PLANS
Plasmonics and nanoantennas for solar cells

Project Leader: ***Giancarlo Righini***

Project Coordinator: ***Maurizio Ferrari*** *(IFN CNR, Trento)*

Participants:

- **Giancarlo Righini,** *Centro Fermi, CF's associate*
- **Fabrizio Coccetti,** *Centro Fermi, technologist ("primo tecnologo")*
- **Enrichi, Francesco**, *Centro Fermi, research grant (exp. 30/4/2018)*
- **Maurizio Ferrari,** *IFN CNR, researcher ("primo ricercatore")*
- **Stefano Pelli,** *IFAC CNR, researcher*
- **Alex Quandt,** *Univ. of Witwatersrand, full prof. and CF's associate*
- **Daniel Wamwangi,** *Univ. of Witwatersrand, lecturer*
- **Lidia Zur,** *Centro Fermi, research grant (exp. 31/12/2018)*

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Place of Work & Collaborations:

- Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
- Istituto di Fisica Applicata Nello Carrara (IFAC CNR), Firenze
- Istituto di Fotonica e Nanotecnologie (IFN CNR), Trento
- Dipartimento di Scienze Molecolari e Nanosistemi, Università Ca' Foscari Venezia
- Dipartimento di Ingegneria Industriale, Università di Padova
- Luleå University of Technology (Luleå, Sweden)
- School of Physics, University of Witwatersrand, Johannesburg (Sud Africa)

This project is co-funded by MAECI *(Ministry of Foreign Affairs) as a 2015-2017* ***great relevance project*** *in the frame of the collaboration between Italy and South Africa (Centro Fermi – University of Witwatersrand)*

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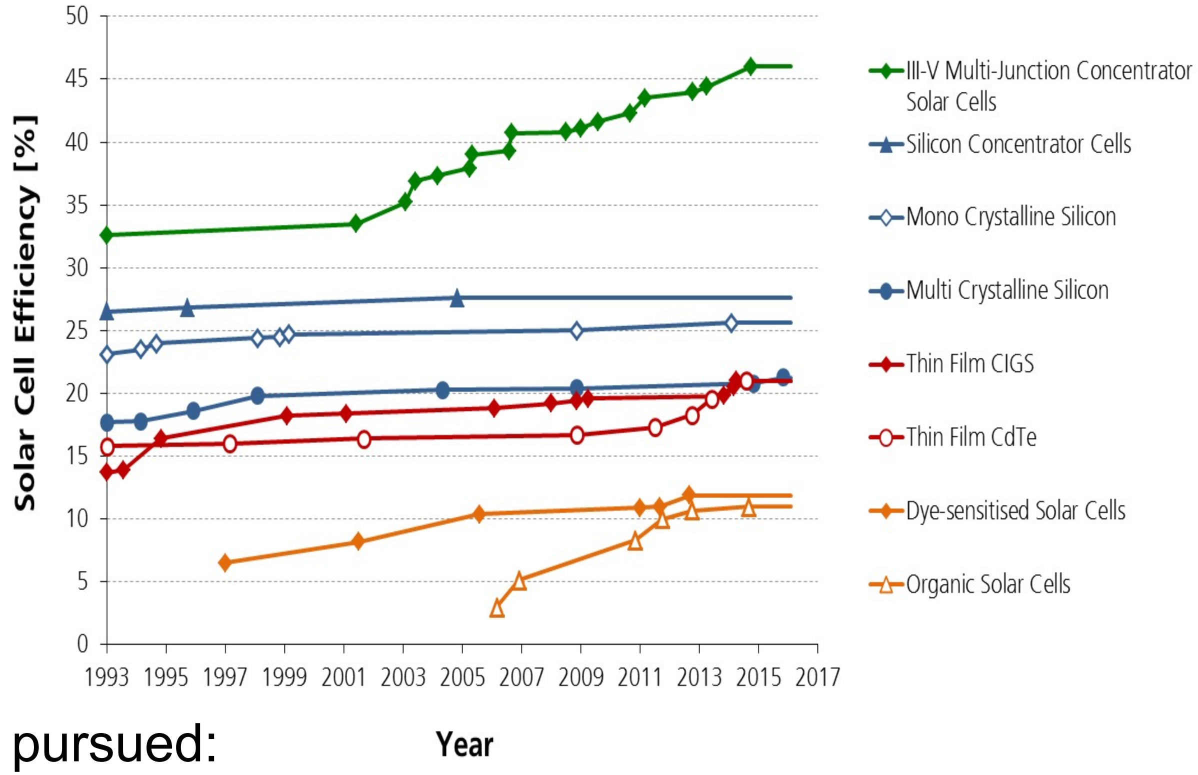
Main goal

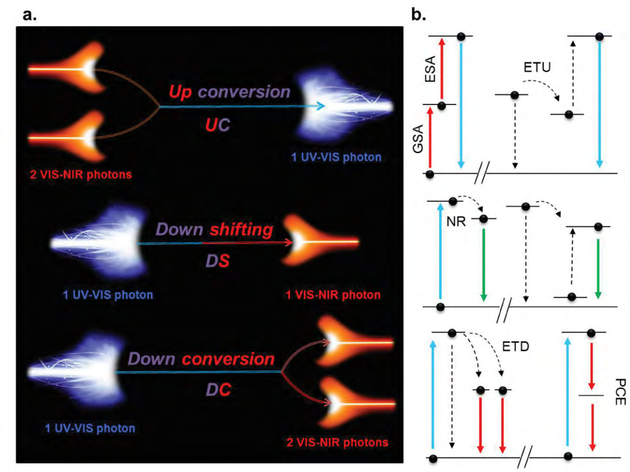
Develop structures and technologies to enhance the efficiency of current (Si) solar cells.

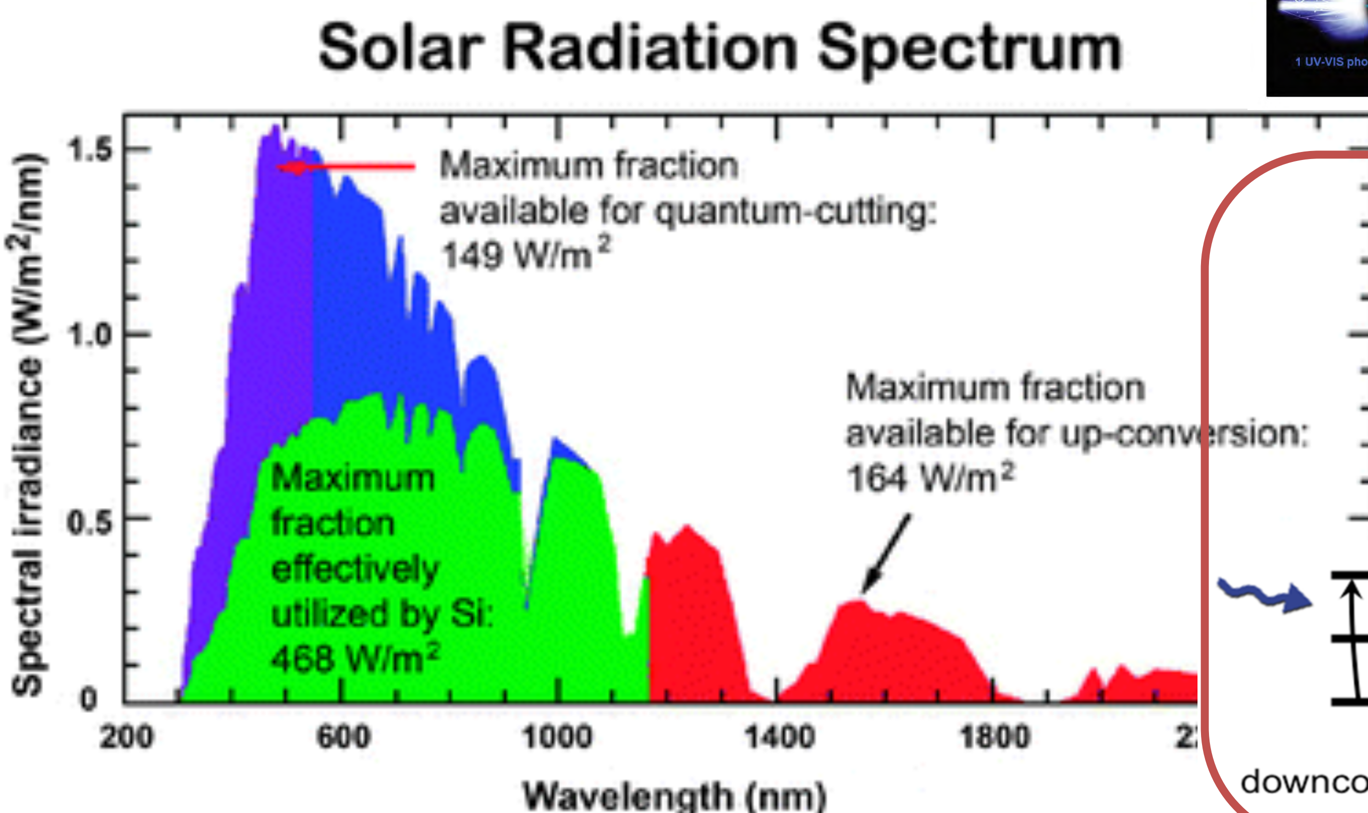


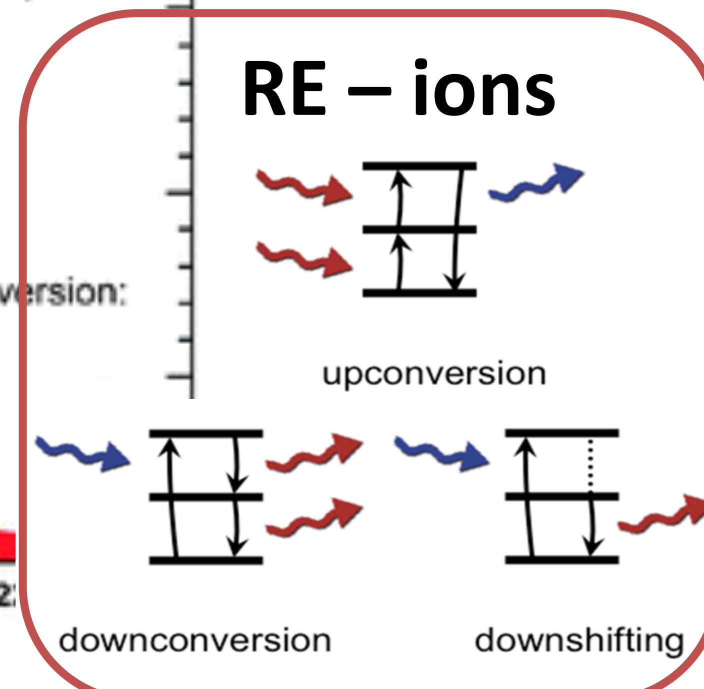
Two approaches are being pursued:

- To increase efficiency through a better exploitation of the solar radiation spectrum (by using **up-** and **down-conversion** of the incident light’s frequency)
- To increase efficiency through a better harvesting of solar radiation (by using **plasmonic** structures)

Better exploitation of the solar spectrum: up- and down- frequency conversion







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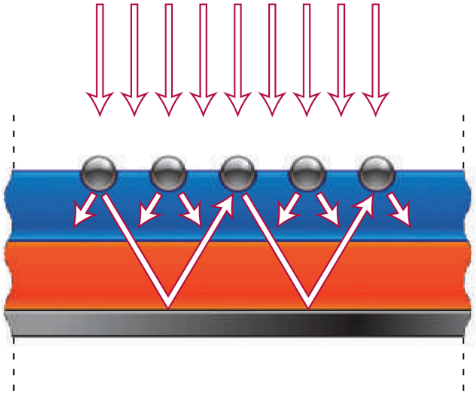
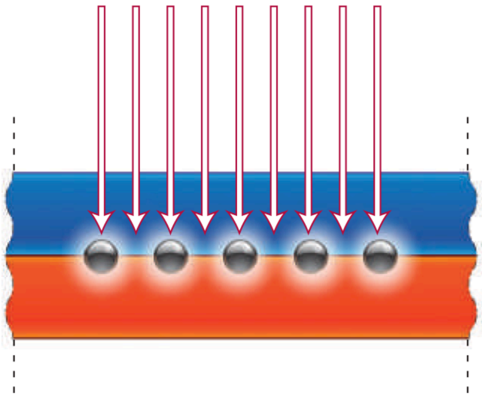
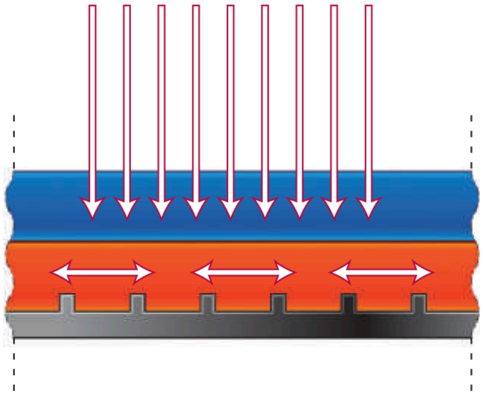


Light trapping by scattering from metal nanoparticles at the surface of the solar cell. Light is preferentially scattered and trapped into the semiconductor thin film by multiple and high-angle scattering, causing an increase in the effective optical path length in the cell.



Light trapping by the excitation of localized surface plasmons in metal nanoparticles embedded in the semiconductor.
The excited particles' near- field causes the creation of electron–hole pairs in the semiconductor.



Light trapping by the excitation of surface plasmon polaritons at the metal/semiconductor interface. A corrugated metal back surface couples light to Surface Plasmon Polariton or photonic modes that propagate in the plane of the semiconductor layer.

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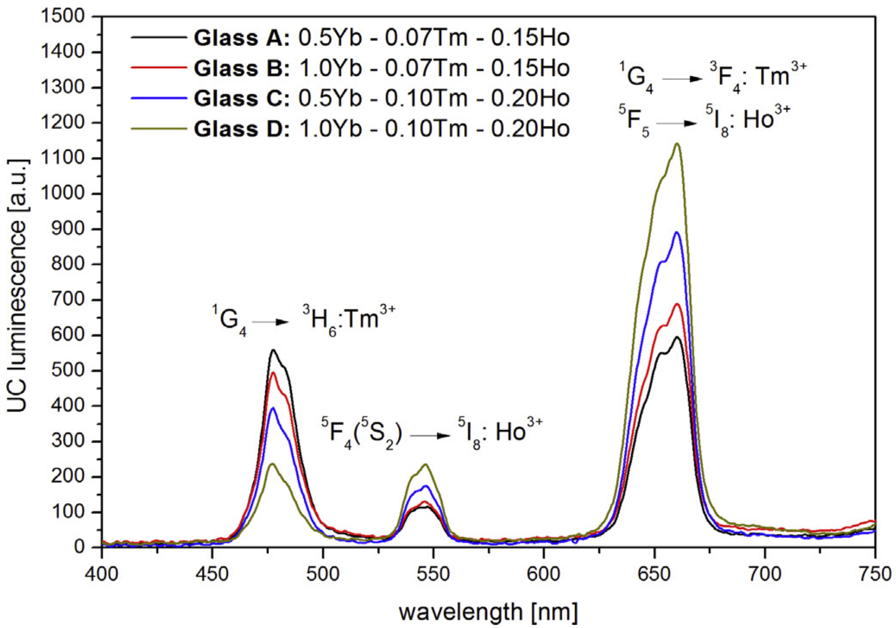
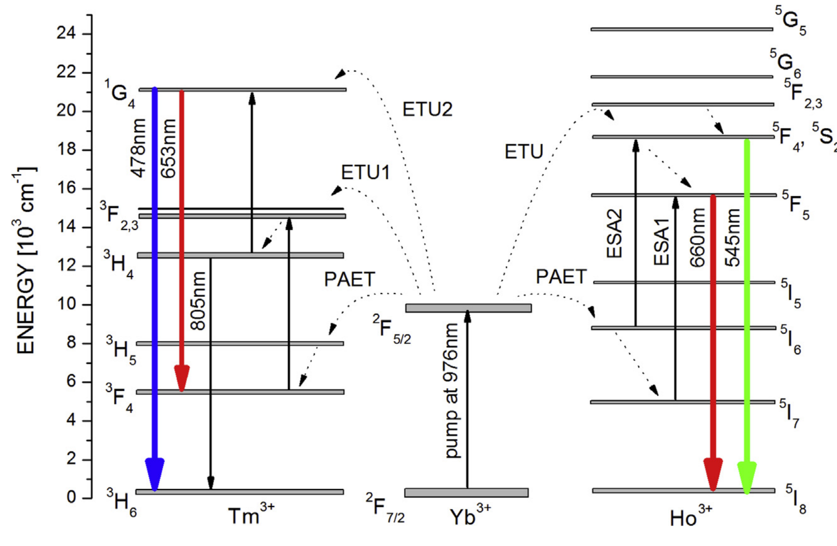
UP Conversion



Luminescence spectra of antimony-germanate glass doped with different content of Yb^{3+} ions and constant Tm^{3+}/Ho^{3+} ratio.

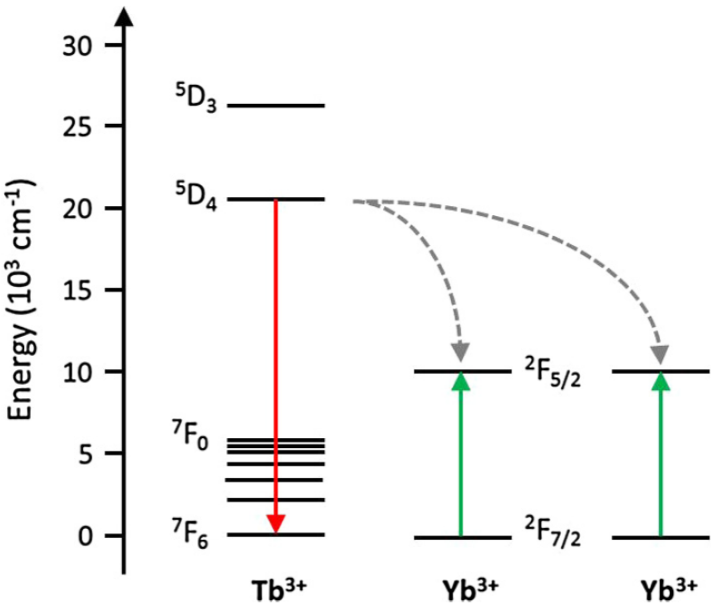


Simplified energy level scheme of Tm^{3+}, Yb^{3+} and Ho^{3+} ions with possible energy transfer up-conversion mechanisms.

G.C.Righini et al., *Investigation of upconversion luminescence in $Yb^{3+}/Tm^{3+}/Ho^{3+}$ triply doped antimony-germanate glass and double-clad optical fiber*, Optical Materials, 58 (2016) 279–284.

DOWN Conversion

Choice of the rare earths



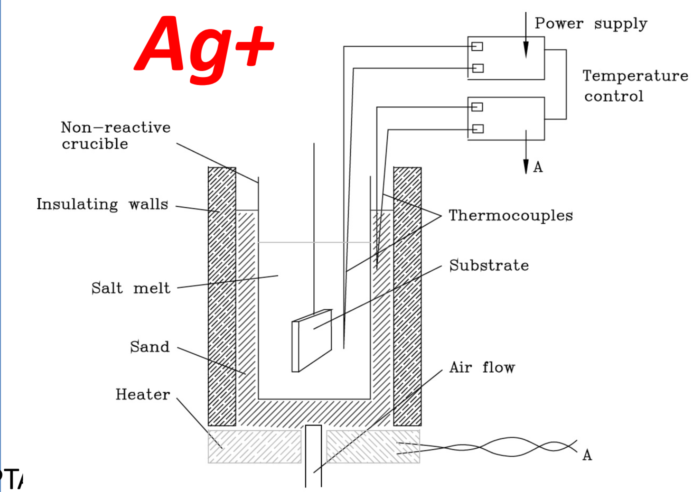
One blue photon @ 488nm

Two infrared photons @ 980 nm

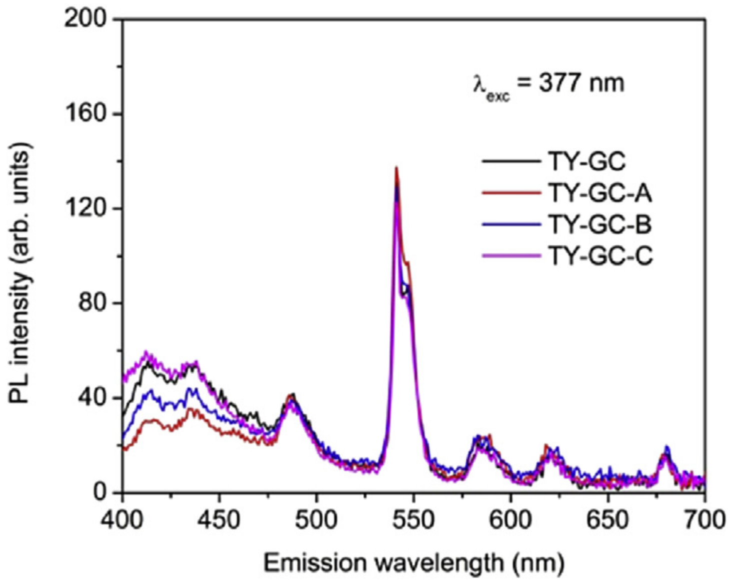
Choice of the host material

SiO_2-HfO_2 glass-ceramics

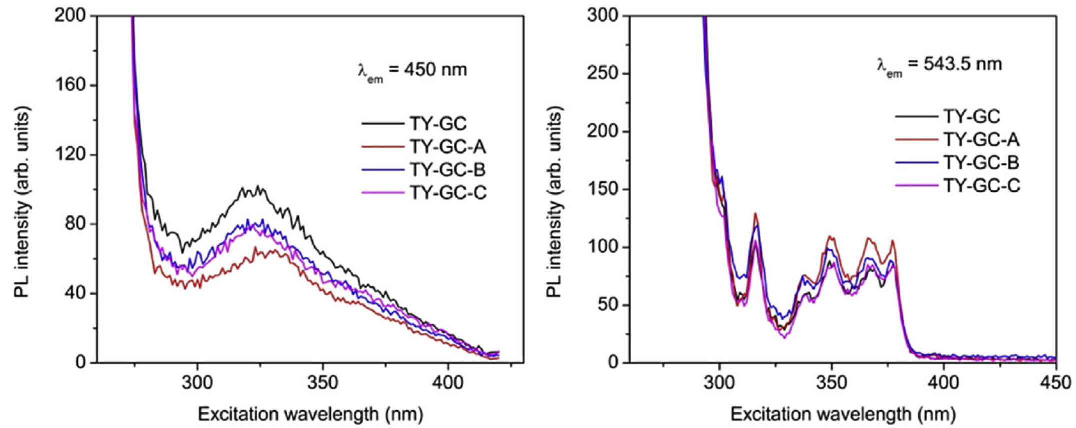
- ✓ Combine the advantages of glasses and the better spectroscopic properties of crystals.



Down Conversion + Ag^+ doping



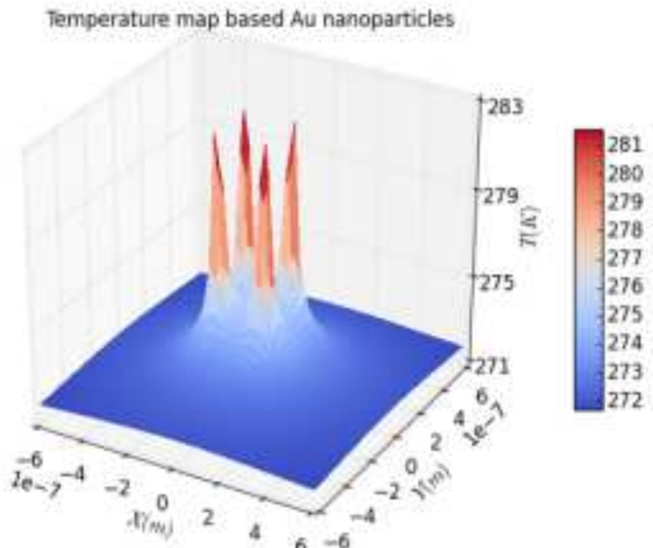
Photoluminescence emission spectra for the TY-GC samples before and after Ag-exchange and annealing; excitation wavelength is 377 nm.



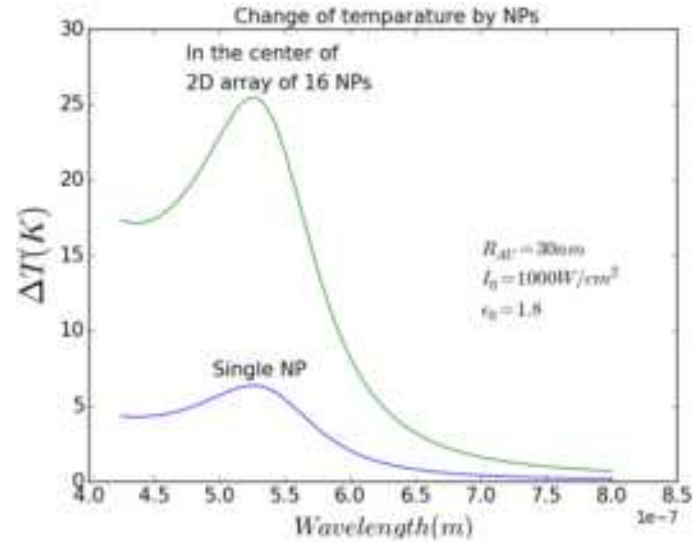
Photoluminescence excitation spectra for the TY-GC samples at 450 nm (left) and 543.5 nm (right) before and after Ag-exchange and annealing.

F. Enrichi et al., *Silver doping of silica-hafnia waveguides containing Tb^{3+}/Yb^{3+} rare earths for downconversion in PV solar cells*, Optical Materials, 60 (2016) 264-269.

Computational Plasmonics



Lateral temperature map for a matrix of 16 gold nanoparticles.



Temperature difference as a function of incoming wavelength for a single gold nanoparticle, and for an matrix of gold nanoparticles.

Simulation code:

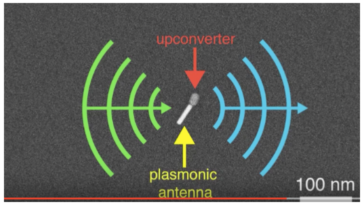
- The MIT Photonic-Bands (**MPB**) package is a package for computing the band structures (dispersion relations) and electromagnetic modes of periodic dielectric structures.
- The MIT Electromagnetic Equation Propagation (**MEEP**) implements the finite-difference time-domain (FDTD) method for computational electromagnetism.
- Custom python addons!!

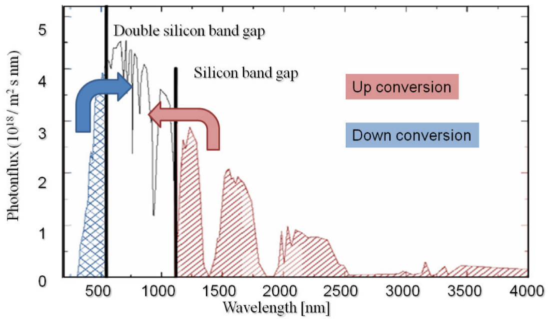
Quandt et al., *Chapter of the book "Computational Plasmonics"*, Springer, in press.

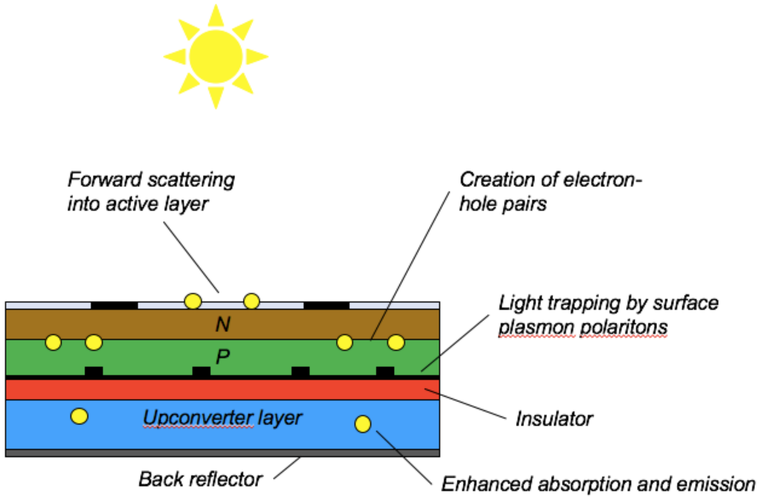
Plan of activities 2017 (this is the last year of the project)

- *Development and characterization of films (glasses and glass-ceramics) containing rare earth ions and Ag^{+};*
- *Development of plasmonic waveguides to capture the solar radiation;*
- *Development of computer codes for the simulation of the proposed structures.*

- ***Development of a proof-of-concept device, with enhanced efficiency with respect to standard silicon solar cells !!***







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CENTRO FERMI
Museo Storico della Fisica e
Centro Studi e Ricerche Enrico Fermi

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Ministero degli Affari Esteri
e della Cooperazione Internazionale

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PLESC

La plasmonica per una migliore efficienza delle celle solari

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- I ricercatori
- Pubblicazioni
- Workshop 2016 Trento
- Workshop 2016 Johannesburg

PLESC

PLESC è un **progetto di grande rilevanza** finanziato dal Ministero degli Esteri e della Cooperazione Internazionale (MAECI) nell'ambito dell'accordo tra Italia e Sud Africa.

Il progetto

Alcune energie rinnovabili, come quelle idroelettriche, marine, eoliche e solari, sono già tecnologicamente mature. Anche se ora è difficile predire se e quale sarà la fonte energetica rinnovabile in grado di soddisfare il fabbisogno mondiale, è certo che l'energia solare avrà un ruolo molto importante. Il settore dell'energia solare può trarre vantaggio dai continui sviluppi di materiali, nanotecnologie e informatica più di quanto possono fare altri settori.
Una soluzione certamente promettente è quella del fotovoltaico a concentrazione (CPV), che usa celle multi-giunzione di semiconduttori III-V, che hanno raggiunto un'efficienza record del 46% (e il Centro Fermi ha in corso un progetto di ricerca sul CPV, in collaborazione con l'Università di Padova e alcune aziende).
Tuttavia attualmente la maggior parte del mercato è costituita da celle di silicio cristallino (costoso e con un record di efficienza pari al 24,4%) o amorfo (meno costoso ma anche meno efficiente). Un limite del silicio è costituito dalla capacità di sfruttare solo una parte dello spettro solare; un modo di allargare la sensibilità spettrale e quindi aumentare l'efficienza può essere quello di usare strutture plasmoniche.

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Expected funding: this project will end this year.

Request of funding by Centro Fermi

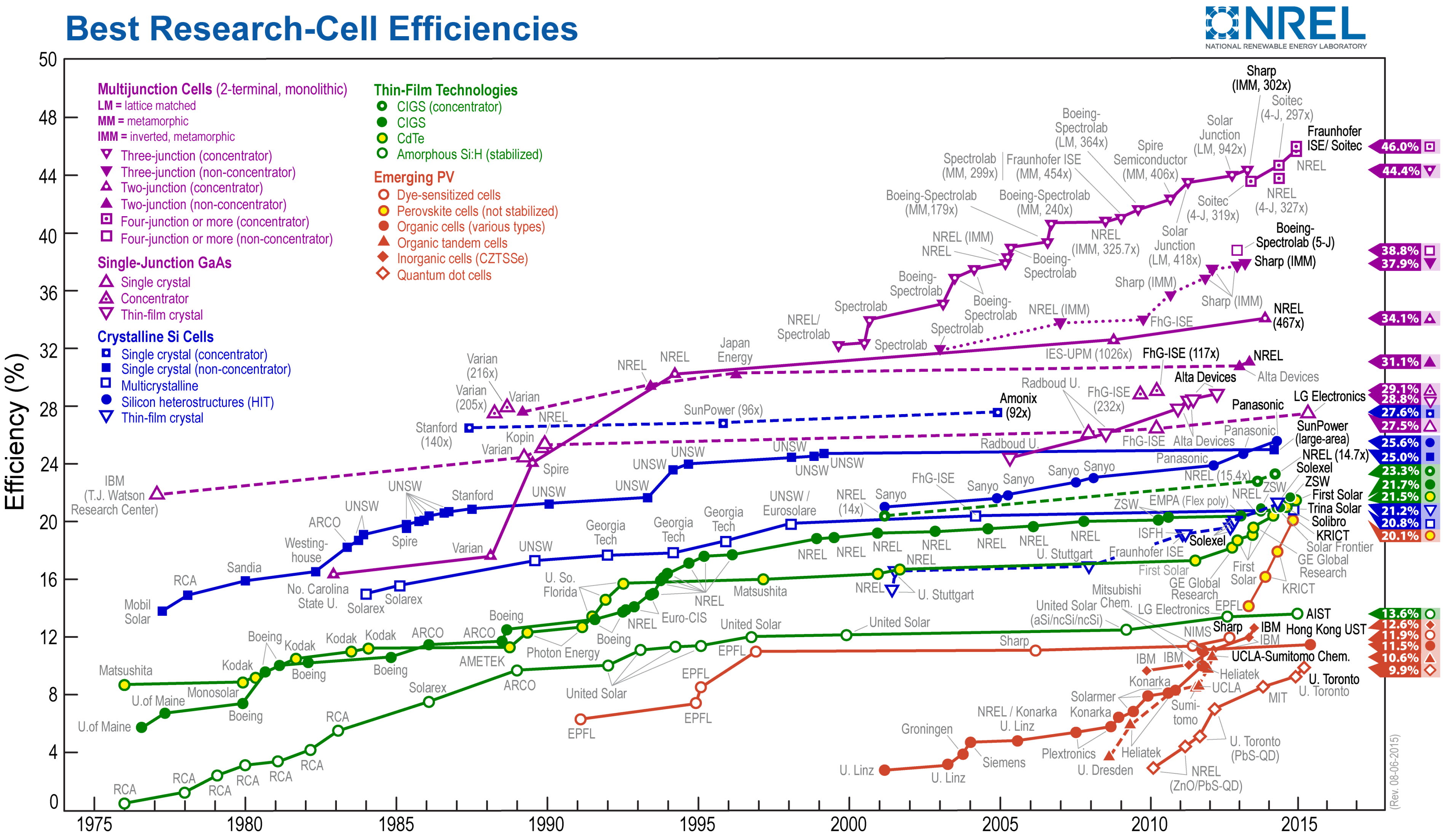
- *In 2017 we ask ~25k€ cash funding to co-finance the contribute given by MAECI.*
- *Part of the co-financing by Centro Fermi is provided in-kind (FC's salary)*

Potential external funding

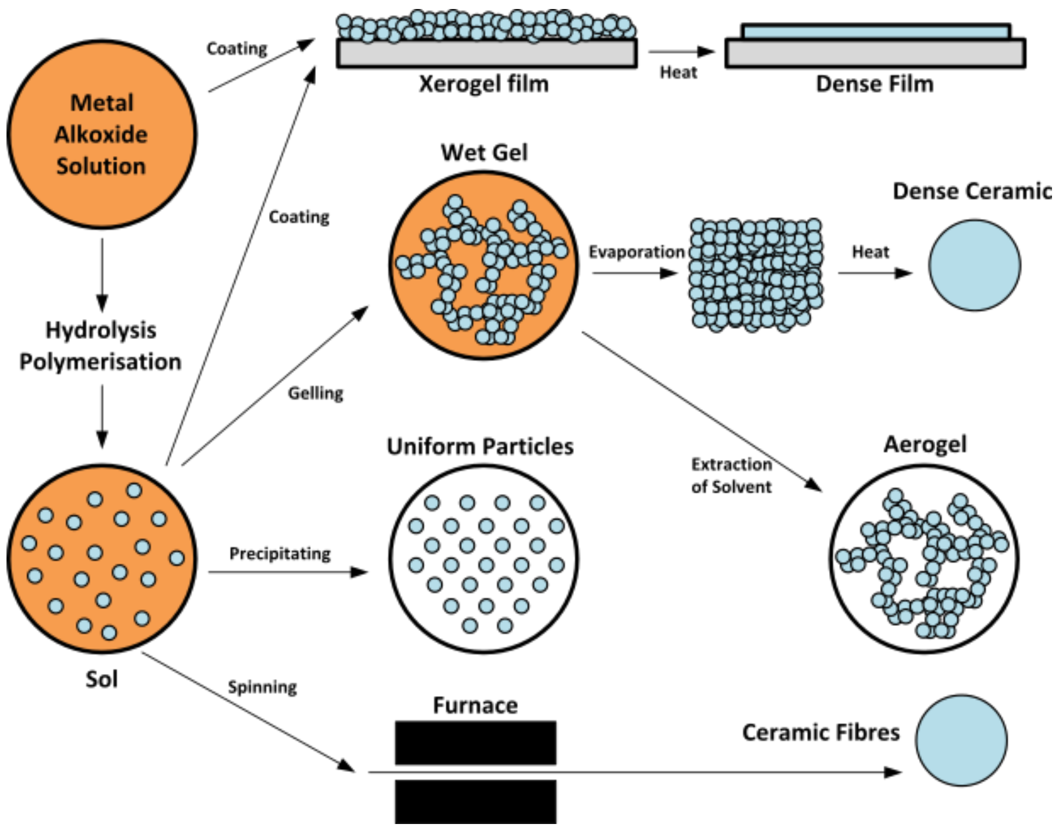
- *The funding by the **Ministry of Foreign Affairs (MAECI)** in 2017 is expected to be ~ **30,000** €. (Science attaché of the embassy in SA took part in our workshop 2016 in Johannesburg).*
- *Luleå University of Technology is financing the activity of Dr. Enrichi (~10,000 €)*

SPARES

Research Cell Efficiency Records



Schematic representation of the different stages and routes of the sol-gel technology.



PLASMONICA e NANOANTENNE per CELLE SOLARI (*PLANS*)

PLASMONS AND POLARITONS

Plasmon	Polariton
Collective oscillations of electron gas (conducting electrons), characterized by plasma frequency $\omega_p^2 = \frac{ne^2}{\varepsilon_0 m^*}$	Quasiparticles that are a mixture of photon modes and polarization modes.
Model: Vibrations of electron gas relative to fixed lattice of positive ions, and within external electromagnetic field.	**Model:** Interaction of electromagnetic field with polarizable matter ($\varepsilon(\omega)$).