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Exploring nonlinear optics effects on rare-earth doped yttria-stabilized zirconia on silicon nitride photonic platform.

A. Ruiz-Caridad^{1,*}, C. Lafforgue^{1,*}, G. Marcaud¹, J. M. Ramirez^{1,2}, L. Largeau¹, T. Maroutian¹, S. Matzen¹, C. Alonso-Ramos¹, G. Agnus¹, S. Guerber^{1,3}, C. Baudot³, F. Boeuf³, E. Cassan¹, D. Marris-Morini¹, P. Lecoeur¹, L. Vivien¹.



¹ Centre de Nanosciences et Nanotechnologies (C2N), Univ Paris Sud, CNRS UMR 9001, Université Paris-Saclay, Orsay, 91405, France.

² III-V lab, a joint lab from Nokia Bell Labs, Thales and CEA, 1 avenue Augustin Fresnel, 91767 Palaiseau Cedex

³ TR&D STMicroelectronics SAS, Crolles, 38920, France

*These authors contributed equally to this work.



Objective and motivation

We envision the hybrid integration of erbium-doped crystalline functional oxides on silicon photonic platforms to develop new integrated light sources and optical amplifiers [1]. Erbium-doped YSZ has non-centrosymmetric structure and may then exhibit second order nonlinearity or second harmonic generation.

Main challenges:

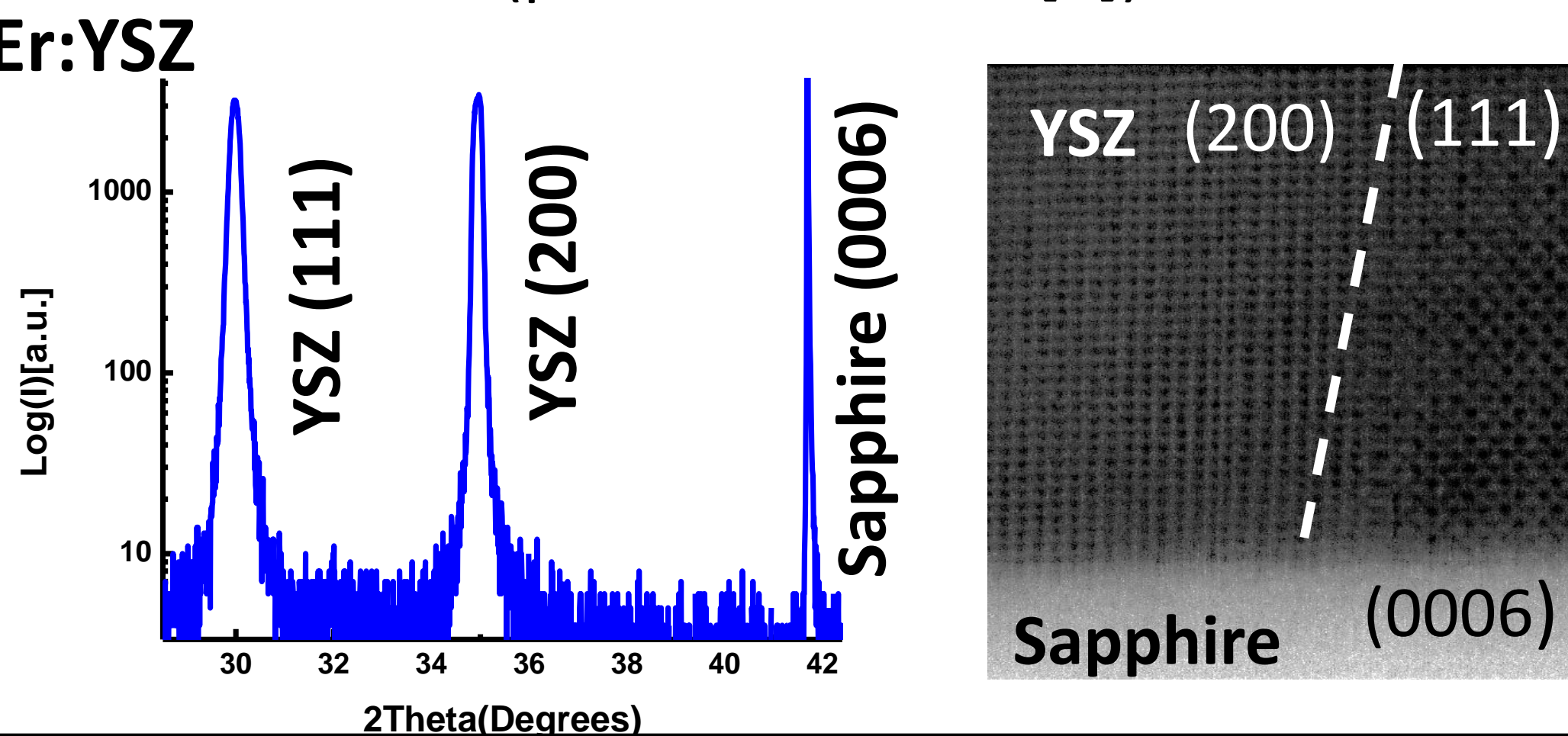
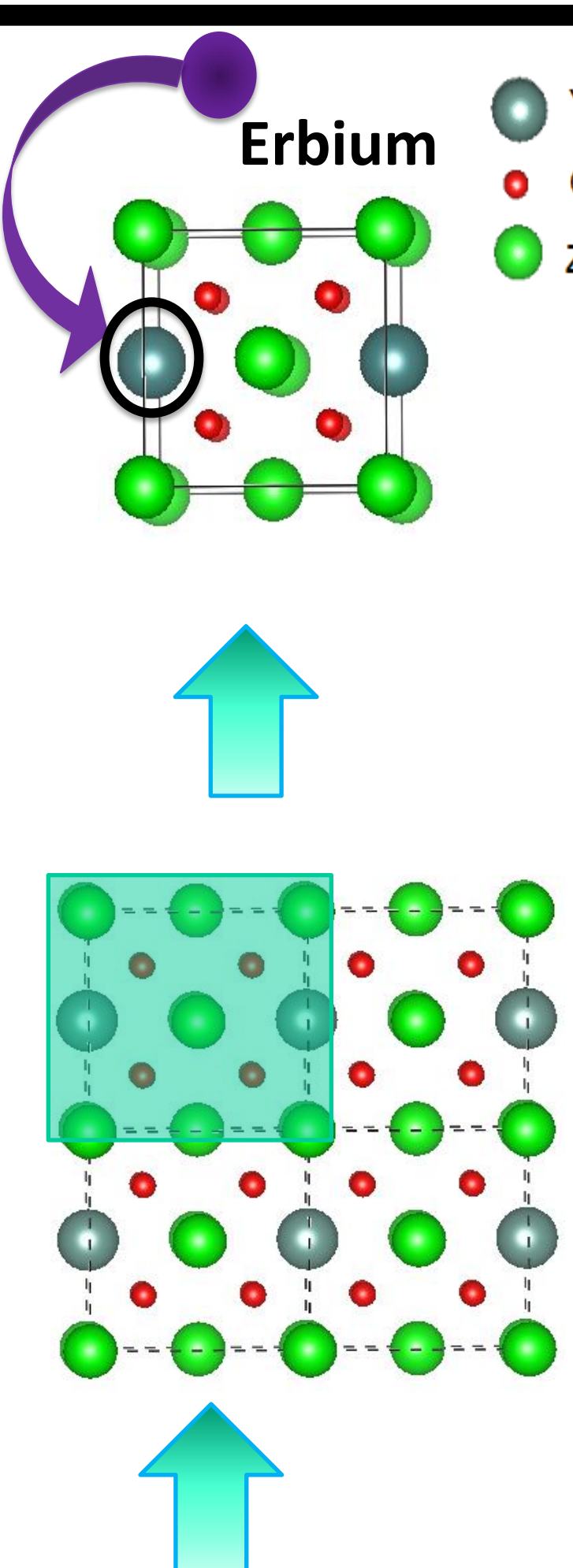
- Engineer high doping level in high quality crystalline films, avoiding quenching effects
- Keep light scattering to a minima [2]

We demonstrated the epitaxial growth of rare-earth oxides on a crystalline substrate, their integration on amorphous optical devices based on silicon and significant luminescence properties.

Synthesis and Structure

Erbium-doped yttria stabilized-zirconia (Er:YSZ) thin films were epitaxially deposited on sapphire by Pulsed Laser Deposition (PLD) at 800°C in an oxygen atmosphere with different concentrations of erbium.

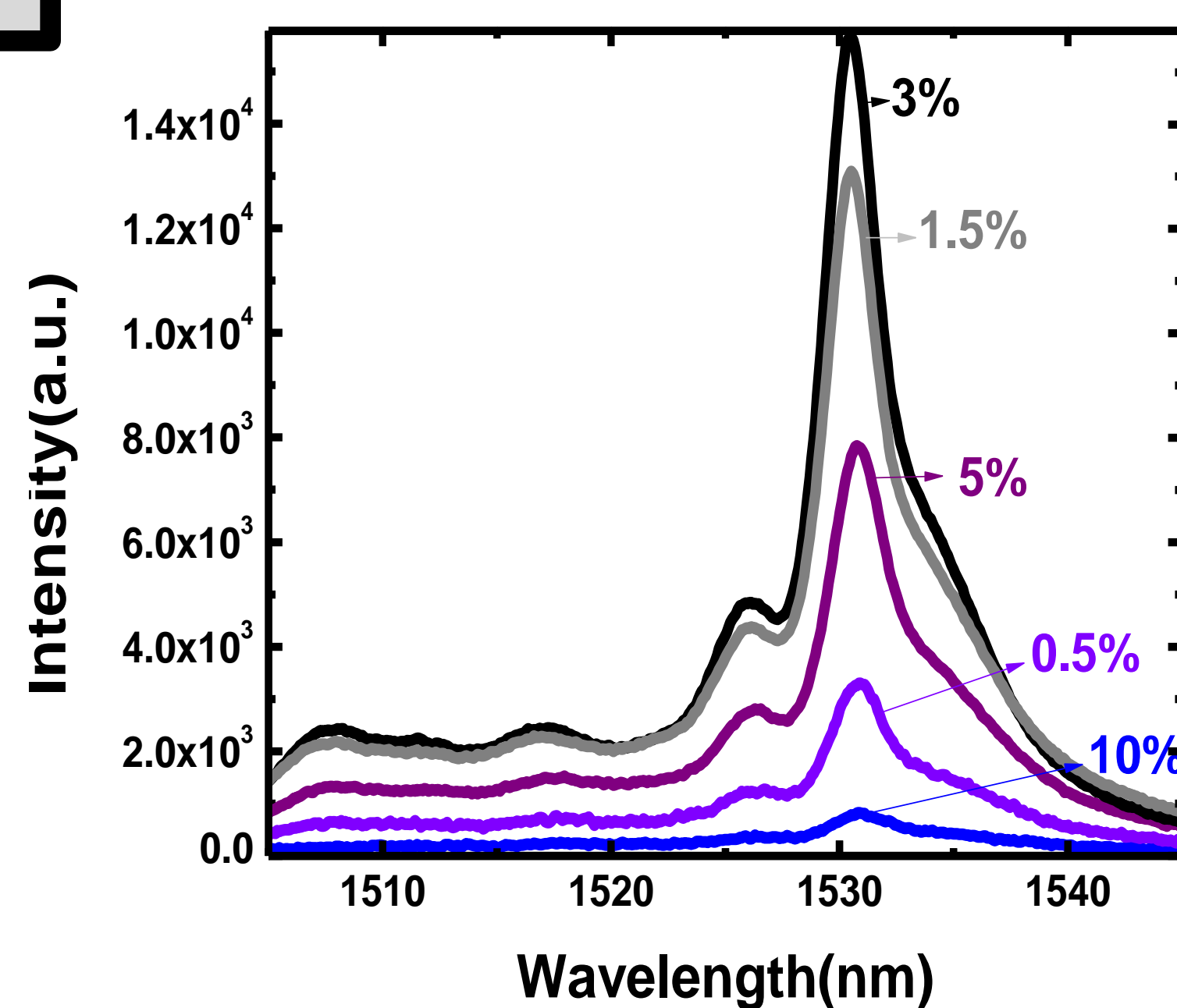
X-ray diffraction performed on Er:YSZ thin films shows two YSZ preferred orientations (111) and (001), as also observed by energy-filtered transmission electron microscopy (EFTEM) for a non doped YSZ matrix. The crystalline quality of the doped layers is similar to YSZ layers deposited on the same substrate under the same PLD conditions (previous studies [3]).



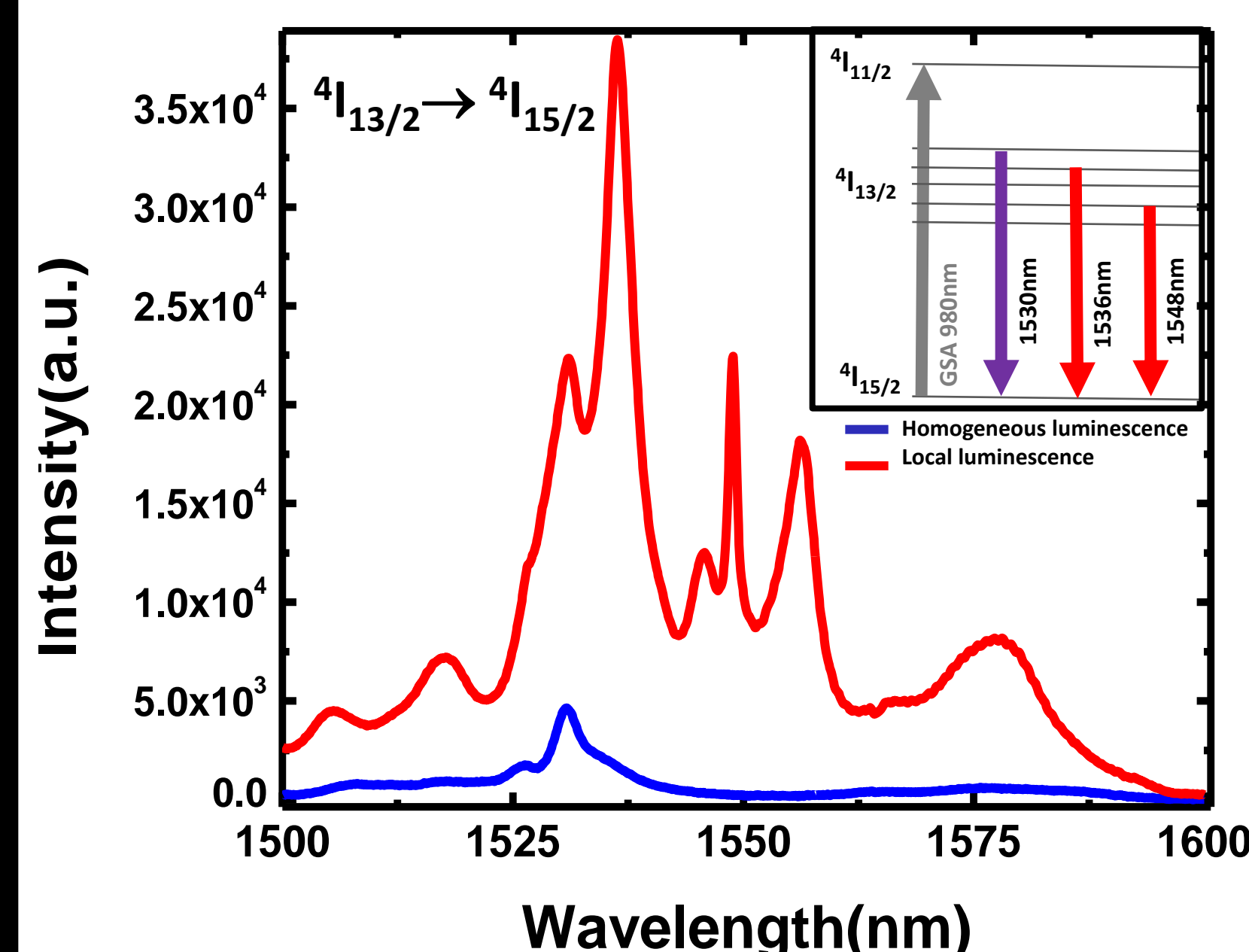
Erbium implementation in YSZ, maintaining non-doped YSZ structural phase.

Optical characterization

Photoluminescence (PL) studies performed for 5 different erbium doping concentrations (0.5, 1.5, 3, 5 and 10%) reveal higher homogeneous optical efficiency of Er:YSZ on sapphire when doped at 3%. For higher doping ratio quenching effects arise.



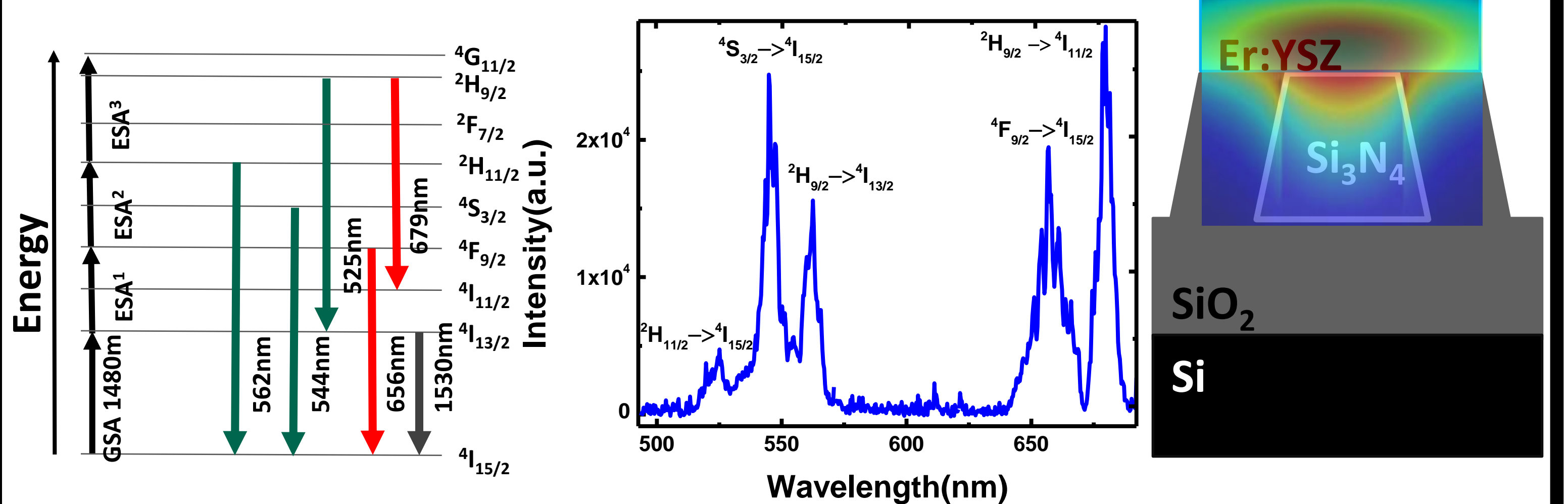
PL measurements for a pump of 980 nm show an homogeneous luminescence at 1530 nm ($^4I_{13/2} \rightarrow ^4I_{15/2}$ transitions) and local Stark effect of the same transition with enhanced emissions at 1530, 1536 and 1548 nm. Previously reported emission at different wavelengths have been related to erbium emplacement within the oxide structure [4].



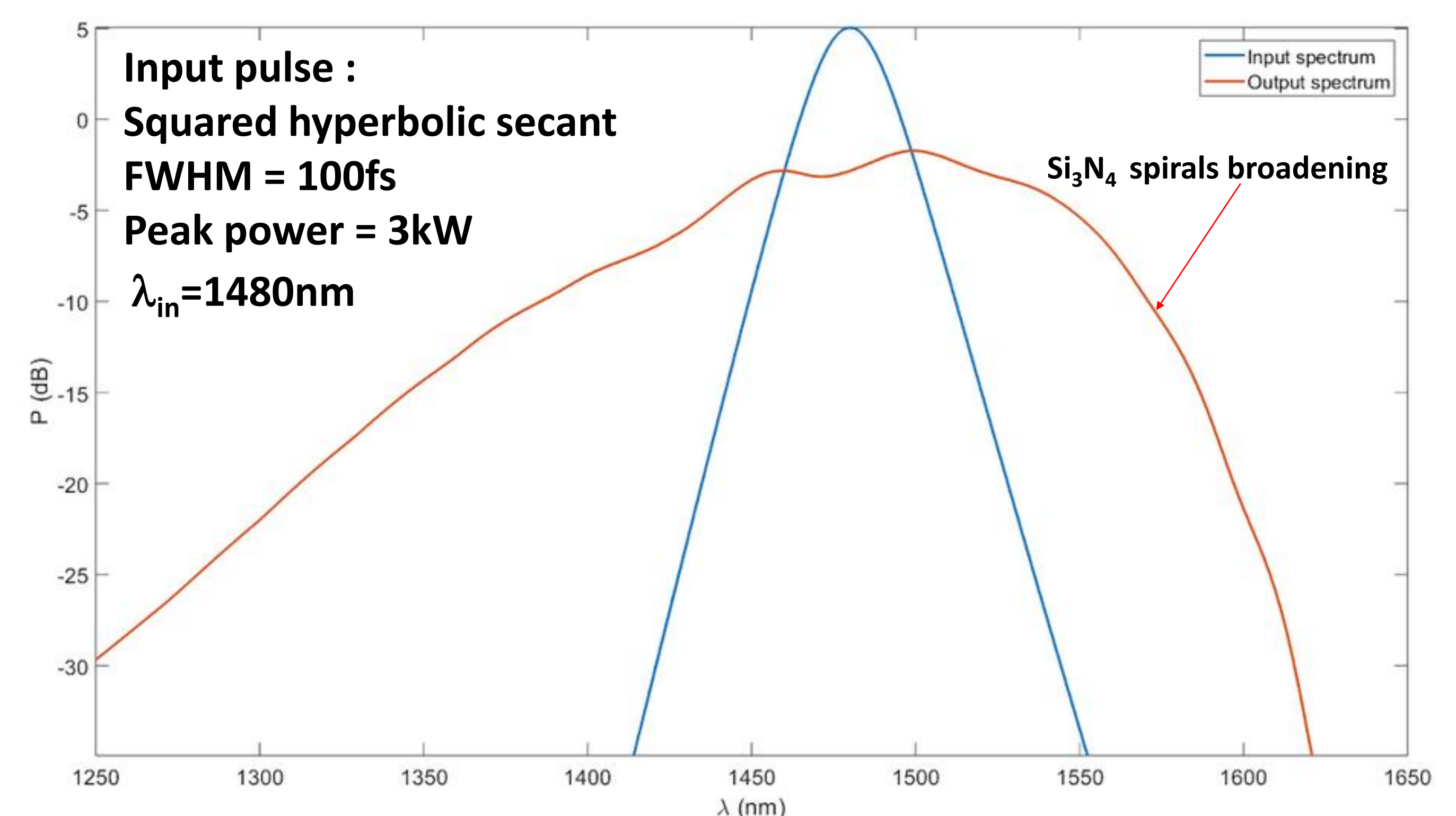
Hybrid integration on SiN_x photonic platform

We implemented Er:YSZ on silicon platform by growing the doped oxide on SiO₂ buried SiN_x waveguides.

- **Visible spectroscopy** when pumping 200 nm thick Er:YSZ on Si₃N₄ spirals at a wavelength of 1480 nm evidences strong up-conversion luminescence of erbium ions at 525, 544, 562, 656 and 679 nm corresponding to $^2H_{11/2} \rightarrow ^4I_{15/2}$, $^4S_{3/2} \rightarrow ^4I_{15/2}$, $^2H_{9/2} \rightarrow ^4I_{13/2}$, $^4F_{9/2} \rightarrow ^4I_{15/2}$ and $^2H_{9/2} \rightarrow ^4I_{11/2}$ transitions, respectively [5]. At the shadow of these results, optical gain might be expected.



- **Nonlinear optics effects:** Simulations based on generalized non-linear Schrödinger equation through a fourth order Runge-Kutta shows the spectral broadening on our Si₃N₄ spirals due to a 3rd order nonlinear phenomenon in the anomalous dispersion regime.



Conclusions and perspectives

- PL studies with pumping at 980 nm on polycrystalline Er:YSZ on sapphire reveal that erbium doping of 3% provides highest efficiencies for 1.53 μm emission.

- Local Stark effect has been observed with enhancement of luminescence.

- Er:YSZ has been grown on integrated optical devices on a silicon platform:

- Strong erbium up-conversion can be observed by visible spectroscopy in Er:YSZ layers with good crystallinity.
- Nonlinear optic simulations primary results show spectral broadening related to non-linear effects on the Si₃N₄ spirals.

References

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- [4] Omi et al. Japanese Journal of Applied Physics 51 (2012).
- [5] Savoini et al. Journal of Alloys and Compounds 323–324 (2001).