Integration of rare earth ions doped Si based down converter layers in an industrial Si solar cell

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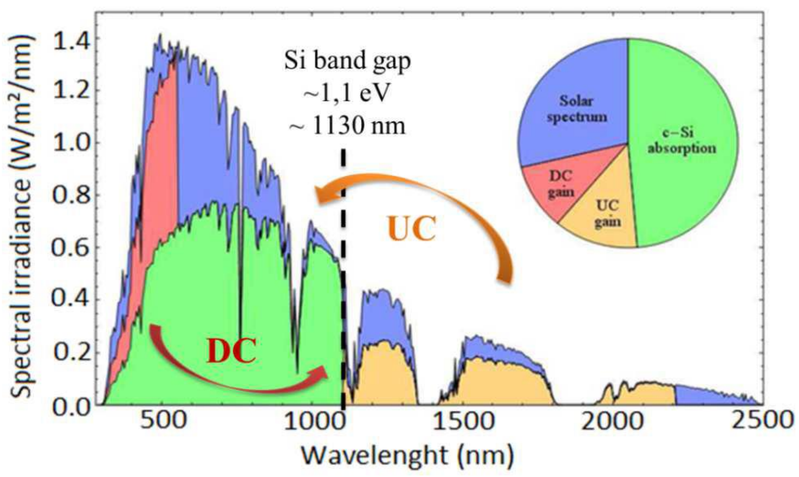
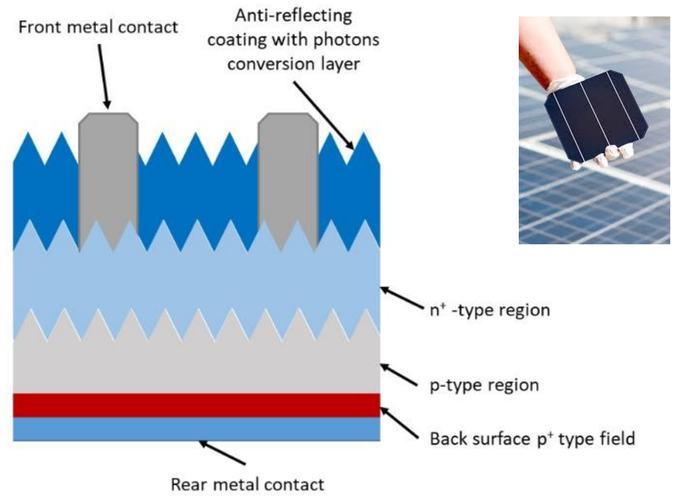
Introduction

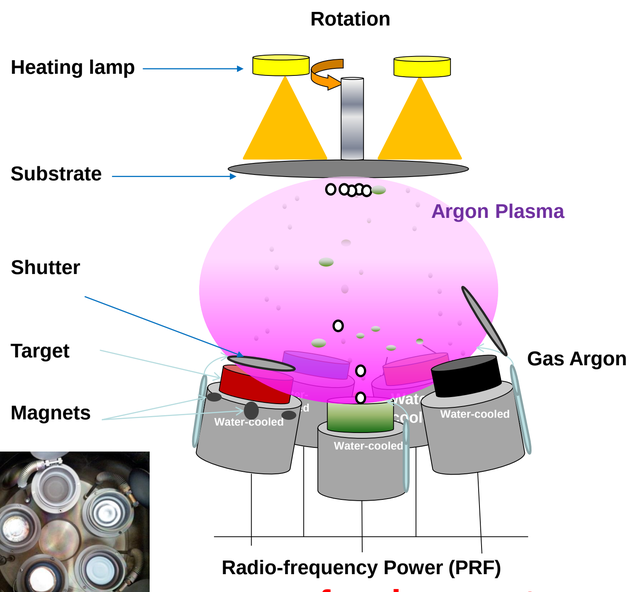
Goal : Improve the efficiency of Si solar cells by down converter layer

- Decrease the thermalization losses due to the spectral mismatch between the solar irradiance and the Si absorption
- Use the optical properties of **rare earth ions** embedded in a Si-based matrix to do **Down-conversion (DC)**





Sample fabrication



confocal magnetron sputtering

Fabrication parameters:

Depositions parameters:

Deposition Temperature , $\mathbf{T_{dp}}$ (°C)

Plasma Pressure, $\mathbf{P_{tot}}$ (sccm)

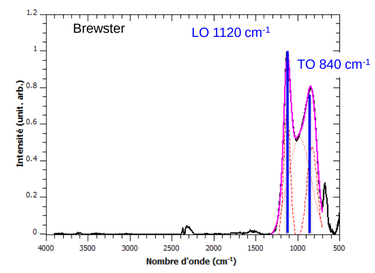
Gaz : Argon and nitrogen

Nitrogen rate, $\mathbf{rN_2}$

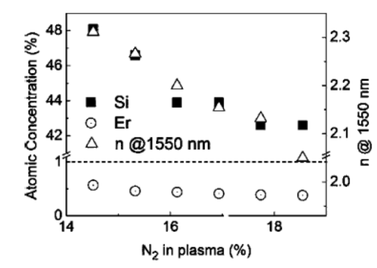
RF Power density on target, $\mathbf{P_{target}}$ (W/cm²)

Depositing time, $\mathbf{t_{dp}}$ (s)

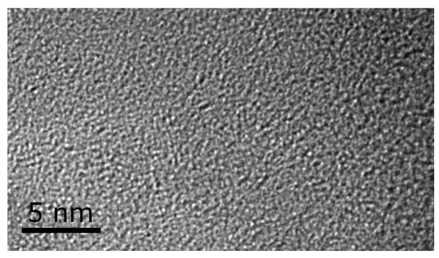
Annealing with rapid or slow ramp of T under specific gas (N_2, Forming…)



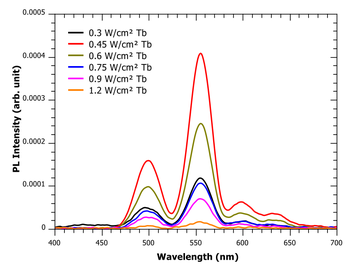
Control of the stoichiometry by tuning the sputtering parameters: SiN_x [FTIR]



Control of refractive index by tuning the sputtering parameters : SiN_x [ELLIPSOMETRY]



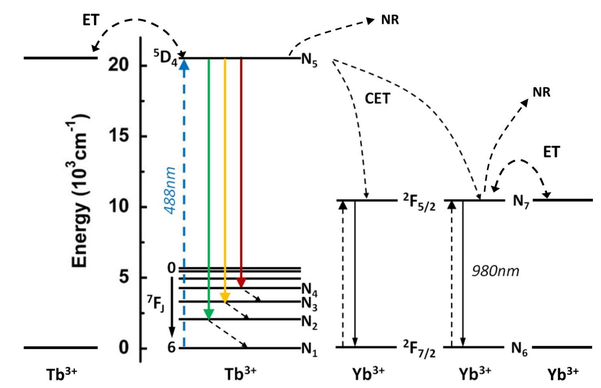
Amorphous and homogenous films: SiN_x [HRTEM]



Si based doped with rare earth ions luminescent layer: SiNx-Tb^{3+}[PHOTOLUMINESCENCE]

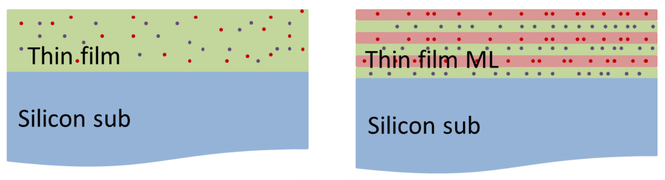
Structural and physical characterization

Monte Carlo Modeling

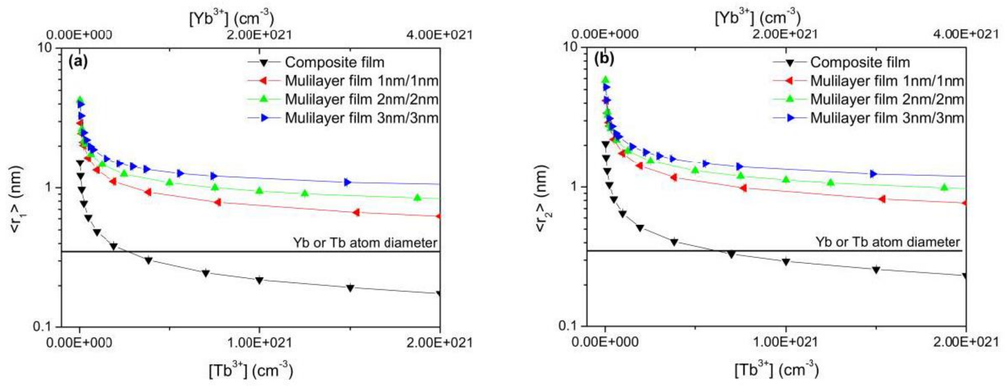


K_{CET} distance dependent and therefore function of concentration [Tb^{3+}] and [Yb^{3+}] and their distribution

$$K_{CET} \propto \frac{1}{r^{6}_{Tb^{3+}-Yb^{3+}} \cdot r'^{6}_{Tb^{3+}-Yb^{3+}}}$$

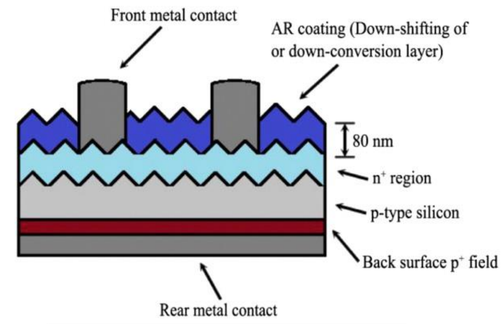


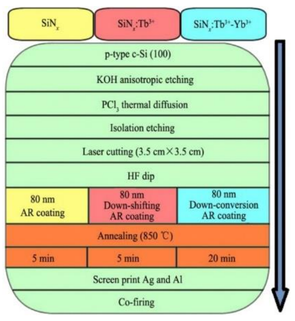
Two kinds of Tb^{3+} -Yb^{3+} co-doped thin films fabricated homogenous and multilayer

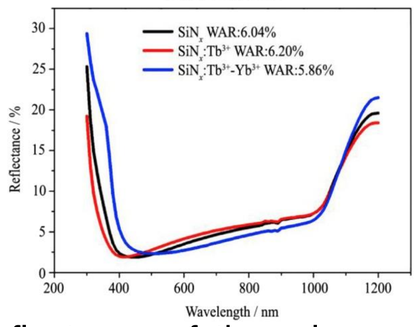


Multilayer prevent aggregation quenching and allow therefore higher doping rate

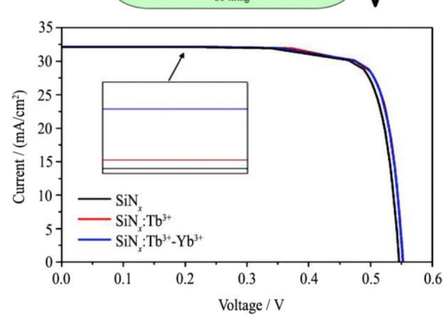
Integration in industrial Si solar cell







Reflectance of three layers deposited on textured emitters



Pseudo *I-V* curves for three c-Si solar cells with SiN_x, SiN_x:Tb^{3+} and SiN_x:Tb^{3+}-Yb^{3+} layers, respectively.

Samples	J_{sc} (mA/cm²)	V_{oc} (V)	Pseudo FF (%)	Pseudo Efficiency (%)	Efficiency to normalized transmission (%)
SiN_x	32.091	0.546	0.804	17.13	18.23
SiN_x:Tb^{3+}	32.098	0.552	0.803	17.31	18.45
SiN_x:Tb^{3+}-Yb^{3+}	32.165	0.552	0.806	17.36	18.44

Relative increase by 1.34% in the solar cell conversion efficiency

Conclusion

- Fabrication of Tb/Yb-doped SiN_x homogenous and multilayer films ->DC optimized films
- Modeling of the DC interaction exchange for both kind of films -> Aggregation of rare earth ions is prevented in multilayer
- Homogenous and multilayer DC layers integrated in Si solar cell -> Homogenous DC layer lead to relative Si solar cell efficiency increase of 1.34%

Normandie Region for support

PHC France-Taiwan ORCHID.

GENESE

E-Ton Solar (Taiwan)

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- *L. Dumont et al, Down-shifting Si-based layer for Si solar applications, Solar Energy, Materials and Solar Cells 169, 132-144, 2017*
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- *Ing Song Yu, et al, Monolithic crystalline silicon solar cells with SiNx layers doped with Tb^{3+} and Yb^{3+} rare-earth ions, Journal of Rare Earths, 37,5, 515-519, 2019*