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

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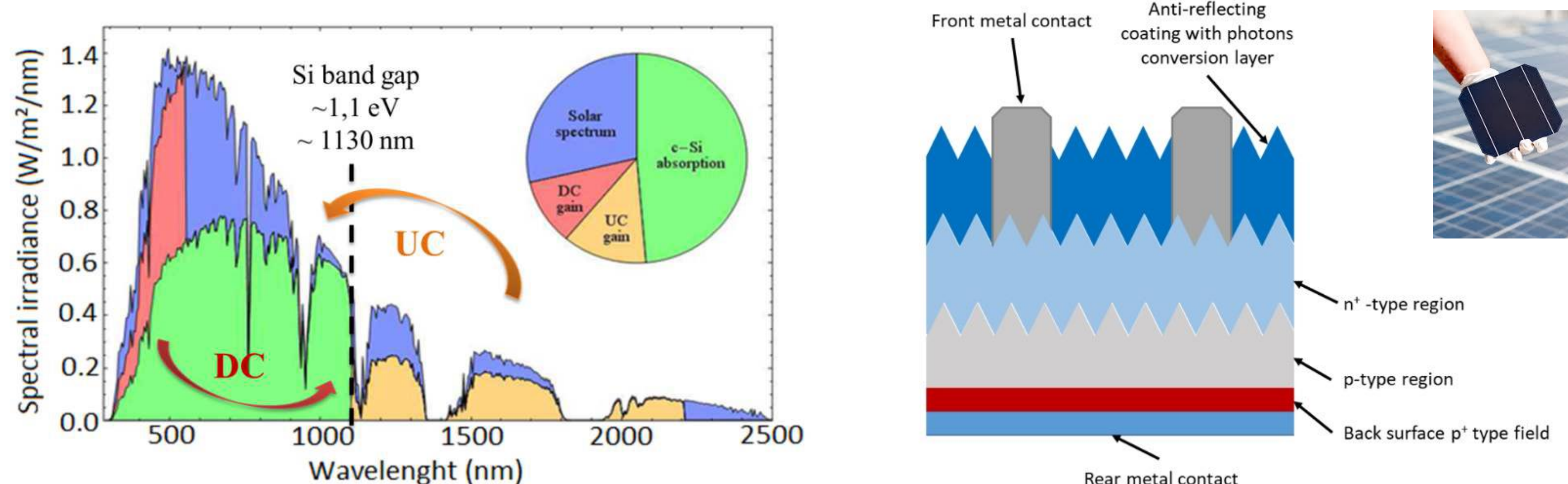
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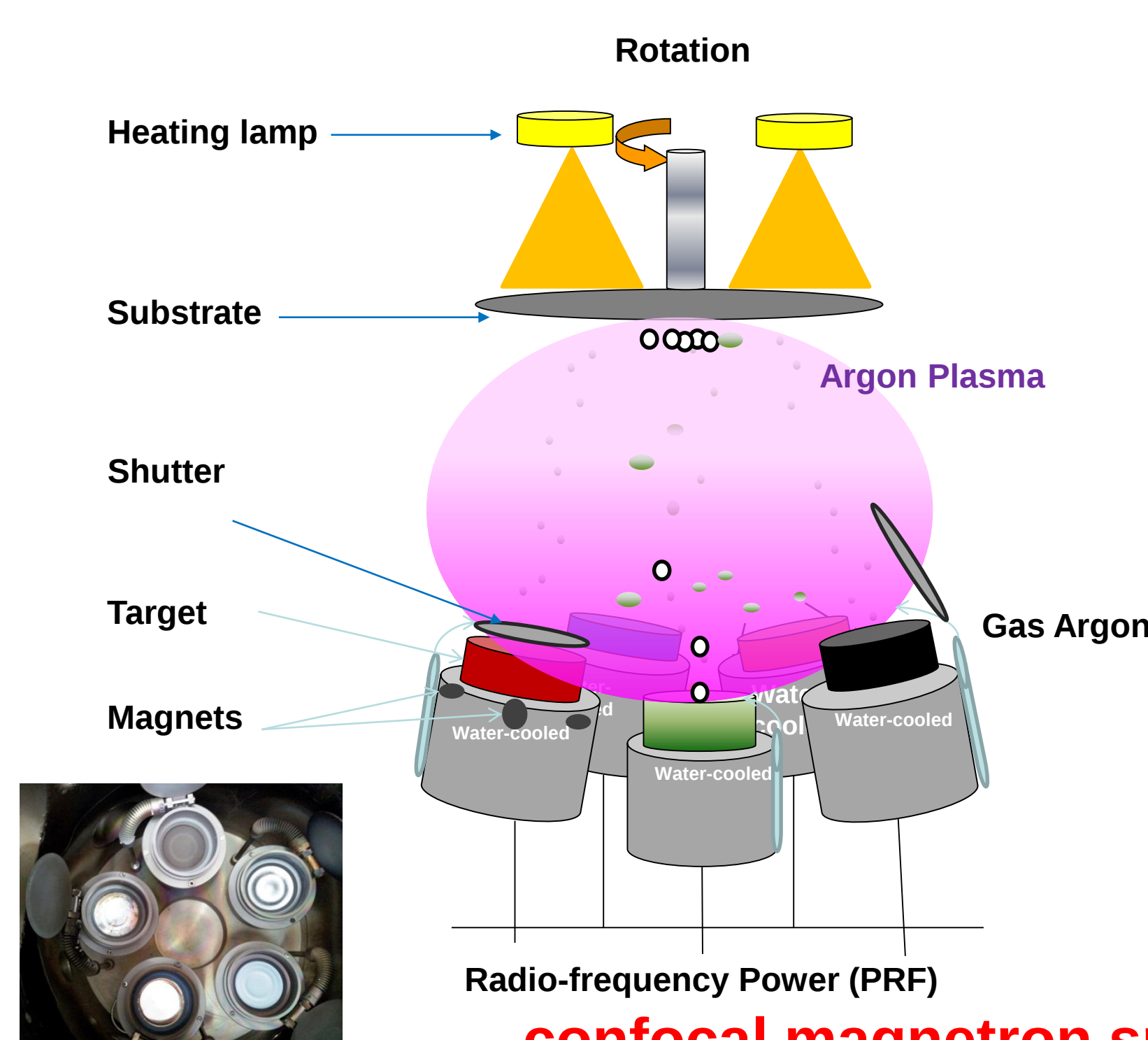
Introduction

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)**



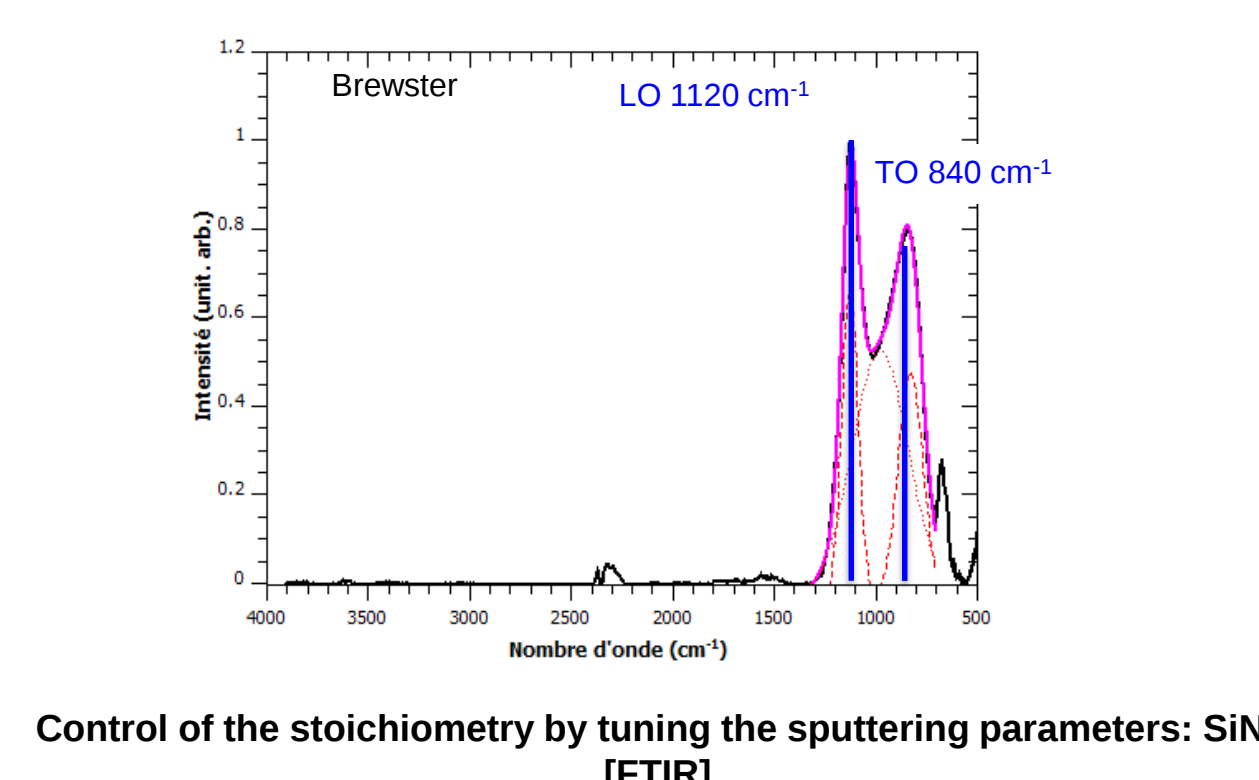
Sample fabrication



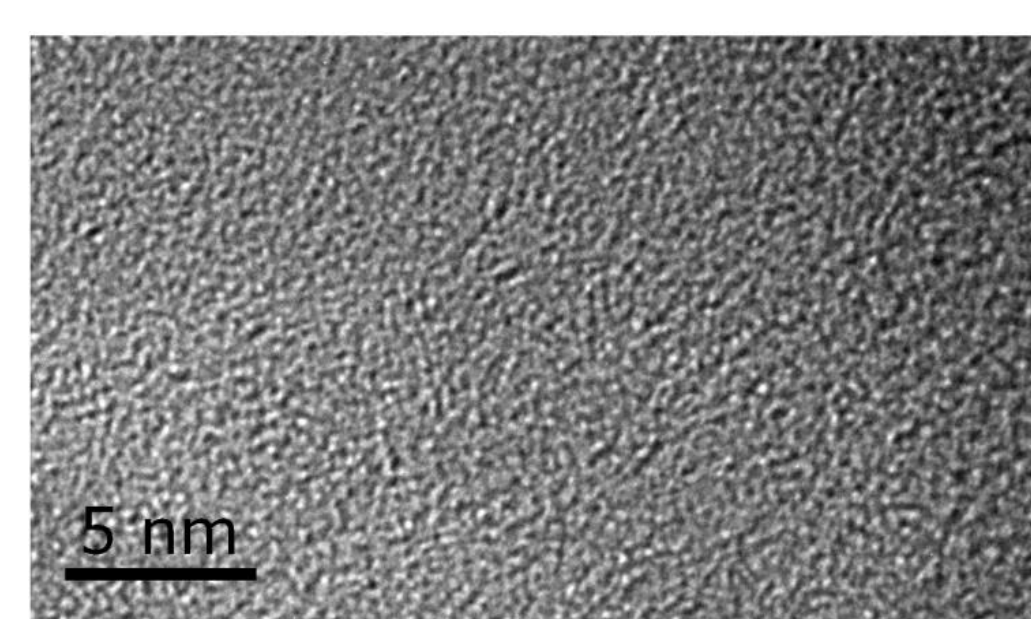
confocal magnetron sputtering

Fabrication parameters:

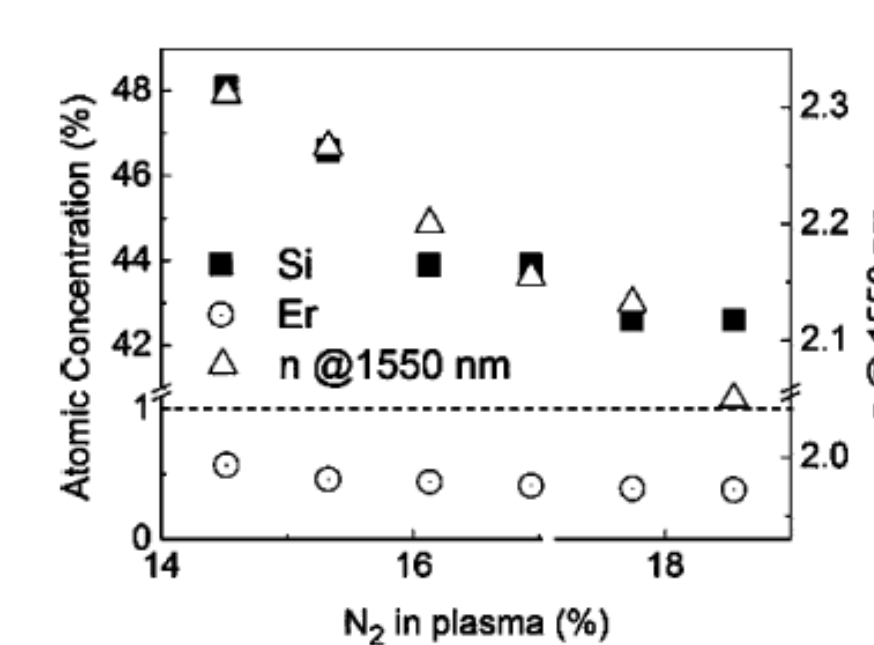
Depositions parameters:
 Deposition Temperature, T_{dp} (°C)
 Plasma Pressure, P_{tot} (sccm)
 Gaz : Argon and nitrogen
 Nitrogen rate, r_{N_2}
 RF Power density on target, P_{target} (W/cm²)
 Depositing time, t_{dp} (s)
 Annealing with rapid or slow ramp of T under specific gas (N_2 , Forming...)



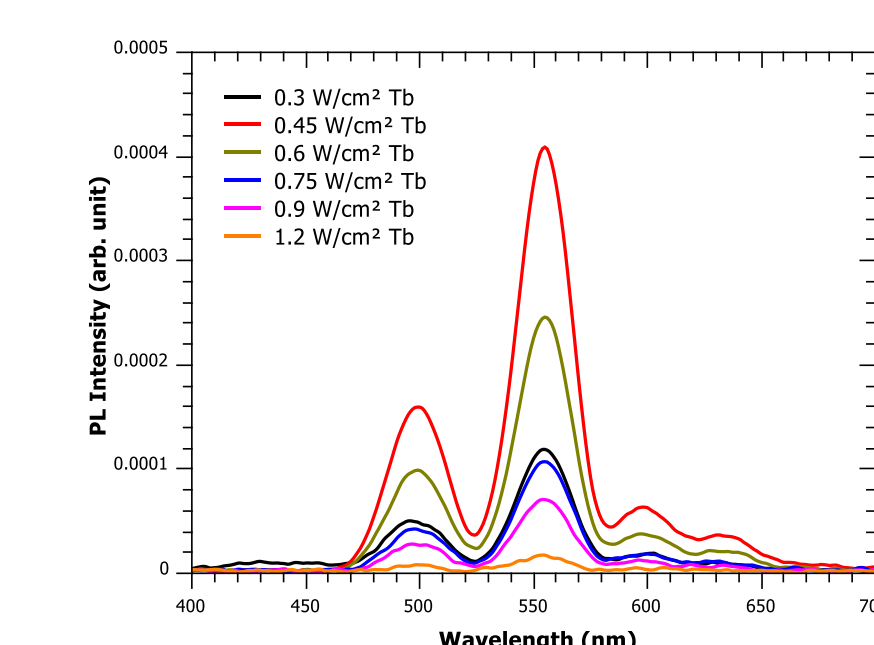
Control of the stoichiometry by tuning the sputtering parameters: Si_{Nx} [FTIR]



Amorphous and homogenous films: Si_{Nx} [HRTEM]



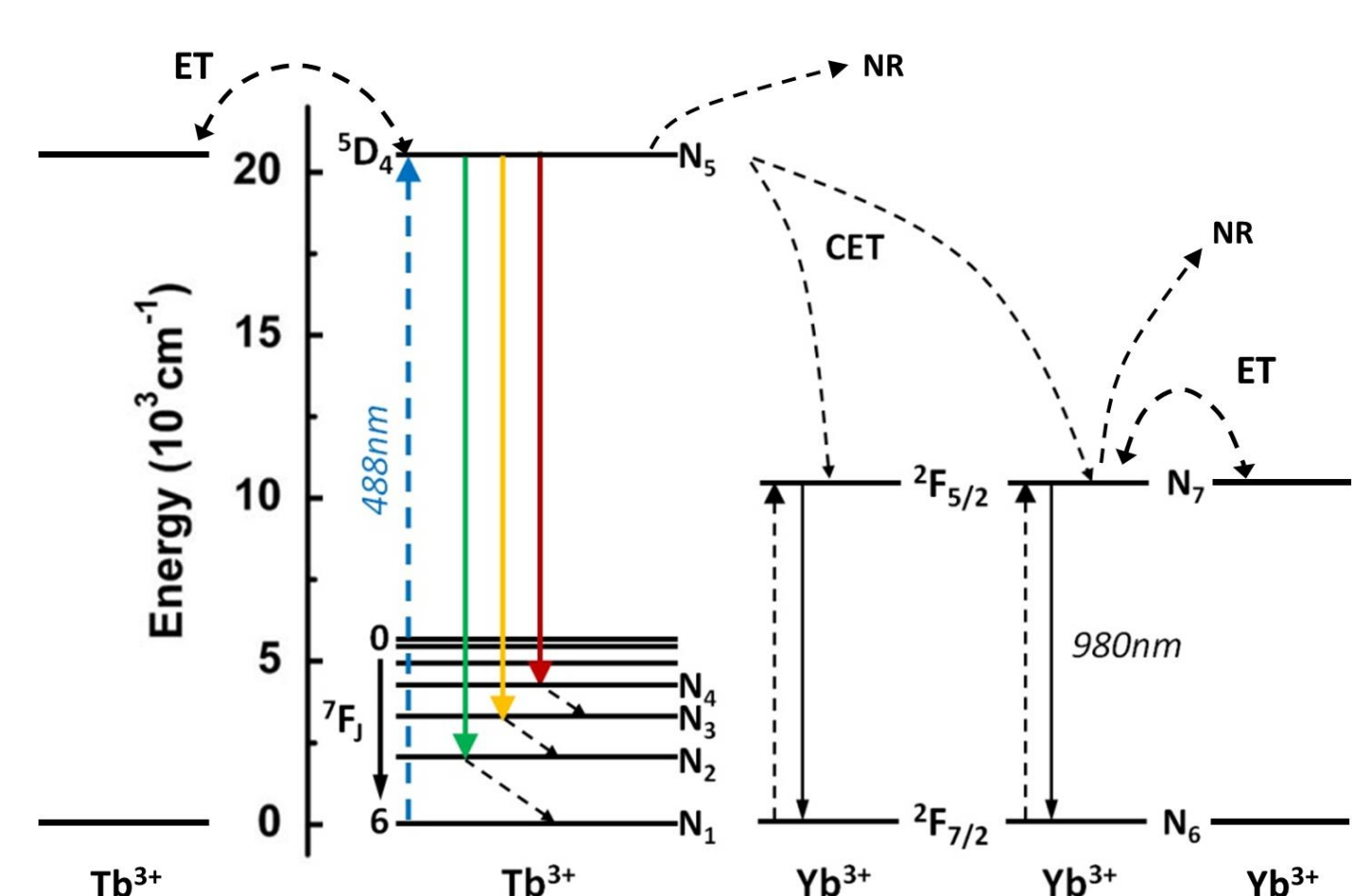
Control of refractive index by tuning the sputtering parameters : Si_{Nx} [ELLIPSOMETRY]



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

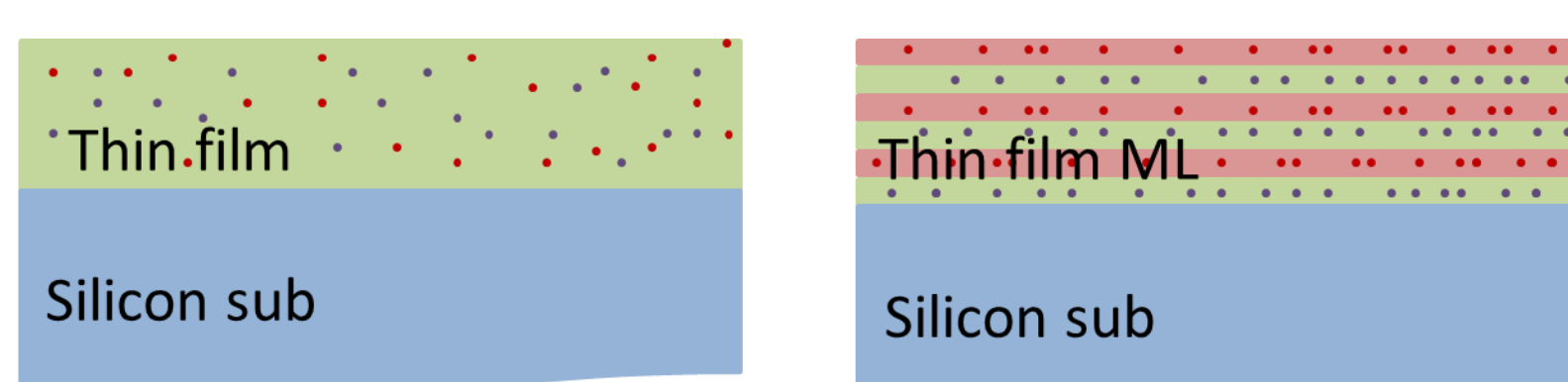
Structural and physical characterization

Monte Carlo Modeling

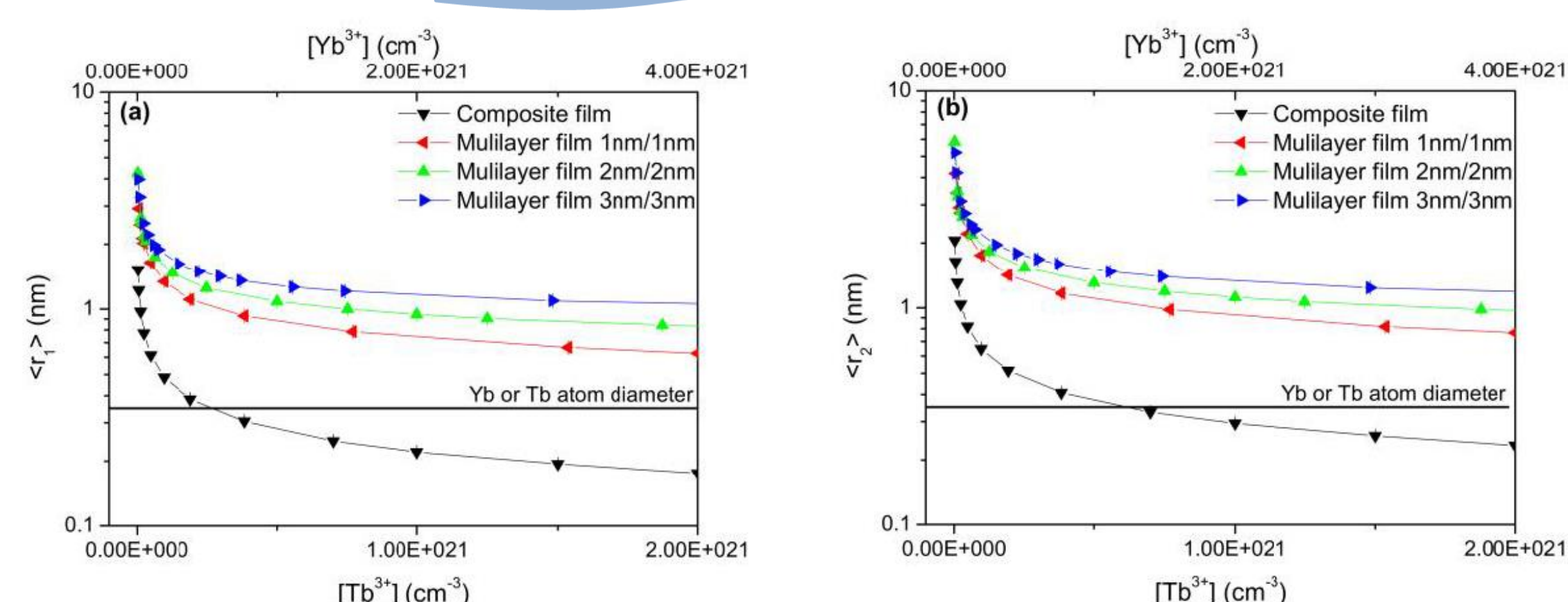


K_{CET} distance dependent and therefore function of concentration $[Tb^{3+}]$ and $[Yb^{3+}]$ and their distribution

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

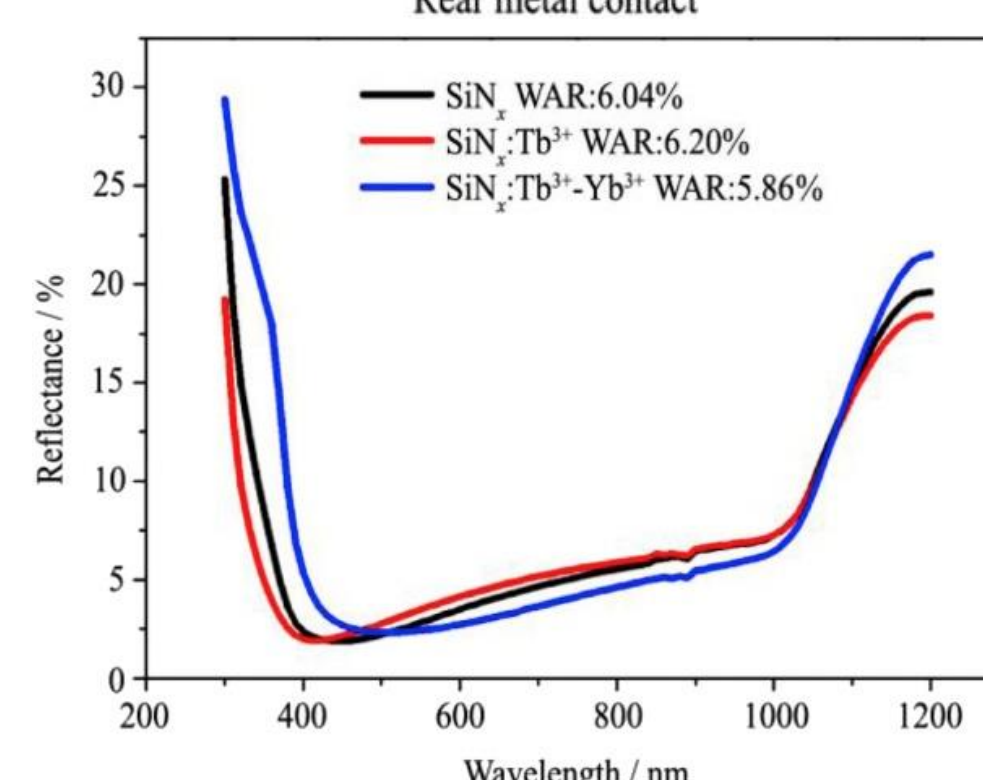
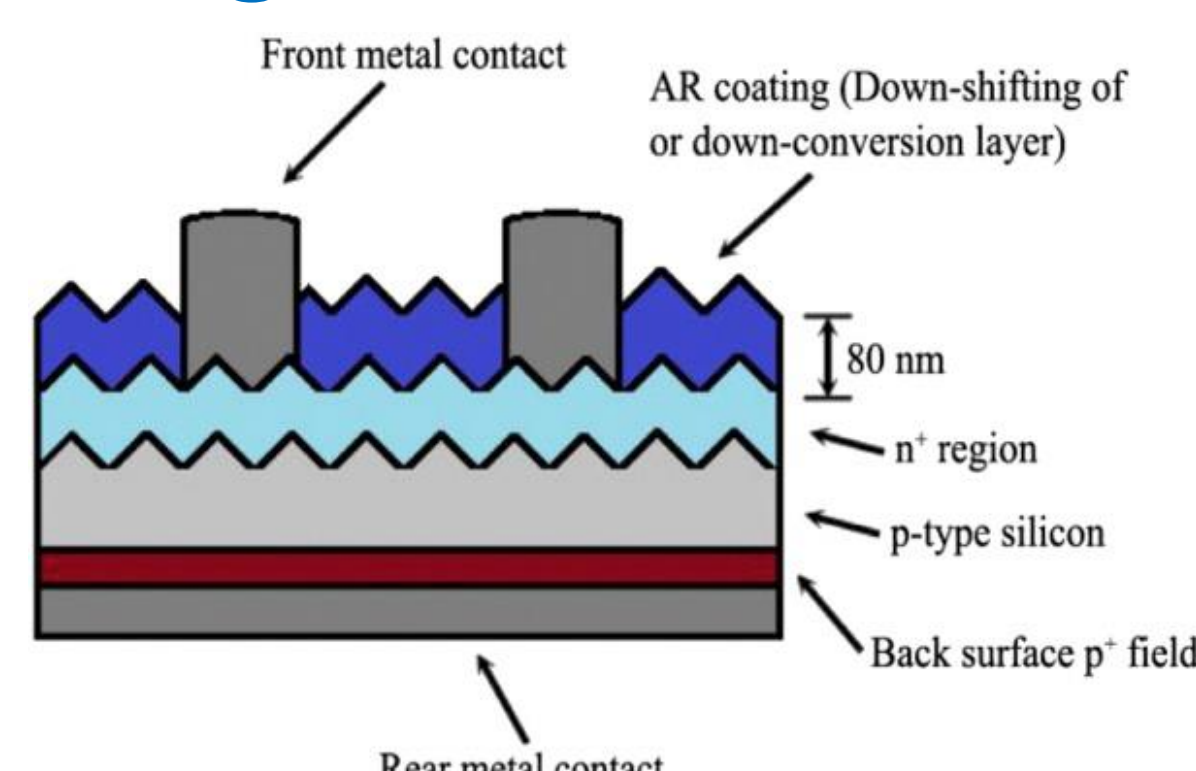


Two kinds of Tb^{3+} - Yb^{3+} co-doped thin films fabricated homogenous and multilayer

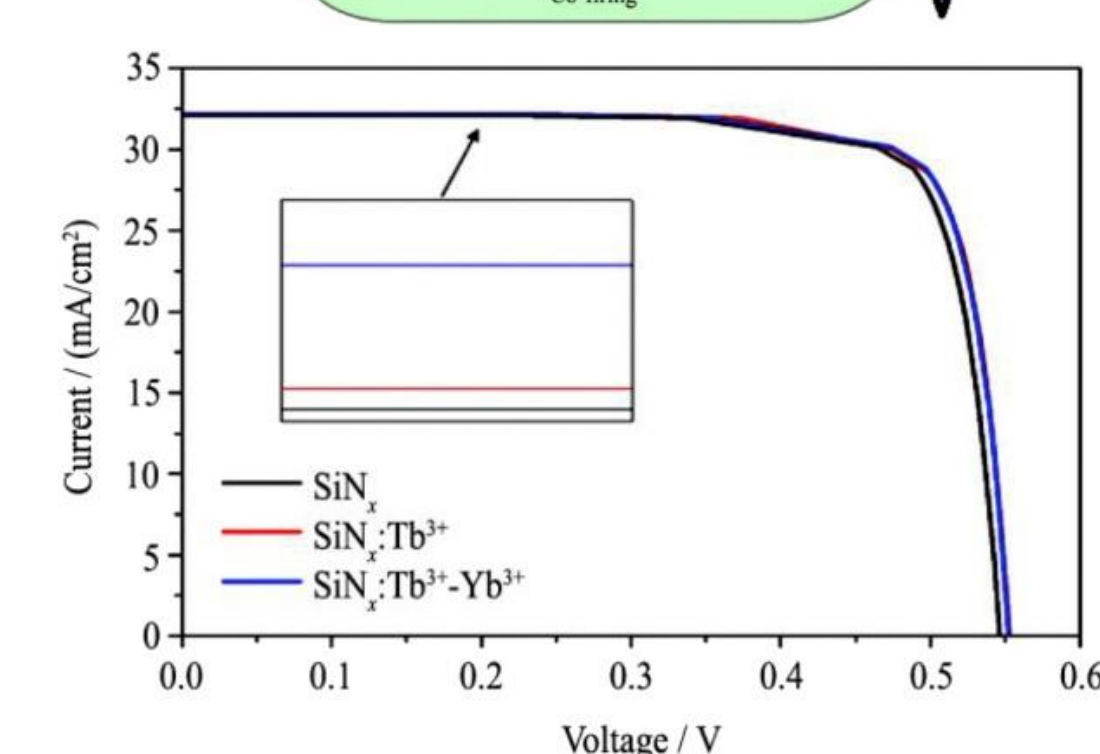
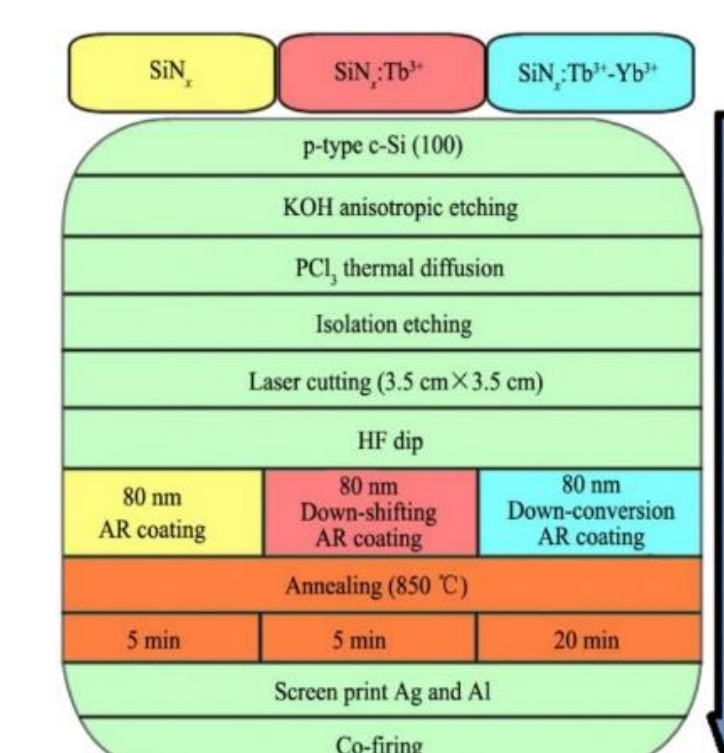


Multilayer prevent aggregation quenching and allow therefore higher doping rate

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 Si_{Nx} , $Si_{Nx}:Tb^{3+}$ and $Si_{Nx}:Tb^{3+}-Yb^{3+}$ layers, respectively.

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