Gain Characterization of Erbium-Doped Tellurium Oxide Coated Silicon Nitride Amplifiers

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Introduction

- Long-range optical fibre telecommunication requires signal amplification in order to maintain an adequate signal-to-noise ratio
- Erbium Doped Fibre Amplifiers (EDFAs) are optimal at maximizing the gain in optical fibres in the C-band (1530-1565 nm), due to their ability to amplify signals at ~1550nm [1][2][3]
- Amplification is achieved via stimulated emission by the transition from the $^4I_{13/2}$ excited state to the $^4I_{15/2}$ ground state in Erbium (Er) [4]

Waveguide Structure

- **Silicon (Si)** serves as a substrate
- **Silica (SiO_2)** serves as a low-loss and stable lower cladding, as well as a surface for growing silicon nitride thin films
- **Silicon nitride (Si_3N_4)** makes up the core, and was chosen due to its low propagation losses (< 0.1 dB/m) [5]
- **Tellurium oxide (TeO_2)** glass lowers optical confinement in the waveguide and allows for high mode overlap with the cladding which is used as a gain medium when doped with Er^{3+} ions [3]
  - This is due to the relative refractive index of TeO_2 to Si and Si_3N_4:

$$n_{Si_3N_4} < n_{TeO_2} < n_{Si}$$

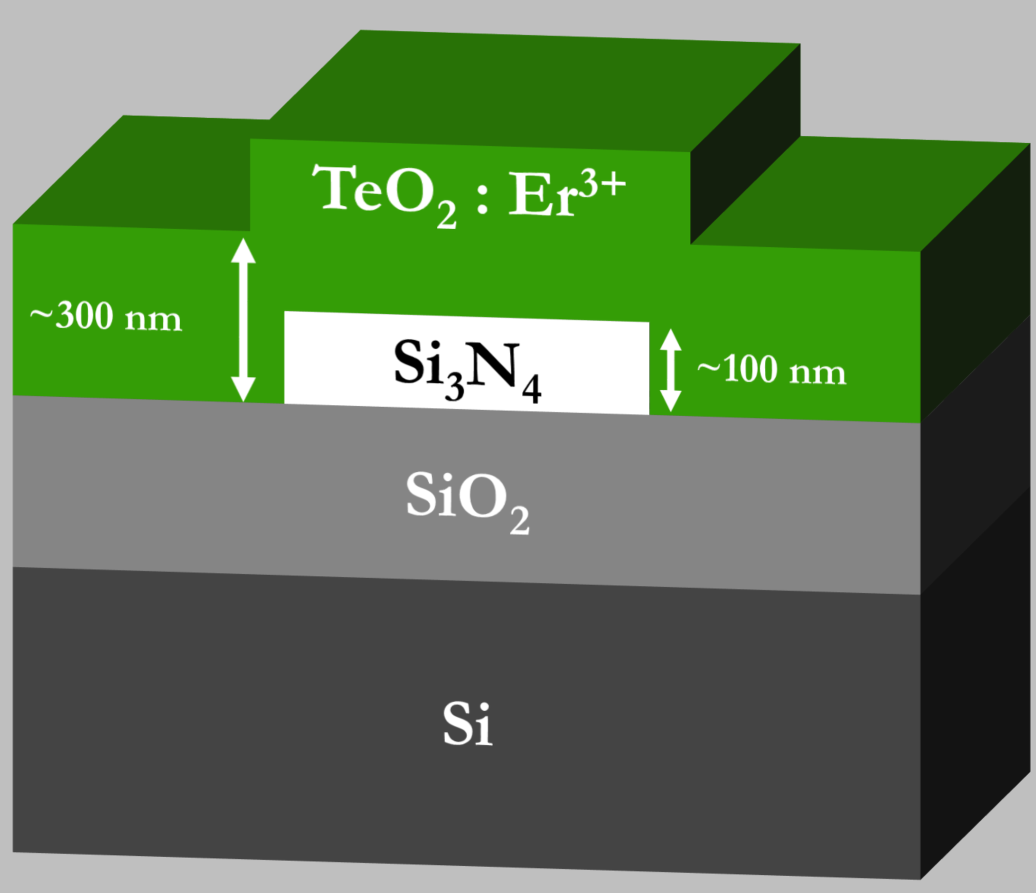
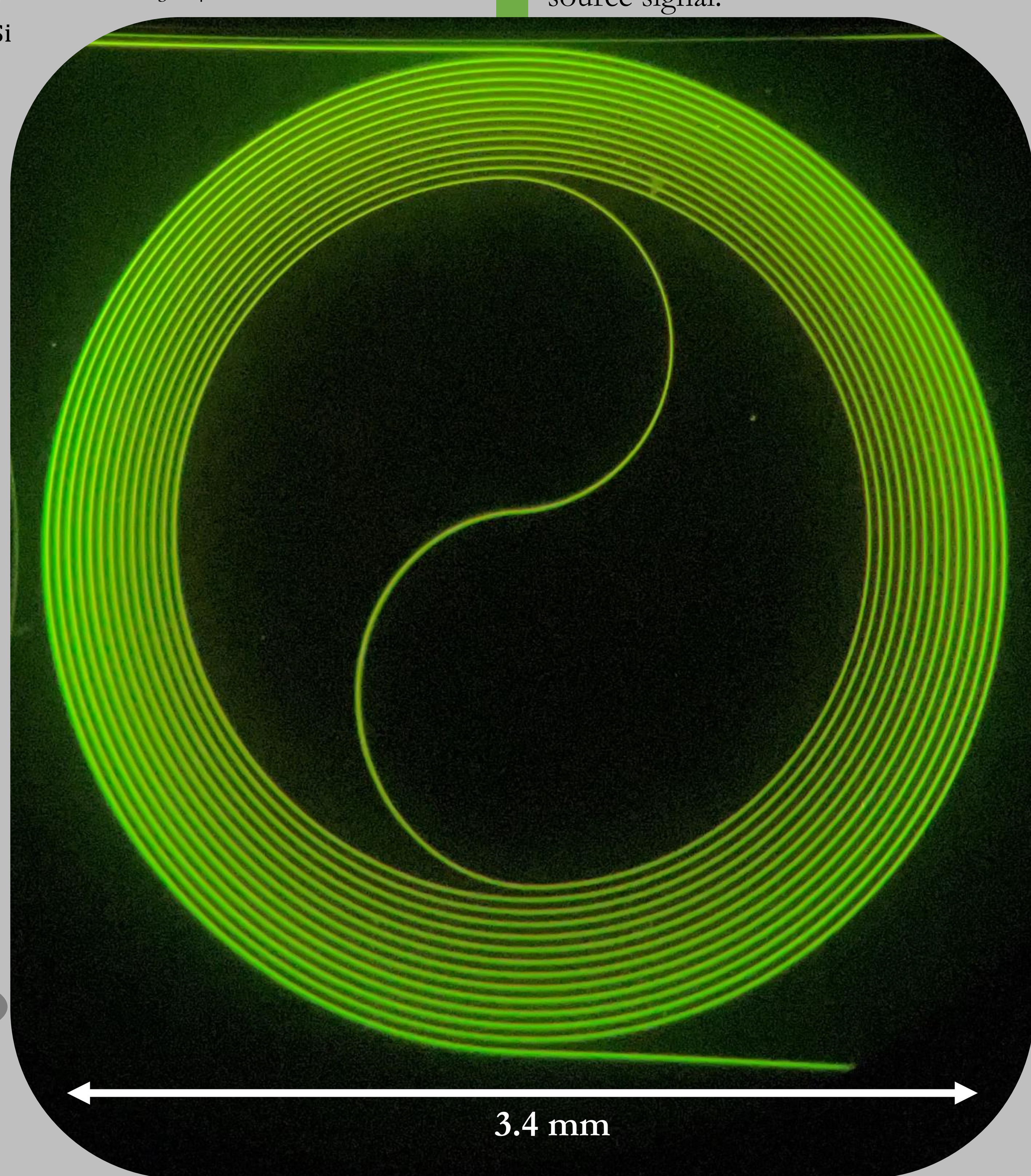


Figure 1. Cross-sectional view of the waveguide. Si and SiO_2 make up the substrate and lower cladding, respectively. A Si_3N_4 core rests on top, with a typical thickness of 100 nm. The Er-doped TeO_2 upper cladding has a typical thickness of 300 nm.



Methods

- A tunable laser signal ranging from 1520-1570 nm was amplified via passing through a spiral waveguide
- The signal output power was 0 dBm, which was decreased to roughly -15 dBm via an attenuator
- Two 1470 nm laser diodes were used to optically pump from both sides of the waveguide

- Passive measurements included fiber-to-fiber transmission and waveguide transmission
- Passive measurements were taken with and without the wavelength division multiplexers (WDMs) in order to separately characterize transmission properties like non-fibre related losses (without WDM) and signal enhancement (with WDM)

- Active measurements were done by measuring the transmission with and without the signal for varying forward and backward pump powers
  - Accounts for amplified spontaneous emission (ASE)

- Polarization paddles were used to change the light polarization to increase coupling
- A long-pass filter was placed before the photodetector in order to filter out the pump wavelength (and other noise) from the amplified signal

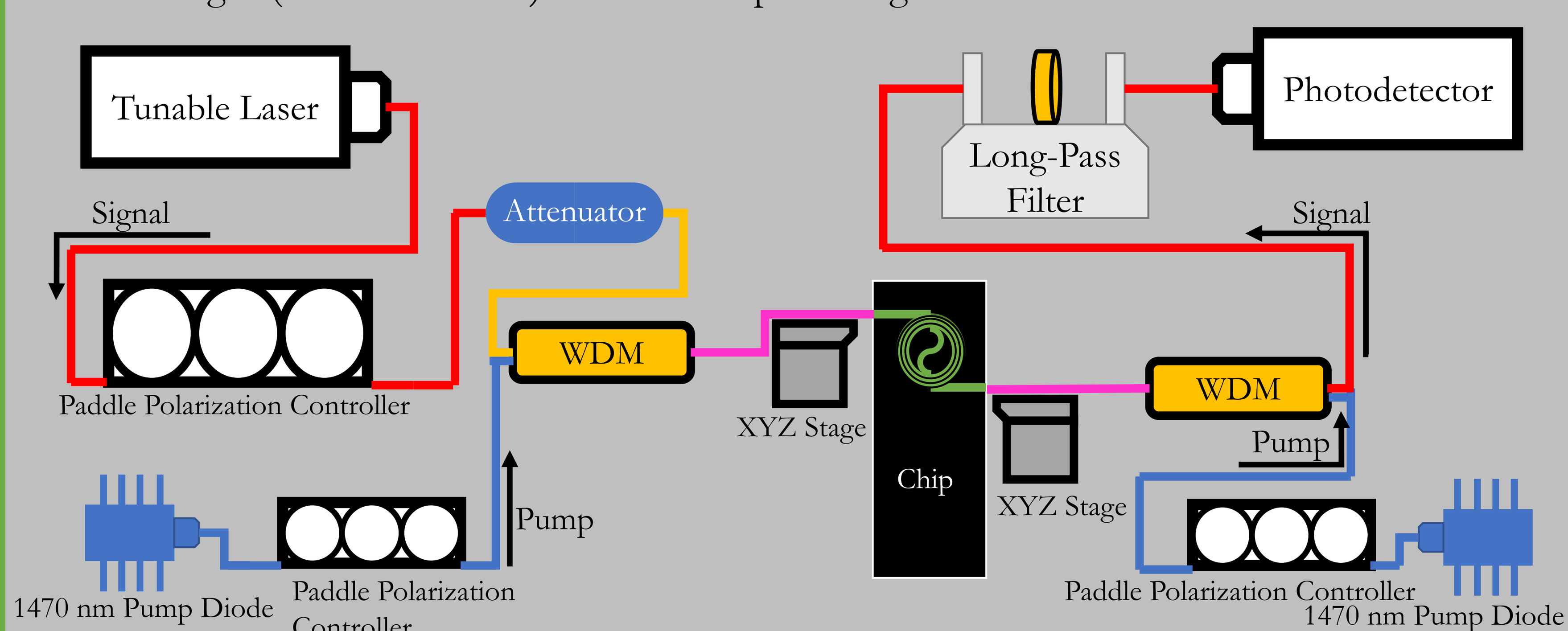


Figure 2. Experimental setup. A signal is sent out of a tunable laser which gets attenuated and then multiplexed with a 1470 nm laser outputted from a pump diode. Another pump diode pumps the device from the opposite direction. XYZ stages are used to couple the light in/out of the device. After getting de-multiplexed out of the device, the signal enters a long-pass filter to cut out the pump generated signal wavelength.

Results

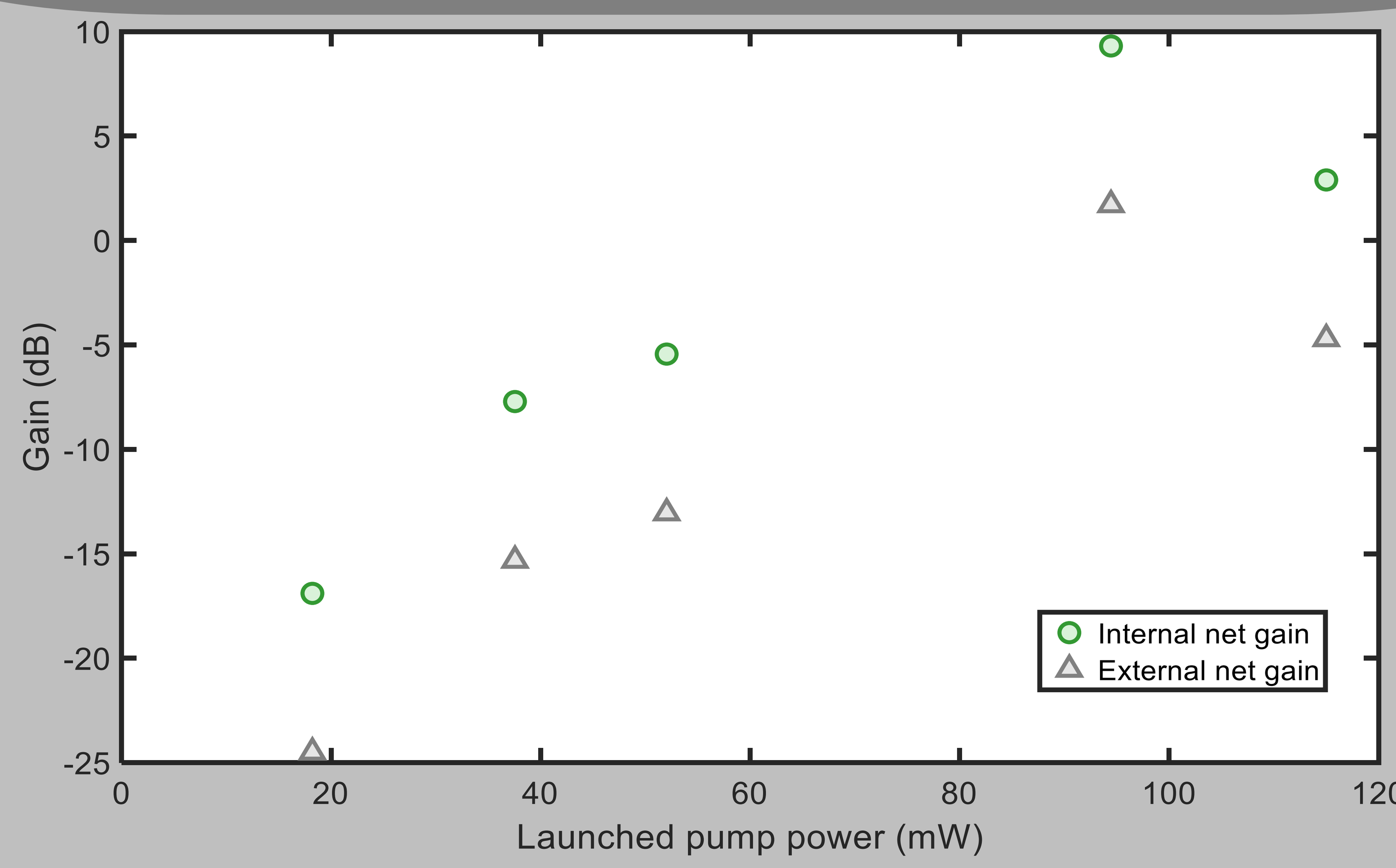


Figure 3. Experimental data from a -15.2 dBm incident signal sent into a 20 cm spiral, where a peak 9.31 dB internal net gain and 1.51 dB external net gain were observed for a 1557 nm source signal.

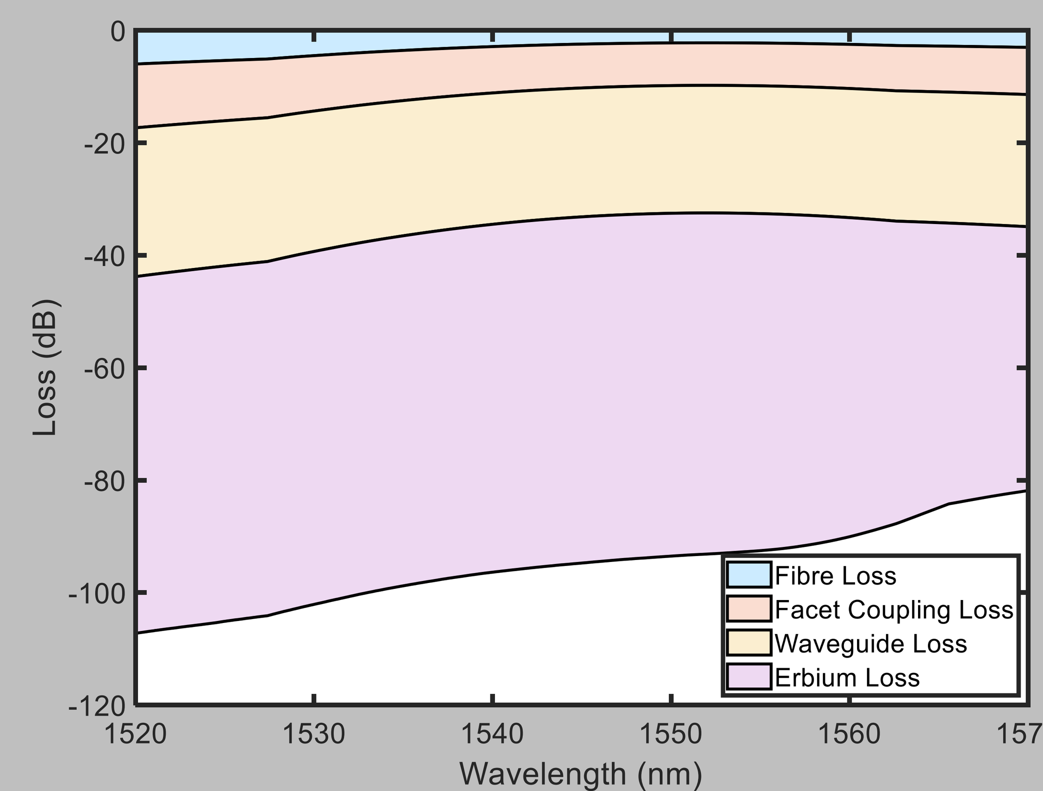


Figure 4. Individual loss contribution breakdown in a setup with a -15.2 dBm incident power signal and a 20 cm spiral.

Waveguide length (cm)	Background Loss (dB/cm)	Erbium Concentration (m^{-3})	Waveguide width (um)	Loss Per Facet (dB)	Internal Gain (dB)	External Gain (dB)
21	0.72	1.55×10^{20}	1.2	2.67	9.31	1.51
11	1.3	4.38×10^{20}	1.6	6.56	11.61	-3.96
16	0.72	1.58×10^{20}	1.2	2.1	7.09	0.64

Table 1. Sample results from characterizing different length waveguides. Samples exhibiting external gain had low facet losses, which contributed to high launched pump powers. All devices had a 100 nm Si_3N_4 core.

Conclusions

Summary

- Preliminary internal and external net gains of 0.44 dB/cm and 0.072 dB/cm respectively were observed in $TeO_2 : Er^{3+}$ coated Si_3N_4

Next Steps

- Take further measurements that check if lasing conditions were reached to confirm external net gain result
- Aim to lower the facet losses in order to optimize fiber-to-chip coupling
- Further investigate the impact of varying the following on gain:
  - Waveguide length
  - Si_3N_4 and TeO_2 thickness
  - Er^{3+} concentration

References

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