Selective contacts for undoped photovoltaic cells fabricated by high pressure sputtering

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Motivation

Explore materials (**TiO_x**) to build an alternative structure of **solar cells** (Dopant Free Asymmetric Heterojunction - DASH) by the unconventional technique of **High-Pressure Sputtering** (HPS)

Overcoming intrinsic limitations of homojunctions and HIT solar cells. **Cheaper and sustainable solar energy.**

Why high pressure?

- Hazardous gaseous precursors
- High temperature processes
- Parasitic absorption

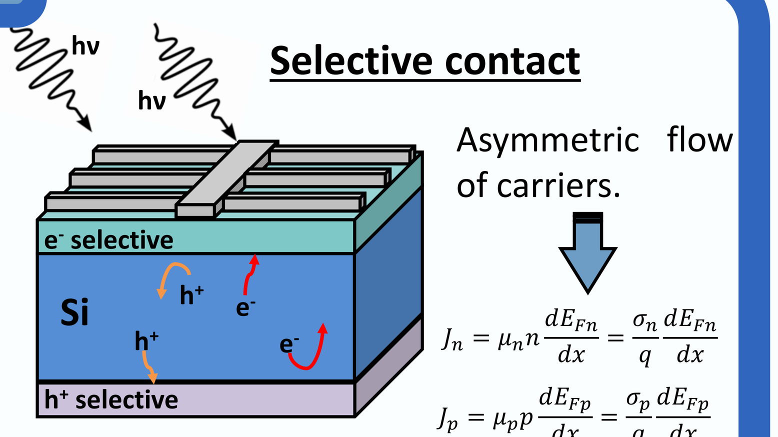
Minimize substrate damage by thermalization of sputtered species.

Mean free path between collisions

$$\lambda = \frac{kT}{\sqrt{2}\pi d^2 p}$$

K – Boltzmann const. [J/K]
T – Temperature [K]
d – Kinetic diameter [pm]
p – pressure [Pa]

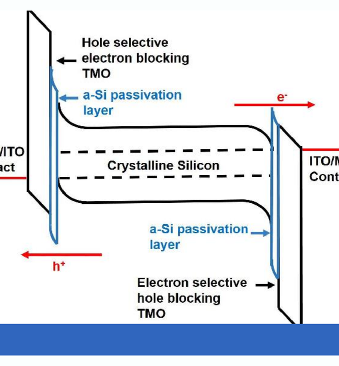
Selective contact



Asymmetric flow of carriers.

$$J_n = \mu_n n \frac{dE_{Fn}}{dx} = \frac{\sigma_n}{q}\frac{dE_{Fn}}{dx}$$

$$J_p = \mu_p p \frac{dE_{Fp}}{dx} = \frac{\sigma_p}{q}\frac{dE_{Fp}}{dx}$$



Energy bands bending with high band gap materials (TMO)

- Easy to produce
- Low cost (low temperature processes)
- Plenty of materials

Experimental

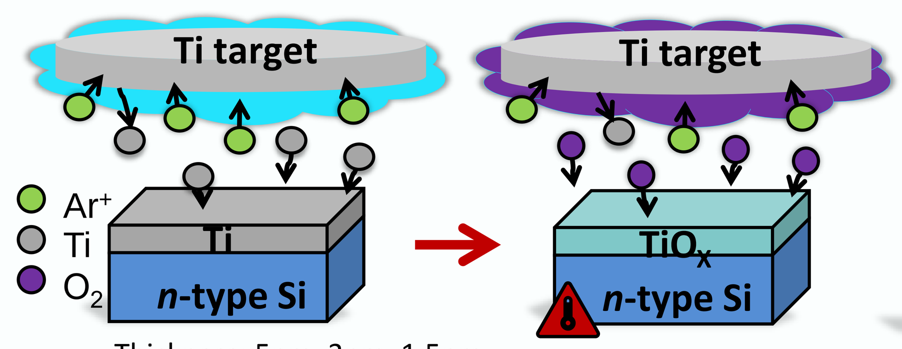
Fabrication process

Deposition of TiO_x at **0,5mbar 45W** by HPS

Two-step deposition method:

To achieve good selectivity and conductivity

Ti deposition + thermal/plasma oxidation



Thickness: 5nm, 3nm, 1,5nm
Deposition rate: ~0,80nm/min
Power density: 2,25 W/cm^{-2}

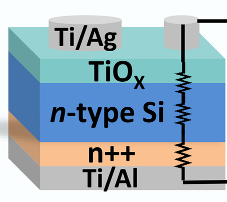
Time: 0,5h – 2h
Temperature: 150°C, 200°C

Structural characterization

XPS → Oxidation states, stoichiometric factor
FTIR → Chemical bond vibrations
Ellipsometer → Refractive index, thickness
TEM → Crystal structure, thickness

Electrical characterization

Cox&Strack → Specific contact resistivity [ρ_c] measurement



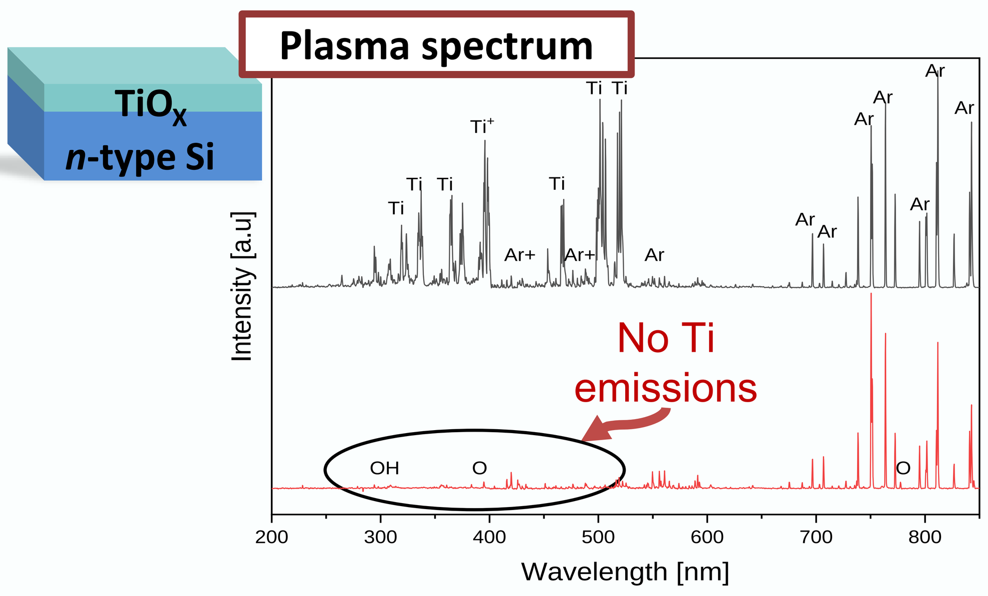
$$R_T \approx \frac{\rho_w}{\pi d} arctan\left(\frac{4t}{d}\right) + \frac{\rho_c}{\frac{1}{4}\pi d^2} + R_O$$

QSS-Photoconductance

→ Carrier lifetime

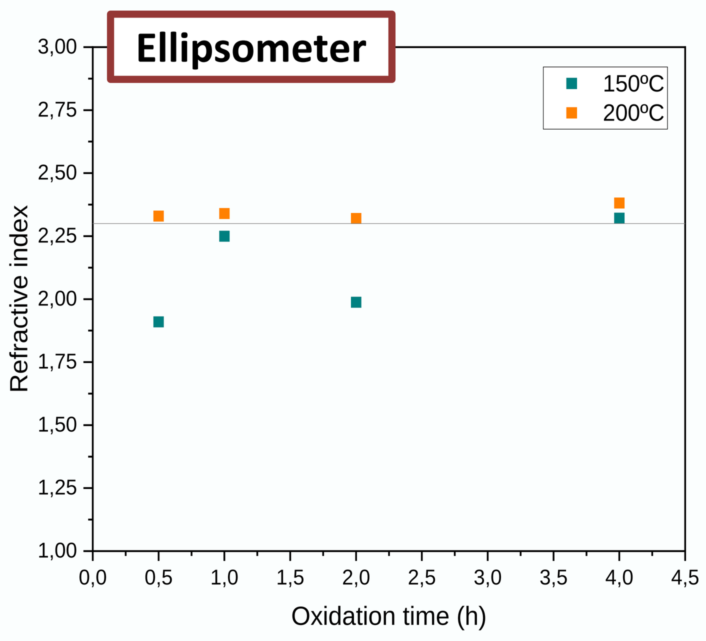
Results

Plasma spectrum



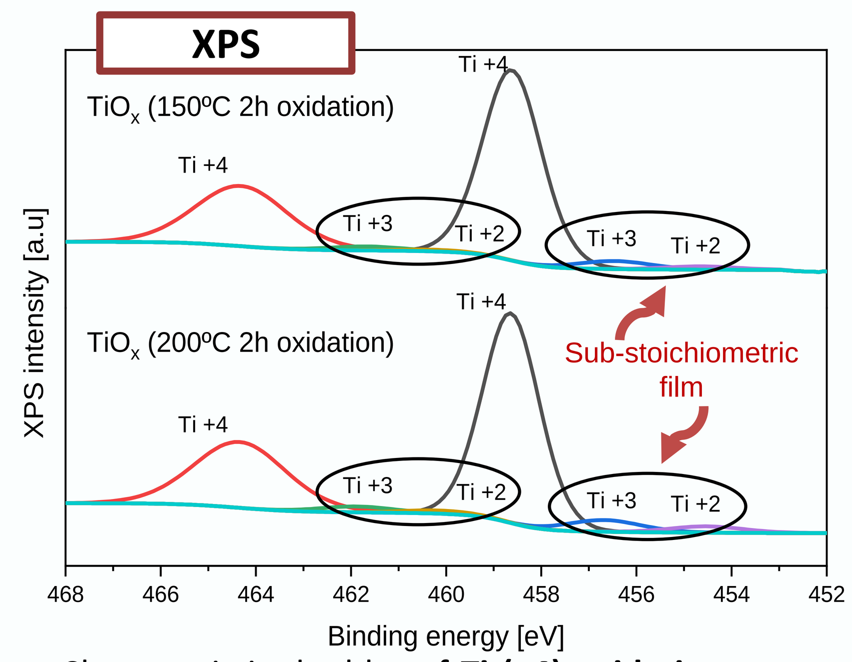
Characterization of plasma processes. In step 2, no Ti emissions are observed (no Ti deposition). **Previous vacuum and target conditioning are extremely important**.

Ellipsometer



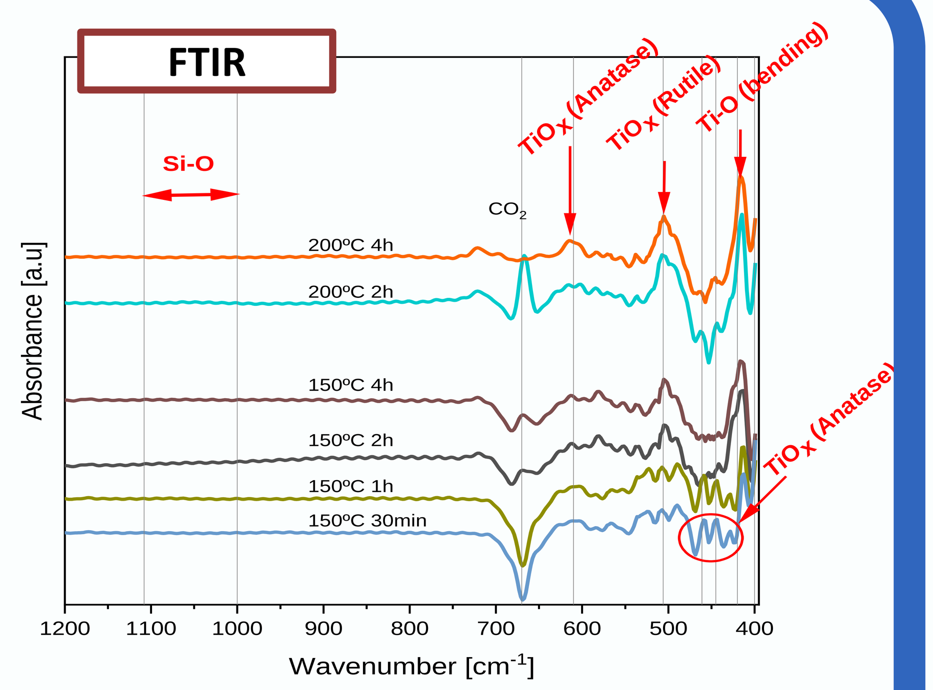
Modification of the refractive index (n) of TiO_x. According to [1] thermal ALD TiO_x *n* ~ 2,3 (at 632nm).

XPS



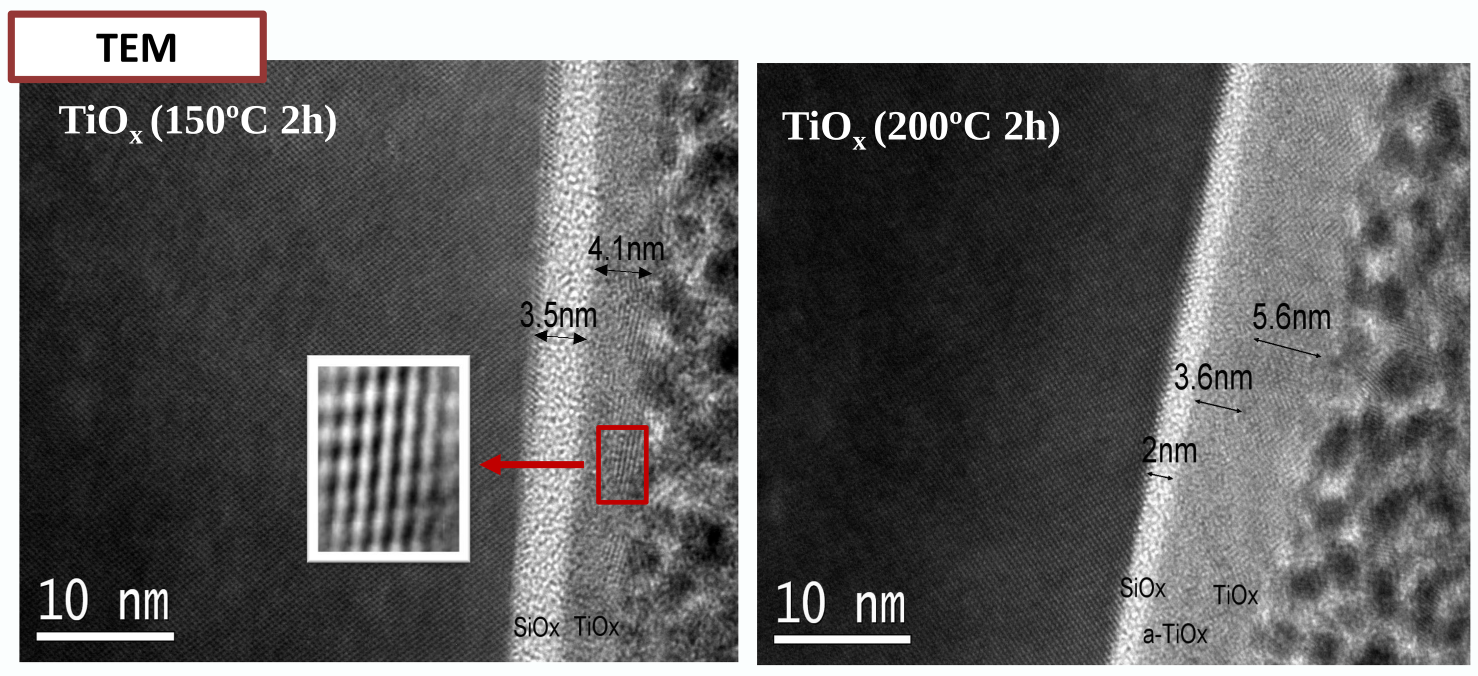
Characteristic doublet of **Ti (+4) oxidation state at 464 eV and 458 eV.** However, the Ti(+3) and Ti(+2) are also present. Oxygen to Ti ratio (x) of ~ 1,94.

FTIR



No significantly Si-O absorption is detected. This might indicate **minimal oxidation in the substrate.** [2]

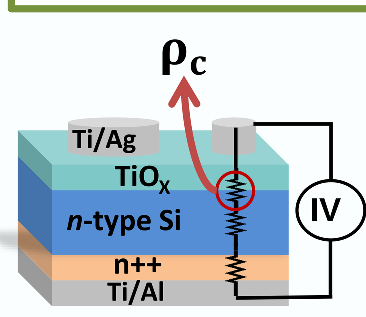
TEM



TEM image shows an **amorphous TiO_x** with some regions that portray embedded nano crystal. Furthermore, a thin **SiO_x film has regrown**, probably due to the diffusion of O_x inside de Ti film.

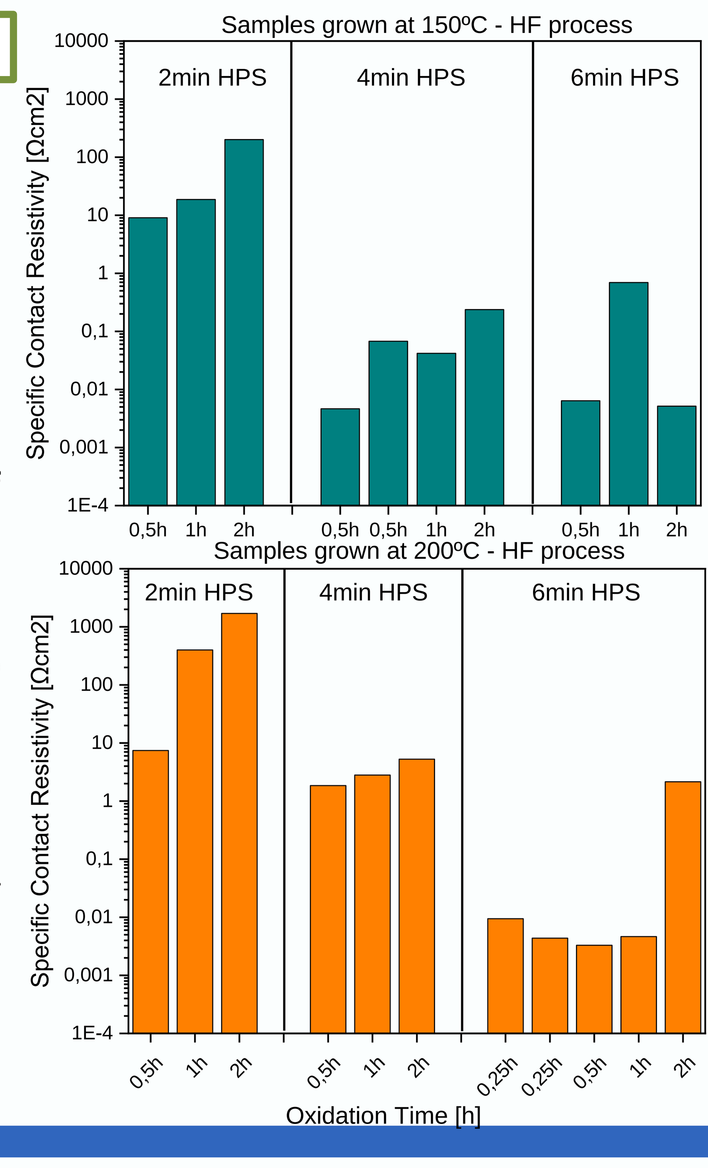
At 200˚C, two different Ti layers appears to emerge. On the surface, there is a crystalline layer. In the middle an amorphous layer is observed.

Cox&Strack

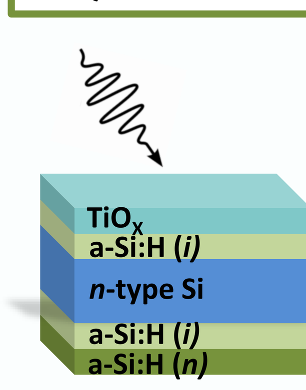


Cox&Strack samples to measure the ρ_c of **TiO_x/n-Si junction.** Three different sputtering time **(6min, 4min and 2min)**, each one grown at **150 ˚C or 200 ˚C.**

With the samples of 6min HPS, ρ_c **~10 $m\Omega cm^2$**, that is within the range of what has been reported with ALD TiO_x [3]

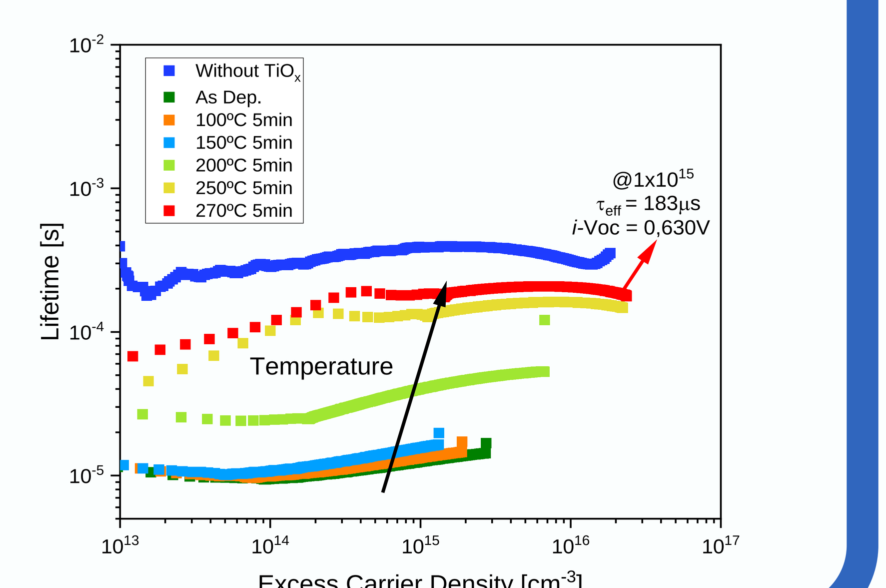


QSS-Photoconductance



To measure the **carrier lifetime of TiO_x + amorphous Si.** Quality of interface i.e., quantity of dandling bonds (unpassivated bonds)

As deposited TiO_x reduce lifetime, but **temperature annealing might recover.**



Conclusions

- We successfully fabricated **high pressure sputtered TiO_x with a 2-step process**. The temperature and the time of oxidation play an important role to achieve a **TiO_x almost stoichiometric** as XPS shows**.**
- FTIR and TEM image depict that the **TiO_x film is principally amorphous** with embedded nanocrystals. When a higher temperature is applied (i.e., 200˚C) the film tends to grow showing some nanocrystalline arrangements.
- We fabricated Cox&Strack structure to measure the **specific contact resistivity (ρ_c) between n-Si and our TiO_x**. The samples of 5nm show the lower ρ_c **~10 $m\Omega cm^2$**, this is in accordance with values obtained with TiO_x fabricated with ALD. Thinner films lead to higher ρ_c values, most likely due to enhanced substrate oxidation.
- We measured the carrier lifetime of **TiO_x + a-Si:H(i)**. A priory the deposition of TiO_x reduce the lifetime, but annealing shows a recovery. The use of a-Si:H (i) appears as a good approach to obtain high lifetime for the use of **TiO_x in selective contacts solar cells structure**.

References

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