EAGLES
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Rare-Earth Doped Glass Materials and Fibre Lasers
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Rare earth activated silica-hafnia glass and glass ceramics to improve the efficiency of photovoltaic solar cells

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FONDAZIONE BRUNO KESSLER

This project is part of a CNRST-Morocco / CNR-Italy agreement

Photovoltaic cells will be delivered by the company:

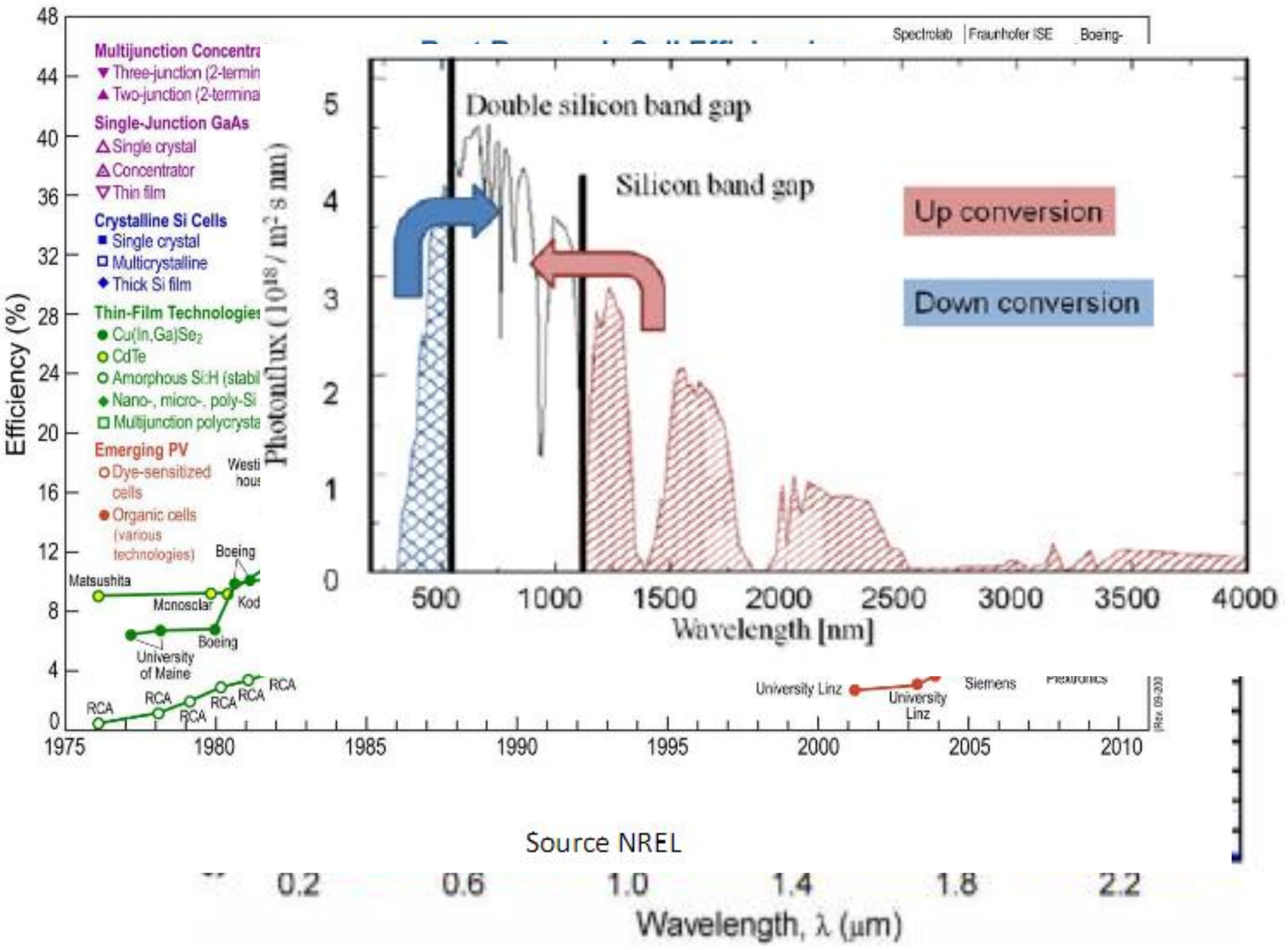
MeridionaleImpianti

Address: Strada provincial Belpasso Bivio Aspro - Piano Tavola 95121 CATALANA Italy

Introduction

Recent years have seen the development of large research on renewable energy and in particular photovoltaic.

•For the multijunction based on GaAs the conversion efficiency reaches more than 40%.
• The conversion efficiency between 20 and 25% crystalline Si.
•while organic emerging sectors the conversion efficiency does not exceed 7- 8%.



Source NREL

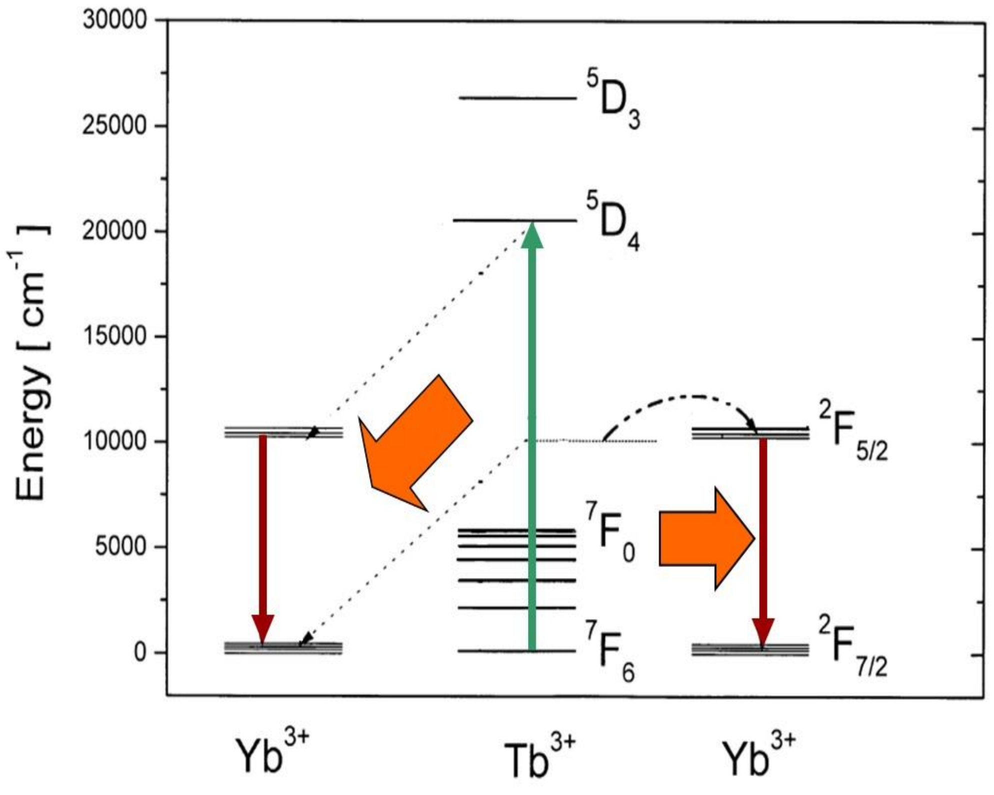
•Photons with energies smaller than the silicon band gap are not absorbed, and their energy is totally wasted.

•Photons with energies larger than twice the silicon band gap are absorbed, but the excess energy is lost to heating.

Down and up converter layer for solar cells

Energy transfer with Tb^{3+}/ Yb^{3+}

Quantum cutting



hv

One blue photon @ 488nm → Two infrared photon @ 980 nm

Down conversion shifts photons from a high-energy band to the maximum absorption band of silicon.

Up conversion

Donor/acceptor	Frequency conversion
Pr^{3+}/Yb^{3+}	Blue (440nm) → NIR (2 emitted photons: 1000 nm)
Tm^{3+}/Yb^{3+}	Blue (478nm) → NIR (2 emitted photons: 1000 nm)
Tb^{3+}/Yb^{3+}	Blue (485nm) → NIR (2 emitted photons: 1000 nm)
Ce^{3+}/Yb^{3+}	UV-blue (4f-5d 330 borate to 450 nm YAG) → NIR
Ho^{3+}/Yb^{3+}	Blue (~450 nm)→NIR (2 emitted photons: 985+1180 nm)
Er^{3+}/Yb^{3+}	Violet-Blue-Green → NIR MP relaxation 4F7/2 (2 emitted photons: 1000 + 1500 nm)

Si c-Si Solar Cell
Up converter layer
hv
hv
hv
Si

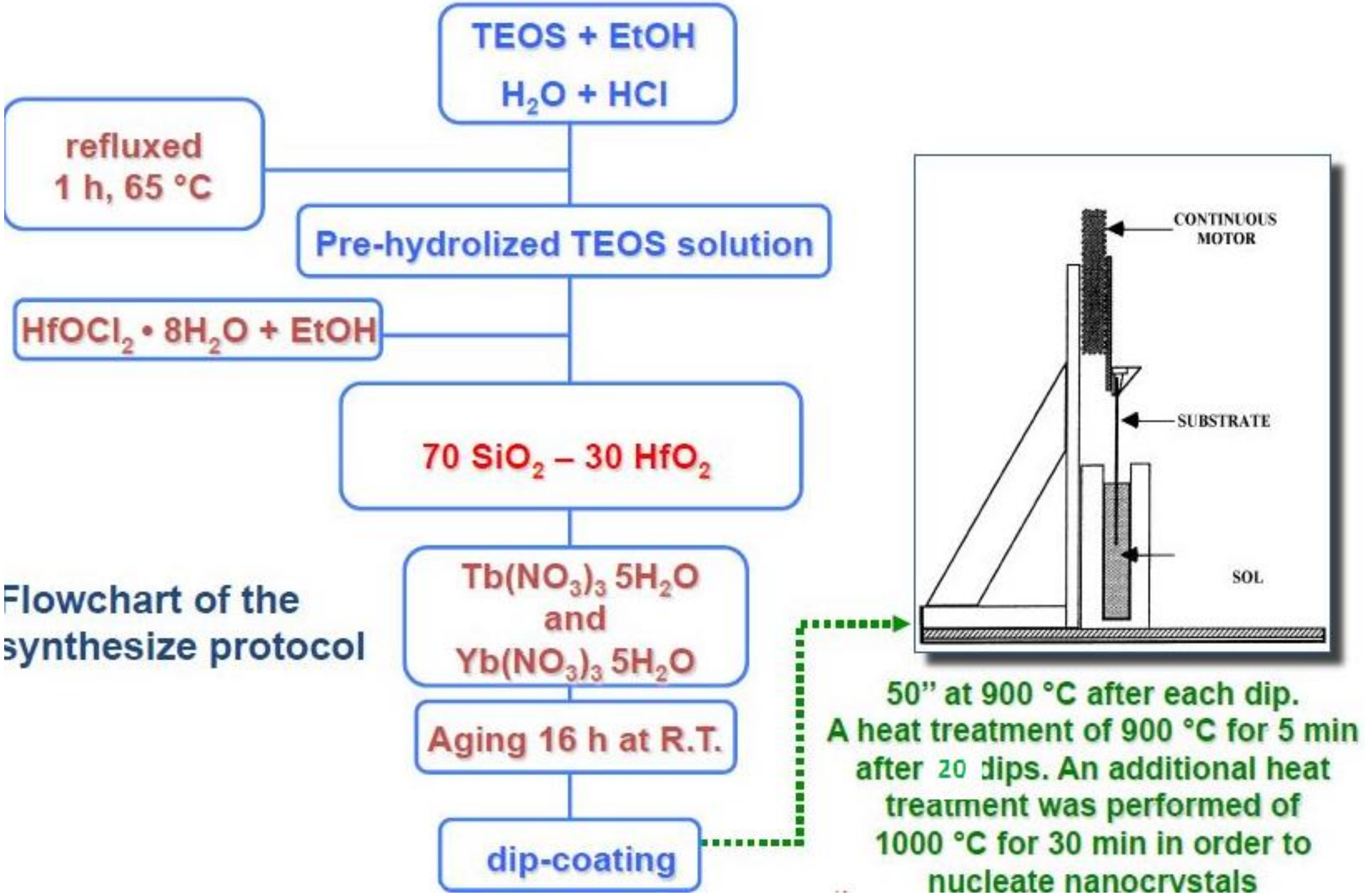
Up conversion shifts photons from a low-energy band to the maximum absorption band of silicon.

Choice of the rare-earth host

Glass Ceramics

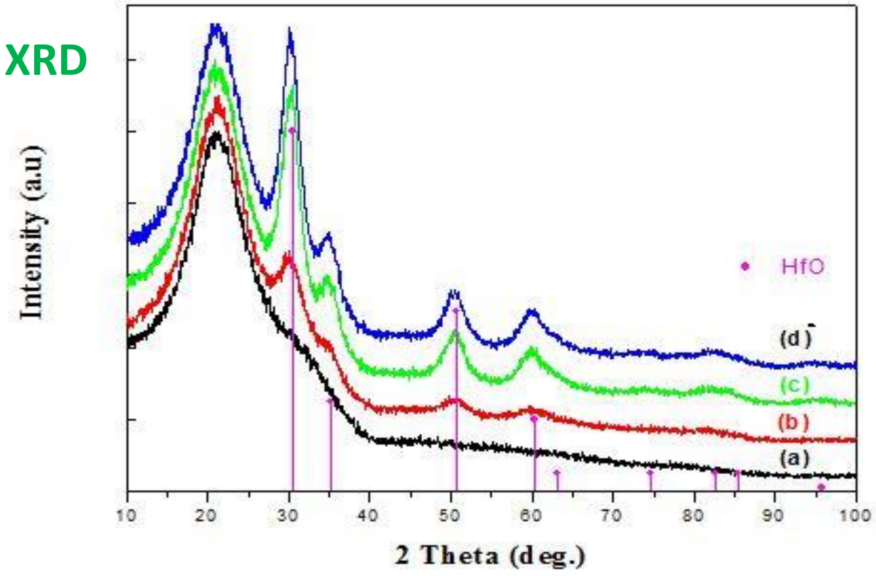
- Combine the advantages of glasses and crystals
- Better spectroscopic properties then glasses
- Transparency

Experimental: synthesize protocol



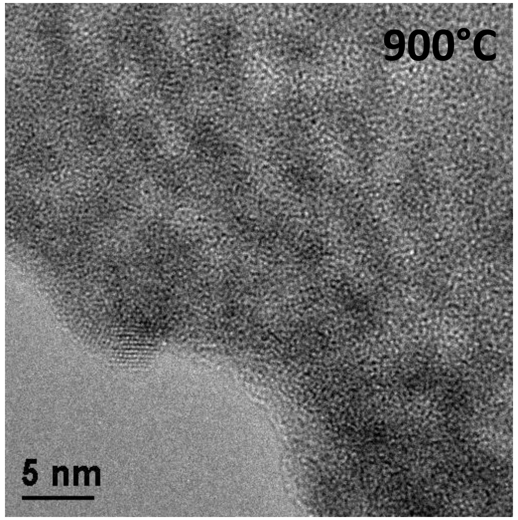
Structural characterization

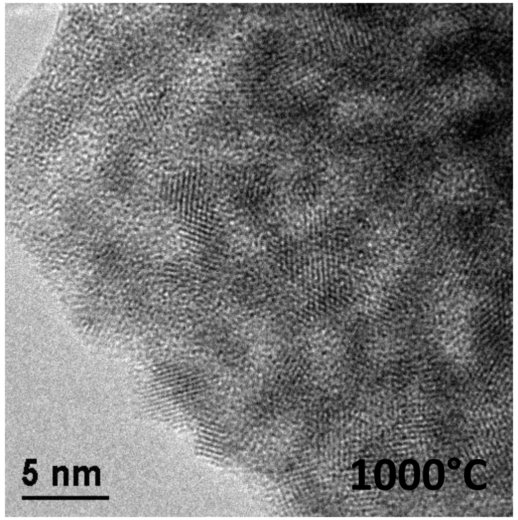
XRD



- Non-crystalline phase (hump centred at 2θ ≈ 21◦) is contributed to the amorphous structure of silica.
- Thin film treated at 900°C is completely amorphous
- Crystallization occurs after heat treatment at 1000°C for 30 min.
- Diffraction peaks become more intensive by increasing the concentration of rare earth →**rare earth ions are embedded in hafnia nanocrystals.**

TEM

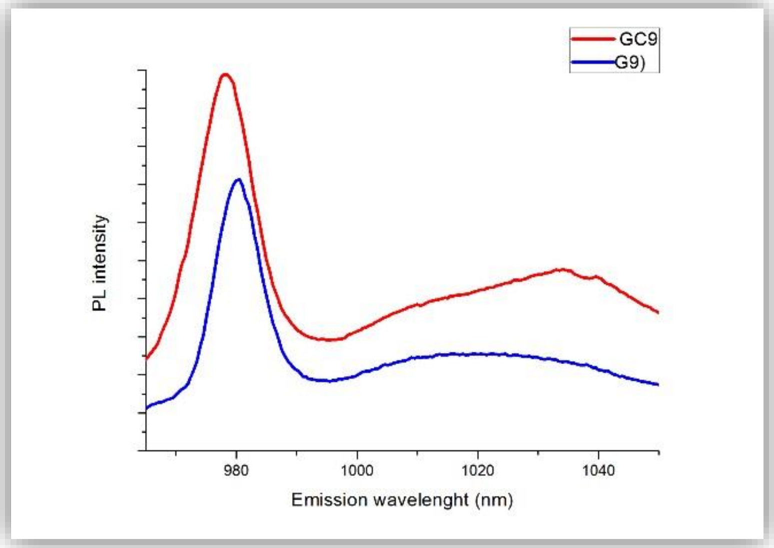




- The difference in the two samples is the final annealing temperature at 900 °C or 1000 °C.
- Sample treated at lower temperature is amorphous
- Higher temperature treatment induces the precipitation of small crystallites whose size is of the order of 2-3 nm.

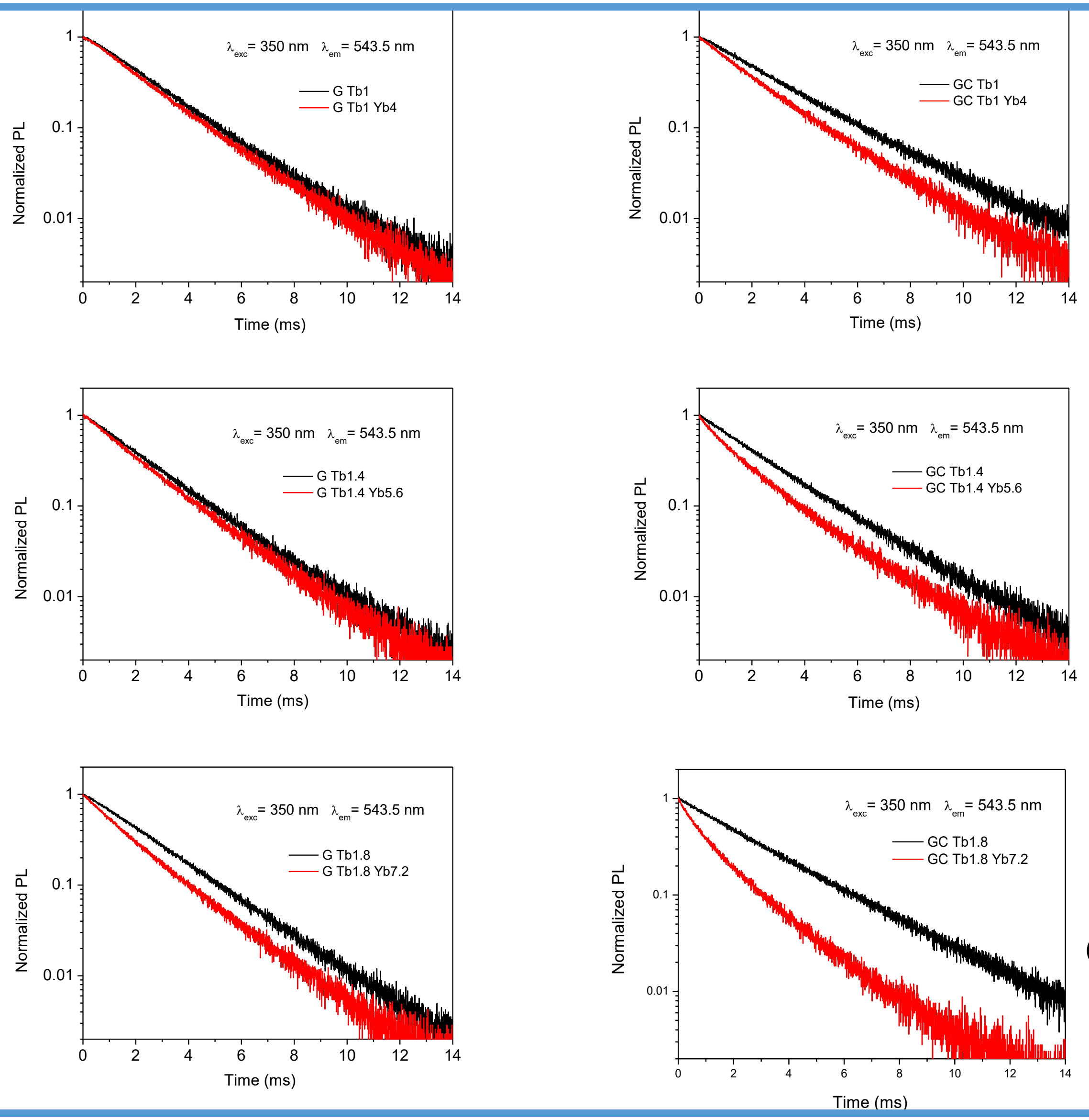
Photoluminescence spectrum

Room temperature photoluminescence spectrum of the $^2F_{5/2} \rightarrow {}^2F_{7/2}$ transition of Yb^{3+} ions after excitation at **476 nm**



The emission of the Yb^{3+} ion after excitation at 476 nm is an indication of the presence of an **efficient energy transfer from Tb^{3+} to Yb^{3+}.**

Decay curves analysis



The evaluation of the energy transfer efficiency between Tb^{3+} and Yb^{3+} can be obtained by comparing the luminescence decay of terbium with and without ytterbium co-doping ions.

Energy transfer efficiency between Tb^{3+} and Yb^{3+} :

$$\eta_{RE-Yb} = 1 - \frac{\int I_{RE-Yb}\,dt}{\int I_{RE}\,dt}$$

The relation between the transfer efficiency and the **effective quantum efficiency is linear and is defined as:**

$$\eta_{EQE} = \eta_{RE-r}(1-\eta_{RE-Yb}) + 2\eta_{RE-Yb}$$

G

Composition (Tb+Yb concentration in mol %)	5%	7%	9%
Transfer efficiency	8.4%	10.3%	26.4%
Effective quantum efficiency	108.4%	110.3%	126.4%

GC

Composition (Tb+Yb concentration in mol %)	5%	7%	9%
Transfer efficiency	24.6%	32.3%	54.6%
Effective quantum efficiency	124.6%	132.3%	154.6%

Conclusion & perspectives

- efficient quantum cutting in Tb^{3+}:Yb^{3+} co-doped $70SiO_2$–$30HfO_2$ glass and glass-ceramic waveguides deposited by a sol-gel
- A fixed concentration rate [Yb]/[Tb] = 4 and increasing rare earths total amounts [Tb+Yb] = 5, 7, 9 have been studied. Structural investigation by XRD and TEM shows that the precipitation of small hafnia nanocrystals
- The waveguiding properties of the films are confirmed and a clear NIR photoluminescence emission around 980 nm is detected, due to the $^2F_{5/2} \rightarrow {}^2F_{7/2}$ transition of Yb^{3+} ions.
- The energy transfer efficiency, estimated from the PL decay curves of the $^5D_4 \rightarrow {}^7F_5$ transition at 543.5 nm of Tb^{3+} ions, increases when increasing the total [Tb + Yb] concentration.
- The best performance is almost 55% and it is obtained for the most doped glass-ceramic sample, while it is only 26% in the glass sample with the same rare earth concentration.

Future work will focus on:

- **Increasing the concentration rare earth ions to increase the effective quantum efficiency**
- **The use of other rare earth couple : Pr/Yb and Er/Yb**

THANK YOU