CSMFO LAB. CHARACTERIZATION and DEVELOPMENT of MATERIALS for PHOTONICS and OPTOELECTRONICS Laboratory

Consiglio Nazionale delle Ricerche
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Dipartimento di Scienze Fisiche e Tecnologie della Materia

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FONDAZIONE BRUNO KESSLER

SiO_2-SnO_2:Er^{3+} glass ceramics for photonics: advances and perspectives

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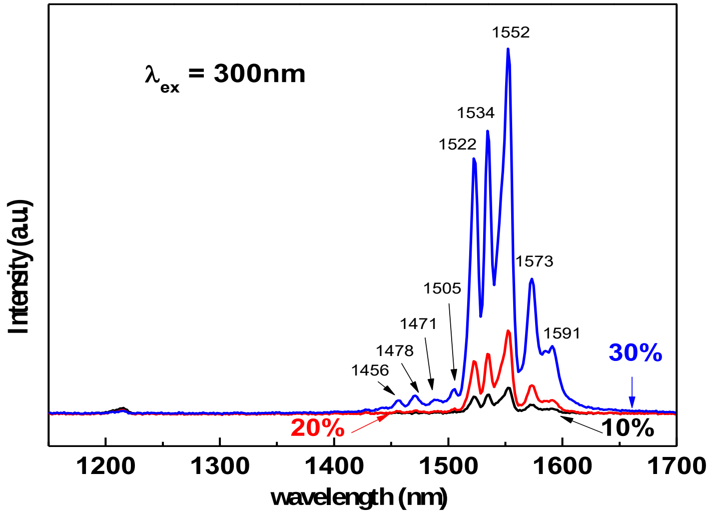
Outline

1) Introduction: advantages of tin dioxide based glass ceramics
2) Numerical simulations
3) Waveguides: characterization and design of integrated structure ideas
4) Monoliths: fabrication and characterization
5) Summary and perspectives

Advantages of tin dioxide based glass ceramics

- **Photorefractivity: $\Delta n \approx -1.6\times10^{-3}$**
  -after UV irradiation at 248 nm*
- **Energy transfer from SnO_2 to Er^{3+} ions**
- **Increase solubility of Er^{3+} ions**
- **Transparent from UV to NIR (400 nm to 3000 nm)**
- **Low non radiative losses**
  -low cut-off phonon energy (SnO_2: 630 cm^{-1} vs SiO_2: 1100 cm^{-1})
  -reduction of quenching effects due to the aggregation of Er^{3+} ions



Photoluminescence spectra of $xSnO_2$-(100-x)SiO_2 doped with 1 mol% of Er^{3+} (x= 10, 20, 30 mol%) (**)

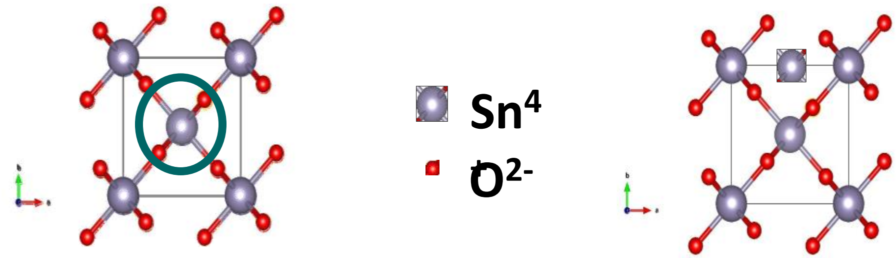
[*] Anna Lukowiak, et. al., "Sol–Gel-Derived Glass-Ceramic Photorefractive Films for Photonic Structures", Crystals 2017, 7, 61; doi:10.3390/cryst7020061

[**] Lidia Zur, et al., *Tin-dioxide nanocrystals as Er^{3+} luminescence sensitizers: formation of glass-ceramics thin films and their characterization*, Optical Materials, 63(2017), pp. 95-100, ISSN:0925-3467, doi: 10.1061/j.optmat.2016.08.041

Numerical simulations (DFT): position of Er^{3+} in the tin dioxide crystal

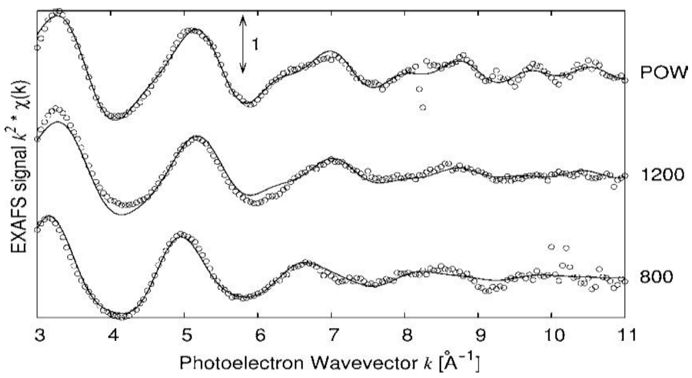
The tin dioxide has only a Wickoff position for defect out of lattice sites with symmetry C_{2h}. The lattice site has a D_{2h} symmetry.

	1° shell distance (Å)	2° shell distance (Å)
C_{2h}	1,6	1,7
D_{2h}	2,1	3,7
EXAFS[*]	2,2	3,7



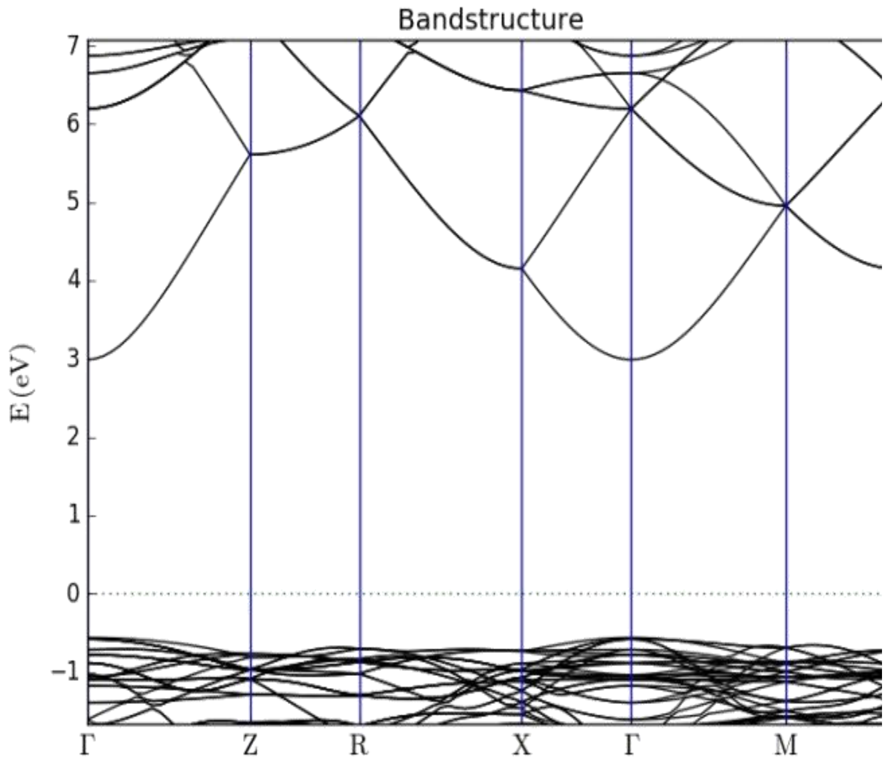
Without interstitial tin

With interstitial tin

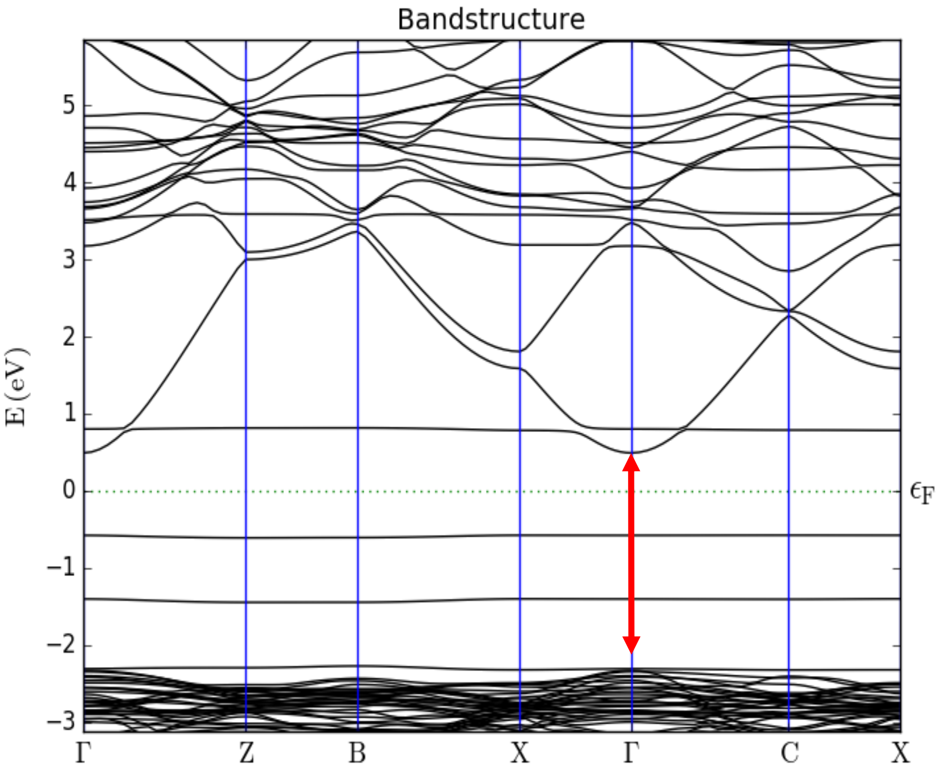


[*] Tran T. T. Van et. al, Erbium-Doped Tin-Silicate Sol–Gel-Derived Glass-Ceramic Thin Films: Effect of Environment Segregation on the Er $^{3+}$ Emission, Science of Advanced Materials, Volume 7, Number 2, Feb 2015, pp. 301-308(8), doi: . 10.1166/sam.2015.2022

Numerical simulations (DFT): band structure of doped tin dioxide

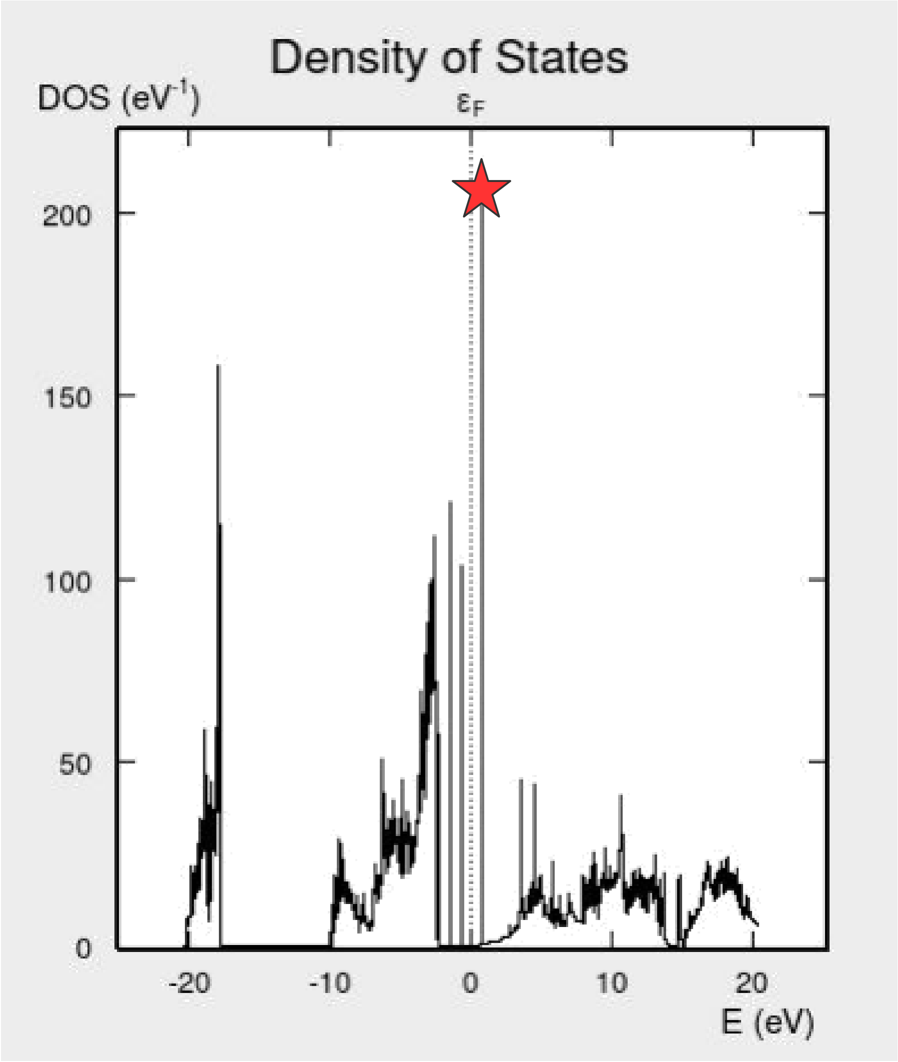


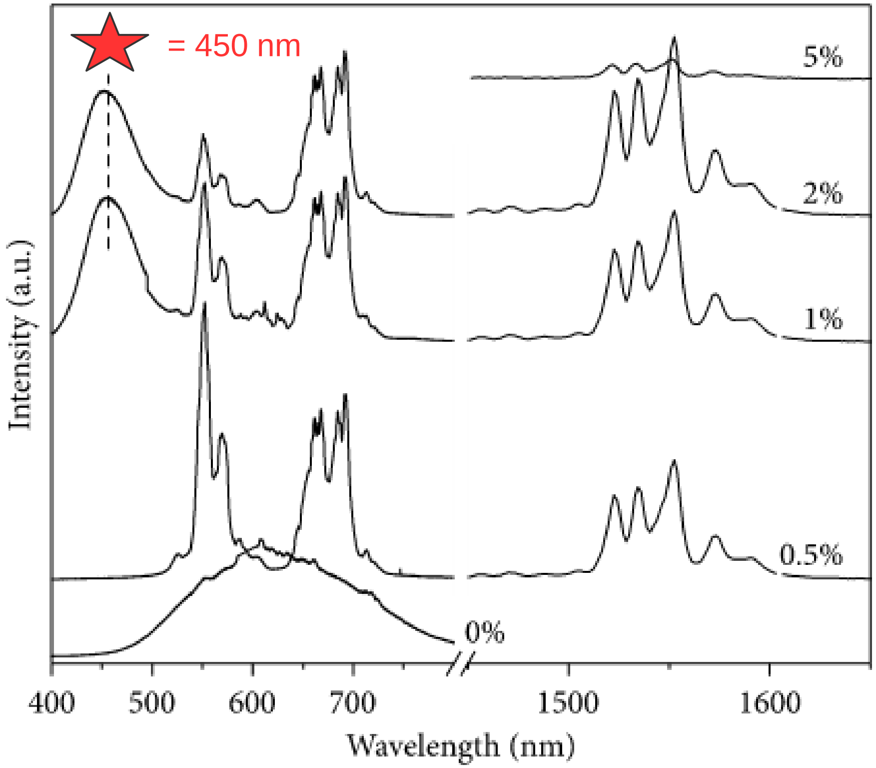
UNDOPED SnO_2 bandstructure



6 mol% Er^{3+} DOPED SnO_2 bandstructure

Numerical simulations (DFT): band structure of doped tin dioxide

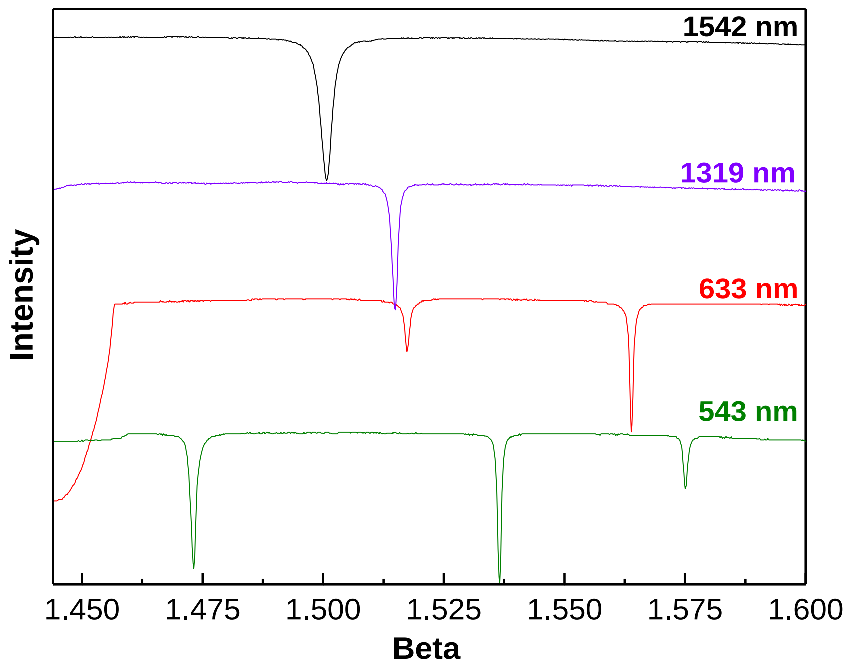




PL spectra with different concentration of Er^{3+} excited at 300nm after annealing at 1000°C [*]

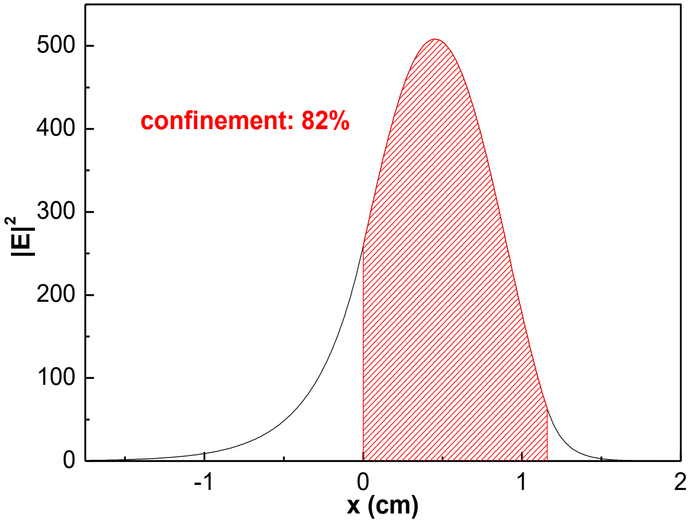
([*] Tran T. T. Van et. al., "Tin Dioxide Nanocrystals as an Effective Sensitizer for Erbium Ions in Er-Doped SnO_2 Systems for Photonic Applications", Journal of Nanomaterials, Volume 2016 (2016), Article ID 6050731 (1-5), doi: 10.1155/2016/6050731)

Spectroscopic and optical properties of tin dioxide based waveguides



M-line measurements of 70%SiO_2-30%SnO_2-0.5%Er^{3+} waveguides

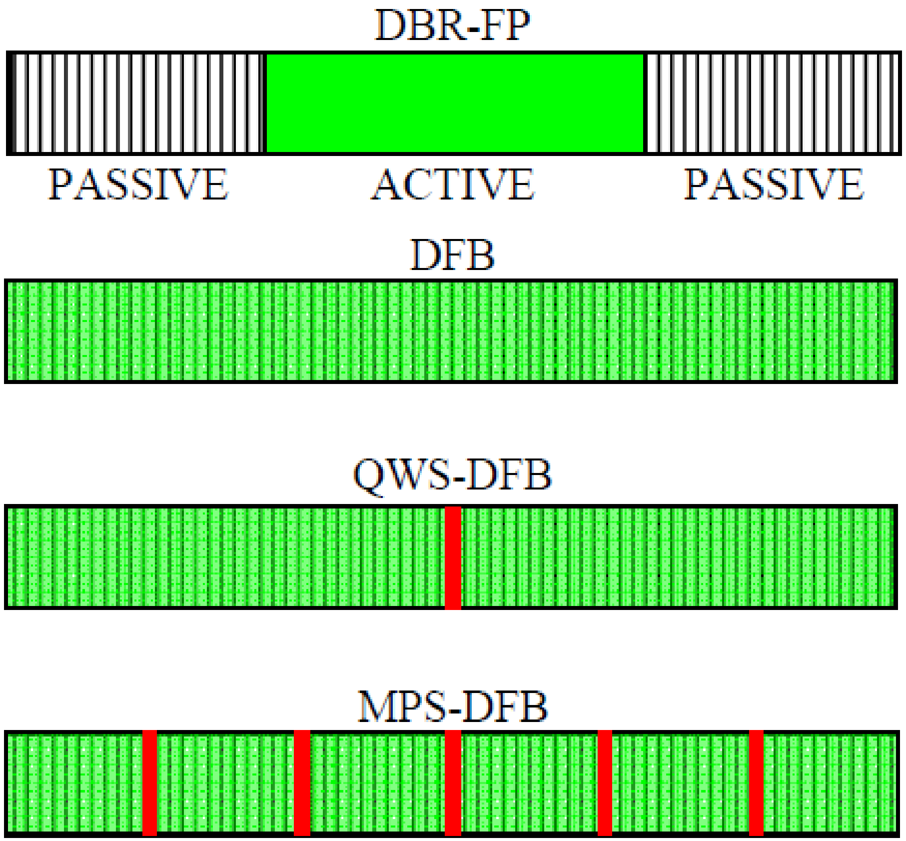
70%SiO_2-30%SnO_2 -0.5%Er^{3+}, HT@ 1000°C for 1h



Confinement calculation of 70%SiO_2-30%SnO_2-0.5%Er^{3+} waveguides @1542nm propagation mode

Integrated structure of SnO_2-SiO_2:Er^{3+}

Different topologies associating an active zone and one (or several) photo-inscribed index grating(s):



i. active Fabry-Perot cavity with passive Distributed Bragg Reflectors (DBR- FP);

ii. active Distributed-Feedback structure (DFB);

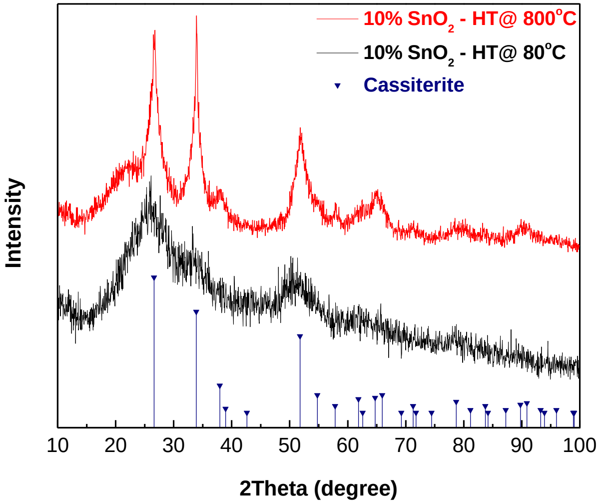
iii. DFB with Quarter-Wave phase Shift (QWS-DFB);

iv. DFB with Multiple Phase Shifts distributed along the cavity (MPS-DFB)

Fabrication procedure for monoliths

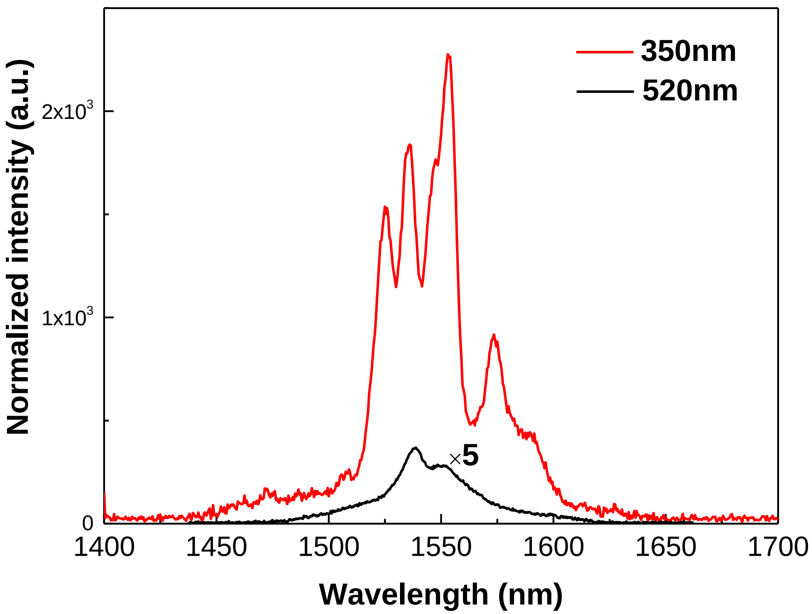
Fabrication process: SOL-GEL	
COMPOSITIONS (mol%)	$xSnO_2$- (100-x)SiO_2-yEr^{3+} x = 5, 10, and 15 mol% y = 0.5 mol%
HEAT-TREATMENT	Stabilized at 800°C for 15h Heat-treated at 950°C (optimizing)

90%SiO_2-10%SnO_2 undoped, before stabilization (right), after stabilization at 800°C (left)

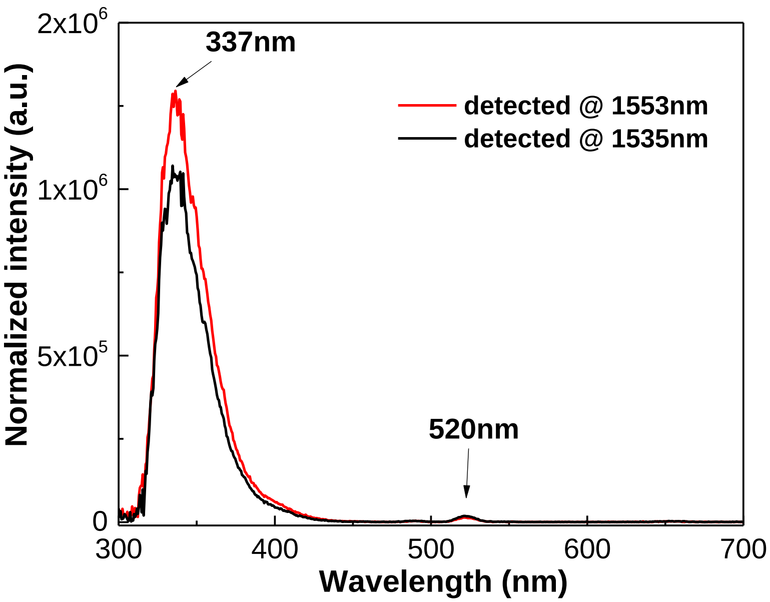


XRD patterns of 90%SiO_2-10%SnO_2:0,5%Er^{3+} monolith after dried at 80˚C and stabilized at 800˚C

Fabrication procedure for glass ceramic monoliths



PL of $90\%SiO_2$-$10\%SnO_2$:$0{,}5\%Er^{3+}$ monolith heat-treated at 800˚C for 20h



PLE of $90\%SiO_2$-$10\%SnO_2$:$0{,}5\%Er^{3+}$ monolith heat-treated at 800˚C for 20h

Summary

- Work in progress...
- The role of SnO_2 nanocrystals as Er^{3+} luminescence sensitizers was experimentally proved
- The location of Er^{3+} inside the crystal as been identified and the band structure has been demonstrated
- The fabrication procedure of monoliths has been developed

Perspectives

- Design and fabricate integrated devices
- Obtain fully densified monoliths
- Obtain a sample with rare earth ions present only in the crystalline phase

Acknowledgements

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