

# Er doping of Si and Si-based media

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## 1. Introduction

Rare-earth-doped materials have been investigated for a number of years in order to develop practical light sources for photonic applications. Among such materials Er-doped crystalline Si (*c*-Si:Er) was believed to be very promising, offering a prospect of using the most advanced electronic technology to manufacture optical elements whose emission coincides with the 1.5  $\mu\text{m}$  minimum absorption band of silica fibers used in telecommunications. However in spite of over three decades of research effort, *c*-Si:Er proved to be notoriously difficult both to understand and to engineer. In that situation a new approach of sensitizing the Er-doped  $\text{SiO}_2$  matrix with silicon nanocrystals (SiNCs) was proposed.

In the past, much research has been done on the optical activity, excitation and recombination paths of  $\text{Er}^{3+}$  ions in  $\text{SiO}_2$  sensitized with SiNCs. This material can also be investigated for potential applications as down converter where, the absorption of a single photon of sufficiently large energy by SiNC results in subsequent excitation transfer to two (or more)  $\text{Er}^{3+}$  ions with lower excitation energy, hence extracting the excess energy of hot carrier in SiNCs.

## 2. Results

When the SiNCs are incorporated in  $\text{SiO}_2$  together with  $\text{Er}^{3+}$  ions, they act as sensitizers of Er-related photoluminescence (PL). In such materials, upon illumination, light is initially absorbed by the SiNCs. The absorbed energy is then transferred to the  $\text{Er}^{3+}$  ions located inside and in the vicinity of the SiNCs, taking these ions to excited states. Two specific  $\text{Er}^{3+}$  ions excitation paths have been identified: a slow (microsecond range) energy transfer between the exciton and one of the higher excited states of  $\text{Er}^{3+}$  ion, and a fast one (nanosecond range) between hot carriers and the first  $^4I_{13/2}$  excited state [1,2]. Of the two, especially the fast excitation path is still insufficiently understood and explored. This is regretful, since it offers a unique pathway of hot carrier energy extraction, with potential for application in 3<sup>rd</sup> generation photovoltaics. Also, recent investigations of PL quantum yield (QY) [3] prove that this process gives a major contribution to the Er-related luminescence.

Since the fast excitation channel concerns “hot” carriers with sufficient excess energy, it can be expected that its efficiency will increase for higher excitation energies. This indeed has been observed [4]. Here we investigate dynamics of SiNC-sensitized Er-PL which allows to readily distinguish between contributions of both excitation channels, which appear in different time windows – see inset of the figure. The main panel zooms in on the initial 300 ps when the hot-carrier-related fast excitation channel takes place. In a full agreement with the previous results on PL QY, we find that it has a threshold activation, for the particular investigated sample, somewhere just below 2.5 eV. In that way, the current study provides a unique fingerprint of this process and proves its existence beyond reasonable doubt. Moreover, we demonstrate that it has a higher

efficiency than the “slow” excitonic path, and completely dominates for high excitation energies, being responsible for more than 90% of the total PL signal at 4 eV pumping. Current investigations aim at evaluation of photovoltaic potential of this essential finding.

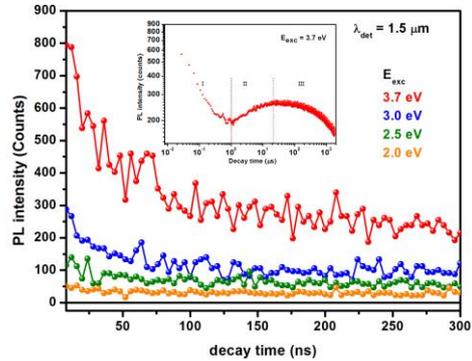


Fig. 1 Initial decay dynamics at 1.5  $\mu\text{m}$  Er-related PL for different excitation energies. Inset: the complete decay dynamics as measured under 3.7 eV excitation.

## 3. Conclusions

- Hot-carrier-to-Er energy transfer has been established beyond reasonable doubt.
- The contribution of the two excitation channels to the total intensity of Er PL has separated
- The dominance of the hot-carrier-related excitation mechanism has been established.

## 4. Open Questions

- What is the most efficient way of material optimization?
- What are the limiting values for the quantum efficiency?
- Can this material be realized as solar spectral shaper for hot carrier energy?
- Can this material be used to increase the efficiency of the solar cell?
- What other rare earth ions can be considered as the alternate of  $\text{Er}^{3+}$  ions for more efficient processes?

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## References

- [1] I. Izeddin, A. S. Moskalenko, I. N. Yassievich, M. Fujii, and T. Gregorkiewicz, Phys. Rev. Lett. **97**, 207401 (2006).
- [2] S. Saeed, D. Timmerman, and T. Gregorkiewicz, Phys. Rev. B **83**, 155323 (2011).
- [3] S. Saeed, K. Dohnalova, E. de Jong and T. Gregorkiewicz, under preparation.
- [4] D. Timmerman, I. Izeddin, P. Stallinga, I. N. Yassievich, and T. Gregorkiewicz, Nature Photon. **2**, 105 (2008).