Submicrometer-width TiO_2 waveguides

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Abstract: We fabricate submicrometer-width TiO_2 strip waveguides and measure optical losses at 633, 780, and 1550 nm. Losses of 30, 13, and 4 dB/cm (respectively) demonstrate that TiO_2 is suitable for visible-to-infrared on-chip microphotonic devices.

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1. Introduction

Titanium dioxide (TiO_2) is a promising material for on-chip nonlinear microphotonic devices. Its high bandgap (3.2 eV) results in high transparency and minimal two-photon absorption over a wide wavelength range (down to 800 nm) [1]. TiO_2's high linear refractive index (n = 2.4 at 800 nm) enables strong optical confinement. Combining sub-micron confinement with its nonlinear index of refraction (8×10^{-19} m^2/W) [2], results in a calculated nonlinear parameter (γ) of up to 50,000 $W^{-1}km^{-1}$. To realize devices, we report on the fabrication of single-mode strip waveguides with submicrometer dimensions in anatase and amorphous TiO_2 and characterize light-guiding losses.

2. Experimental

We deposit our TiO_2 thin films on oxidized silicon substrates using reactive sputtering of titanium metal in an oxygen/argon environment [3]. These amorphous and anatase films are 240 and 80 nm thick, respectively. Using prism coupling, we measure the refractive indices (planar losses) of 2.31 (1.0 dB/cm) and 2.43 (3.5 dB/cm) in the amorphous and anatase films, respectively, at a wavelength of 826 nm.

Next, we define our TiO_2 strip waveguides using electron beam (e-beam) lithography with a 300-nm-thick positive e-beam resist. After developing the resist, we evaporate a chromium film and perform metal liftoff to realize a chromium etch mask. We transfer the pattern into the TiO_2 film using electron cyclotron resonance reactive ion etching with a CF_4/H_2 gas mixture. We remove the remaining Cr using Cr-etchant and spin on a fluorpolymer layer as a top cladding. We prepare the end-facets by cleaving the chip with a diamond pen.

The resulting waveguides are 6-mm-long *S*-shaped waveguides on 3 mm x 10 mm samples. Using a commercial mode-solver, we design them to be single mode near 800 nm with widths of 200 and 500 nm (amorphous) and 600 nm (anatase) with a minimum bend radius of 60 μm to avoid significant loss.

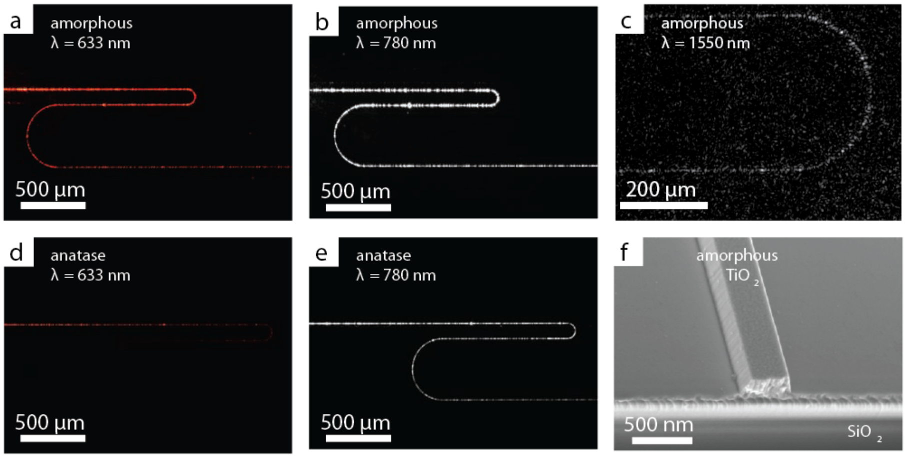

Fig. 1 Optical images of visible and NIR light guided in amorphous (a-c) and anatase (d and e) TiO_2 waveguides. Scanning electron micrograph of an amorphous TiO_2 waveguide (f).

We characterize the losses by launching visible- (633 and 780 nm) and NIR- (1550 nm) light into the TiO_2 strip waveguides using objective and lensed fiber coupling (respectively). We control the polarization using a free-space (fiber) polarizer for visible (NIR) propagation. We determine the optical loss by measuring the relative intensity of scattered light along the waveguide using a camera attached to a microscope [21].

3. Results

Figure 1 shows optical images of light propagation in our TiO_2 waveguides for several wavelengths and dimensions using the transverse-electric polarization. We use the scattered light intensity to determine the propagation loss of these waveguides, shown in Fig. 2. The amorphous waveguides exhibit the lowest losses with values of 4 ± 2 dB/cm (1550 nm), 13 ± 1 dB/cm (780 nm), and 30 ± 1 dB/cm (633 nm). The losses in anatase are considerably higher. In addition, we observe a significant decrease in loss following cladding deposition for the same anatase waveguide – from 80 ± 3 to 29 ± 1 dB/cm at 780 nm. Lastly, we could not couple into any of the anatase waveguides at 1550 nm.

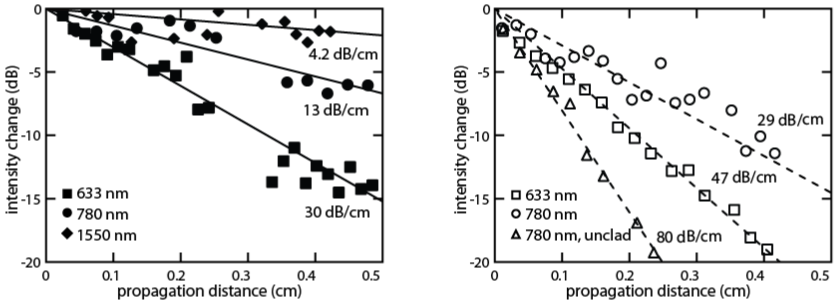

Fig. 2 Relative scattered light intensity and fitted propagation loss (solid line) in amorphous (left) and anatase (right) TiO_2 strip waveguides.

4. Discussion

We observe light propagation over mm-lengths scales at both visible and infrared wavelengths in on-chip submicrometer-wide amorphous and anatase TiO_2 waveguides. The amorphous TiO_2 waveguides support guided modes over a wider wavelength range and exhibit lower propagation losses. Losses in these amorphous films at 1550 nm comparable to those reported for other high-index-contrast waveguides [4]. These lower losses, combined with the amorphous film's higher deposition rate, suggest that we can achieve greater fabrication and design versatility using amorphous TiO_2 for microphotonic devices.

Although the losses are higher for the polycrystalline anatase phase, our results are still promising. We expect higher losses due to scattering at the polycrystalline grain boundaries. However, amorphous TiO_2 films crystallize at relatively low temperatures [5], thus the anatase phase presents a more stable film capable of sustaining a higher thermal load. In addition, cladding the anatase waveguides enhances their transmission characteristics considerably and on-going investigations may reduce the losses further. Based on these measurements, we conclude that both types of TiO_2 waveguides exhibit losses suitable for devices utilizing sub-millimeter length-scales.

4. Summary

We fabricate submicrometer-width TiO_2 strip waveguides and measure optical losses at 633, 780, and 1550 nm. Losses of 30, 13, and 4 dB/cm (respectively) demonstrate that TiO_2 is suitable for visible-to-infrared on-chip microphotonic devices.

5. References

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