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XXXII Cycle

Photonic Management for Quantum Dot Solar Cells

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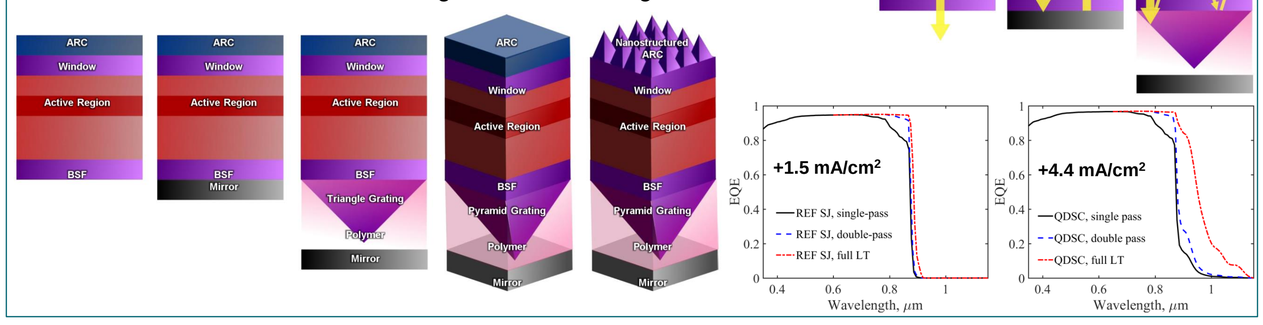
Supervisor: Prof. Federica Cappelluti

Research context and motivation

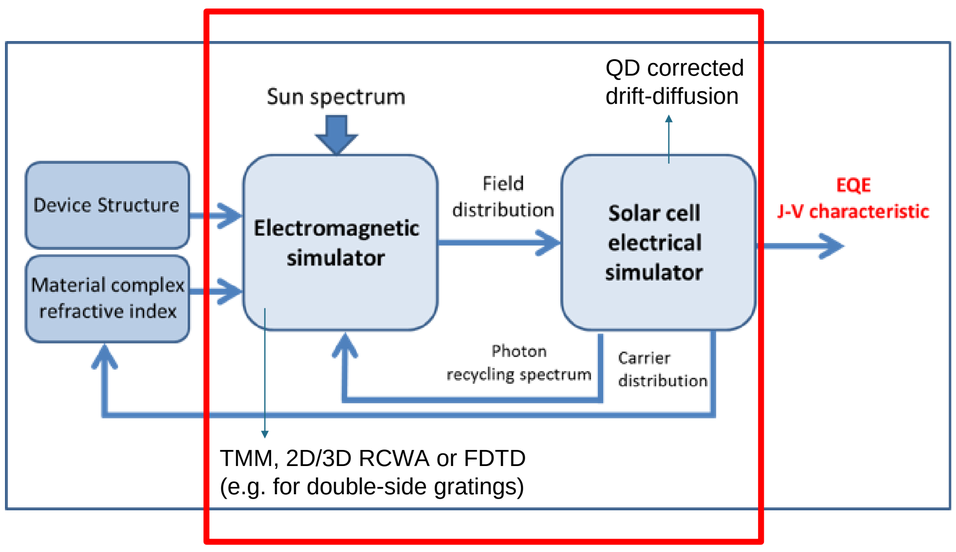
Light-Trapping Enhanced Solar Cells

- Substrate removal enables the integration of rear reflectors
- Photonic management is indispensable to achieve high efficiency for ultrathin cells or ones utilizing weak absorbing materials.



Addressed research questions/problems

Coupled ELM - transport simulation



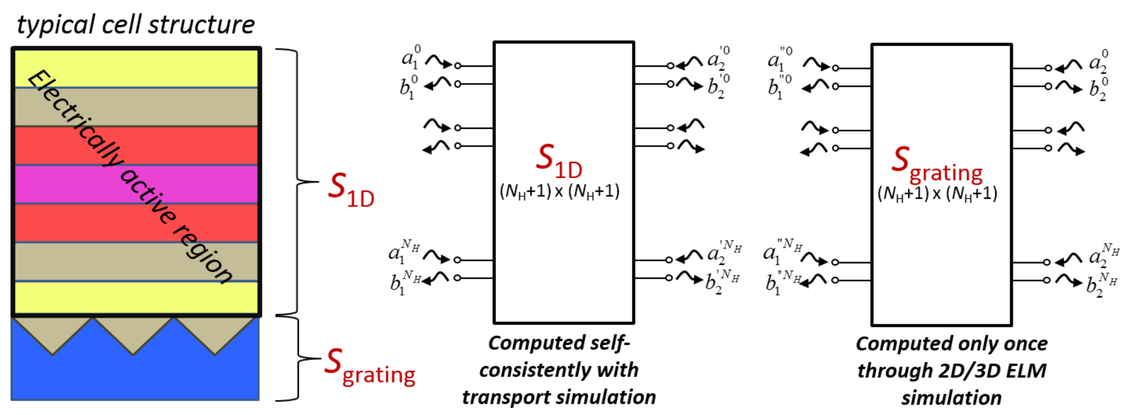
Self-consistency needed for

- QDs owing to strong dependence of optical properties on local carrier density
- Photon-recycling

Challenge: a "brute-force" feedback is too much computationally intensive for cells with textured surfaces (2D and 3D full ELM required)

Adopted methodologies

- Relying on the structure periodicity, the electromagnetic field is expanded in terms of **Floquet modes** (plane waves)
- Study the **multilayer planar** (where photogeneration must be enhanced) and the **patterned regions** (requiring intensive full-wave ELM simulations) ***separately***
- The optical response of each region is described by a **multimode scattering matrix**. The optical response of the solar cell is described by **cascading $S_{grating}$ and S_{1D}**



List of attended classes

- 01RLUPE – Solid state physics/Electronic devices (2016, 12 credits)
- 01NOPOQ – Photonic devices (2016, 6 credits)
- 01QRNRV – Electromagnetic dosimetry in MRI (2017, 4 credits)
- 01RZLKI – Nanometric dielectrics: Achievements & future challenges (2017, 4 credits)
- 01QFDRV – Photonics: a key enabling technology for engr. applications (2017, 5 credits)
- 02RHQRV – Intellectual Property Rights, Technology Transfer and Entrepreneurship (2017, 9 credits)

Awards

Best Poster Award

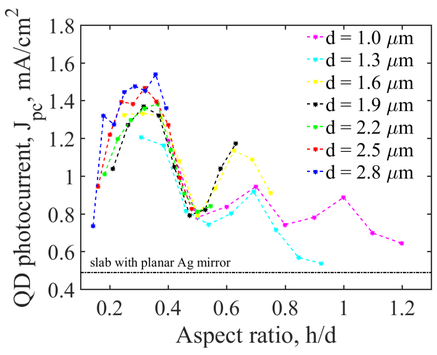
Photovoltaics School, Les Houches School of Physics, Chamonix, France, March 2018

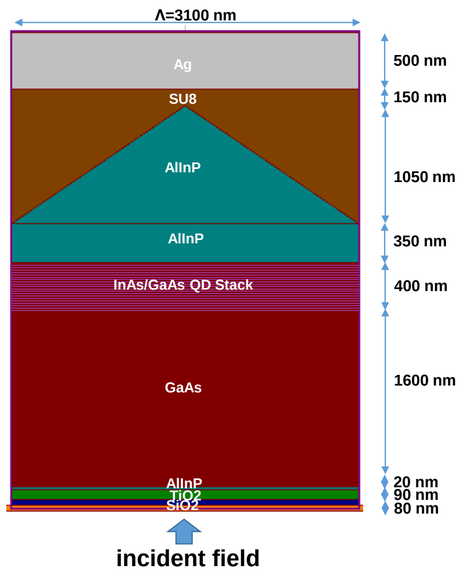
Novel contributions

Cascaded ELM model validation

The method is now assessed on a realistic solar cell, with the following simulation features:

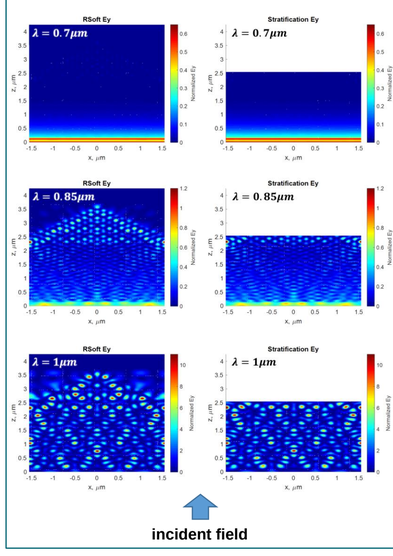
- RSoft DiffractMOD (Commercial RCWA)
- Harmonics = 50
- Resolution in Z direction = 10 nm
- Wavelength range = 400 – 1200 nm
- TE Mode





ELM model validation

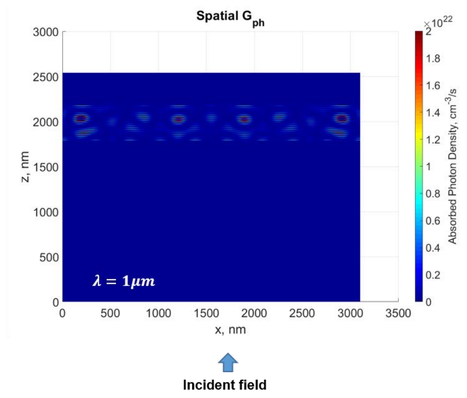
Cascaded structure *E*-field maps. The E_y fields are reconstructed with high accuracy.



Using the electrical field map and the optical models for the materials, it is possible to compute the photogeneration rate assuming quantum yield = 1 (for each photon absorption, one e/h pair)

$$g_{ph}^{V}(\lambda) = \int_V n\alpha|\mathbf{E}|^2 dV(\lambda)\, SPF(\lambda)$$

V : volume
n : refractive index
α : absorption coefficient
SPF : incident photon density for AM1.5G



Future work

- Fully coupled electrical-optical simulations
- Equivalent pyramidal grating modelling
- Simulating random textured surfaces
- Applying light trapping concepts on different cell configurations
- Novel solar cell parameter optimization methods

Submitted and published works

- Cappelluti, F., Tukiainen, A., Aho, T., **Elsehrawy, F.**, et. al, 2019. Quantum dot based thin-film III-V solar cells. In *Quantum Dot Optoelectronic Devices*. Springer, New York, NY. Submitted.
- Aho, T., Tukiainen, A., Ranta, S., **Elsehrawy, F.**, Raappana, M., Isoaho, R., Aho, A., Cappelluti, F. and Guina, M., 2019. Influence of a back reflector to thin-film MBE grown III-V quantum dot solar cell. *Applied Physics Letters*. Submitted.
- Aho, T., Tukiainen, A., Ranta, S., **Elsehrawy, F.**, et. al, 2019. Enhancement of EQE for MBE grown InAs/GaAs Quantum Dot Solar Cell with Back Reflector. In *2019 IEEE 46th Photovoltaic Specialists Conference*.
- **Elsehrawy, F.**, Tibaldi, A. and Cappelluti, F., 2019, February. Efficient multiphysics modeling of thin-film solar cells with periodically textured surfaces. In *Physics, Simulation, and Photonic Engineering of Photovoltaic Devices VIII* (Vol. 10913, p. 109130K). International Society for Optics and Photonics.
- Khalili, A., Tibaldi, A., **Elsehrawy, F.** and Cappelluti, F., 2019. SPIE Photonics. Multiscale device simulation of quantum dot solar cells. In *Physics, Simulation, and Photonic Engineering of Photovoltaic Devices VIII* (Vol. 10913, p. 109131N).
- **Elsehrawy, F.**, et. al, 2018. Improved Light Trapping in Quantum Dot Solar Cells Using Double-sided Nanostructuring. In *Optics and Photonics for Energy and the Environment* (pp. JM4A-5). Optical Society of America.
- Cappelluti, F., Kim, D., Eerden, M., Cédola, A.P., Aho, T., Bissels, G., **Elsehrawy, F.**, et. al, 2018. Light-trapping enhanced thin-film III-V quantum dot solar cells fabricated by epitaxial lift-off. *Solar Energy Materials and Solar Cells*, *181*, pp.83-92.
- Aho, T., Guina, M., **Elsehrawy, F.**, Cappelluti, F., et. al, 2018, June. Metal/Polymer Back Reflectors with Diffraction Gratings for Light Trapping in III-V Solar Cells. In *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)* (pp. 2847-2851). IEEE.
- **Elsehrawy, F.**, Niemi, T. and Cappelluti, F., 2018. Guided-mode resonance gratings for enhanced mid-infrared absorption in quantum dot intermediate-band solar cells. *Optics express*, *26*(6), pp.A352-A359.
- Aho, T., Guina, M., **Elsehrawy, F.**, Cappelluti, F., et. al, 2018. Comparison of metal/polymer back reflectors with half-sphere, blazed, and pyramid gratings for light trapping in III-V solar cells. *Optics express*, *26*(6), pp.A331-A340.
- Aho, T., Niemi, T., Cappelluti, F., Tukiainen, A., **Elsehrawy, F.** and Guina, M., 2017. Structured Metal/Polymer Back Reflectors for III–V Solar Cells. In *Optics and Photonics for Energy and the Environment* (pp. JW5A-23). OSA.
- **Elsehrawy, F.**, Niemi, T. and Cappelluti, F., 2017. Guided-mode resonance gratings for intermediate band quantum dot solar cells. In *Optical Nanostructures and Advanced Materials for Photovoltaics* (pp. PM3A-4). OSA.
- Cappelluti, F., Cedola, A.P., Khalili, A., **Elsehrawy, F.**, et. al, 2017. Enabling high-efficiency inas/gaas quantum dot solar cells by epitaxial lift-off and light management. In *2017 IEEE 44th Photovoltaic Specialists Conference (PVSC)*.
- **Elsehrawy, F.**, Cappelluti, F., et. al, Back grating optimization for light trapping in thin-film quantum dot solar cells. In *19th Italian National Conference on Photonic Technologies (Fotonica 2017)* (pp. 1-4). IET.

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering