Tantalum pentoxide micro-resonators for frequency comb generation

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Abstract. We present the design, fabrication, simulation and initial characterisation of tantalum pentoxide (Ta_2O_5) optical waveguides and micro-ring resonators for the purpose of supercontinuum and frequency comb generation. Spectral broadening results are presented for linear Ta_2O_5 waveguides for a range of central pump wavelengths between 900 nm and 1500 nm. These results are used as the basis for the dispersion engineering and development of Ta_2O_5 micro-ring resonators. The losses for sputtered and TEOS PECVD deposited SiO_2 top cladded waveguides are characterised using a Fabry-Pérot loss measurement set-up. A solver based on the Lugiato-Lefever equation is presented and used to simulate the expected emission from the Ta_2O_5 micro-ring resonators. Promising initial experimental results show critical coupling and a Q-factor of 3.7×10^4.

1 Introduction

The generation of supercontinuum and frequency combs through spectral broadening in linear waveguides and micro-ring resonators (MRRs) sees many potential applications in fields such as metrology and optical sensing. We present supercontinuum generation in tantalum pentoxide (Ta_2O_5) waveguides and preliminary experimental results towards frequency comb generation in Ta_2O_5 MRRs.

We use Ta_2O_5 sputtered on oxidised silicon wafers as a wave-guiding layer. Ta_2O_5 presents a number of advantages over other commonly used materials in integrated photonics. The linear refractive index of Ta_2O_5 is similar to that of Si_3N_4 at 1550 nm, and the nonlinear refractive index of Ta_2O_5 has been reported to be a factor of 3 greater than that of stoichiometric Si_3N_4 and an order of magnitude greater than of Si, suggesting that Ta_2O_5 is an interesting material for the generation of Kerr frequency combs [1]. Additionally, Ta_2O_5 can be doped with rare-earth elements, such as Er, Nd and Yb, which allows for the creation of waveguide lasers.

2 Linear waveguides for supercontinuum generation

The spectral broadening response of the waveguides was characterised as a function of pump central wavelength. Using the combination of a *Coherent Chameleon* and an optical parametric oscillator (OPO), $\leq$ 200 fs pulses at an 80MHz repetition rate are generated for a range of central pump wavelengths between 900 nm and 1500 nm. The best spectral broadening response is shown in an uncladded, 700×2200 nm linear waveguide for a pump power of 200 mW and central pump wavelength between 900 and 1500 nm and can be seen in Figure 1, showing significant broadening over the majority of pump wavelengths.

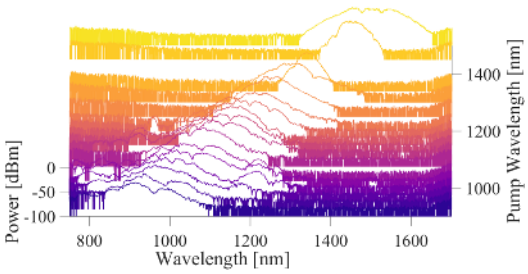

Figure 1: Spectral broadening data for a Ta_2O_5 waveguide for pump wavelengths between 900 and 1500 nm in the TM polarisation [2].

Our simulation solves the generalised nonlinear Schrödinger equation (GNLSE) using the split-step Fourier method. The model [3] allows for the comparison of experimental spectra with simulations for different waveguide modes. Figure 2 shows agreement between the recorded spectrum (blue) for a sputtered SiO_2 cladded 3200×700 nm Ta_2O_5 waveguide and the simulated spectrum for a TM_{02} mode (green) for a pump wavelength of 1050 nm.

A Fabry-Pérot loss measurement set-up was used to characterise the propagation losses of the Ta_2O_5 waveguides for a pump wavelength of 1 µm [4]. Propagation losses in Ta_2O_5 waveguides with RF-sputtered sil-

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ica cladding have been determined to be approximately 3 dB/cm.

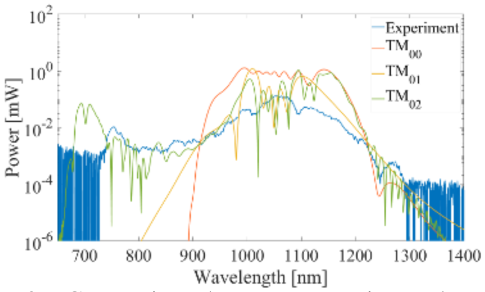


Figure 2: Comparison between experimental measured spectrum and the GNLSE simulated spectra for the TM_{00}, TM_{01}, and TM_{02} modes, showing agreement between the TM_{02} and the measured spectrum.

3 Micro-ring resonators towards frequency comb generation

In order to simulate the expected response from our MRRs, we have developed a Lugiato-Lefever equation (LLE) solver, based on our GNLSE model. The LLE solver uses a continuous wave laser input and periodic boundary conditions in order to simulate MRRs with different radii at different pump wavelengths and powers. As in the case of the GNLSE, the dispersion coefficient, β_2, is calculated for different waveguide geometries and MRR radii by simulating the change in the effective refractive index, n_{eff}, of a chosen mode over a range of frequencies. Variations in waveguide height, waveguide width, etch depth and MRR radius are simulated in order to engineer the waveguides towards broadening around a pump wavelength of 1550 nm. Figure 3 shows the simulated output of a 1500×800 nm Ta_2O_5 MRR with a radius of 180 µm, with a power of 20 mW coupled into the waveguide and a pump wavelength of 1550 nm, resulting in a comb with spectral bandwidth of ≈ 1000 nm.

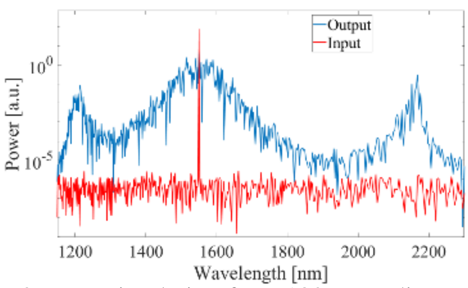
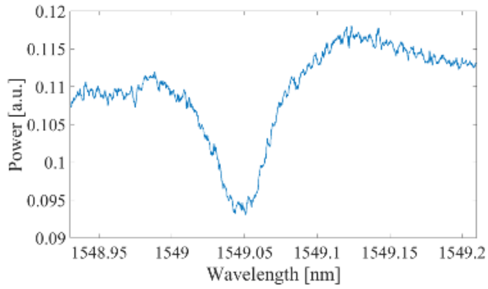


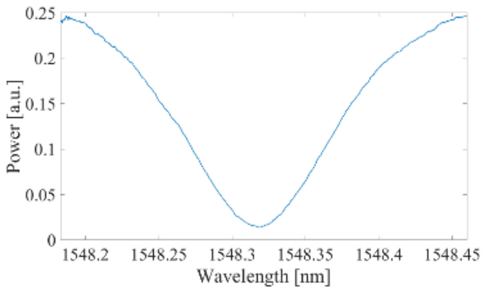
Figure 3: LLE simulation for a 180 µm radius MRR for a pump power of 20 mW and wavelength of 1550 nm.

Figure 4a shows experimental results of Ta_2O_5 MRRs. We show a resonance in a MRR with radius 180 µm at a pump wavelength of 1549.07 nm, yielding a Q-factor of 3.7×10^4 in a chip cladded with RF-sputtered SiO_2.

Figure 4b shows experimentally measured critical coupling, which will be necessary for the generation of a frequency comb, in a Ta_2O_5 MRR with a radius of 200 µm and at pump wavelength of 1548.33 nm. The losses in the system were too great to generate sidebands. In order to decrease our losses and increase our Q-factors further, an investigation into SiO_2 deposited by TEOS PECVD is ongoing, and we have experimentally measured a decrease in the waveguide propagation loss by approximately 1 dB/cm in a linear waveguide (bringing it down to 2 dB/cm).



(a) Experimental results from 180 µm radius MRR yielding a Q-factor of 3.7×10^4.



(b) Critical coupling in a MRR with radius 200 µm.

Figure 4: Preliminary experimental results for the output power from Ta_2O_5 MRRs showing a Q-factor of 3.7×10^4 (a) and critical coupling (b).

4 Conclusion

We have previously shown supercontinuum generation in Ta_2O_5 waveguides with excellent agreement with our GNLSE solver. We present preliminary experimental results from Ta_2O_5 MRRs showing critical coupling and Q-factor measurements up to 3.7×10^4 which agrees with our LLE simulations. Simulations of the next generation of Ta_2O_5 MRRs predict Kerr combs with spectral broadening of ≈ 1000 nm, thanks to improved silica cladding deposition and updated designs of racetrack resonators.

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