Ytterbium-Doped Tantalum Pentoxide Waveguide Lasers

A. Aghajani 1, G.S. Murugan1, N.P. Sessions1, V. Apostolopoulos2, J. S. Wilkinson1

1 Optoelectronics Research Centre, University of Southampton, Southampton, England
aa15v07@soton.ac.uk, smg@orc.soton.ac.uk, np5@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:Ta2O5 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. Ta2O5 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 erbium1 and neodymium2, a large third nonlinearity3 and a high refractive index (n ≈ 2.124 at λ ≈ 980 nm)3, 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:Ta2O5 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 Ta2O5 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:Ta2O5 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 (~6.2x1020 atoms/cm3) 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:Ta2O5 to provide the lowest optical loss with an acceptable deposition rate6.

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.

Waveguide and lasing characteristics

The spectral characteristics of Yb:Ta2O5 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:Ta2O5, using the estimated
concentration of ytterbium ions in Ta₂O₅ (6.2×10²⁰ atoms/cm³). The absorption bands of ytterbium at 935 nm and 975 nm are clearly visible with a peak absorption cross section (σₘₐₓ) of 2.75 ± 0.17×10⁻²⁰ cm² evident in the pump band at 975 nm. The peak emission cross section (σₑₘₑₙ) was also estimated using the reciprocity method from the absorption cross section, giving a peak emission cross section of 2.9 ± 0.7×10⁻²⁰ cm² 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.

![Graph of laser output power versus launched pump power and lasing spectrum of Yb:Ta₂O₅](image)

**Fig 2:** a) Laser output power versus launched pump power b) Lasing spectrum of Yb:Ta₂O₅

**Conclusion**

In conclusion, we have demonstrated a Yb:Ta₂O₅ 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**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nₛₐ</td>
<td>Yb dopant concentration</td>
<td>6.2×10²⁰ cm⁻³</td>
</tr>
<tr>
<td>σₘₐₓ</td>
<td>Peak absorption cross section</td>
<td>2.75×10⁻²⁰ cm²</td>
</tr>
<tr>
<td>σₑₘₑₙ</td>
<td>Peak emission cross section</td>
<td>2.9×10⁻²⁰ cm²</td>
</tr>
<tr>
<td>λₚ</td>
<td>Pump wavelength</td>
<td>977 nm</td>
</tr>
<tr>
<td>λₛ</td>
<td>Signal wavelength</td>
<td>1015-1020 nm</td>
</tr>
</tbody>
</table>

**Table 1:** Spectroscopic parameters for Yb:Ta₂O₅

**References**