Ophellia

ON-CHIP PHOTONICS ERBIUM-DOPED LASER FOR LIDAR APPLICATIONS

PPTF
Polish Technological Platform on Photonics

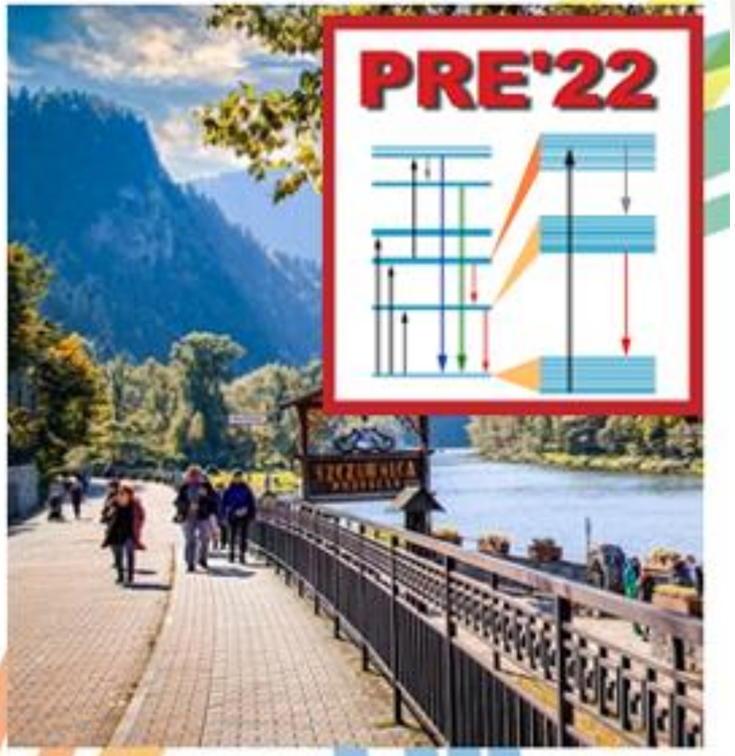
PHOTONICS SOCIETY OF POLAND
PSP

XVIth International Conference on Molecular Spectroscopy

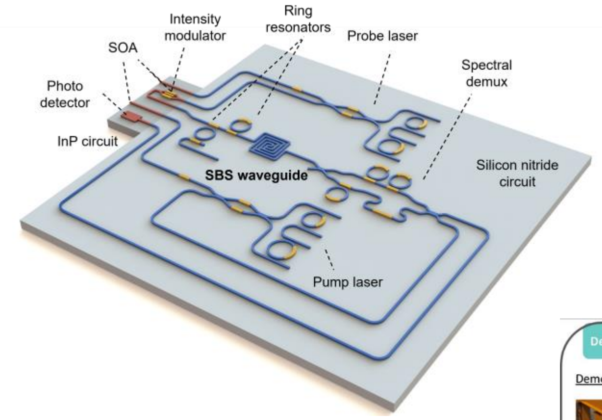
ICMS 2022

Szczawnica, 11-14.09.2022

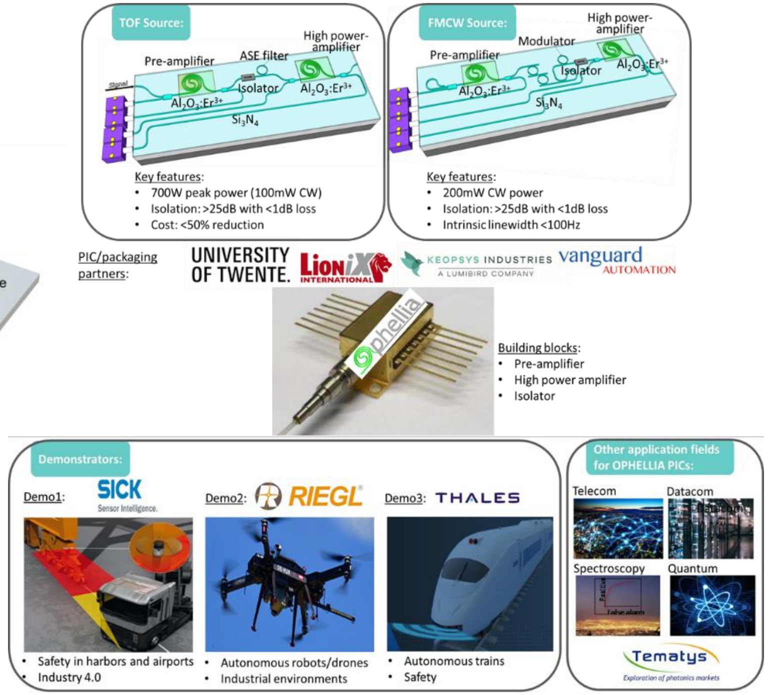
PRE'22-Poland



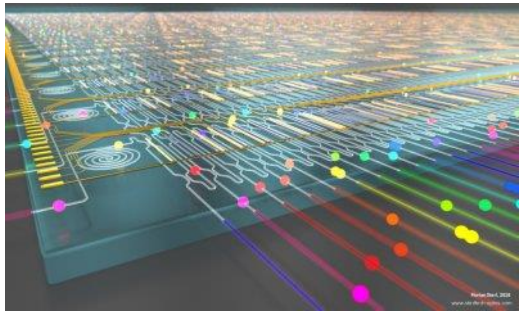
At the UT we carry out research in Integrated Photonics covering materials, devices and systems for different applications, including RF photonics, LiDAR, sensing and quantum technology



Brillouin gain in Si_3N_4

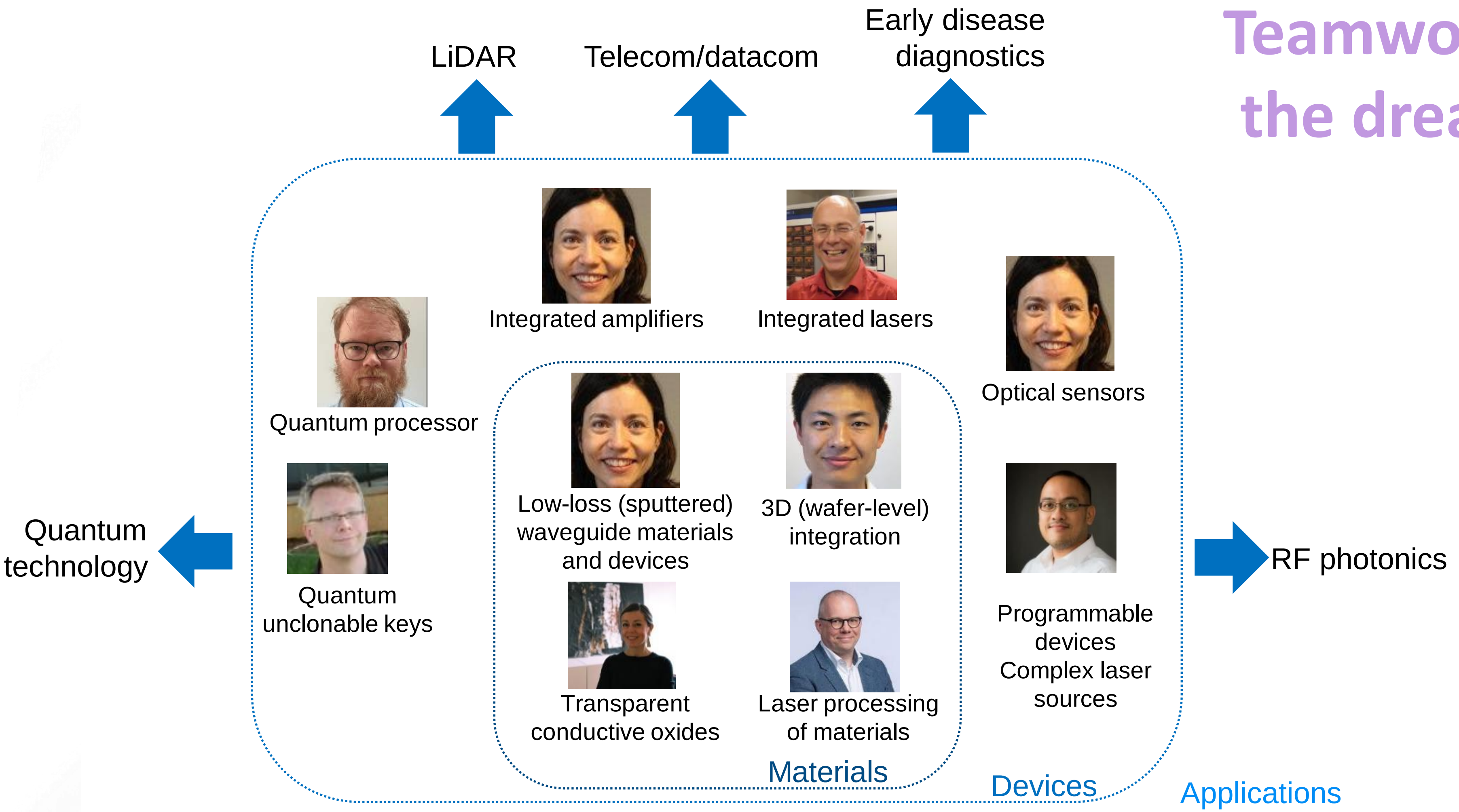


Integrated LIDAR systems



Quantum processing

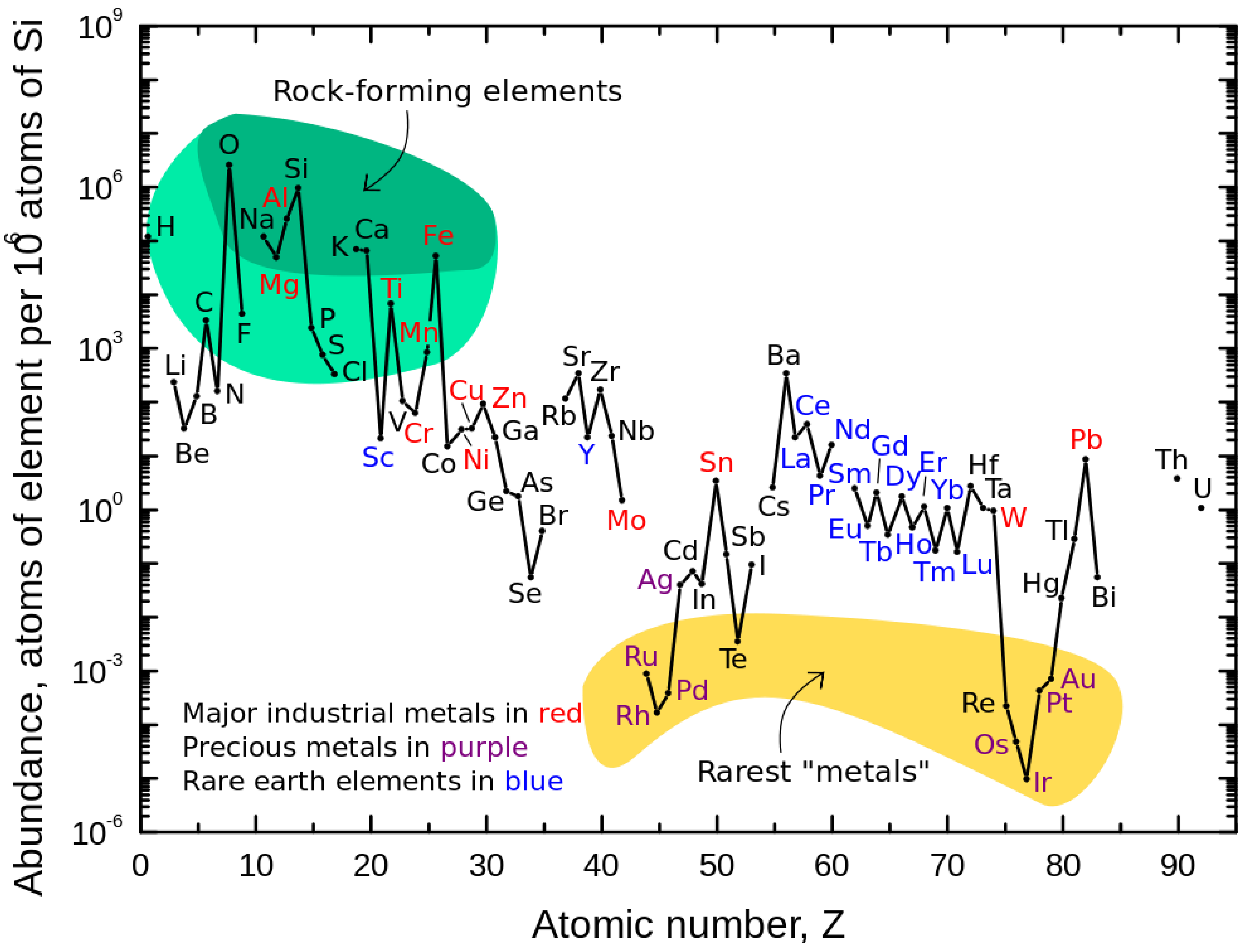
Teamwork makes the dreamwork!



MESA+ INSTITUTE

- 1250 m^2 Class 10,000 cleanroom
- 1000 m^2 of specialized equipment
- Deposition (PVD + CVD), lithography, e-beam, SEM, TEM, etching, dicing, annealing etc.

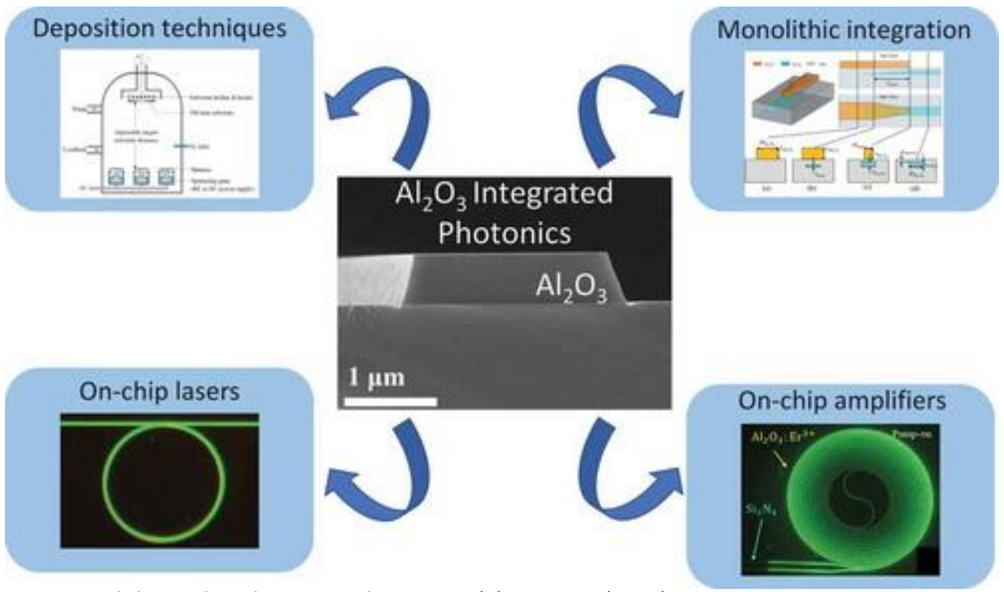
INTEGRATED PHOTONIC PLATFORMS



Si

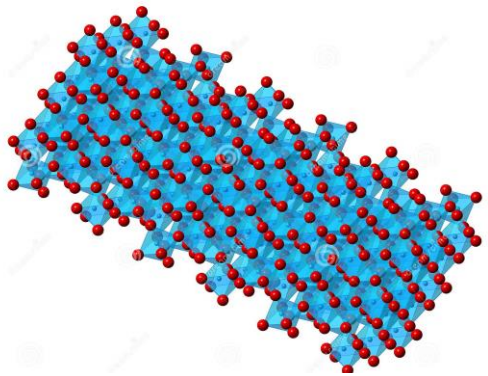
AL_2O_3 AS PHOTONIC MATERIAL
OPTICAL PROPERTIES

- Large transparency window: UV-mid-IR
- Low propagation losses: 5 dB/m
- Moderate refractive index: ~1.72 @1550 nm
- Wafer level deposition
- High rare-earth ion solubility
- In the Nanolab→ RF reactive sputtering

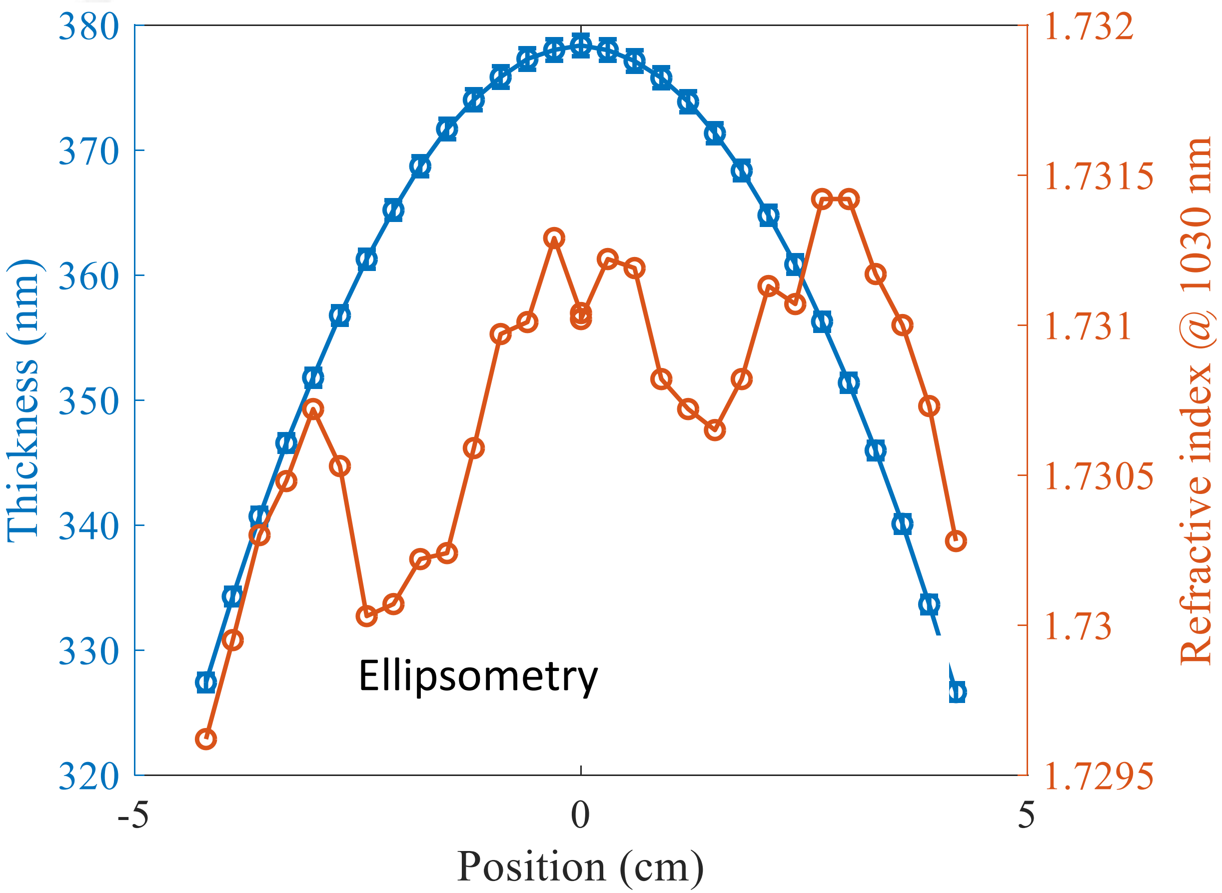


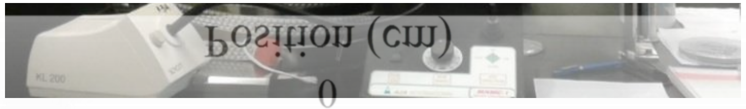
[Review: Hendriks et. al. , Advances in Physics: X, 6 (1), 1833753 (2021)

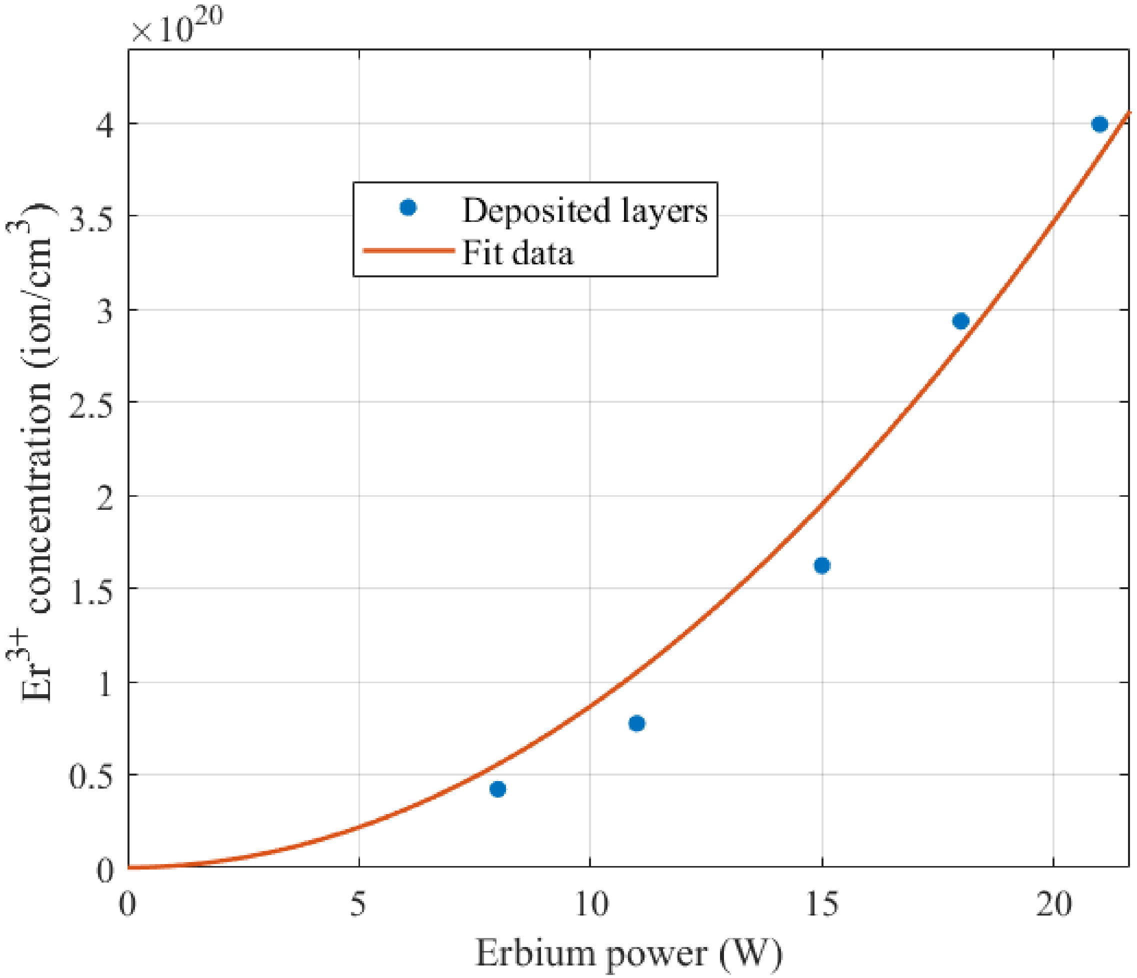
- Rich history in photonics
- Naturally occurring in crystalline state as corundum, forming popular gems such as ruby and sapphire

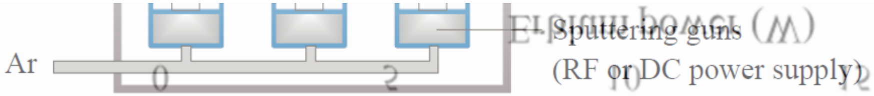


AL_2O_3 PROCESS FLOW – CMOS COMPATIBILITY



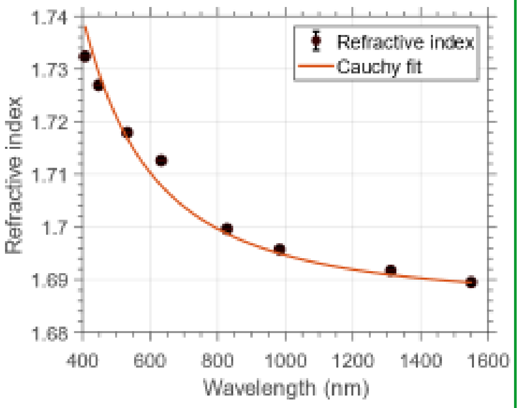






[J.Bradley, PhD thesis, UT, 2009]

REFRACTIVE INDEX AND
5% RELATIVE BIAS, 700°C SET SU

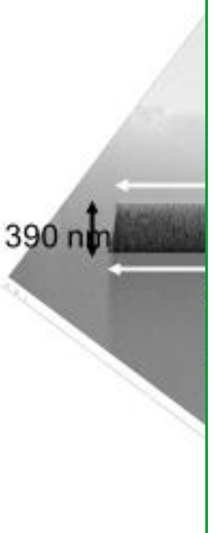


- 1.8 dB/c
- 0.025 dB

UNIVERSITY OF TWENTE.

CHANNEL
SETTINGS: 5

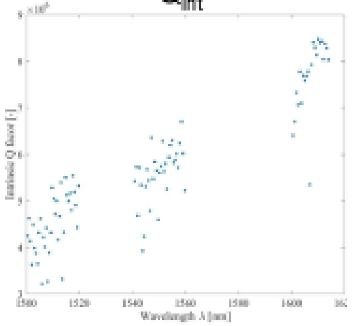
Channel



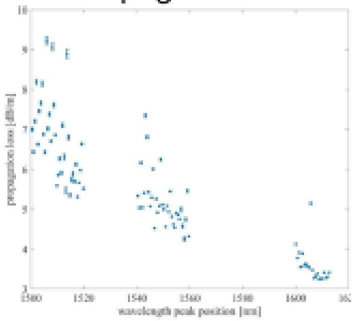
UNIVERSITY OF TW

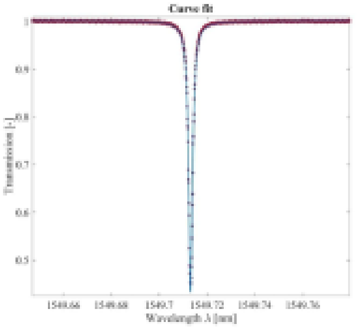
CHANNEL WAVEGUIDE CHARACTERIZATION
MICRORING RESONATOR RESONANCE ANALYSIS (400µm radius, 1200nm coupling gap)

Q_{int}



Propagation loss



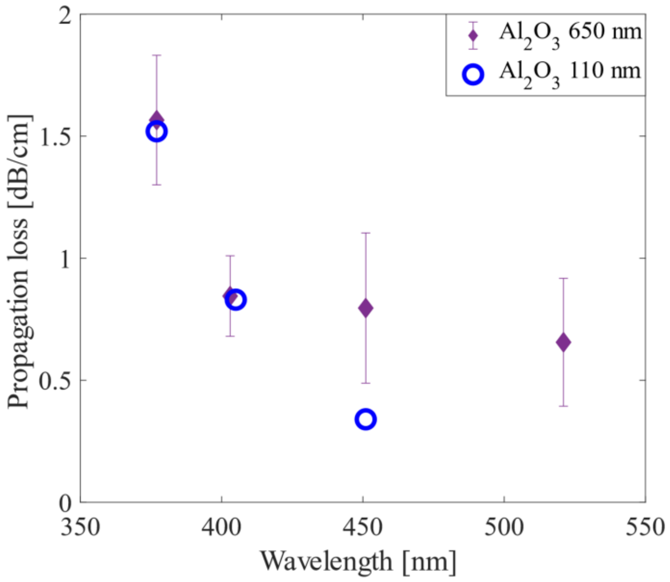


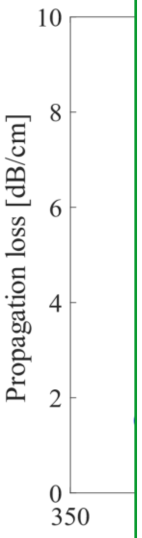
Propagation loss:
@1550nm: ~5 dB/m, Qint~6x10[6]
@1610nm: ~3dB/m, Qint~8.5x10[6]

UNIVERSITY OF TWENTE. 10

ALUMINIUM OXIDE WAVEGUIDE

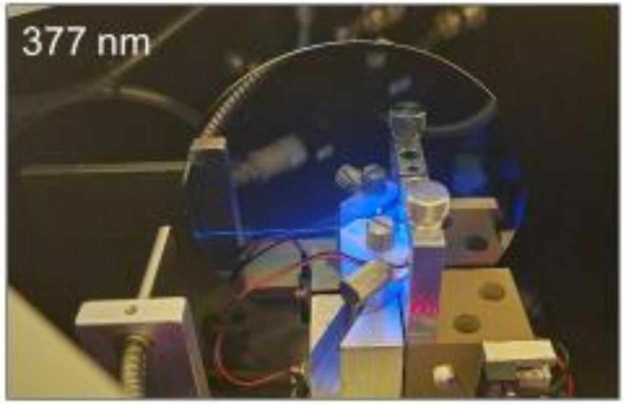
PROPAGATION LOSSES IN THE UV-VISIBLE

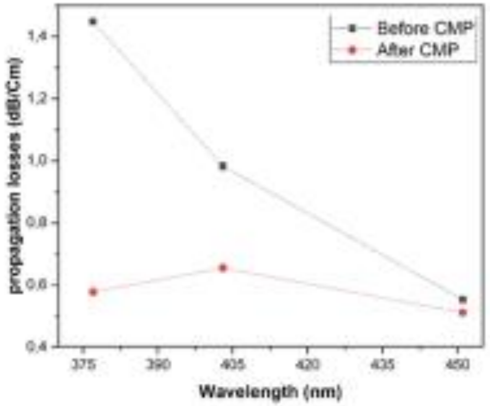




Al_2O_3 FOR OPERATION BELOW 400 nm

CHEMICAL MECHANICAL POLISHING



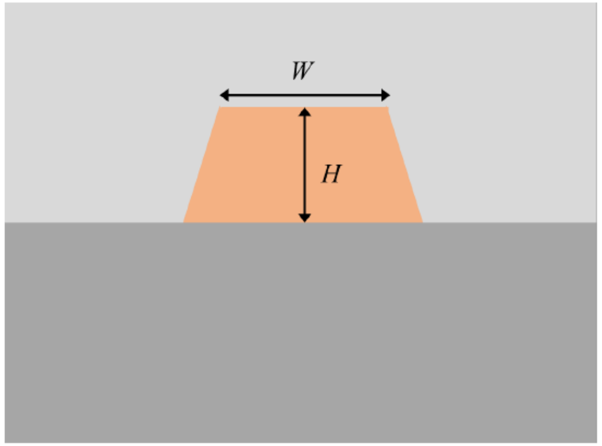


- 0.6 dB/cm loss at 377 nm after CMP (0.8 dB/cm improvement)
- Surface roughness measured with AFM (0.2nm RMS)

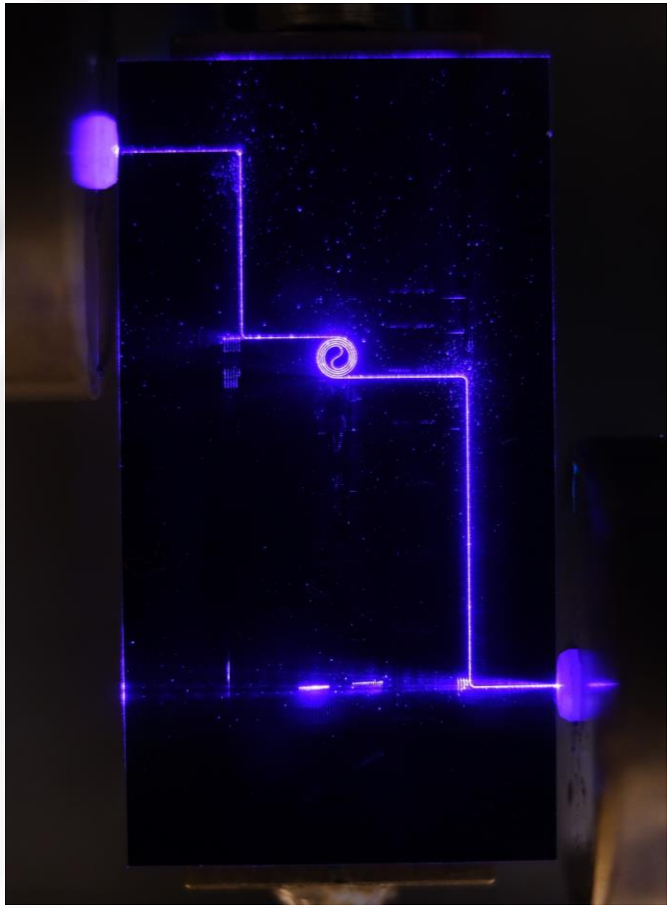
UNIVERSITY OF TWENTE. [European Conference on Integrated Photonics (ECIO 2022)] 16

BROADBAND WAVEGUIDE TRANSPARENCY

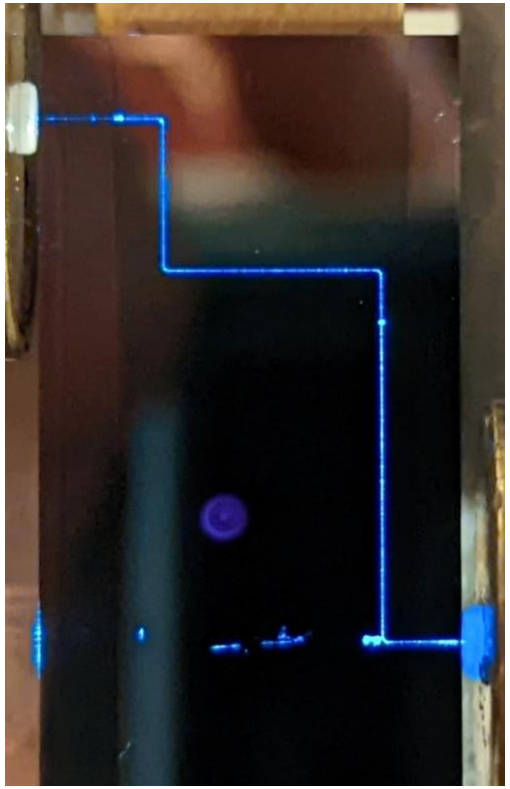
Soon to be sold from a foundry near you!



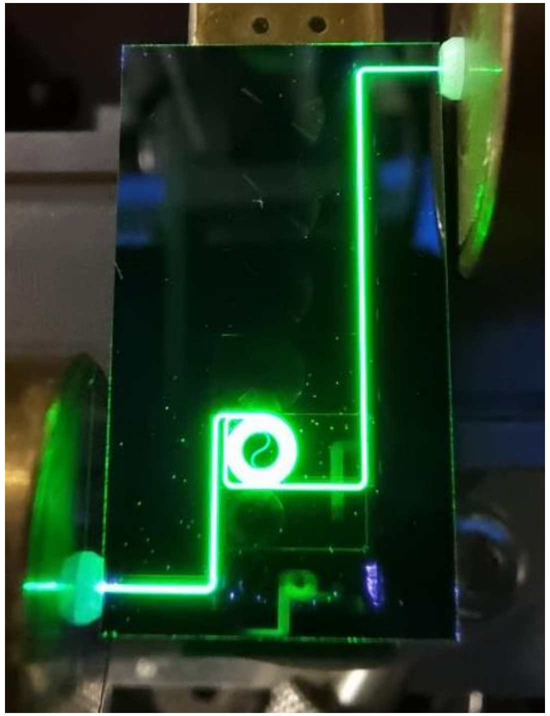
1.4 dB/cm losses measured at 375 nm



405 nm transmission



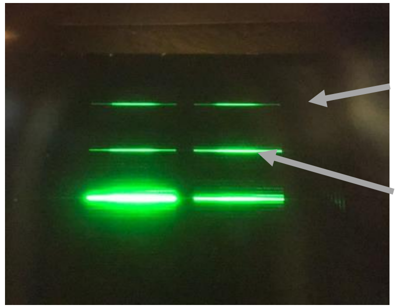
980 nm pumped $Al_2O_3:Er^{3+}$



632 nm alignment

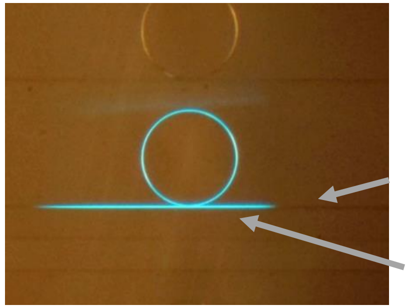
Double layer

A stack of two (or more) independent photonic layers interconnected by vertical adiabatic or resonant couplers



Single layer

Single passive photonic layer with incrustations of active gain material (photonics damascene process)
→ seamless transitions between layers



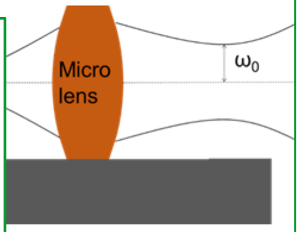
[J. Mu, et. al. "Monolithic Integration of Al_2O_3 and Si_3N_4 Toward Double-Layer Active-Passive Platform, " IEEE J. Selec. Top. Quant. Electron. 25, 8200911 (2019)]
[C. I. van Emmerik, et. al., "Single-layer active-passive Al_2O_3 photonic integration platform," Opt. Mater. Express 8, 3049-3054 (2018)]

3D INTEG
3D PRINT

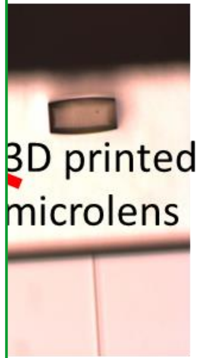
A
-
-
-

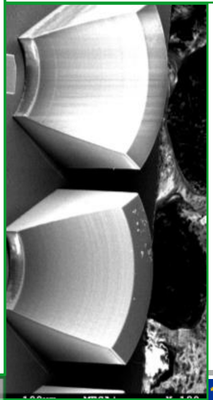
UNIVERSITY OF T

Side view



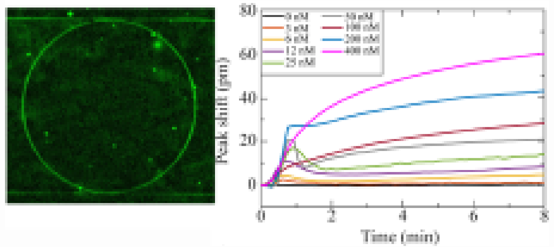
~30 µm





DEVICES
OPTICAL BIOSENSORS (I)

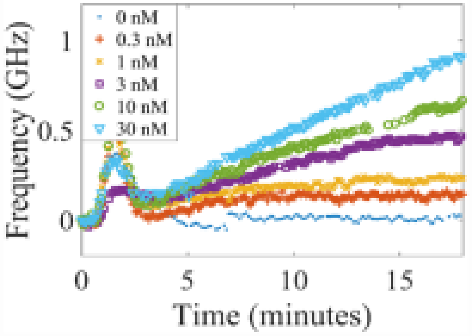
Passive Al_2O_3 microring sensors



- Bulk refractive index sensitivity: ~100 nm/RIU
- Noise: 0.05 pm
- Limit-of-detection (LOD) ~1e-6 RIU
- LOD 3 nM S100A4 protein

[M. De Goede, et. al., Optics Express (2019)]

Active Yb^{3+}:Al_2O_3 microring sensors



- Heterodyne detection
- Bulk refractive index sensitivity ~22nm/RIU
- Noise: ~ 0.026 pm
- LOD: ~$3x10^{-6}$ RIU
- LOD 0.3 nM S100A4 protein

[M. De Goede, et. al., Optics Letters (2019)]
[M. De Goede, et. al., OSA Sensors, Invited presentation]

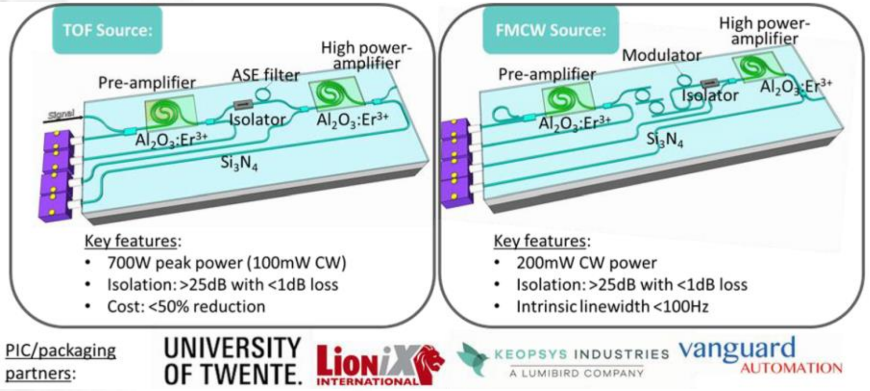
UNIVERSITY OF TWENTE.

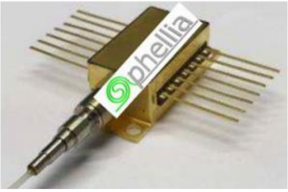
19

OBJECTIVES - On-chip PHotonics Erbium-doped Laser for LIdar Applications

The objective of OPHELLIA is to develop novel materials and integration technology for the realization of innovative PIC[(a)] building blocks to develop PIC-based laser sources for emerging TOF[(b)] and FMCW[(c)] LiDAR[(d)] applications.

These LIDAR will **be low cost and low size** thanks to the high **chip integration** and **tolerant packaging** technology while, at the same time, exhibit the same or even higher performance than existing solutions.

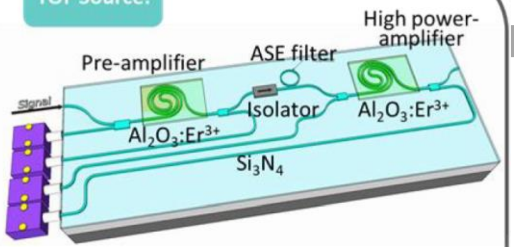




[(a)]PIC: Photonic integrated circuit [(b)]TOF: Time of flight [(c)]FMCW: Frequency-modulated continuous-wave [(d)]LiDAR: Light detection and ranging

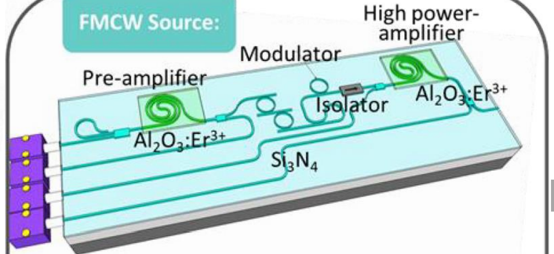
EXPLOITATION AND DEMONSTRATIONS

TOF Source:



Key features:
- 700W peak power (100mW CW)
- Isolation: >25dB with <1dB loss
- Cost: <50% reduction

FMCW Source:



Key features:
- 200mW CW power
- Isolation: >25dB with <1dB loss
- Intrinsic linewidth <100Hz

New material, PIC blocks, packaging…

Demo1: SICK Sensor Intelligence.

Safety in harbour and airport / Industry 4.0

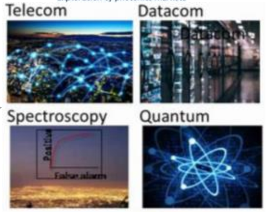
Demo2: RIEGL

Autonomous robots/Drones
Industrial applications

Demo3: THALES

Autonomous train / Traffic safety

Tematys
Exploration of photonics markets

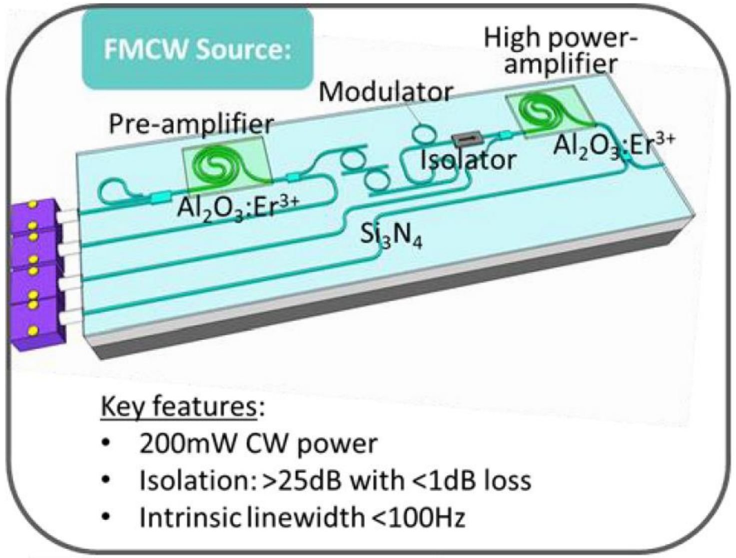


Exploitation of the results in other potential applications

- **Fully integrated product combined with cladding which may require annealing**

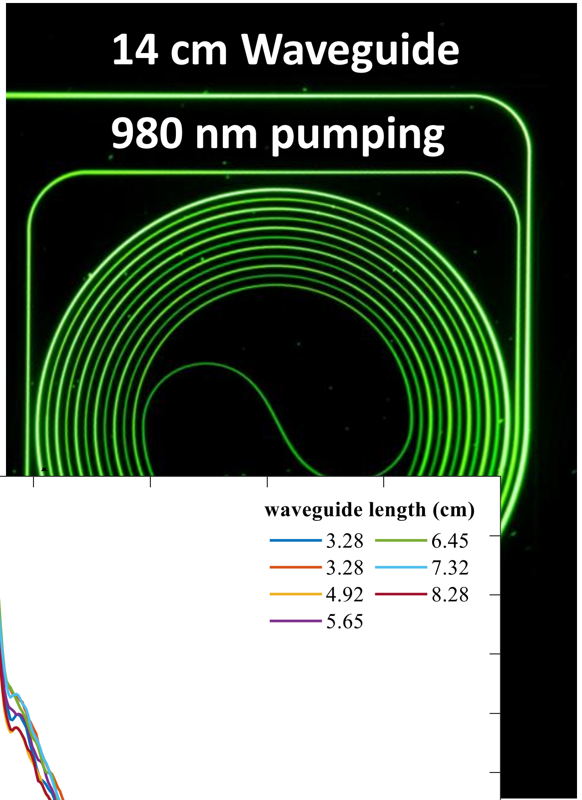
- **Amorphous alumina suffers mechanical failure from annealing – polycrystalline host provides higher thermal budget**

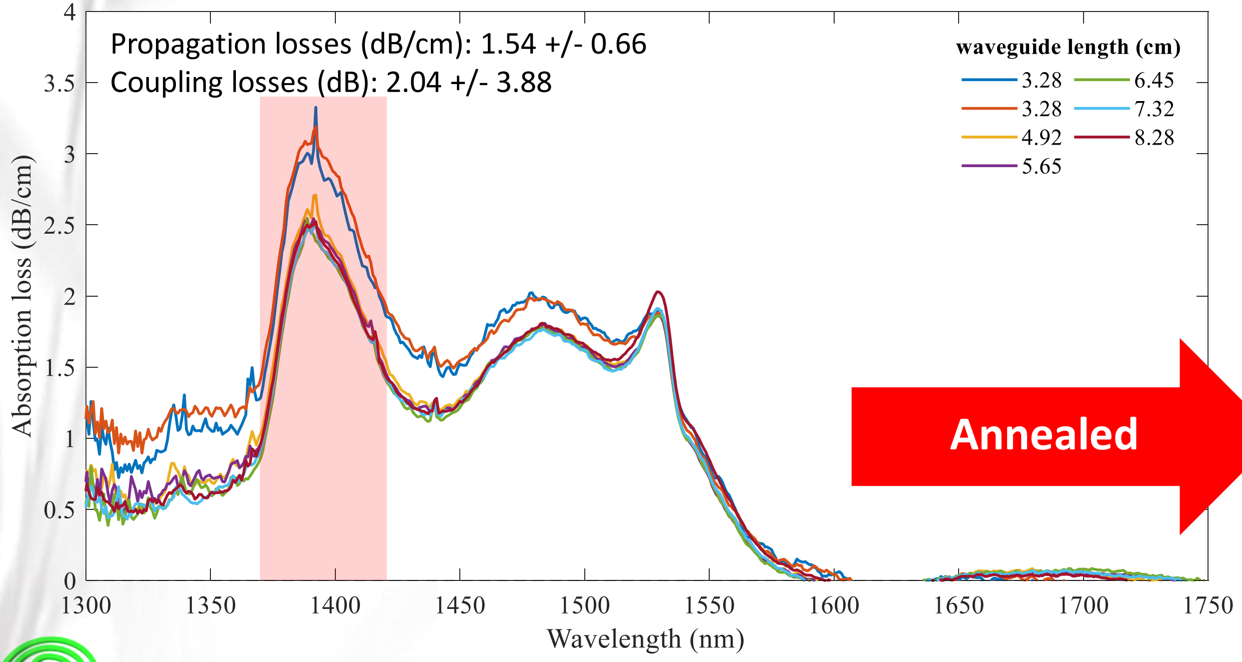
- **Polycrystalline host provides lower losses across broader wavelength range**



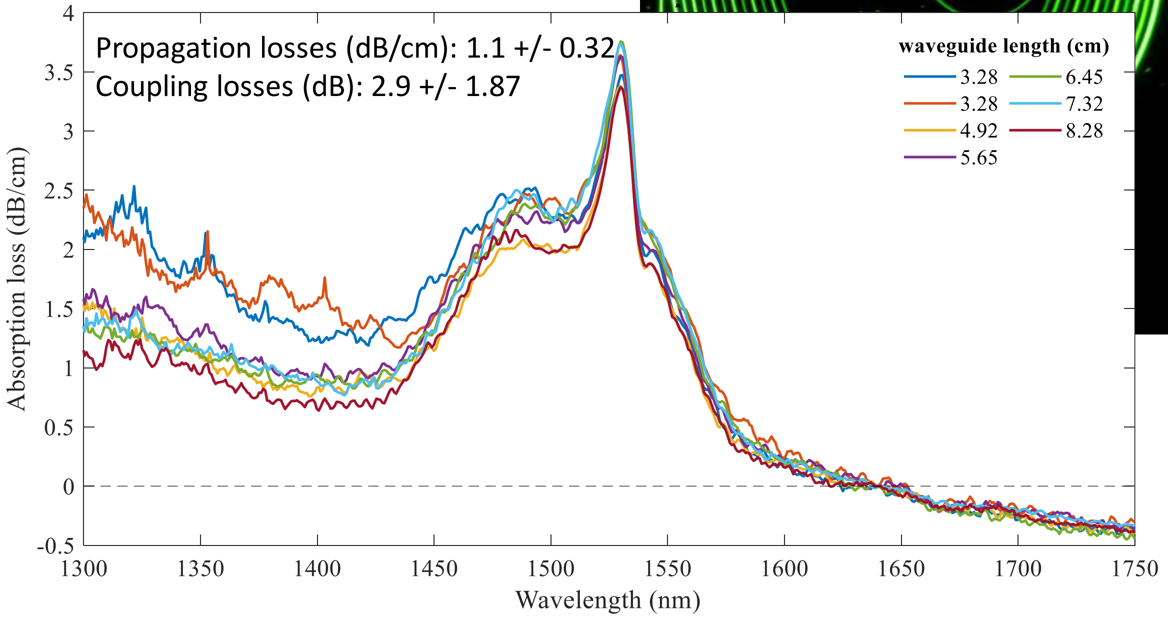
Preliminary Findings – Polycrystalline Host

- **Initial results limited by absorption and propagation losses**
- **OH likely leading to reduction of lifetime and 1380 nm absorption – clustering of Erbium ions present**
- **Annealing high thermal budget host intended for reduction of losses. 1100 °C removes OH signature, but crystalizes host – fast decay (short lived lifetime) observed**



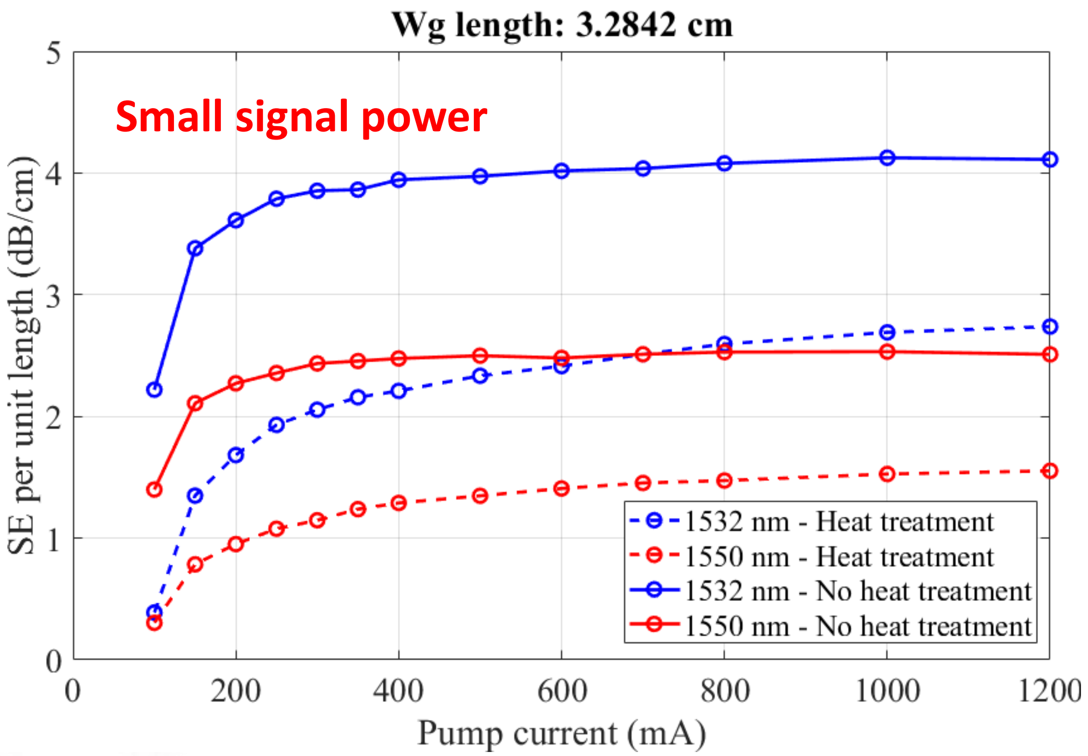


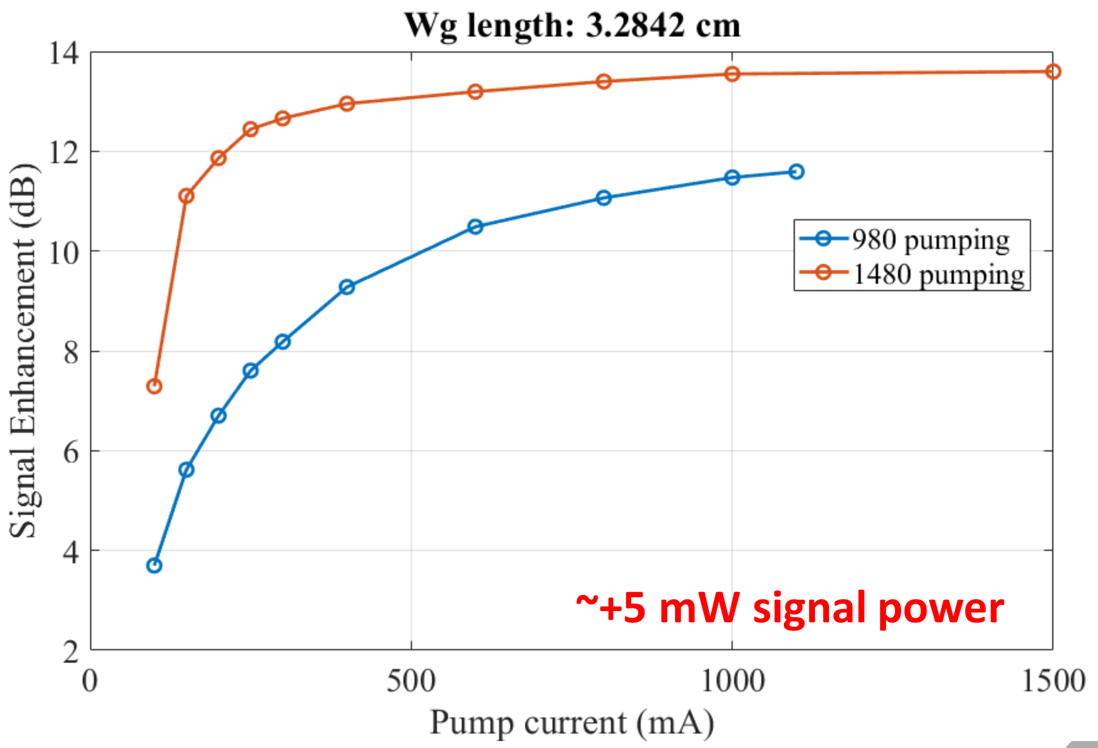
Annealed



Pumping Wavelength Considerations

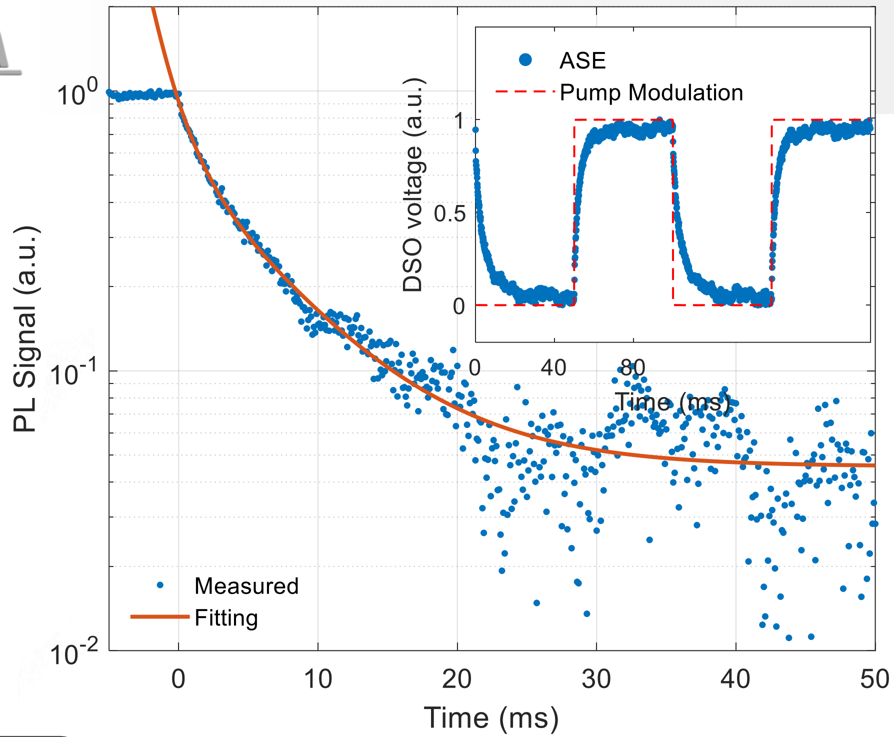
- High output power primary goal for project (100 mW+ at 1550 nm)
- Current high temperature heat treatment introduces high absorption losses, and fast decay
- Stable lifetime across fabrication steps required

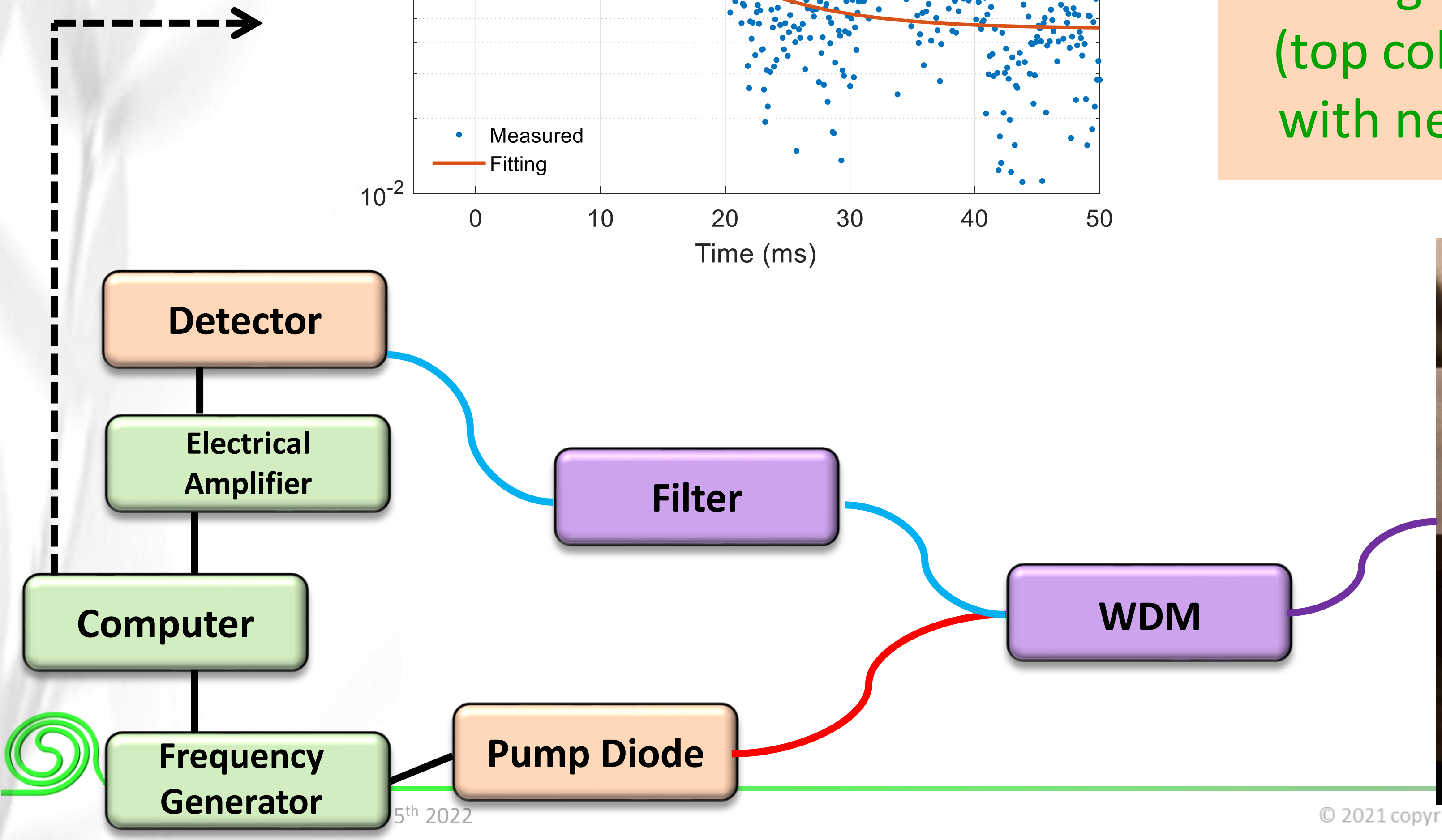


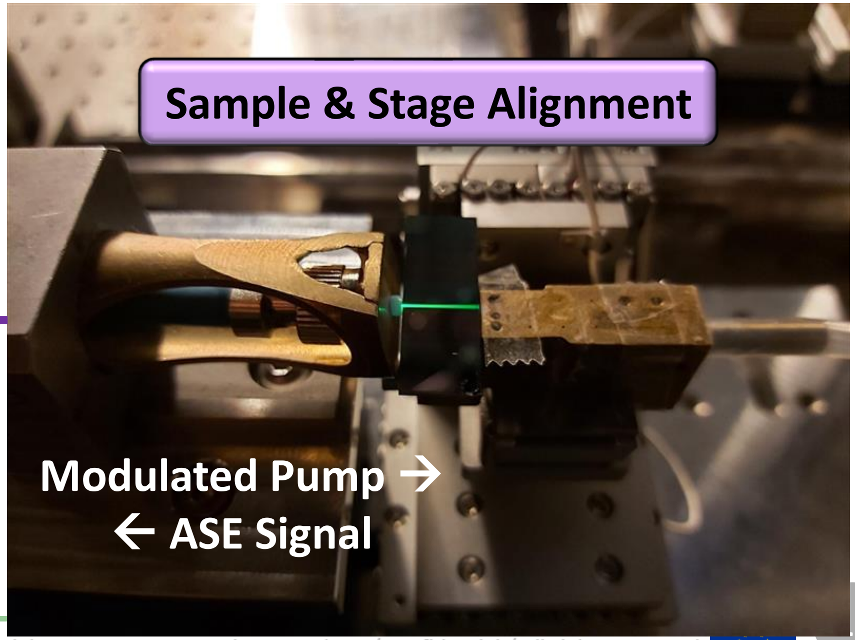


PL Setup

Planar or waveguide modes excited via 976 nm pump, back reflected ASE signal filtered through WDM to photodetector (top collection method possible with new fibers coming soon…)







Lifetime for Er^{3+} samples during steps of fabrication

- Expected O-H contamination from storage of samples in ambient
- Lifetime measurements also used to determine if cladding introduces O-H leading to fast decay (quenching)
- Annealing too high reduces lifetime

Sample State	Lifetime (ms)
'Old' fully fabricated	4.81 +/- 0.14
'Old' fully fabricated (annealed)	2.80 +/- 0.39
As deposited (slab mode)	7.24 +/- 1.44
Etched (multi-mode waveguides)	6.91 +/- 0.55
Cladded	6.64 +/- 1.65
Heat Treatment (650 °C)	6.56 +/- 2.87

Measurements repeated over 30 days?
Further passivation required?
To be measured…..

Ambient storage

Lifetime reliable indicator for clustering?
Pump absorption measurements coming soon….

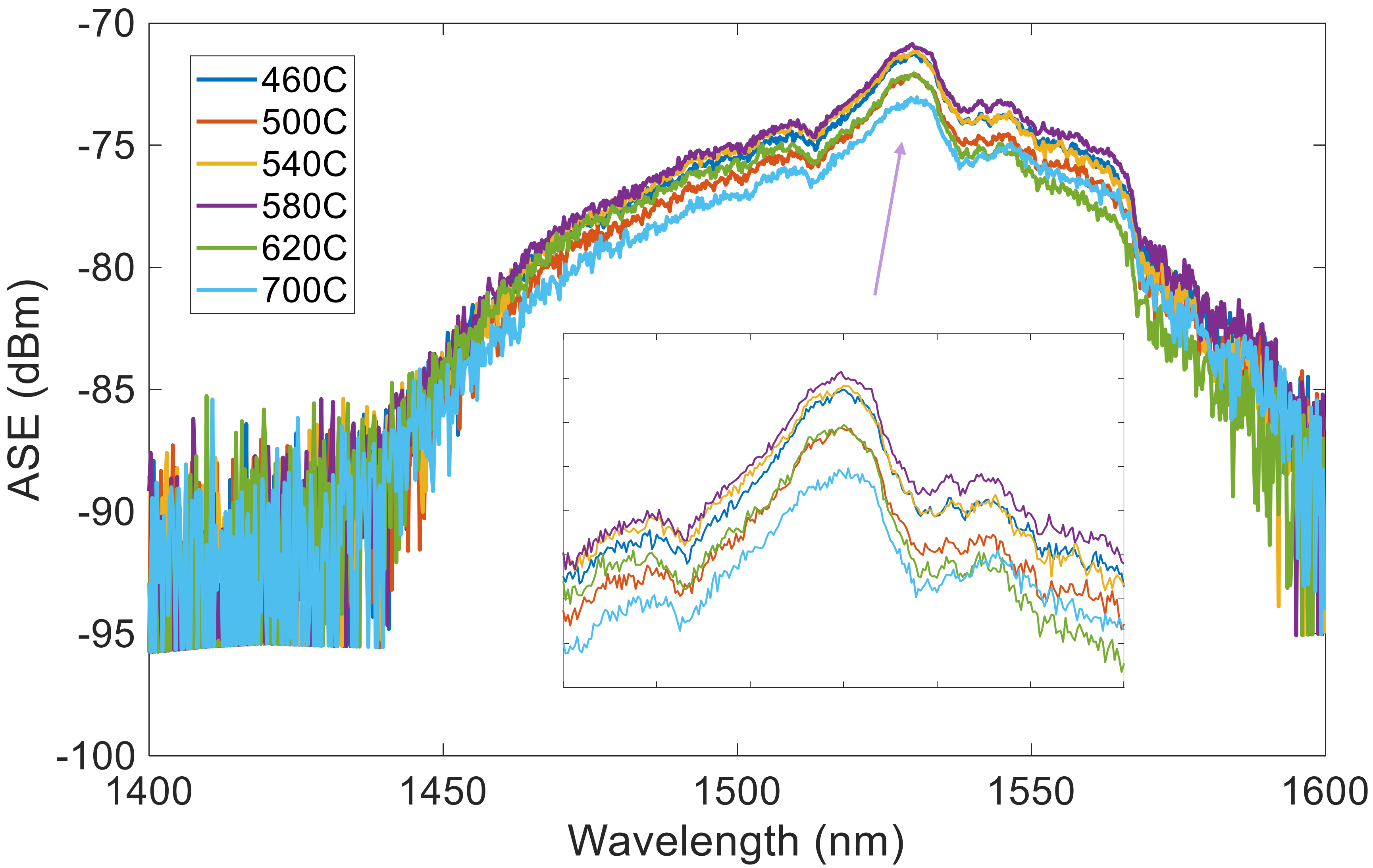
Nitrogen purged cabinet

Are ions clustering at grain boundaries?
Is erbium oxide forming in the matrix?...

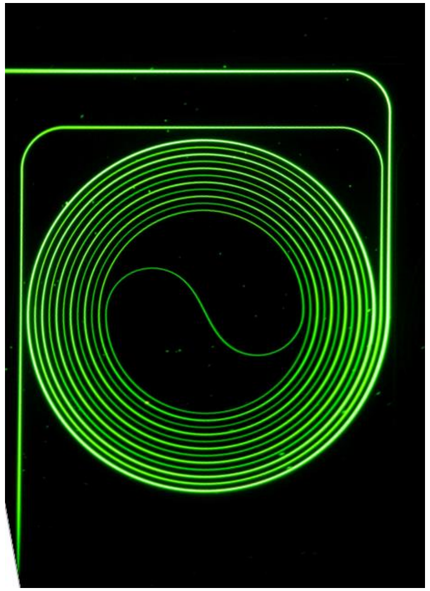
LIFETIME FOR Er^{3+} SAMPLES OF VARYING DEPOSITION TEMPERATURE AND EXPOSURE TECHNIQUES

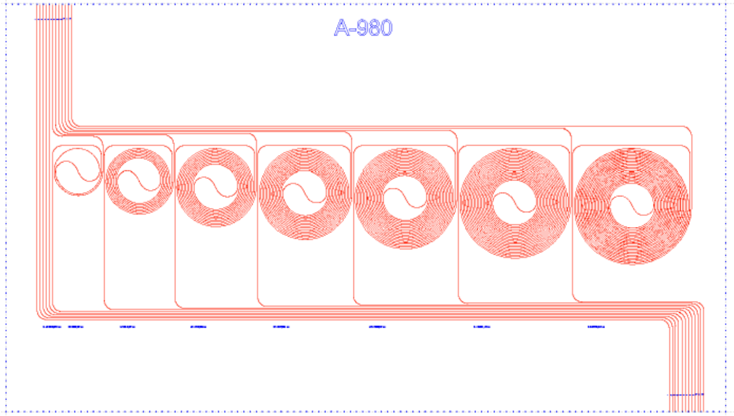
Film ID	Refrac index 1030 r
CO220603	1.6664
CO220601	1.6660
CO220602	1.6680
CO220604	1.6700
CO220605	1.6900
CO220606	1.7313

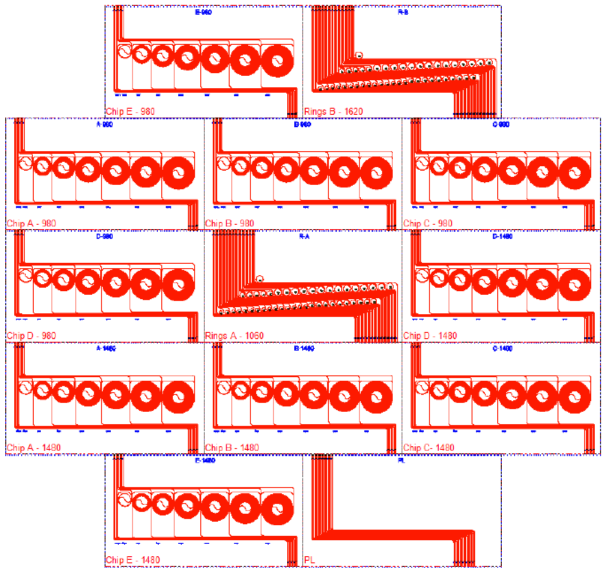
Waveguides etched, cladded, unannealed (multi-mode)	Fi
	CO
	CO



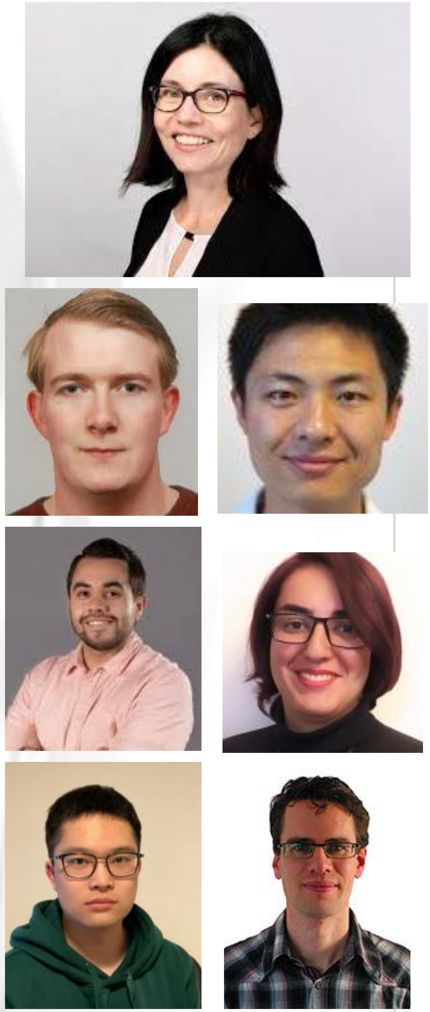
- New round of chips ready for measuring with nitrogen purged storage during fabrication
- Systematically investigate more temperatures to see affect on signal enhancement, propagation and absorption losses, quenching, and lifetime
- Quantify crystallinity with TEM & XRD
- Investigate variety of dopant concentrations to achieve highest gain and output power using 1480 nm pumping







FINAL ACKNOWLEDGMENTS & GENERAL INFORMATION



Programme(s): H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT)

Topic(s): ICT-37-2020 - Advancing photonics technologies and application driven photonics components and the innovation ecosystem

Call for proposal: H2020-ICT-2020-2

Funding Scheme: RIA - Research and Innovation action

More information:

https://lidar-ophellia.eu

https://cordis.europa.eu/project/id/101017136

PARTNERS

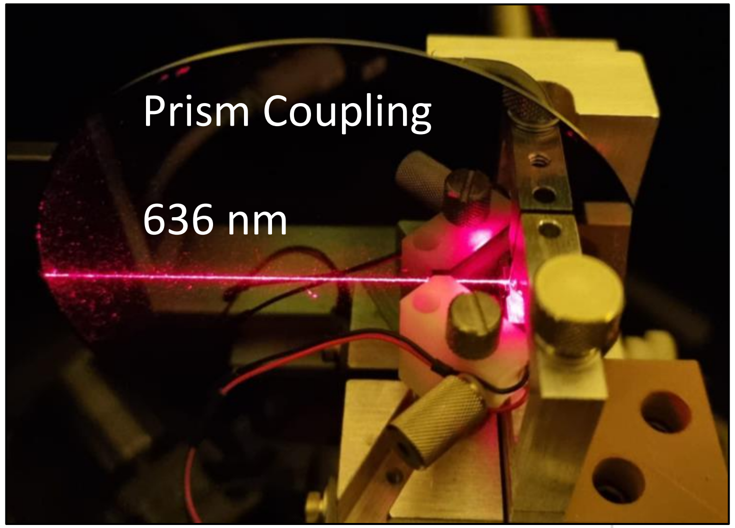
UNIVERSITEIT TWENTE NL (COORD.)	NL
KEOPSYS INDUSTRIES	FR
LIONIX INTERNATIONAL BV	NL
VANGUARD AUTOMATION	DE
THALES France	FR
SICK AG Germany	DE
RIEGL RESEARCH FORSCHUNGSGESELLSCHAFT MBH	AT
TEMATYS	FR

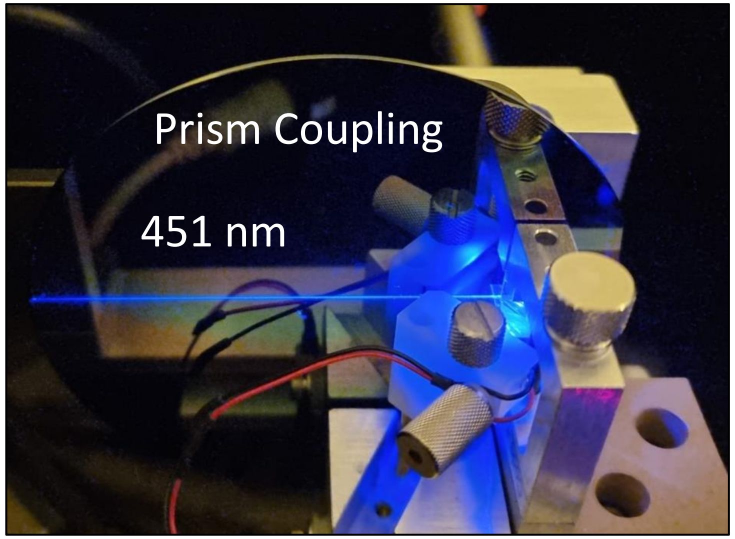
DZIĘKUJĘ!

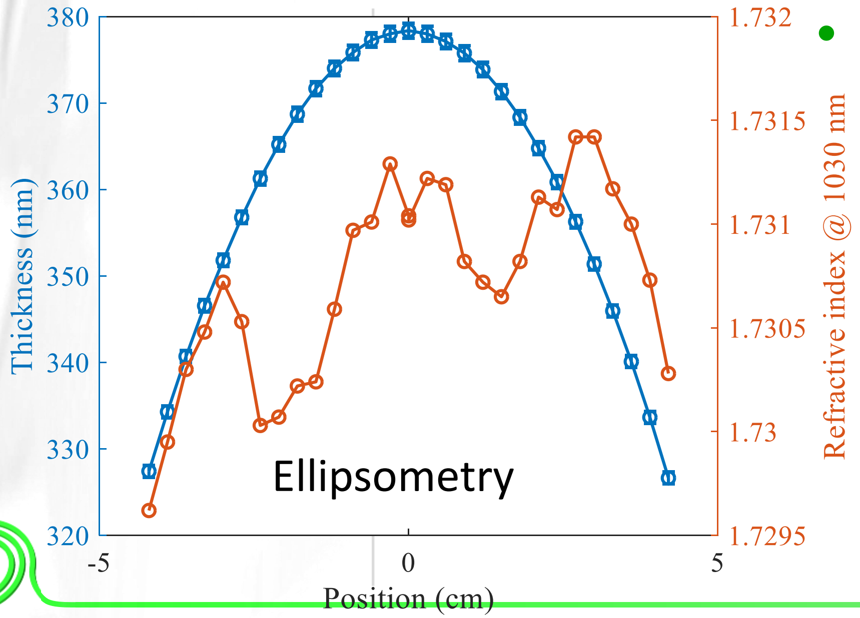
Thank you for your attention! Happy to take questions.

Reactive Magnetron Sputtering & Characterization

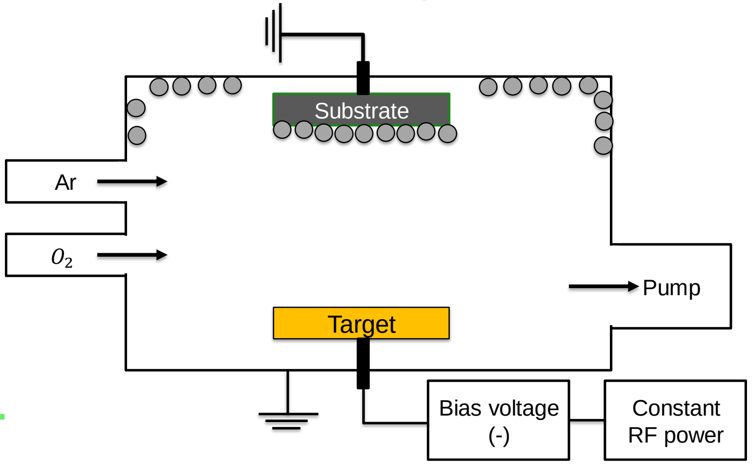
Er Power (W)	15
T (°C)	740
Dep. rate (nm/min)	4.44
n (@ 1030 nm)	1.731
Losses @ 451 nm (dB/cm)	2.79
Losses @ 636 nm (dB/cm)	0.73
Losses @ 978nm (dB/cm)	1.13

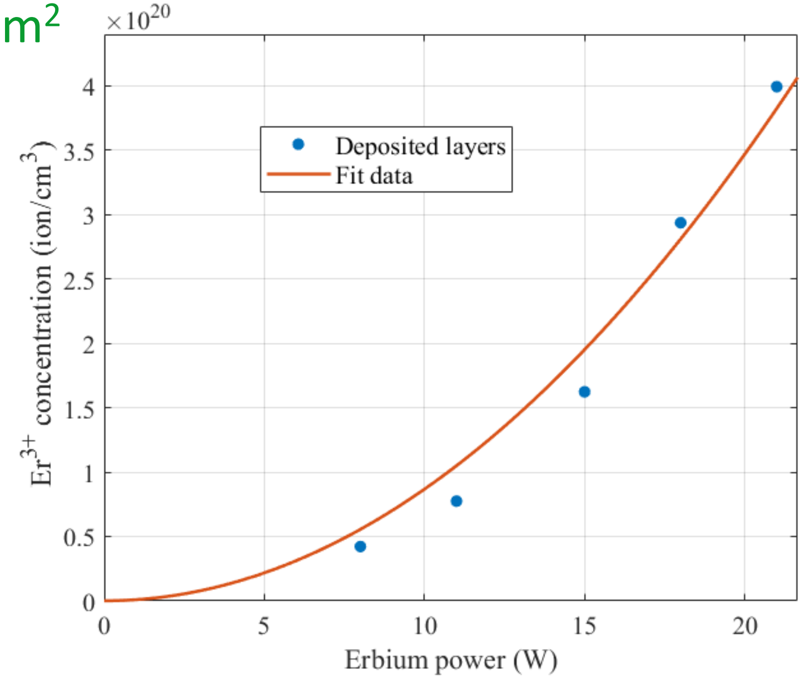






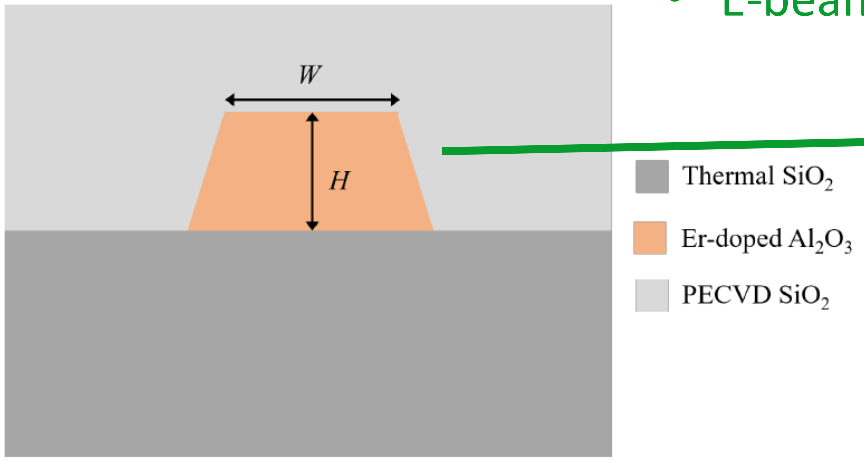
- Er^{3+} concentration of 1.62×10^{20} ion/cm^2 fit from RBS

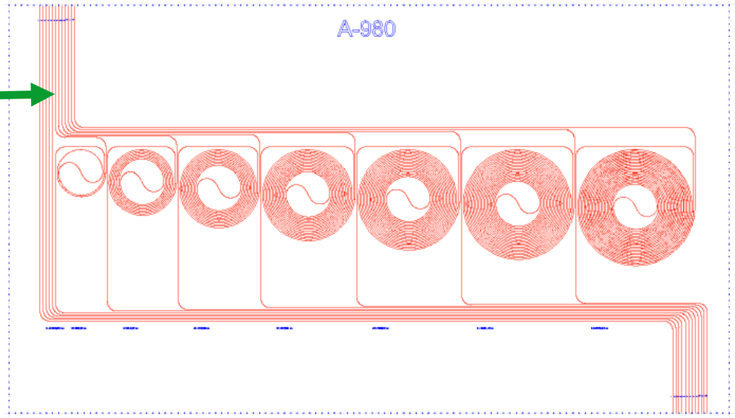


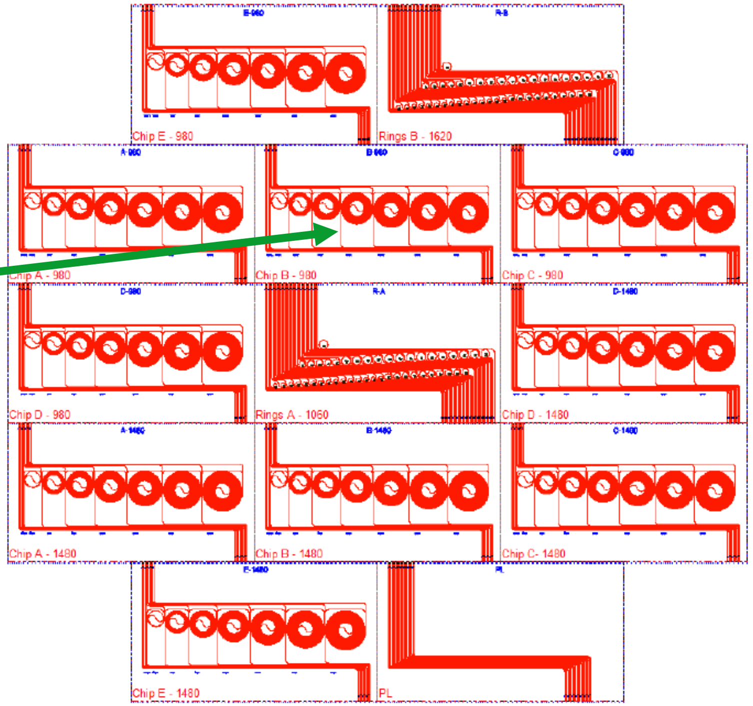


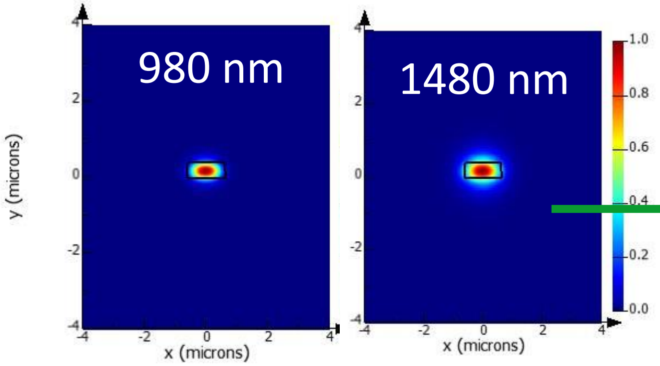
WAVEGUIDE DESIGN & COUPLING SIMULATIONS

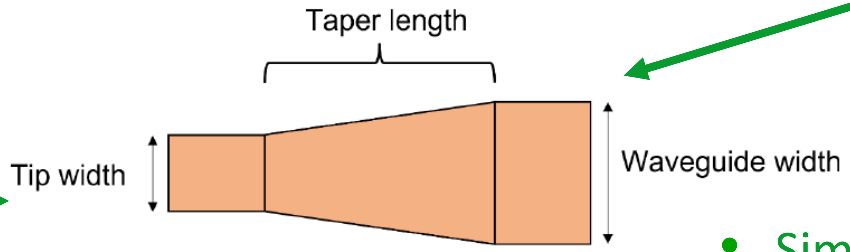
- E-beam, RIE (BCl3 -HBr), CVD (SiO_2), Dicing



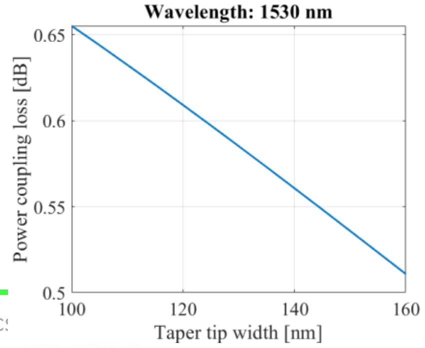


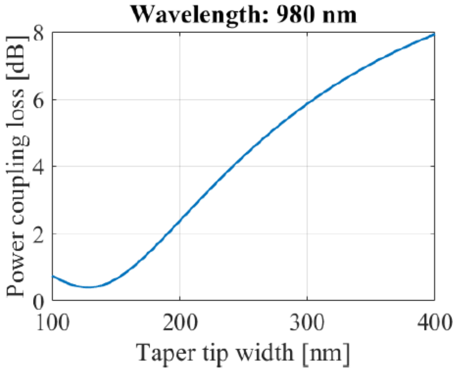


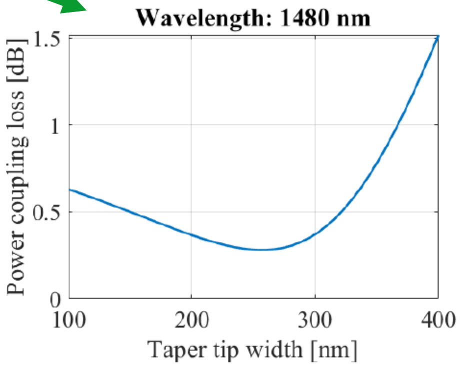


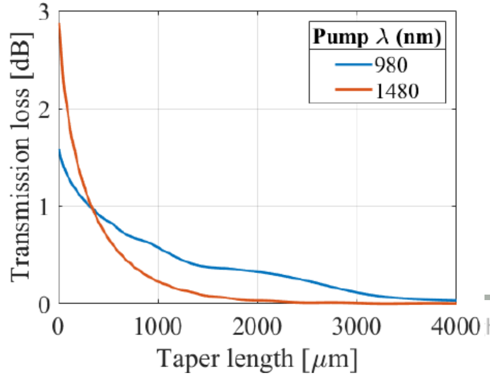


- Simulations to ensure efficient pump coupling
- 140 nm used for 980 nm coupling





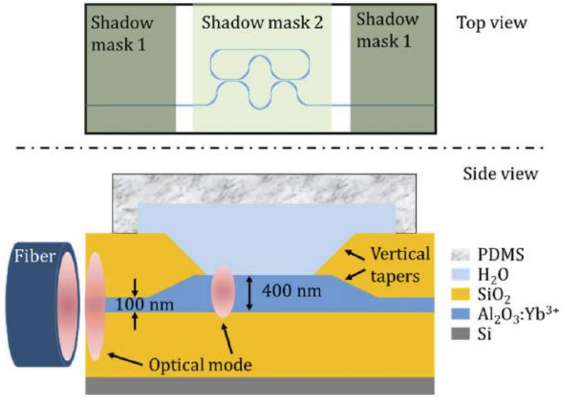


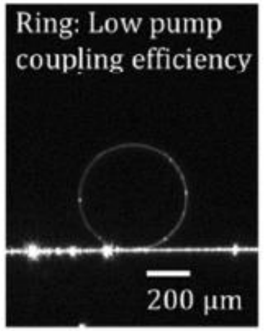


Dr. Lantian Chang
Assistant Professor
Optical Sciences

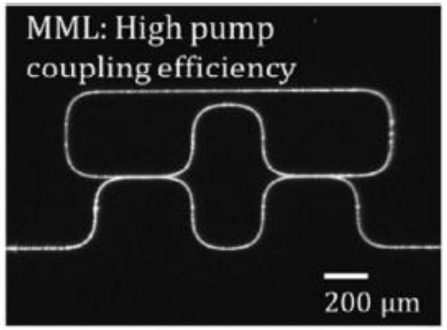
Modular microring laser cavity sensor (Yb^{3+})

Vol. 29, No. 2 / 18 January 2021 / Optics Express

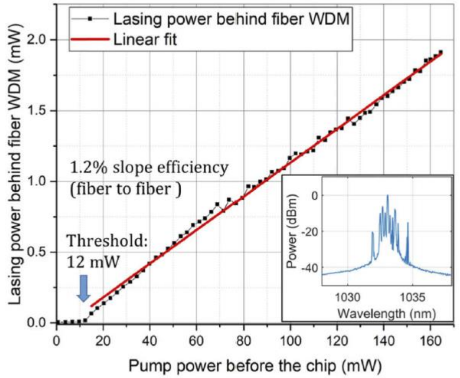




VS.



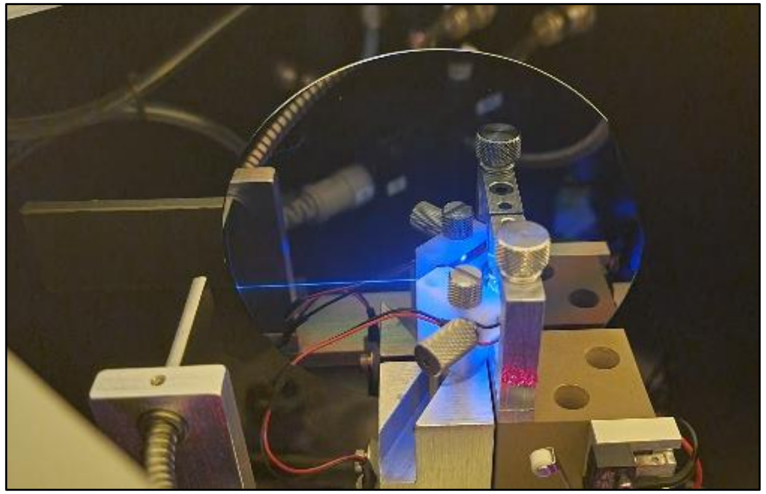
- Fiber-to-fiber slope efficiency of up to 1.2%
- 3σ limit of detection (LOD) of 3.1 × 10−7 RIU

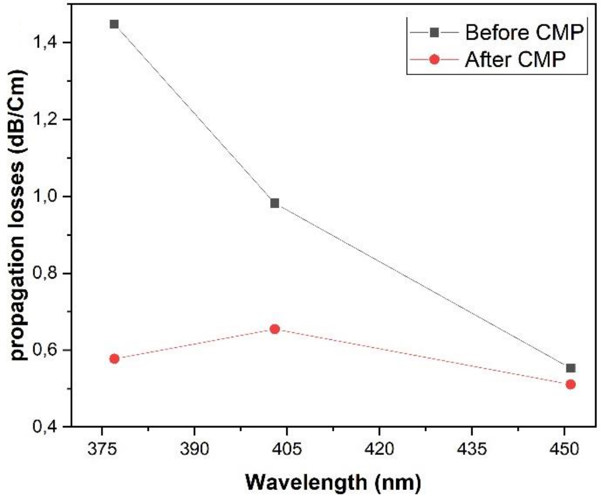


Soheila Mardani Mehrabad
PhD Candidate at University of Twente

Low-loss chemical mechanically polished Al_2O_3 thin films for UV integrated photonics

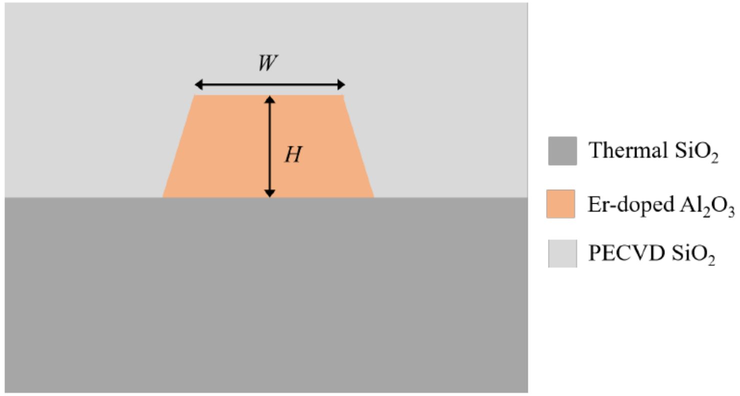
4 May 2022 / European Conference on Integrated Photonics





- 0.6 dB/cm loss at 375 nm after CMP (0.8 dB/cm improvement)
- Surface roughness measured with AFM

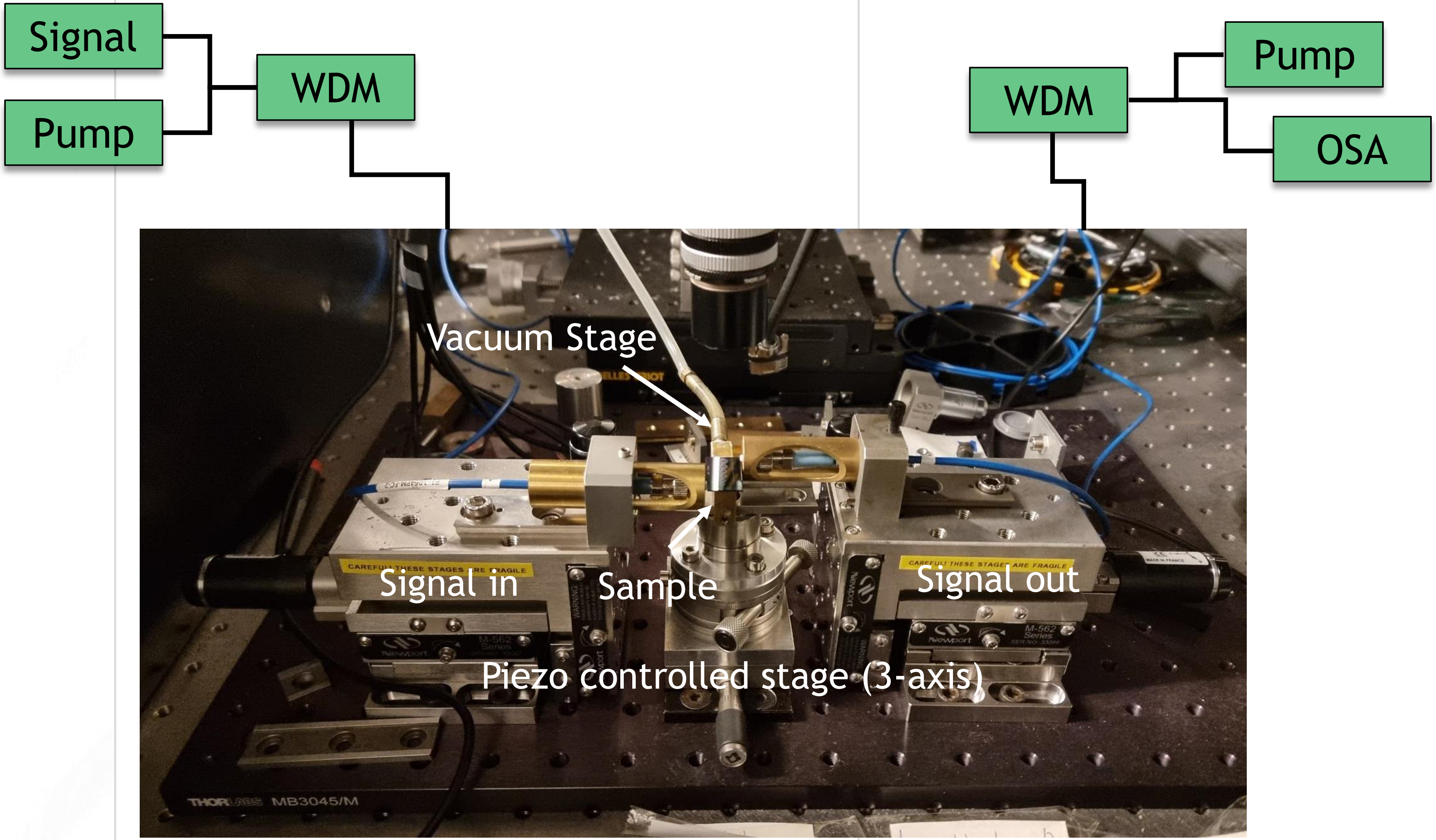
- First study focusing on new high index (~1.731 @ 1030 nm) films deposited at high temperature (700+ °C)
- Initial deposited wafers used for verifying choice between 980 vs 1480 nm pumping
- After initial gain & spectroscopy measurements, samples are to be annealed and re-measured
- Multi-layer integration with Si_3N_4 fabrication after optimization of $Al_2O_3:Er^{3+}$ strip waveguides



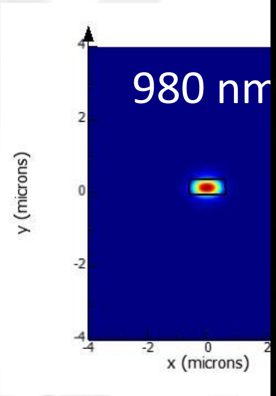
Carlos Osornio-Martinez
PhD Candidate at University of Twente

ING. Meindert Dijkstra
Support Staff at University of Twente

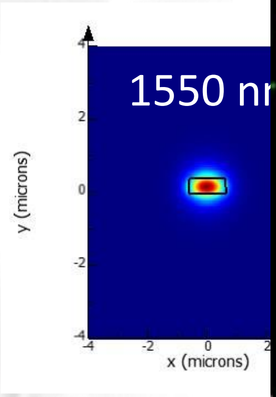
Optical Pumping Measurement Setup (980 nm PM butt coupling)

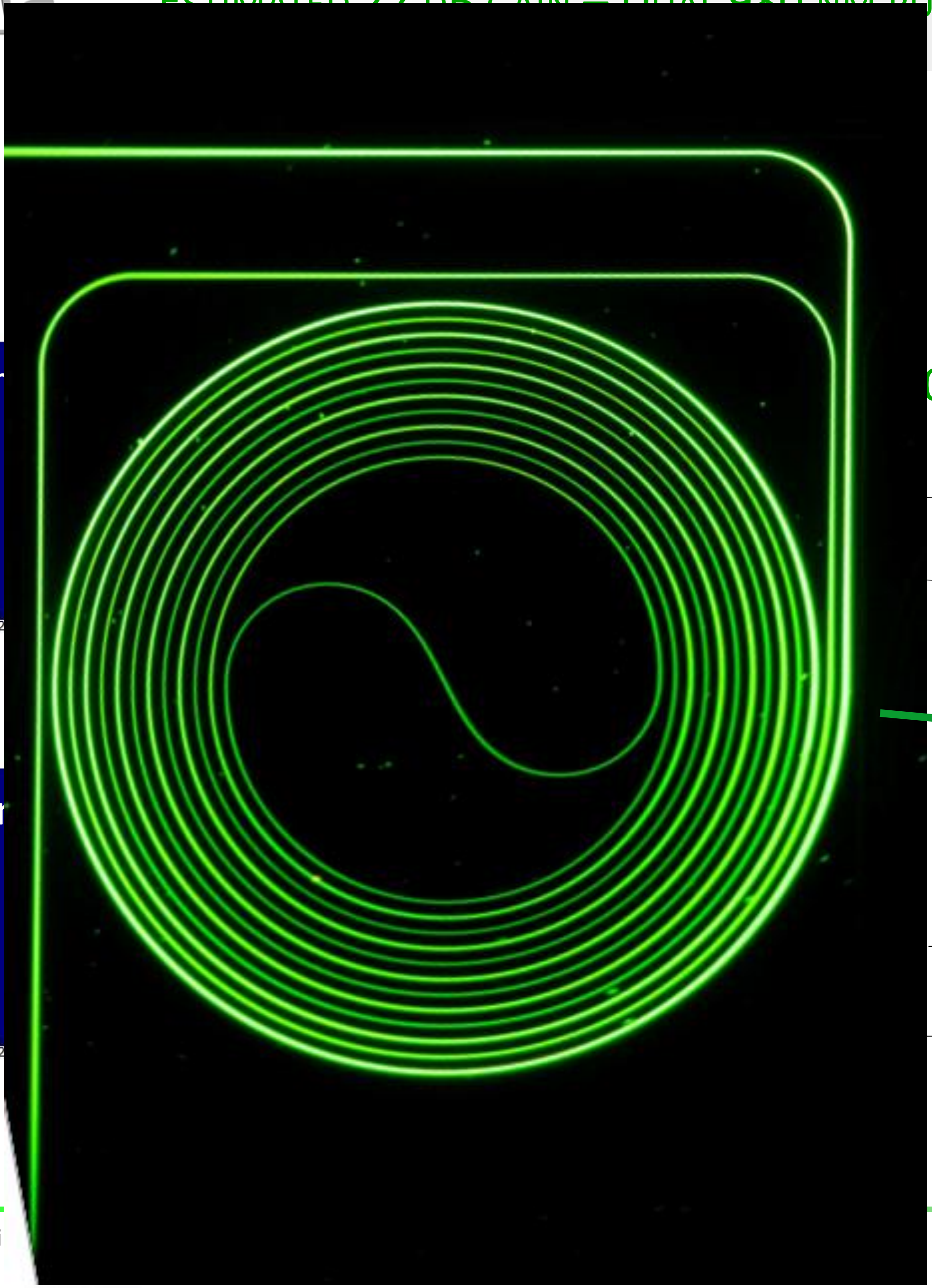


ESTIMATED 22 DB GAIN – DUAL 980 NM PUMPING, -10 DBM 1530 NM SIGNAL SETTING

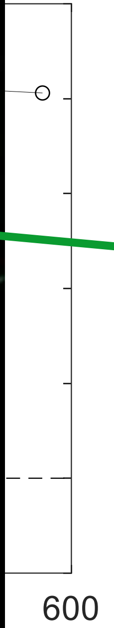


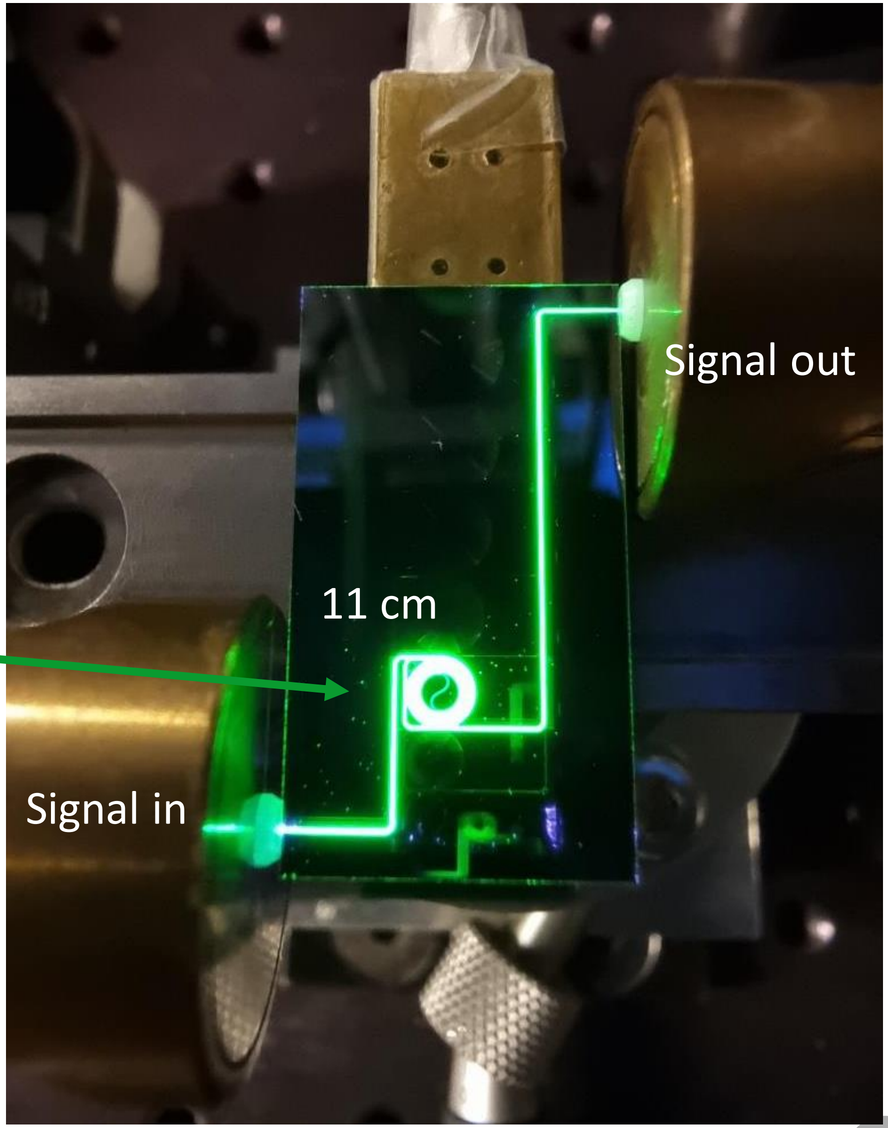
~1.2 x 0.4

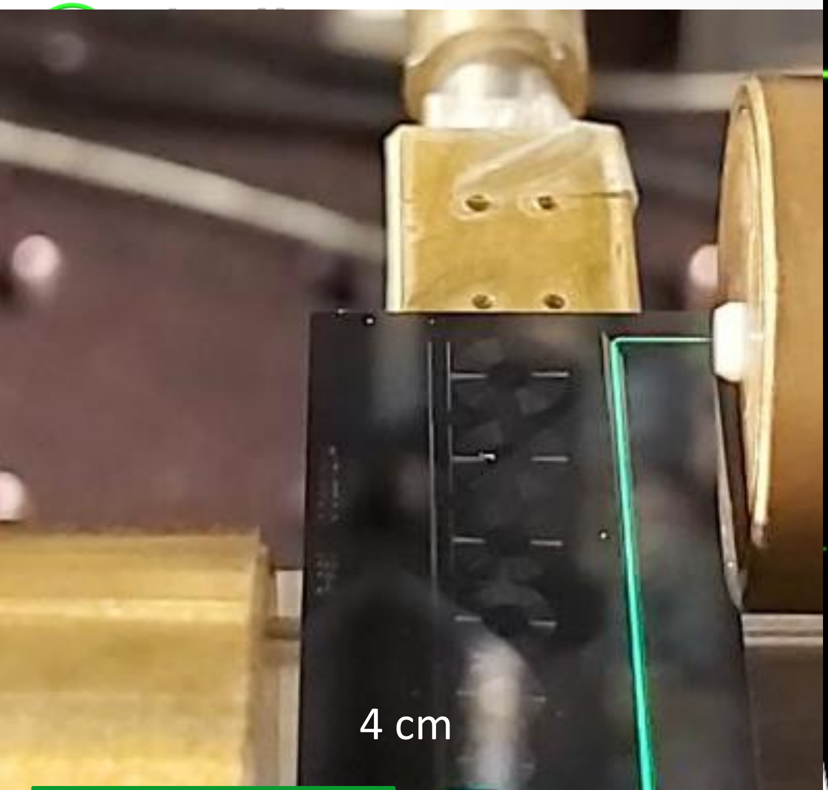


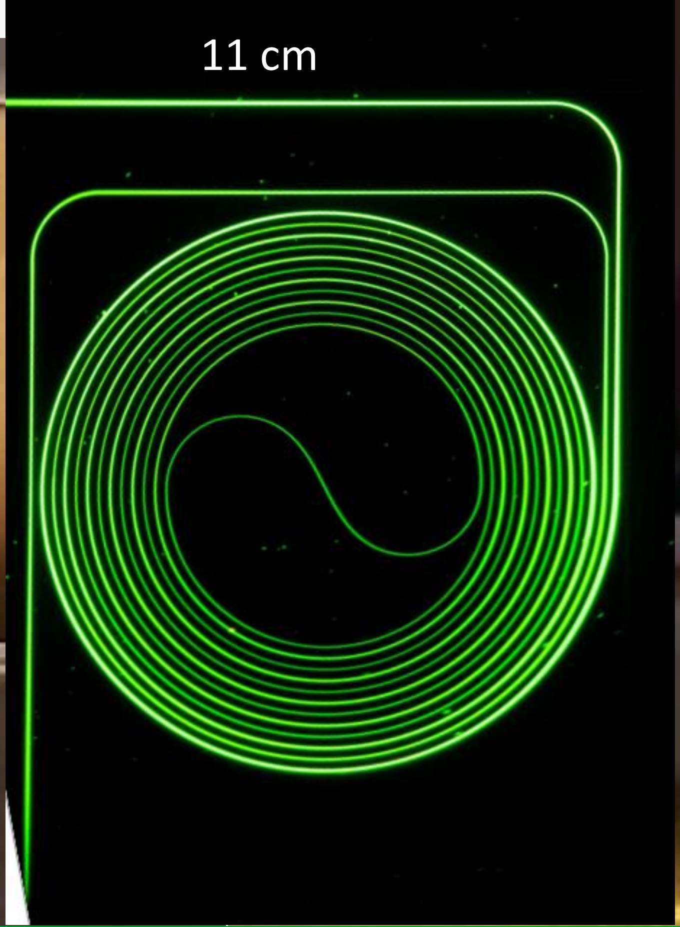


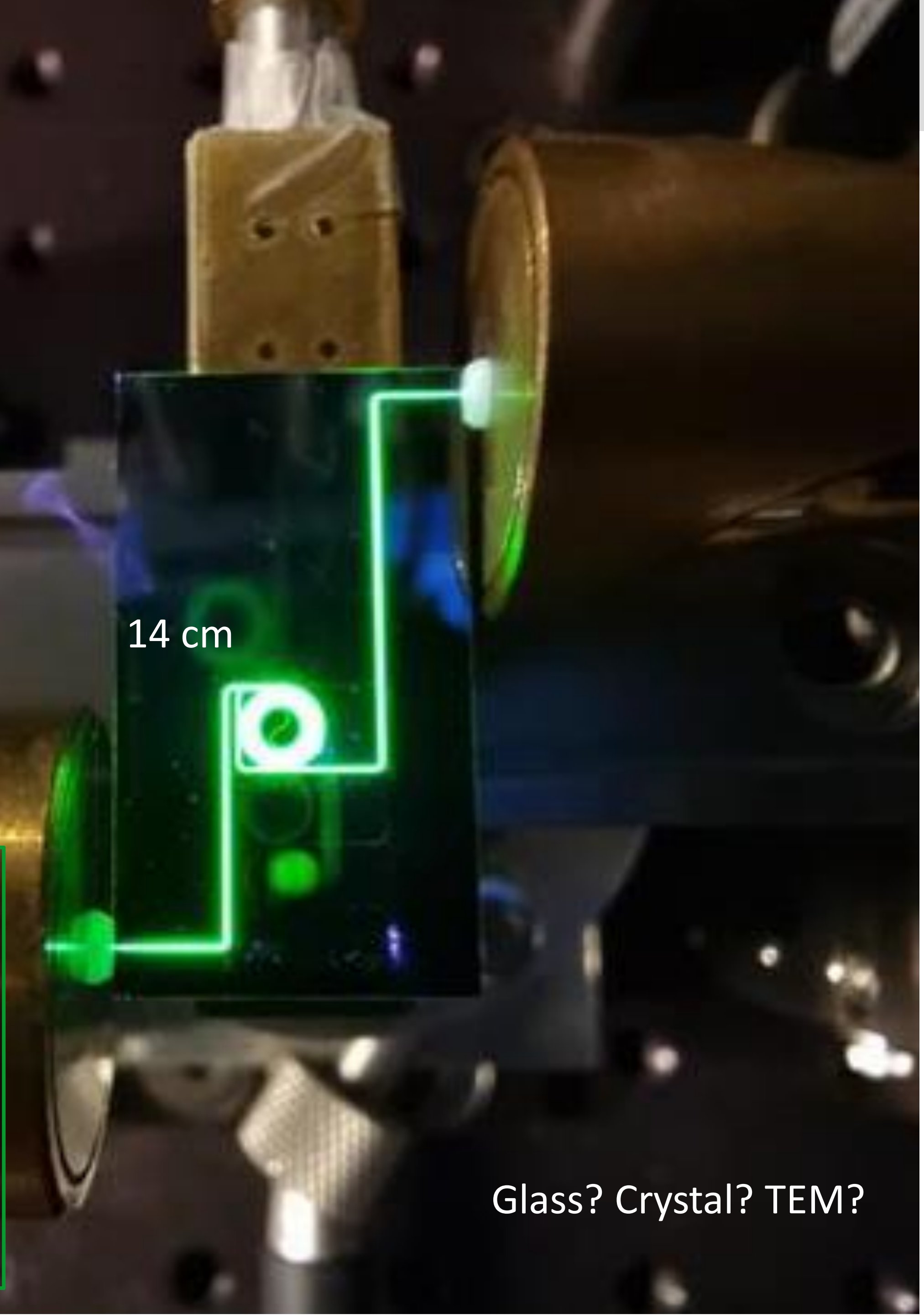
0 nm











Next Steps

- Varying spiral lengths to be investigated for a variety of Er^{3+} concentrations, waveguide cross sections, and signal powers
- Spectroscopic parameters and loss/gain to be assessed after annealing samples at 700+ °C (PL + Lifetime & Quenching)
- Preliminary measurements point towards promising net gain for high power amplifiers and laser cavities