Spectral broadening of femtosecond pulses in polycrystalline anatase titanium dioxide waveguides

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Abstract: We observe the first nonlinear spectral broadening of femtosecond pulses in single-mode anatase TiO_2 waveguides at 793 and 1565 nm. The broad applicability and low two-photon absorption of TiO_2 makes it a promising material for integrated photonics.
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1. Introduction

Titanium dioxide (TiO_2) is an emerging material for on-chip nonlinear microphotonic devices, which balances a strong optical nonlinearity with a high refractive index, and wide wavelength transparency. TiO_2 is most comparable to silicon nitride, displaying visible transparency and minimal two-photon absorption for wavelengths near 800 nm [1]. However, TiO_2 has a Kerr nonlinearity that is three-times stronger than silicon nitride (8×10^{-19} m^2/W), it possesses a higher refractive index (2.4 versus 2.0), and it can be deposited at low temperatures (< 400 °C), allowing for back-end integration with silicon microphotonic devices. To explore the scope of future nonlinear applications in TiO_2, we report the first observations of spectral broadening in polycrystalline anatase TiO_2 waveguides at both 793 and 1565 nm.

2. Experimental details

We structure two sets of waveguides in 250-nm thin films of polycrystalline anatase TiO_2, deposited on oxidized silicon substrates using reactive sputtering of titanium metal in an oxygen/argon environment. We define S-shaped, strip-waveguides using electron beam lithography, then form waveguides by reactive ion etching with a chromium mask [2]. We clad the resulting waveguides with a transparent fluoropolymer and cleave the chip to prepare end-facets. The waveguides are 200 and 900 nm wide and are 6 and 9 mm long for measurement at 793 and 1550 nm, respectively.

We launch femtosecond pulses using objective coupling into the waveguides and record the output spectra as a function of pulse energy using a spectrometer and an optical spectrum analyzer (793 nm and 1565 nm, respectively). We use 100 fs pulses from a Ti:Sapphire oscillator centered at 793 nm and 190 fs pulses from an optical parametric oscillator tuned to 1565 nm. We control the power and polarization using a half wave-plate followed by a polarizer.

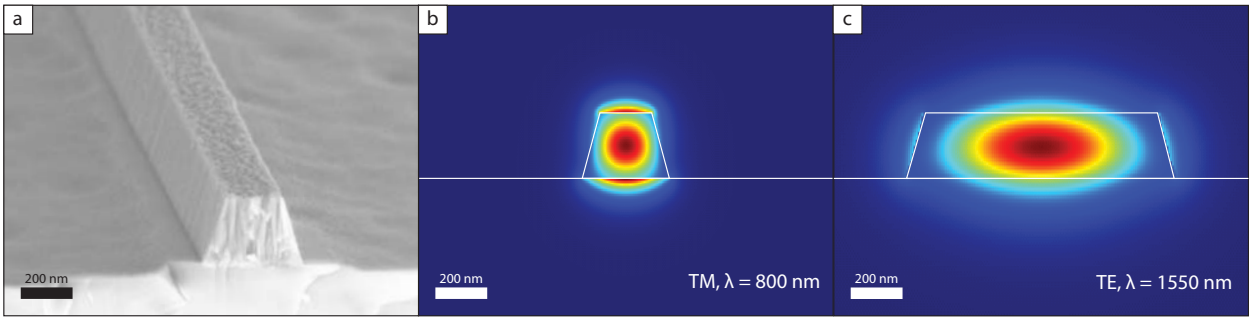

Fig. 1 Scanning electron micrograph of a 200-nm wide polycrystalline anatase TiO_2 waveguide (a) and mode profiles for the 200-nm-wide (b) and 900-nm-wide (c) waveguides for measurements at 793 and 1565 nm, respectively.

3. Results

Figure 1 shows a cross section of a polycrystalline anatase waveguide without top-cladding and the mode-profiles corresponding to our measurements at 792 and 1565 nm. Figure 2 shows the spectra obtained after pulse

propagation in a 200-nm and a 900-nm waveguide (793 nm and 1564 nm, respectively). We observe broadening by a factor of 3.2 around 793 nm and 3.8 around 1550 nm for 46 and 231 pJ pulses as measured at the –15 dB point, respectively. In addition, we observe a shift of the peak wavelength during 793-nm measurements and additional peaks forming during 1565-nm measurements.

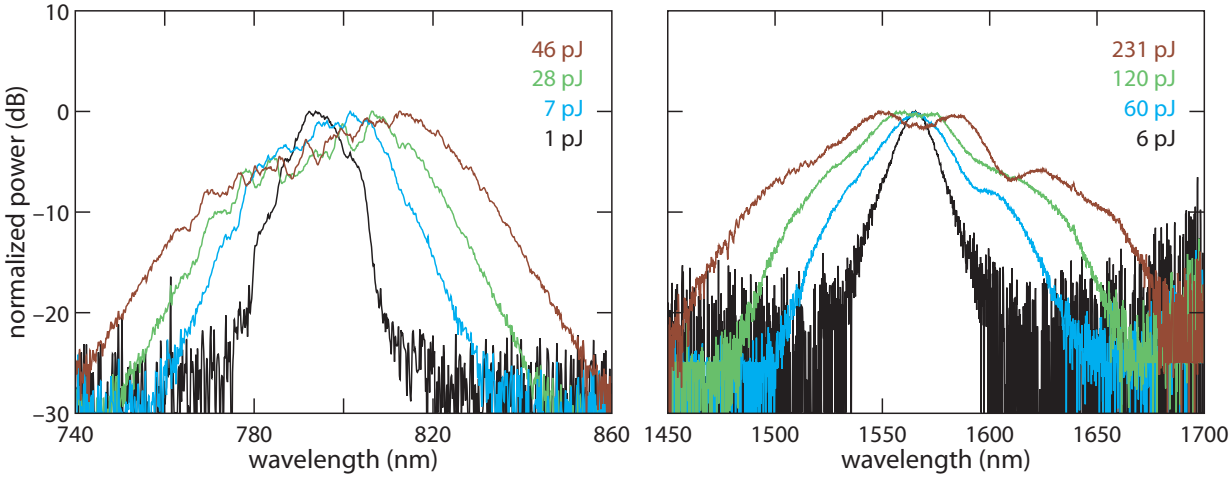

Fig. 2 Spectral broadening of femtosecond pulses in anatase waveguides centered at 795 nm (left) and 1565 nm (right).

4. Discussion

We report the first observation of spectral broadening in polycrystalline anatase TiO_2 waveguides at two wavelengths which span the octave from the interconnect band around 793 nm to the U-band. The spectra around 793 nm display more pronounced broadening at lower pulse energies. This may be attributed to different effective areas, resulting in large changes to the effective nonlinearity [3]. Estimated effective nonlinearities are 39.4 and 7.6 $W^{-1}m^{-1}$ for the 800-nm and 1550-nm waveguides, respectively. Thus, the Kerr coefficient at these wavelengths is likely very similar. The shift in the peak of the spectrum at 793 nm, as well as the asymmetrical structure in the measurements at 1565 nm are consistent with intra-pulse Raman scattering by the strong 141 cm^{-1} anatase Raman peak.

The devices we establish here represent the first nonlinear application of integrated TiO_2 photonics. All measurements were extremely stable with time and repeatable, indicating the robustness of the material. As with silicon photonics, waveguide dispersion is extremely tunable in TiO_2, which will enable further applications such as supercontinuum sources [4], comb generation[5] and wavelength conversion. In addition, the low two-photon absorption may lead the way to ultrafast, non-resonant all-optical switching applications. Based on these first nonlinear results in TiO_2 waveguides, we show that TiO_2 is a promising material for future integrated nonlinear photonics applications.

4. Summary

We demonstrate spectral broadening in anatase TiO_2 waveguides near 800 and 1550 nm. Using pulse energies of tens to hundreds of pJ, we observe broadening factors greater than 3. We conclude that TiO_2 has considerable potential for further on-chip nonlinear optical applications.

5. References

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