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Ytterbium-Doped Tantalum Pentoxide Waveguide Lasers

A. Aghajani [1], G.S. Murugan[1], N.P. Sessions[1], V. Apostolopoulos[2], J. S. Wilkinson[1]

[1] *Optoelectronics Research Centre, University of Southampton, Southampton, England*
aa15v07@soton.ac.uk, smg@orc.soton.ac.uk, nps@orc.soton.ac.uk, jsw@orc.soton.ac.uk
[2] *School of Physics and Astronomy, University of Southampton, Southampton, England*
v.apostolopoulos@soton.ac.uk

Abstract: We have demonstrated a Yb:Ta_2O_5 waveguide laser fabricated by RF magnetron sputtering on oxidised silicon. The waveguide laser was end-pumped with a laser diode at 977 nm and lasing was observed between 1015 and 1020 nm. The launched pump power threshold and slope efficiency were measured to be ~25 mW and 1.78 %, respectively.

Introduction

Integrated channel waveguide solid-state lasers are key components in the quest for fully integrated optical circuits with advanced functionality such as tunability and pulsed operation. Ta_2O_5 has been selected as the host material for the realization of a compact, integrated ytterbium doped waveguide laser as it offers many important attributes such as good ability to host rare-earth ions, as demonstrated with erbium[1] and neodymium[2], a large third nonlinearity[3] and a high refractive index ($n \approx 2.124$ at $\lambda \approx 980$ nm)[4], and is suitable for mode-locking. High index contrast between the waveguide core and cladding provides for low-loss tight bend radii enabling the development of compact and ultra-small photonic circuits due to the strong confinement of the optical modes.

In this work, we present for the first time lasing behaviour for Yb:Ta_2O_5 rib waveguides and quantify the absorption and emission cross-sections of the material and the threshold, slope efficiency and emission spectrum of waveguide laser.

Device design and fabrication

Rib waveguides in Ta_2O_5 were designed for single mode (SM) operation between 970 nm and 1100 nm, covering the signal and pump wavelengths of Yb-doped materials. Rib waveguide dimensions of 1 μm rib height and 150 nm etch depth were selected using Soref et al.[5] method.

A Yb:Ta_2O_5 film of 1 μm was deposited by RF magnetron sputtering from a power-pressed tantalum pentoxide target, doped with 2.5 wt% of ytterbium oxide (~6.2×10^{20} atoms/cm^3) onto a silicon substrate coated with a 2.5 μm thermally-grown silica layer. The conditions used for the deposition process were 20 and 5 sccm of argon and oxygen gas flow, a substrate temperature of 200°C and magnetron power of 300 W. These conditions were previously optimized for Er:Ta_2O_5 to provide the lowest optical loss with an acceptable deposition rate[6].

The rib waveguides were structured by conventional photolithography and argon ion beam milling (IBM). Channel waveguides were fabricated with an etch depth of 150 nm and with widths ranging from 1 to 10 μm. Once the structuring process was complete, a 1.6 μm thick silica overcladding was deposited on top of the waveguide core, producing a protection layer and a symmetrical waveguide. For preparation for optical measurements the wafer was cut into smaller samples and end facets were polished to optical quality.

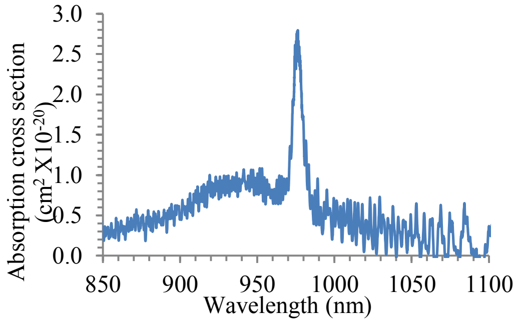

Fig 1: Absorption cross-section

Waveguide and lasing characteristics

The spectral characteristics of Yb:Ta_2O_5 were unknown so an absorption spectrum was obtained to determine the ytterbium cross section at the pump (977 nm) wavelength. Broadband (700 – 1700nm) light from a tungsten halogen lamp was coupled into a 3 mm long waveguide using a monomode fibre and collected at the output using a multimode fiber. The collected light was fed into an optical spectrum analyzer (OSA). Fig 1 shows the absorption cross section of Yb:Ta_2O_5, using the estimated concentration of ytterbium ions in Ta_2O_5 (6.2×10^{20} atoms/cm^3). The absorption bands of ytterbium at 935 nm and 975 nm are clearly visible with a peak absorption cross section (σ_{abs}) of $2.75 \pm 0.17 \times 10^{-20}$ cm^2 evident in the pump band at 975 nm. The peak emission cross section (σ_{em}) was also estimated using the reciprocity method from the absorption cross section, giving a peak emission cross section of $2.9 \pm 0.7 \times 10^{-20}$ cm^2 at 975 nm.

A 10.8 mm long laser cavity was formed using the reflections from the parallel optically polished end facets alone, which were estimated to have a Fresnel reflectivity of 12 % at the waveguide-air interface. To demonstrate lasing, the pump was butt-coupled into the end facet of a 3 µm wide waveguide using a monomode fibre, exciting the fundamental mode. Light emerging from the output was collected using a ×40 objective lens and passed through a set of long pass filters with a cut-off wavelength of 1 µm to remove the residual pump radiation. The wavelengths at which lasing occurred ranged from 1015 nm to 1020 nm as shown in Fig. 2b. The lasing output power is plotted against the launched pump power, Fig. 2a, and the laser threshold and single-ended slope efficiency were determined to be ~25 mW and 1.78 %, respectively.

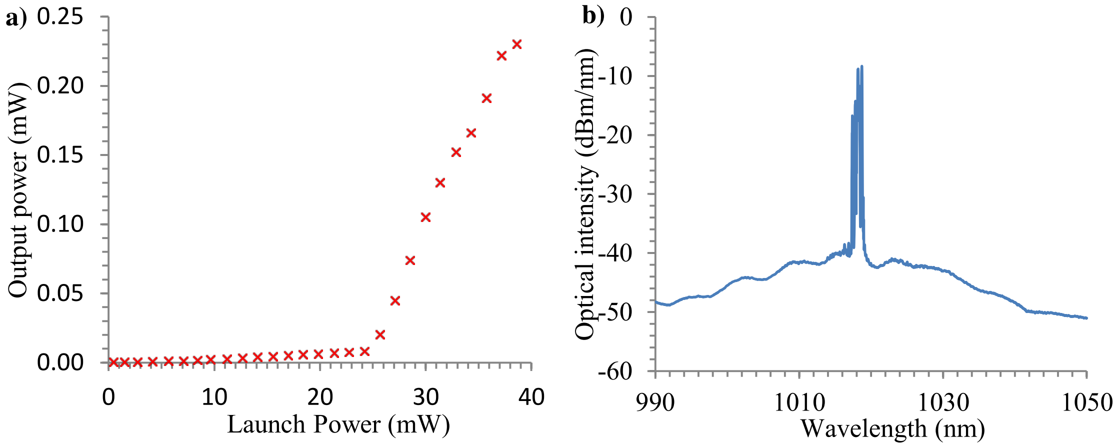

Fig 2: a) Laser output power versus launched pump power b) Lasing spectrum of $Yb:Ta_2O_5$

Conclusion

In conclusion, we have demonstrated a $Yb:Ta_2O_5$ waveguide laser fabricated by RF magnetron sputtering on a silicon wafer, and determined spectroscopic parameters and lasing characteristics. The waveguide laser was end pumped with a laser diode at 977 nm and lasing was observed between 1015 and 1020 nm using only the polished facets as mirrors. The launched pump power threshold and slope efficiency were measured to be ~25 mW and 1.78 %, respectively. This material system has demonstrated that compact continuous wave lasing is achievable, providing a platform to develop monolithically integrated components and devices. Improvements in lasing characteristic can be realised through optimisation of cavity mirrors, or with ring resonators exploiting the high index contrast. The gain properties and nonlinearity of the material, and their fabrication with CMOS-compatible processes, offers a potential route to low-cost mass production of highly functional integrated mode-locked and tunable lasers.

Symbols	Definition	Values
N_o	Yb dopant concentration	6.2×10^{20} cm^{-3}
σ_{abs}	Peak absorption cross section	2.75×10^{-20} cm^2
σ_{em}	Peak emission cross section	2.9×10^{-20} cm^2
λ_p	Pump wavelength	977 nm
λ_s	Signal wavelength	1015-1020 nm

Table 1: Spectroscopic parameters for $Yb:Ta_2O_5$

References

1. A. Z. Subramanian, C. J. Oton, D. P. Shepherd J. S. Wilkinson, *Photon. Technol. Lett,*. **22**, pp. 1571-1573, (2010).
2. B. Unal et al., *J. Quantum Electron.*, **41**, pp. 1565-1573, (2005)
3. C. Y. Tai et al., *Optics Express*, **21**, pp 5110 - 5116 (2004)
4. A. Z. Subramanian, *Tantalum Pentoxide Waveguide Amplifier and Laser for Planar Lightwave Circuits*, University of Southampton thesis (2011)
5. R. Soref, J. Schmidtchen, K. Petermann, *J. Quantum Electron.*, **27**, pp. 1971-1974, (1991)
6. A.Z. Subramanian, G.S. Murugan, M.N. Zervas, J.S. Wilkinson, *J. Lightwave Technol.*, **30**, pp. 1455-1462 (2012).