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Engineering erbium-doped oxide thin layers for integrated photonics

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Objective and motivation

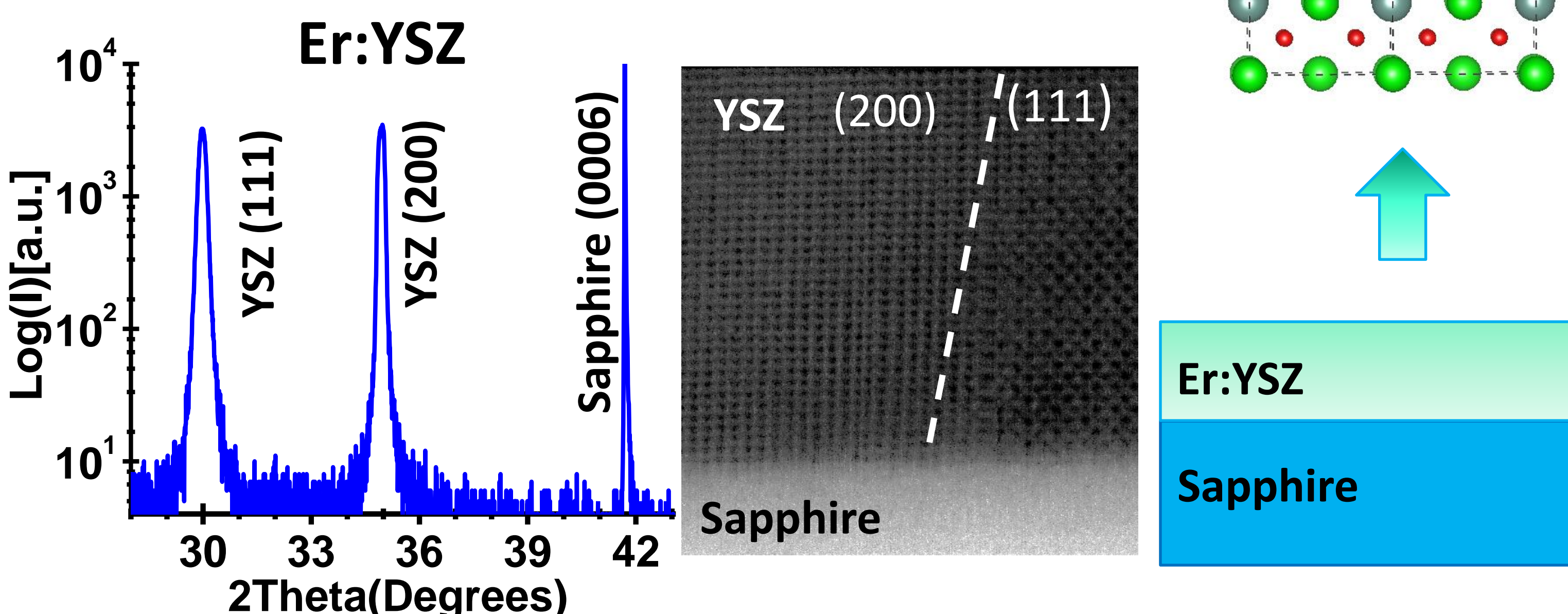
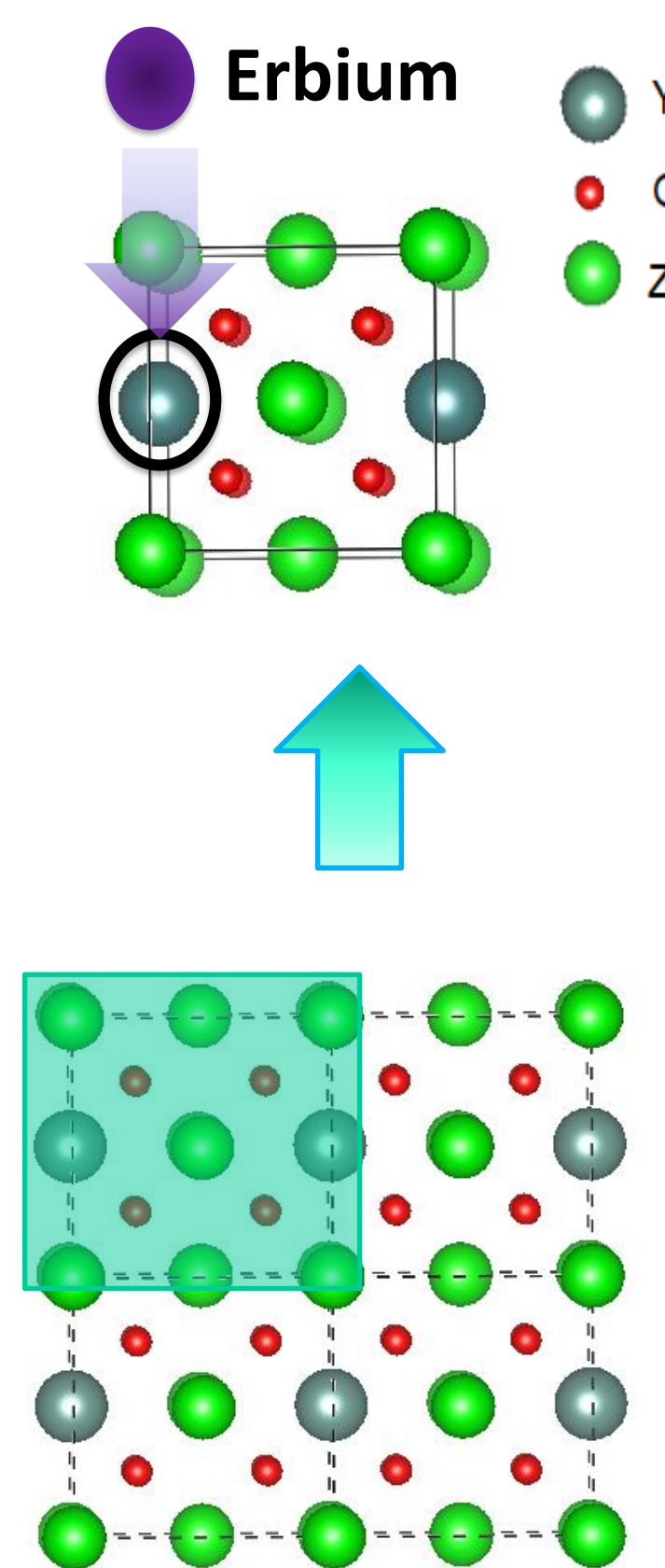
We envision the hybrid integration of erbium-doped crystalline functional oxides on silicon photonics platform to develop new integrated light sources and optical amplifiers [1].

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 O₂ 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].

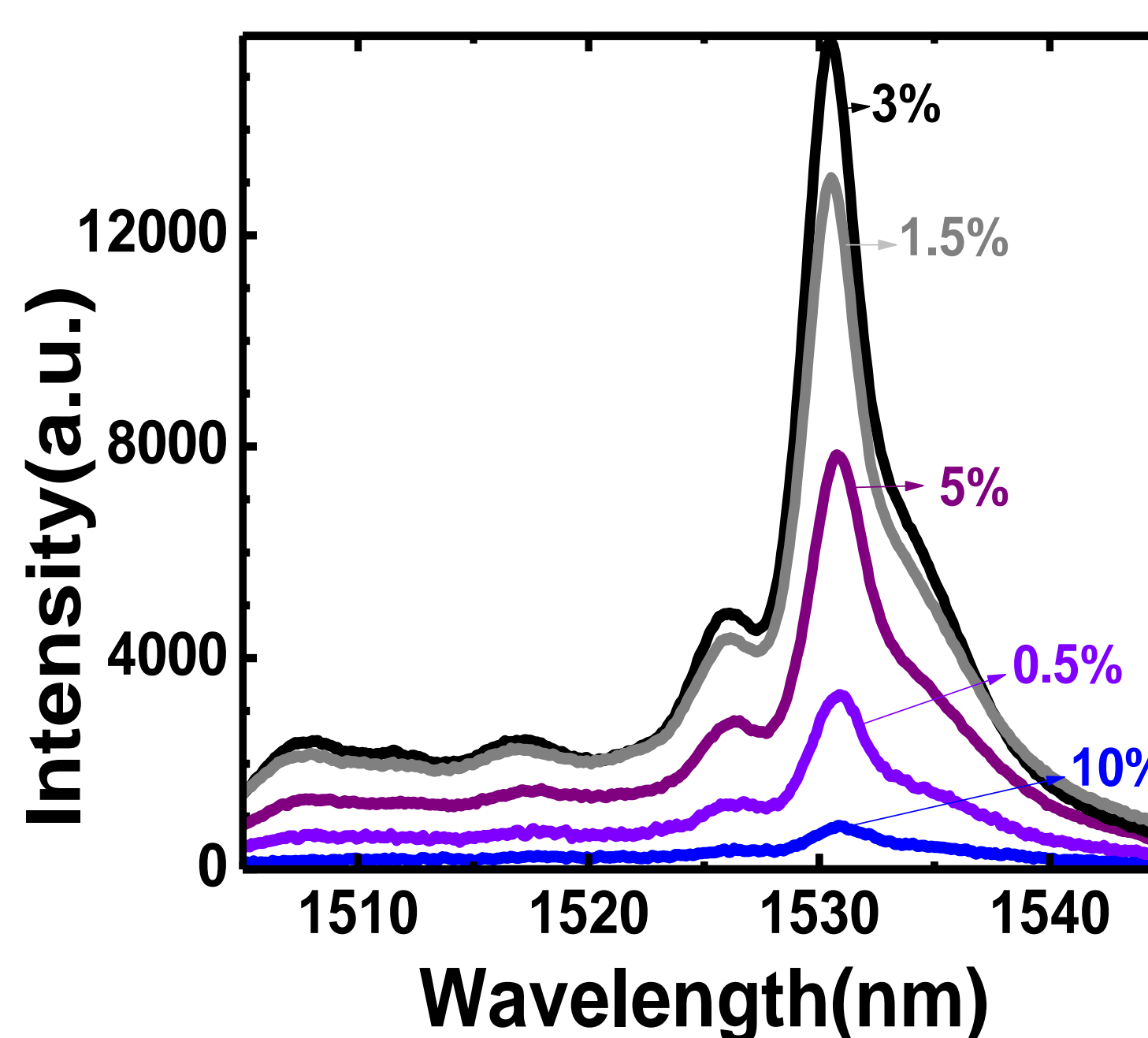


Erbium implementation in YSZ, maintaining non-doped YSZ structural phase.

Optical characterization

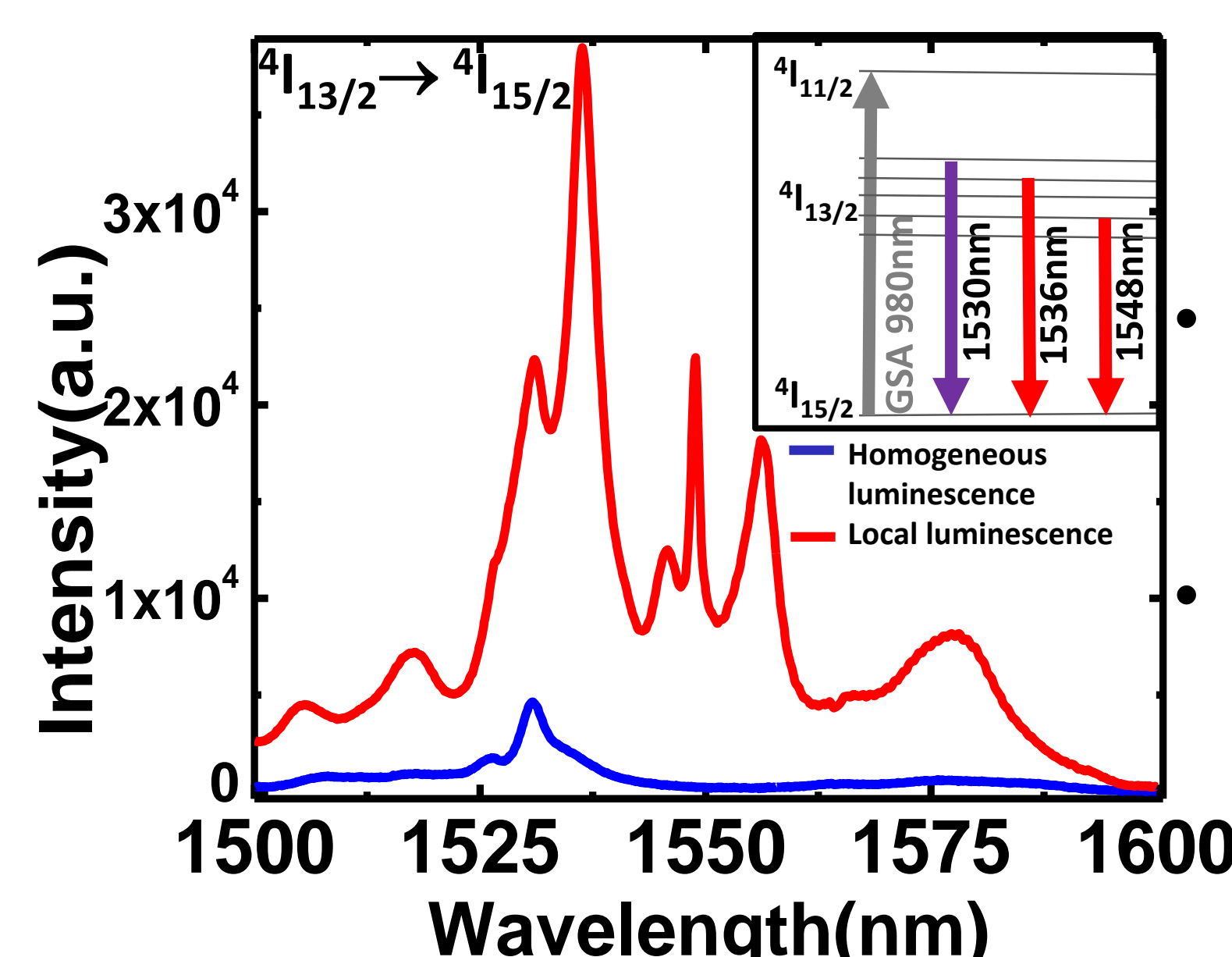
Photoluminescence (PL)

- 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].

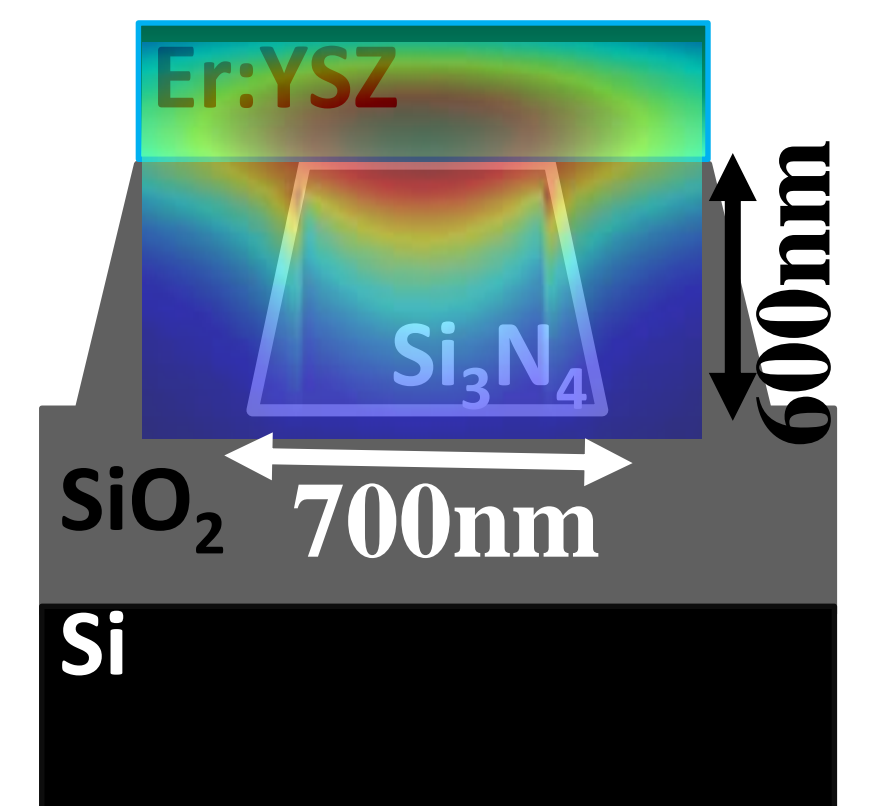


Hybrid integration on SiN_x photonic platform

Implemented Er:YSZ on SiO₂ buried SiN_x waveguides on Si.

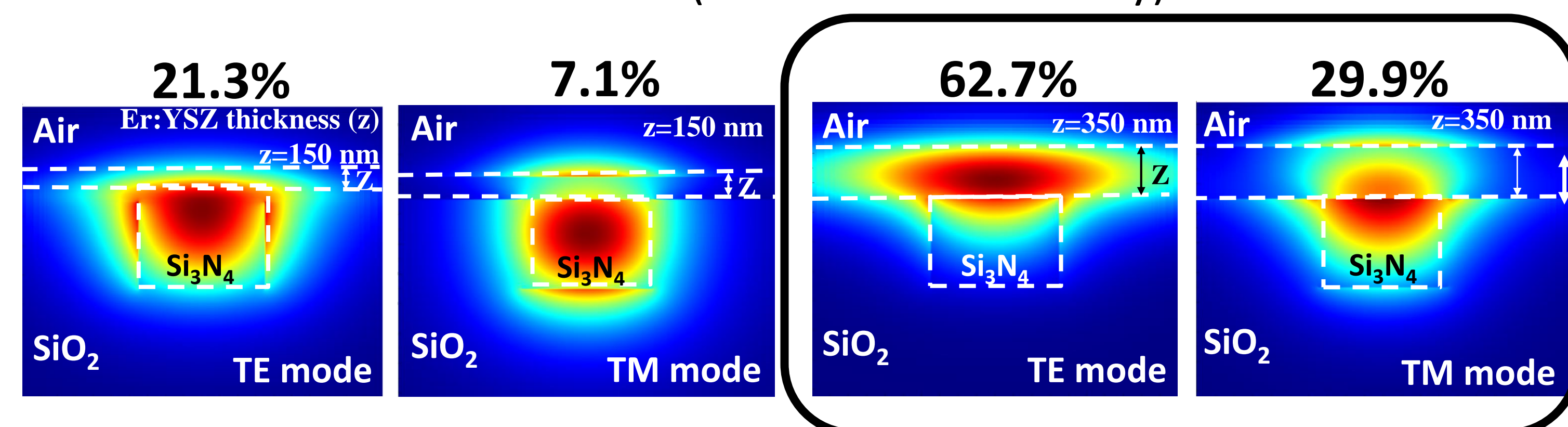
- **Optimum Er:YSZ/Er³⁺ thickness simulations ($\lambda=1550$ nm):**

- ✓ Trade off in mode confinement in Er and SiN_x waveguide.
- ✓ Reduction of propagation loss



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

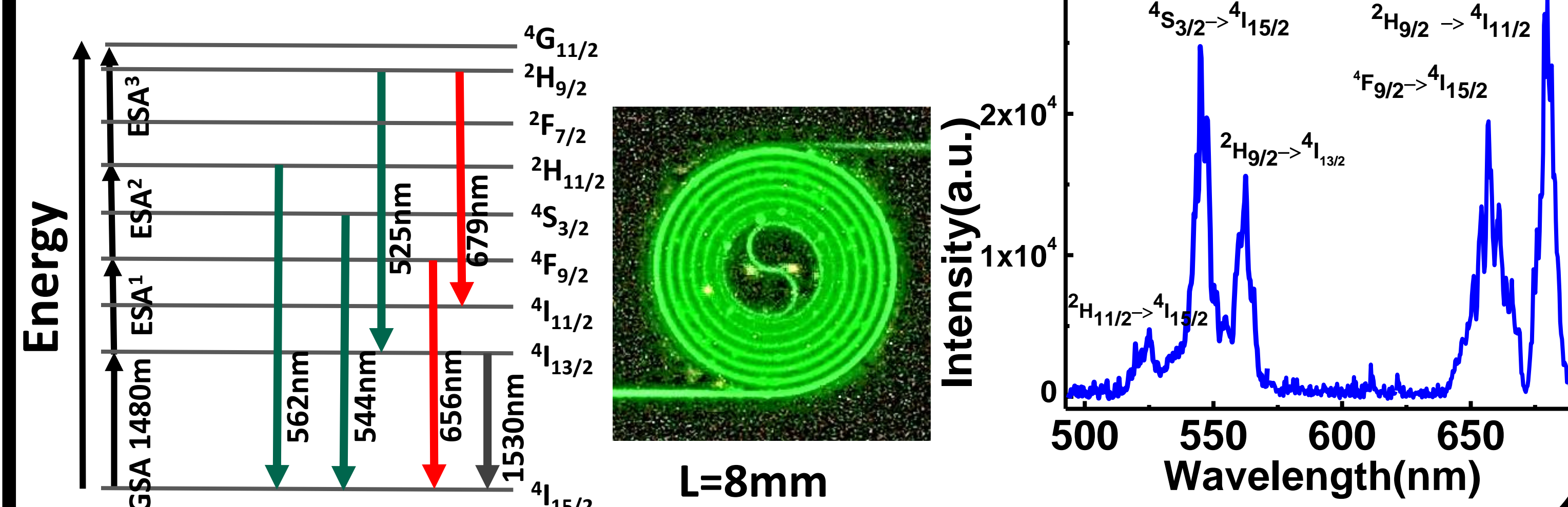
Mode's fraction confined in YSZ (electric field intensity):



- **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 μ m emission.
- Local Stark effect has been observed with strong enhancement luminescence.
- Er:YSZ has been grown on integrated optical SiN_x 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_x platform at 1.53 μ m to demonstrate on-chip optical amplifiers at telecom wavelengths.

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).