TiO_2 as a material platform for all-optical logic

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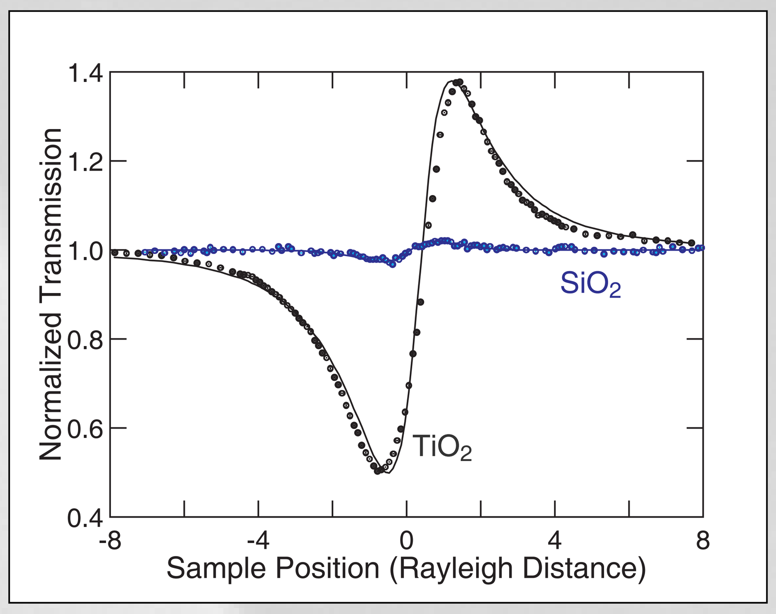
Introduction

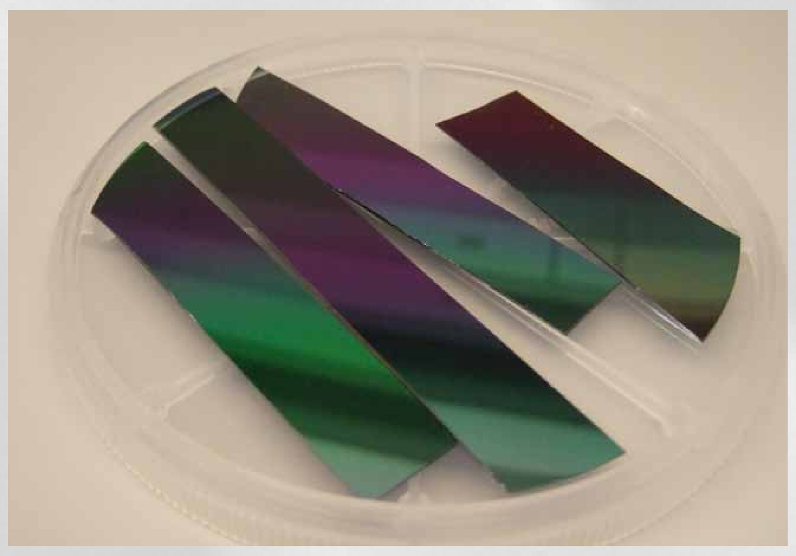
We identified TiO_2 as a promising yet unexplored material for on-chip nonlinear optics near 800 nm. Its high refractive index of 2.4 and large nonlinearity can strongly enhance nonlinear interactions. Our goal is to realize nanophotonic devices for all-optical modulation, logic and wavelength conversion.

We measure the nonlinear refractive index of bulk TiO_2 (rutile) using the z-scan technique (at 800 nm). The normalized transmission for silica and TiO_2 at the same intensity is shown on the left (solid lines are theoretical fits). We measure a 30-fold increase over fused silica (SiO_2).



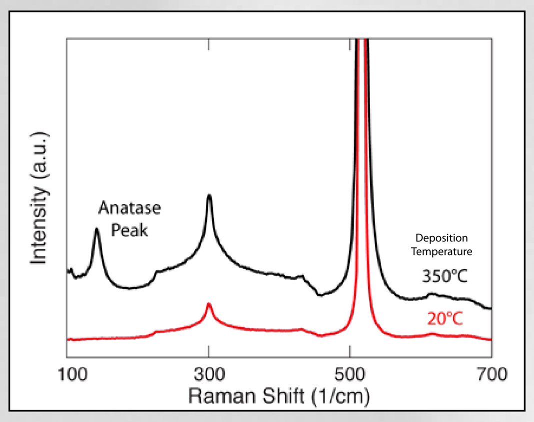
TiO_2 Thin Films

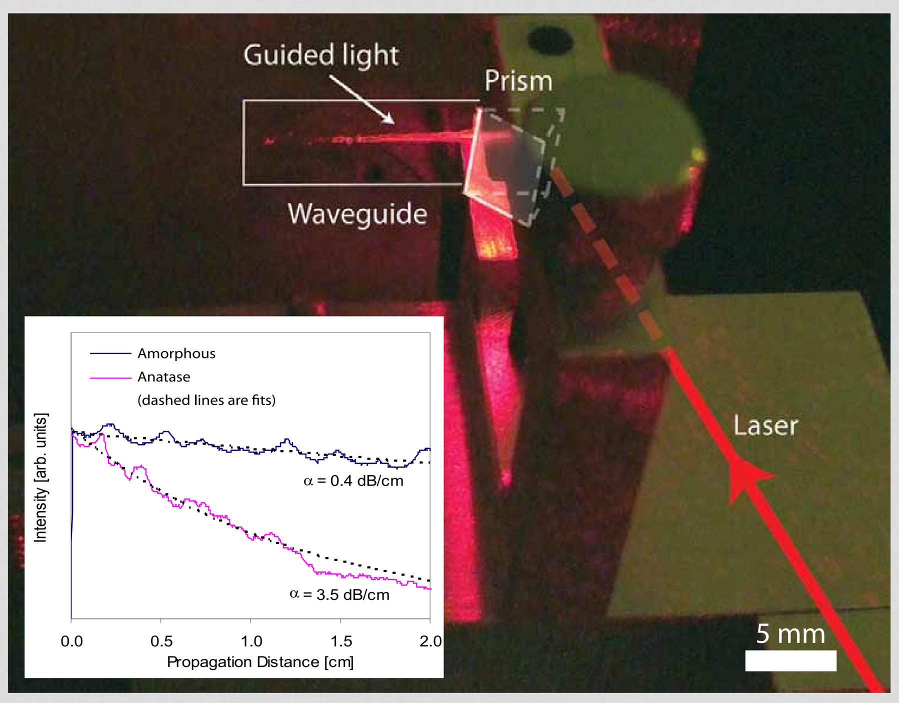
We require high quality thin films of TiO_2 with low waveguiding losses. TiO_2 can exist in an amorphous phase as well as several crystalline phases including anatase and rutile. These different phases impact the linear and nonlinear optical properties and can dramatically affect the waveguiding losses. Consequently, we explore different deposition techniques including sputtering, electron beam evaporation, atomic layer deposition and the sol-gel method.



Thin Film Characterization

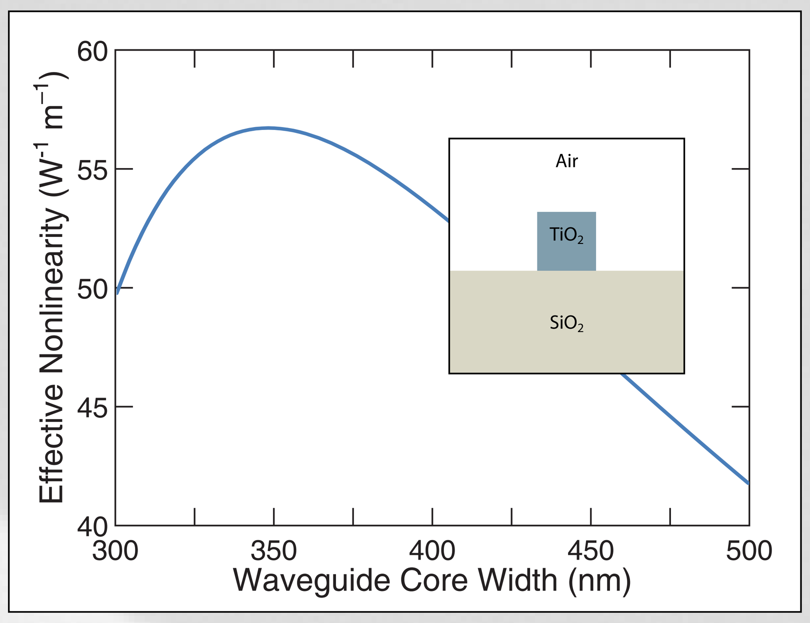
We rely on a suite of metrological techniques to fully characterize our thin films. Using TEM and Raman spectroscopy (right), we determine the crystallinity of our films. Ellipsometry provides detailed information about the refractive index and material dispersion. Using prism coupling (left) with a scanning fiber, we directly measure planar waveguiding losses (inset). Using reactive sputtering of titanium metal with oxygen, we achieve amorphous and anatase TiO_2 films with losses of 0.4 dB/cm and 3.5 dB/cm at 826 nm (respectively).



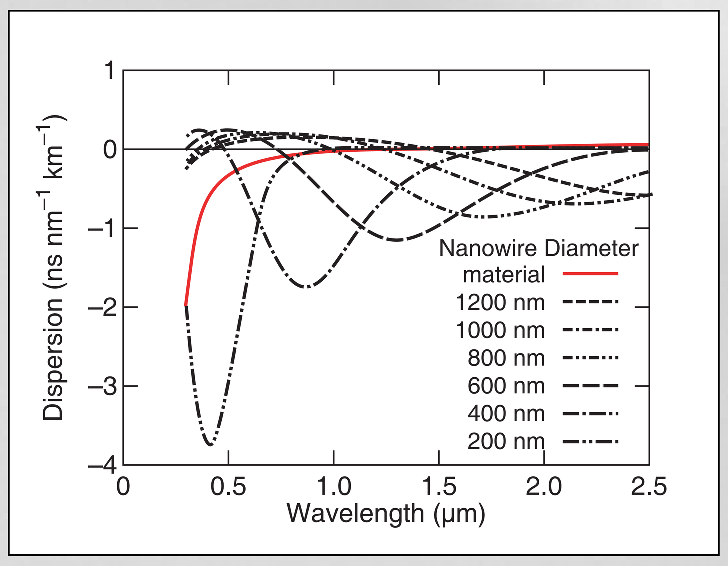


Simulation

To optimize the performance of a nonlinear interferometer, the effective nonlinearity (the rate of nonlinear phase accumulation) must be maximized. This parameter depends on the material properties and the dimensions of the waveguide. Plotted on the right is the effective nonlinearity for a square TiO_2 waveguide at a wavelength of 800 nm.

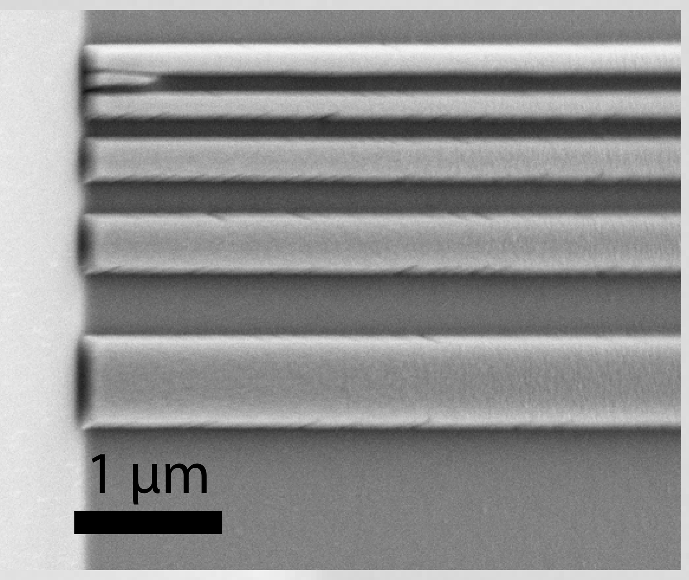


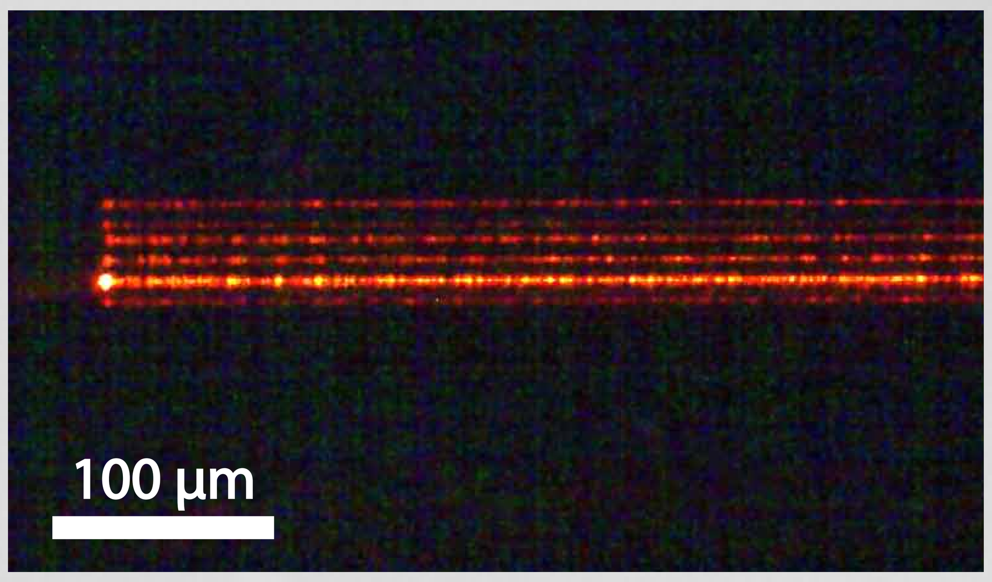
By engineering cross-sectional dimensions, we can overcome material dispersion using waveguide dispersion. Here, we demonstrate the dispersion flexibility using silica nanowires with an air cladding (left). Although material dispersion is normal, it is possible to achieve anomalous dispersion simply by reducing the diameter below 1200 nm. The same principle can be applied to TiO_2 waveguides.



Waveguide Fabrication

We fabricate waveguides with nanometric dimensions using electron-beam lithography and reactive ion etching. Pictured below is a test pattern with ~100 nm features (left) and light being guided in a 400 nm waveguide (right, 2nd line from bottom).





Outlook

We established TiO_2 as a novel platform for on-chip nonlinear optics and are fabricating interferometers to demonstrate ultrafast all-optical switching and logic. Our effort pioneering this material will enable other applications such as wavelength converters and optical regenerators for high-speed interconnects as well as resonators and supercontinuum generators for applications in biology, sensing and diagnostics.

Harvard University Center for Nanoscale Systems

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