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► **To cite this version:**

Alicia Ruiz-Caridad, G Marcaud, J M Ramirez, L Largeau, T Maroutian, et al.. Engineering erbium-doped oxide thin layers for integrated photonics. International School of Oxide Electronics, Jun 2019, Cargese, France. hal-02933703

**HAL Id: hal-02933703**

**<https://hal.science/hal-02933703>**

Submitted on 8 Sep 2020

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# Engineering erbium-doped oxide thin layers for integrated photonics

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## Objective and motivation

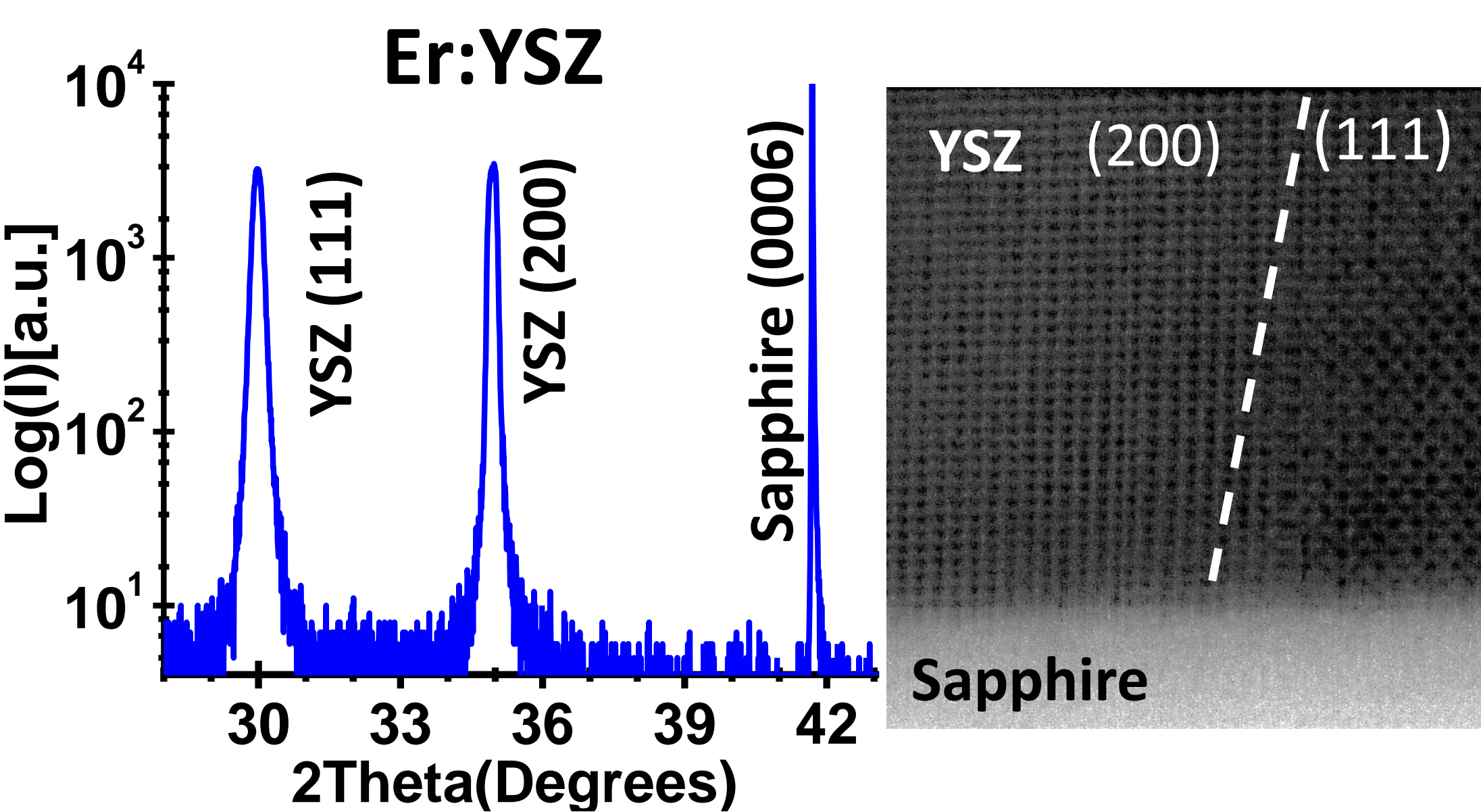
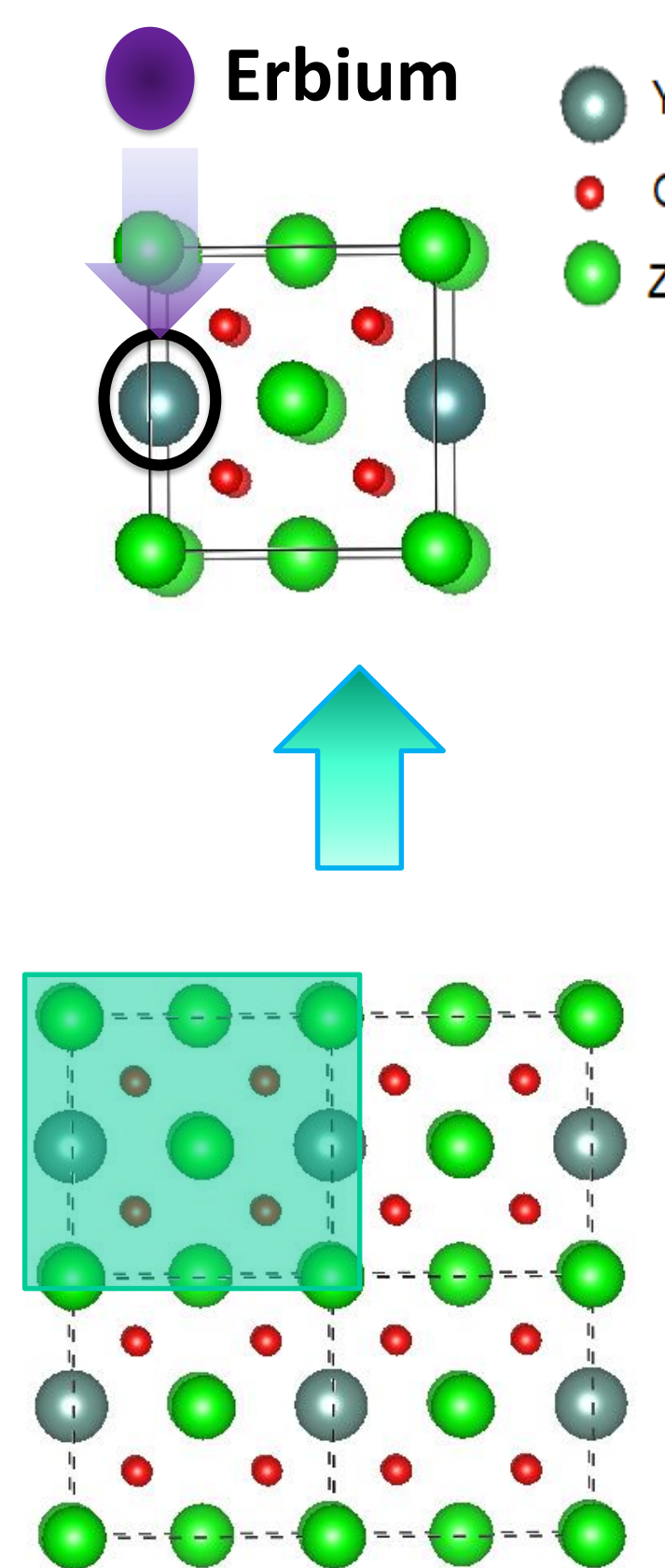
We envision the hybrid integration of erbium-doped crystalline functional oxides on silicon photonics platform to develop new integrated light sources and optical amplifiers [1].

Main challenges:

- Grow high crystalline quality films
- Engineer high doping concentration of erbium;
- Reducing propagation loss [2]
- Avoid quenching effects

## Synthesis and Structure

- Growth of Erbium-doped yttria stabilized-zirconia (Er:YSZ) thin films:
  - ✓ Epitaxially on sapphire by **Pulsed Laser Deposition (PLD)** at 800°C in O<sub>2</sub> atmosphere.
  - ✓ different concentrations of erbium.
- **X-ray diffraction**: two YSZ orientations (111) and (001).
- **Energy-filtered transmission electron microscopy (EFTEM)** for non doped YSZ proves same preferred orientations [3].

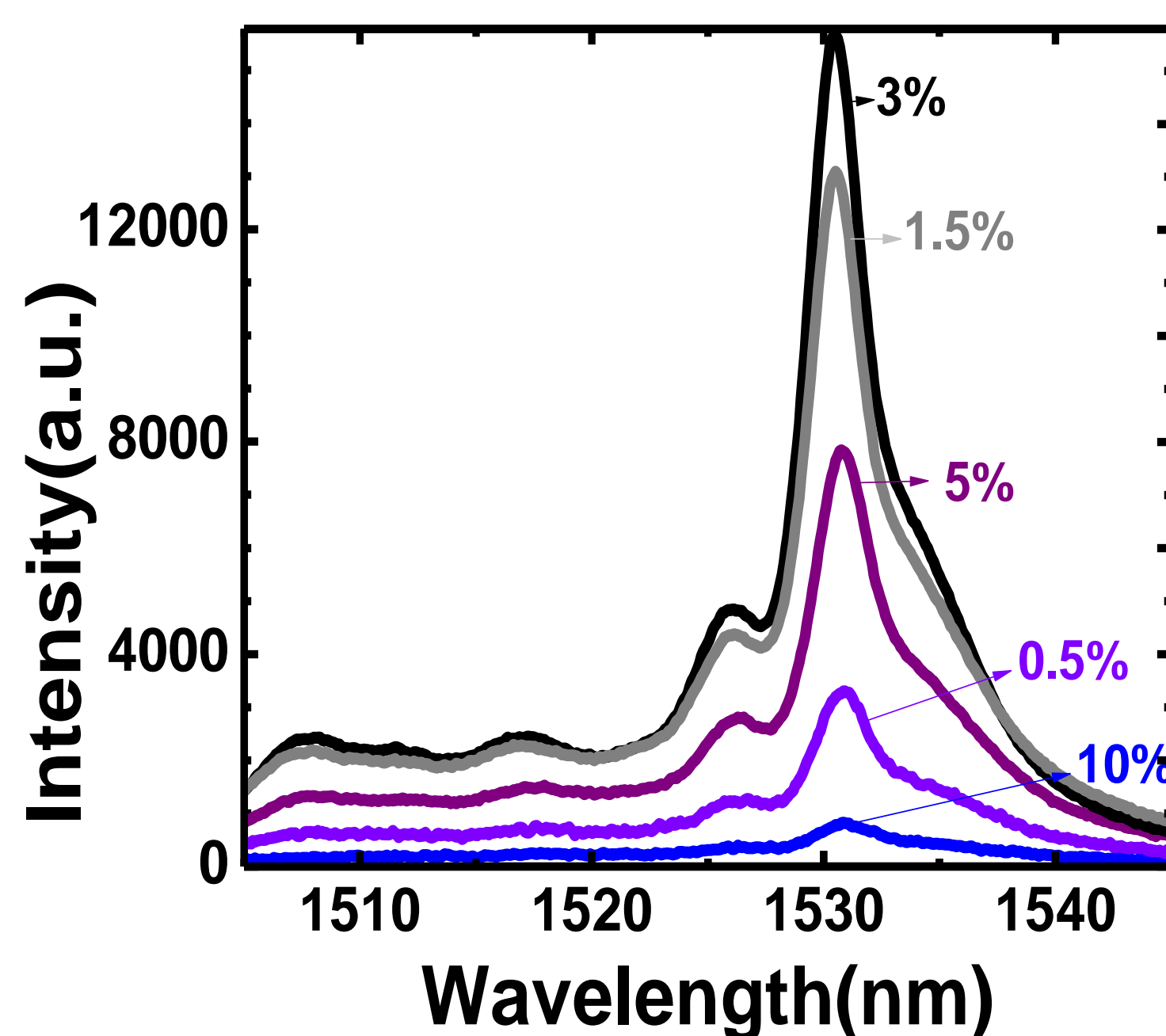


Erbium implementation in YSZ, maintaining non-doped YSZ structural phase.

## Optical characterization

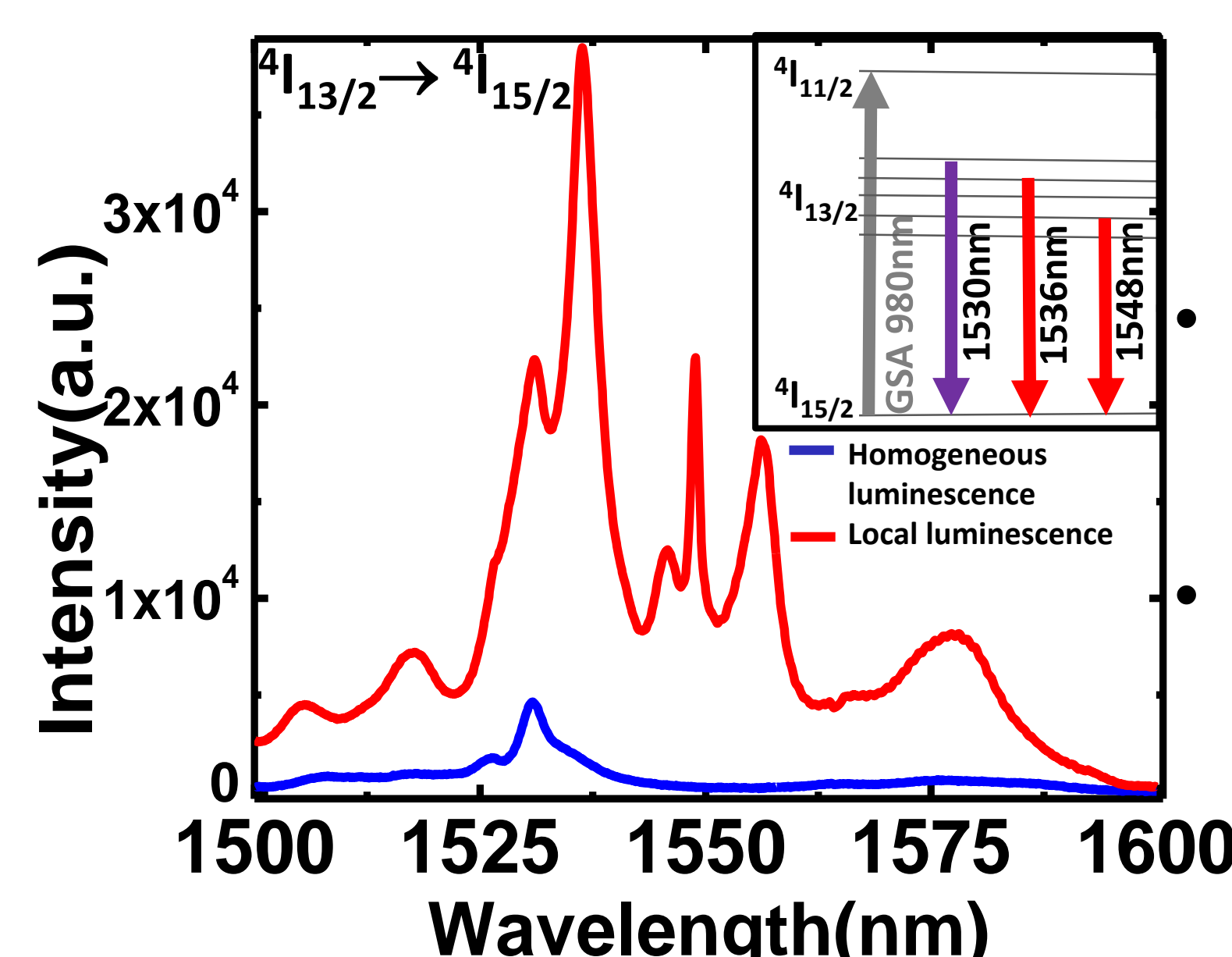
### Photoluminescence (PL)

- Erbium doping concentrations (0.5, 1.5, 3, 5 and 10%) reveal higher optical efficiency for 3%Er:YSZ on sapphire.
- For higher doping ratio quenching effects arise.



Luminescence at 1530 nm ( $^4I_{13/2} \rightarrow ^4I_{15/2}$  transitions)

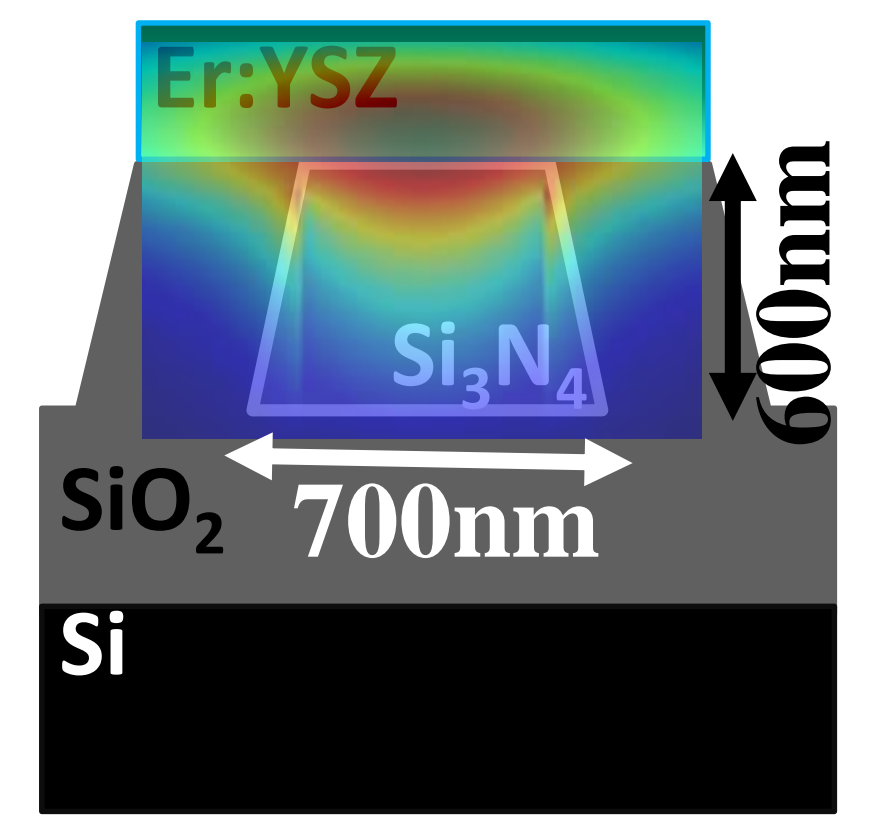
Local Stark effect on same transition with enhanced intensity related to erbium emplacement within the oxide structure [4].



## Hybrid integration on SiN<sub>x</sub> photonic platform

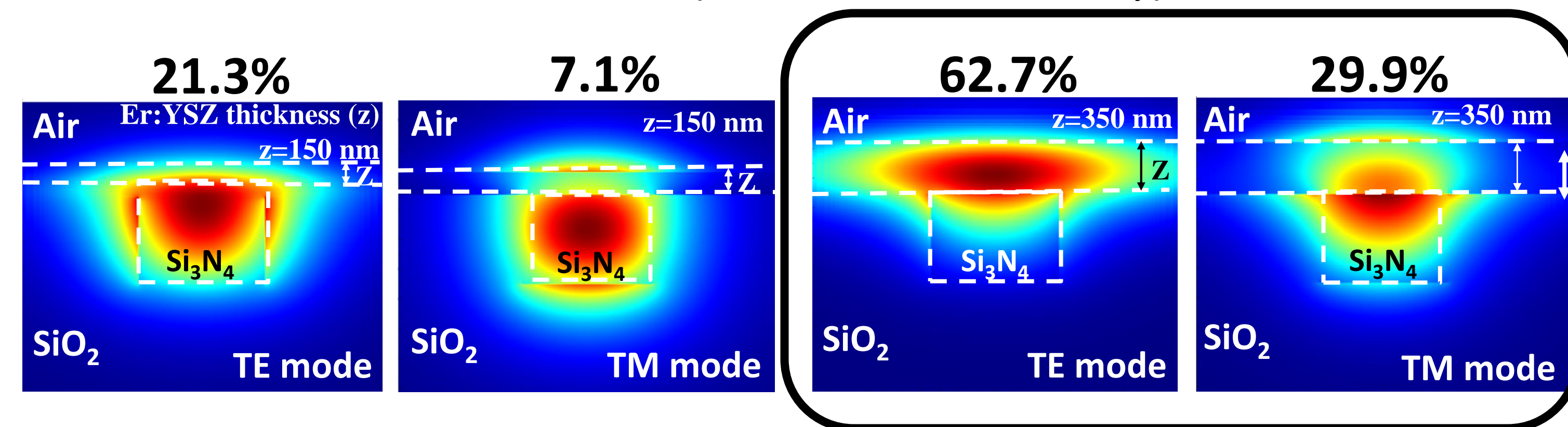
Implemented Er:YSZ on SiO<sub>2</sub> buried SiN<sub>x</sub> waveguides on Si.

- **Optimum Er:YSZ/Er<sup>3+</sup> thickness simulations** ( $\lambda=1550$  nm):
  - ✓ Trade off in mode confinement in Er and SiN<sub>x</sub> waveguide.
  - ✓ Reduction of propagation loss



- **Simulation results for Er:YSZ thicknesses of 150 and 350 nm:**

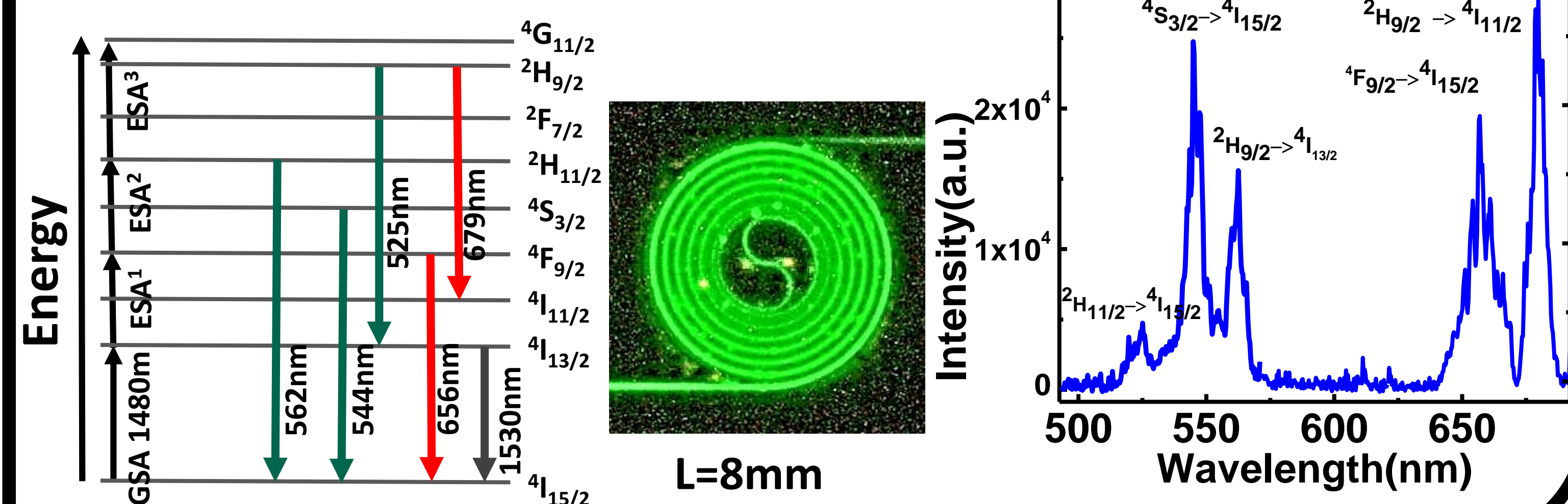
Mode's fraction confined in YSZ (electric field intensity):



- **Visible spectroscopy (pump wavelength at 1480 nm)**

✓ up-conversion luminescence of Er ions at 525, 544, 562, 656 and 679 nm from  $^2H_{11/2} \rightarrow ^4I_{15/2}$ ,  $^4S_{3/2} \rightarrow ^4I_{15/2}$ ,  $^2H_{9/2} \rightarrow ^4I_{13/2}$ ,  $^4F_{9/2} \rightarrow ^4I_{15/2}$  and  $^2H_{9/2} \rightarrow ^4I_{11/2}$  transitions, respectively [5].

✓ At the shadow of these results, **optical gain might be expected**.



## 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  $\mu$ m emission.
- Local Stark effect has been observed with strong enhancement luminescence.
- Er:YSZ has been grown on integrated optical SiN<sub>x</sub> devices.
  - ✓ Strong erbium up-conversion is observed in Er:YSZ layers.
- Future work will focus on the study of gain in Er:YSZ on the hybrid SiN<sub>x</sub> platform at 1.53  $\mu$ m to demonstrate on-chip optical amplifiers at telecom wavelengths.

## References

- [1] Bradley et al. Laser Photonics Review 5, No.3, 368–403 (2011).
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- [3] Marcaud et al. Physical Review Materials 2, 035202 (2018).
- [4] Omi et al. Japanese Journal of Applied Physics 51 (2012).
- [5] Savoini et al. Journal of Alloys and Compounds 323–324 (2001).