# 酸化チタンを正孔コンタクトとして用いた新型結晶シリコン太陽電池の開発


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## Motivation

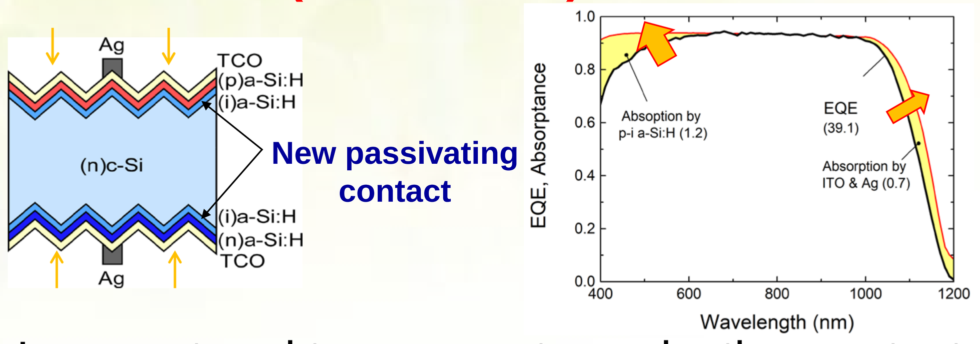
### Novel passivating contacts

**Bifacial SHJ**

**☺Excellent performance, bifaiciallity, outdoor performance**

**☹Parasitic absorption by a-Si:H**

**☹CAPEX (PECVD tool)**

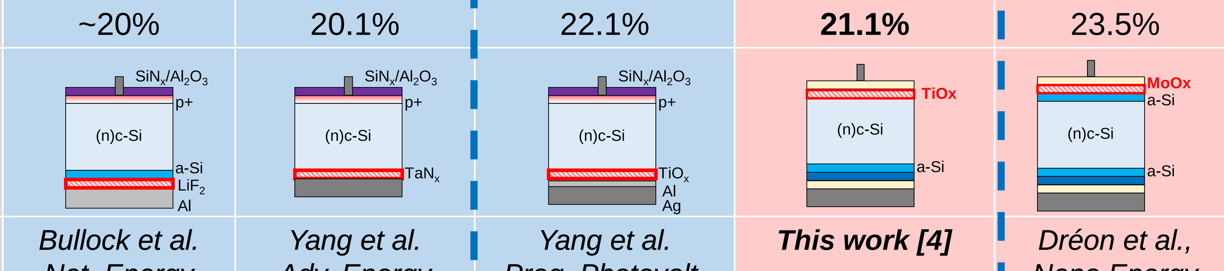



Low cost and transparent passivating contact that can replace a-Si:H

➤**Metal-oxide semiconductors**

### Non-Si passivating contacts

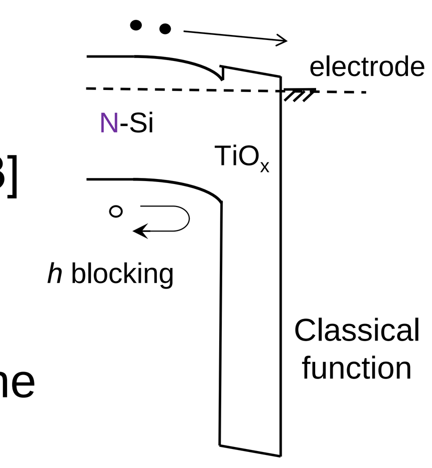
**Metal oxides, nitrides, fluorides**

| Work function | low | | | ? | high |
|---|---|---|---|---|---|
| Material | $LiF_x$ | $TaN_x$ | $TiO_x$ | **$TiO_x$** | $MoO_x$ |
| Carrier selectivity | $e^-$ | $e^-$ | $e^-$ | **$h^+$** | $h^+$ |
| Buffer layers | a-Si:H | w/o | w/o | w/o | a-Si:H |
| efficiency | ~20% | 20.1% | 22.1% | **21.1%** | 23.5% |
| Structure |  | | | | |
| Ref. | *Bullock et al. Nat. Energy (2016)[1]* | *Yang et al. Adv. Energy Mater. (2018) [2]* | *Yang et al. Prog. Photovolt. (2017) [3]* | ***This work [4]*** | *Dréon et al., Nano Energy (2020) [5]* |

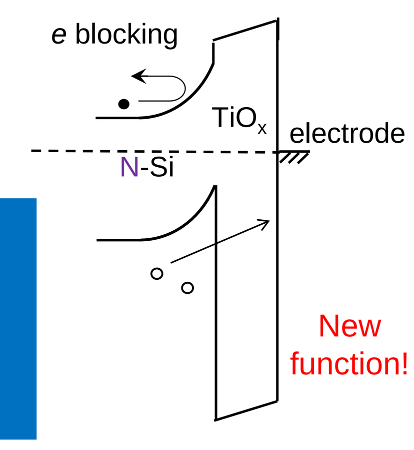
- various electron/hole selective materials
- **preferably buffer free**
- **preferably transparent if applied as window**

### $TiO_x$

- $TiO_x$ ($TiO_2$) electron contact by thermal-ALD provides η=22.1%[3]
- $TiO_x$ used as electron contacts in non-Si PV [6]
- Electron selectively ascribed to the asymmetric band offset [7]



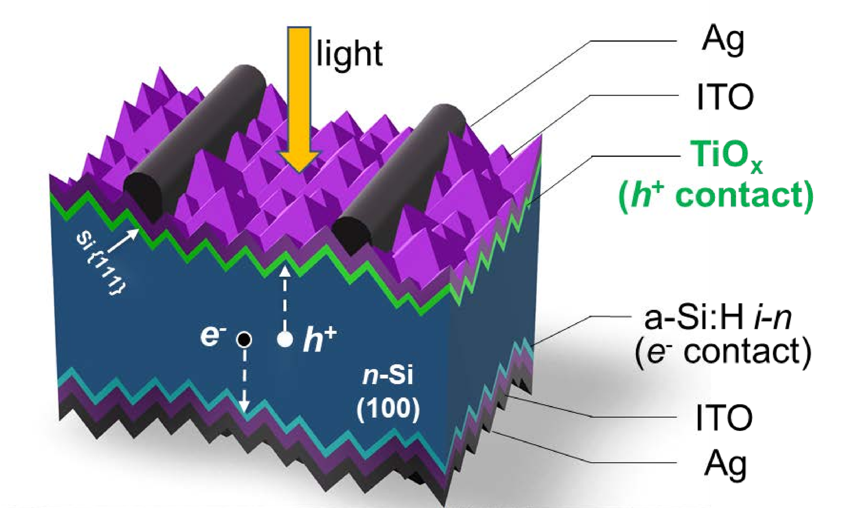

- **Recently, we find that $TiO_x$ can be tuned to work as hole selective contact [8,9]**

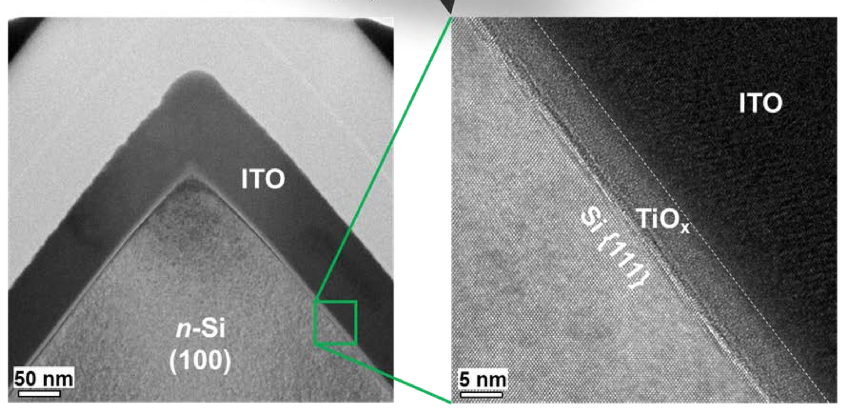


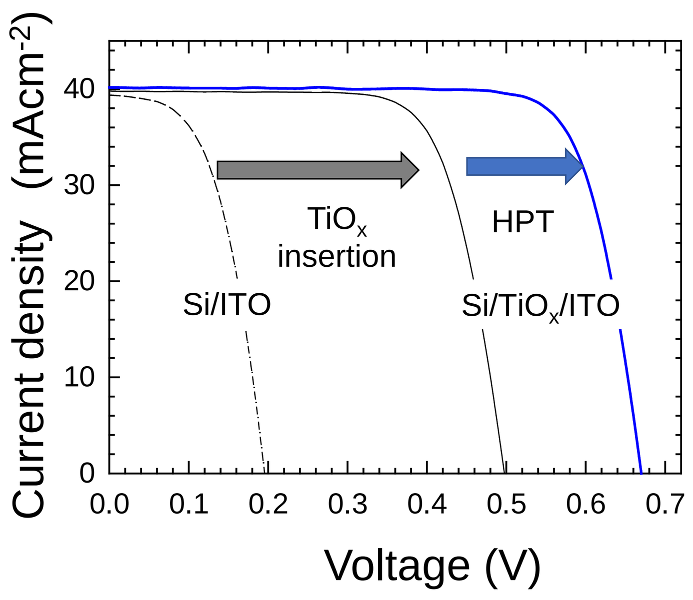

➤Contradiction to the previous understanding…

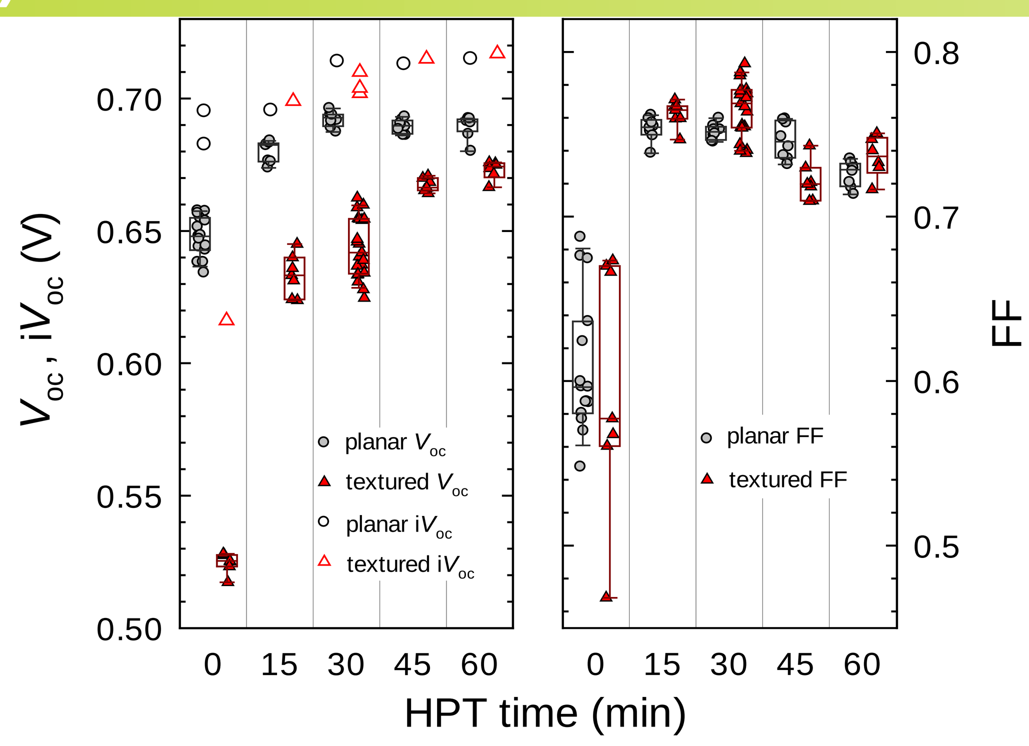
➤Can $TiO_x$ actually work as hole transport layer in solar cells?

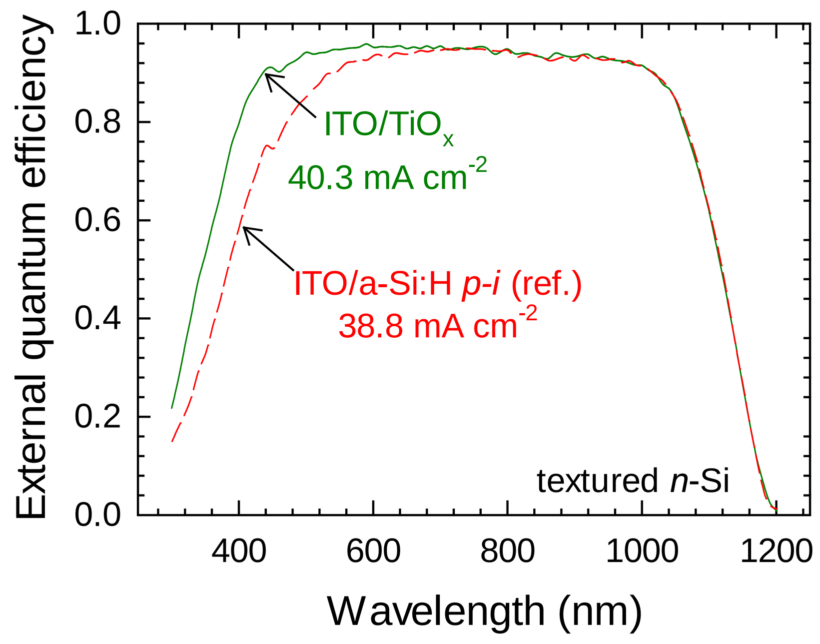
## Solar cells featuring ALD-$TiO_x$ hole contacts (textured Si)



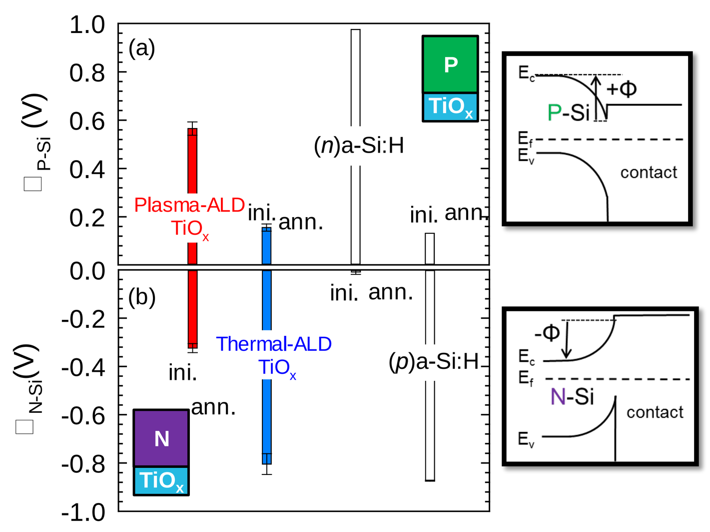




- Conformal deposition of $TiO_x$ layer (5 nm) by thermal-ALD on Si pyramids
- $TiO_x$ layer works as hole contact (emitter)
- Hydrogen plasma treatment (HPT) improves $V_{oc}$ and FF significantly
- A 21.1% independently-confirmed efficiency is demonstrated

- Marked gain in blue response ($\Delta J_{sc}$~1.5 $mAcm^{-2}$)
- UV induced degradation is an emerging issue

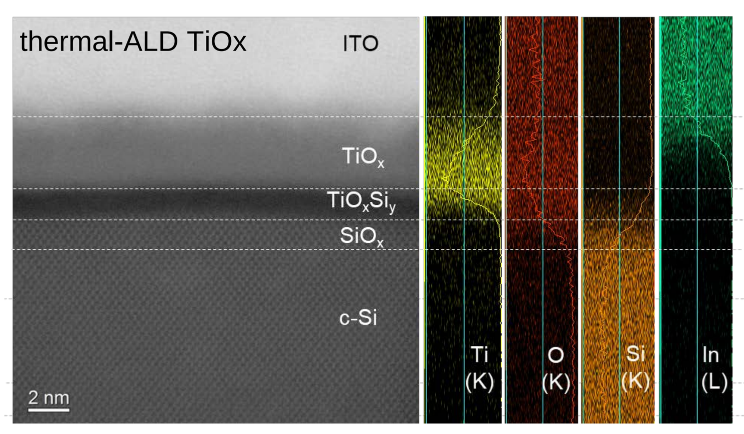
## Origin of the hole selectivity and hole collection mechanism

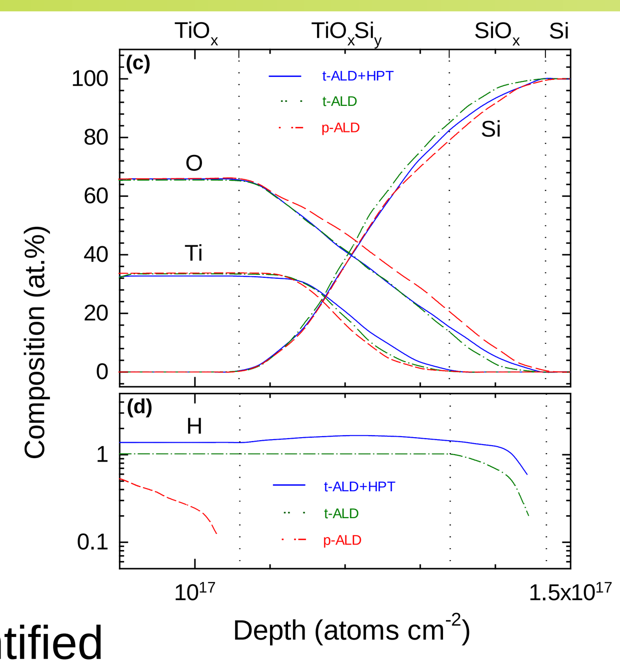
**Surface photovoltage (SPV) measurement**




- Opposite polarity of induced band bending (Φ) by two ALD processes
- C-V indicates negative fixed charge in thermal-ALD $TiO_x$ [9]

**TEM and RBS-ERDA analysis**



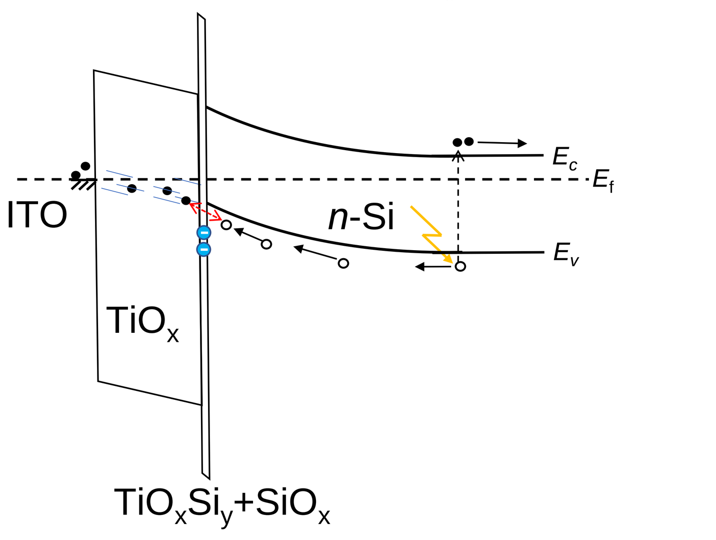




- Intermixing ($TiO_xSi_y$) layer (~2 nm) identified
- Difference found in atomic profiles in the $TiO_xSi_y$ layer

→ possible origin of the negative charge generation

- thermal-ALD $TiO_x$ contains 1 at.% hydrogen → passivation mechanism
- HPT slightly modifies interface composition and increase H content >1 at.%

**Possible band diagram**




- Negative fixed charge and (high WF) ITO create induced-junction in *n*-Si
- Hole (electron) transport via the localized states in $TiO_x$

## Conclusions

- $TiO_x$ acting as an efficient hole selective passivating contact is demonstrated for textured Si.
- HPT drastically improves both passivation and hole selectivity.
- Parasitic absorption loss due to a-Si:H is almost completely removed thanks to the high transparency of $TiO_x$ .
- A 21.1% confirmed efficiency is demonstrated.

## Outlook

- Improving initial performance and UV tolerance.
- $TiO_x$/Si/$TiO_x$ cell development and application for tandem devices.

## References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