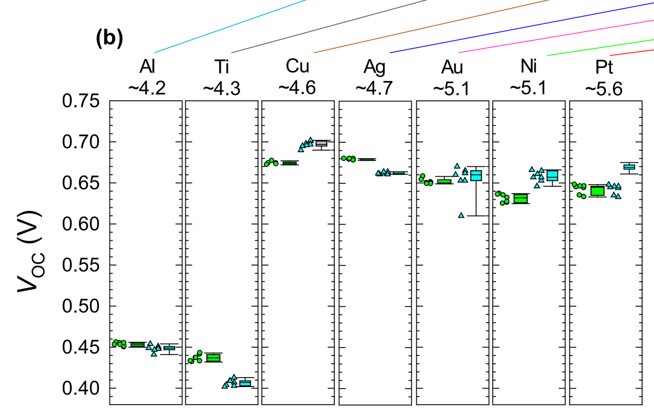
Impact of capping metal



- High J_{sc} is obtained when using metals exhibiting high infrared reflectivity (e.g. Al, Cu, Ag, Au) .
- Abrupt change occurs in V_{oc} at WF~4.3-4.6 eV.
- FF is less dependent on WF but some metal results in high and low FF.
- Efficiency is mostly determined by V_{oc}. Ag provides the best performing device.

PL measurements on device



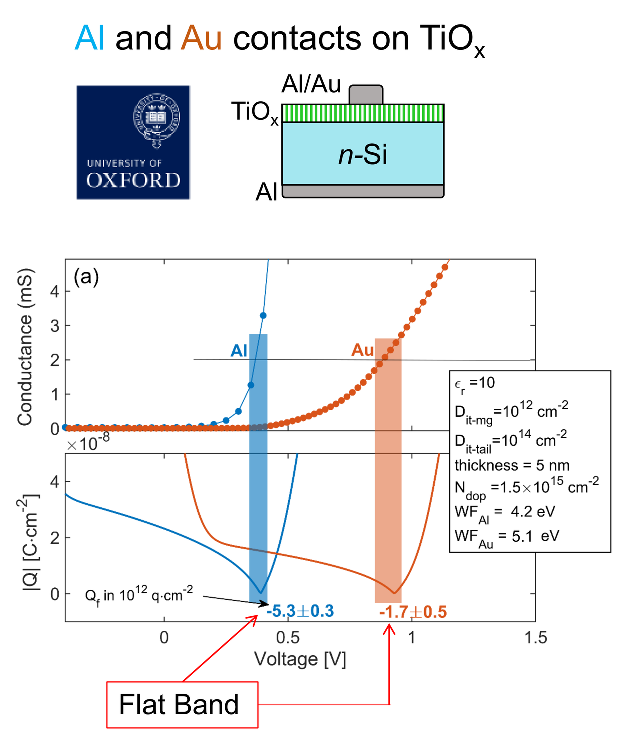


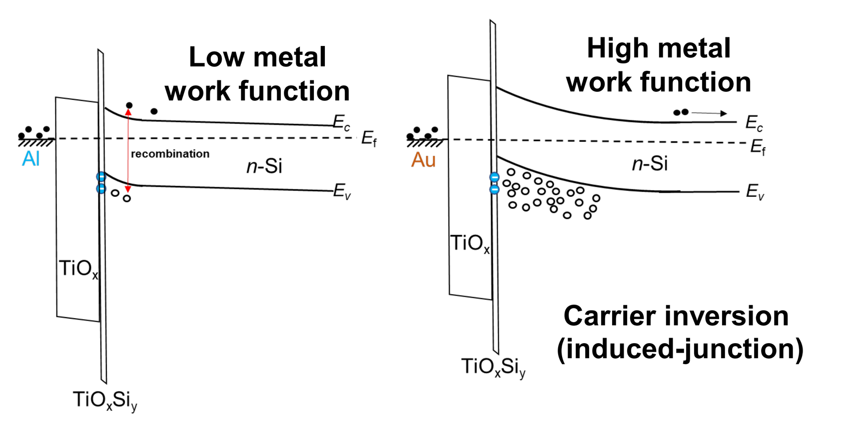
PL signal intensity correlates well with V_{oc}.

- High lifetime (>3 ms) was confirmed prior to metallization.
- PL measurements (λ=850 nm) was done on finished solar cells.
- PL signal intensity reflects passivation degree at the rear surface.
- Low-WF metals (Al, Ti): Passivation degradation occurs only for metallized area.
- High-WF metals: Relatively, high passivation performance obtained. PL reflected by the rear metal contributes to enhancing PL signal (Cu, Ag, Au).

Results and discussion II

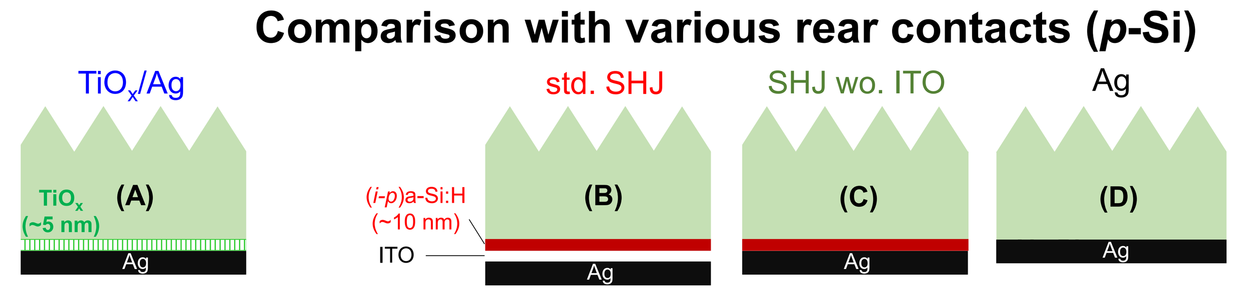
Conductance-Voltage (G-V) measurements (conducted at Univ. Oxford)

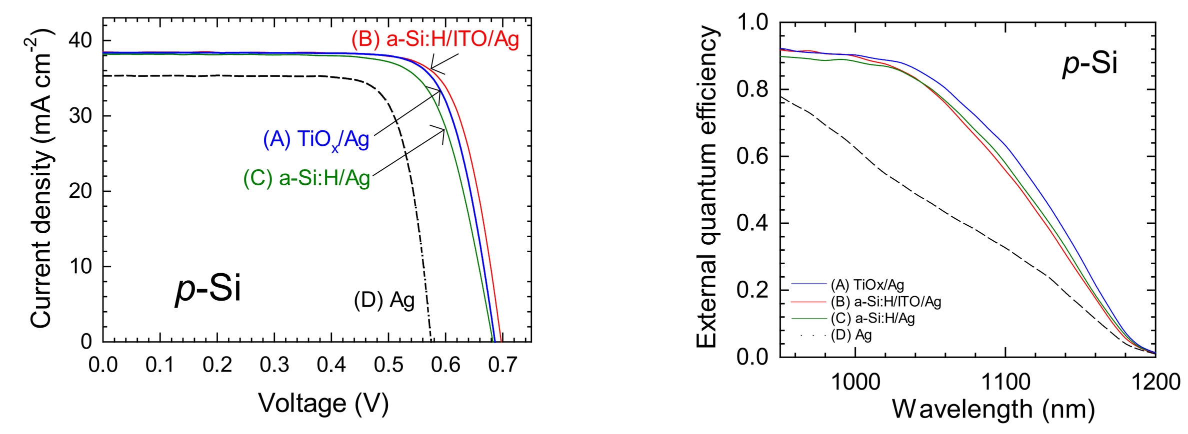




- G-V: flat band occurs at higher voltages for high-WF metal (V_{FB}(Al): ~0.4 V, V_{FB}(Au) : ~0.9 V).
- Analysis [4] indicates the presence of negative fixed charge (>10^{12} cm^{-2}) in the TiO_x, independent of the capping metal.
- Field-effect passivation is a major mechanism.
- High-WF metal is important to retain carrier inversion for *n*-Si (carrier accumulation for *p*-Si).

Comparison with various rear contacts (*p*-Si)





- Comparable IV performance (20.3%, *p*-Si) with the conventional SHJ (a-Si:H *i-p*/ITO/Ag) rear contact.
- Similar result obtained for *n*-Si (rear junction) cell.
- Highest IR response.
- Efficiency is limited by the low J_{SC} due to parasitic absorption of front layers (ITO, a-Si:H *i-n*).

Conclusion & Next plan

- ALD-TiO_x is applied to the rear of Si solar cells as a full-area hole-selective passivating contact.
- Passivation is greatly influenced by the WF of capping metal. WF>4.6 eV is essential to retain field-effect passivation and hole selectivity.
- TiO_x/Ag contact performs as high as SHJ with an improved infrared reflectivity. Proof-of-concept devices show 20% efficiency for both *p*-Si and *n*-Si solar cells.
- TiO_x/metal as an alternative contact in PERC is proposed, which is expected to provide less process complexity and improved performance (e.g., from 2D to 1D carrier transport and higher infrared reflectivity).

References

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