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Supercontinuum generation in titanium dioxide waveguides

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INTRODUCTION

Optical supercontinuum are a fundamental topic that has stimulated a tremendous practical interest since the early works of Alfano et al. in the 70s in bulk components. Photonic crystal fibers have then brought some remarkable potentialities in tailoring the dispersive properties of a waveguide while maintaining a high level of confinement over significant propagation distances. The next breakthrough is to further reduce the footprint of the nonlinear component and to achieve the generation of optical supercontinuum on a photonic chip. To reach this aim, several platforms have been successfully investigated such as silicon, silicon germanium, silicon nitride, chalcogenide waveguides to cite a few. Each material has obviously specific advantages but also limitations including strong two-photon absorption and the associated free carrier absorption, low refractive index, low handling power, etc.

We discuss here the design and fabrication of a new component made on an alternative platform that remains relatively unexplored: titanium dioxide (TiO$_2$). This material benefits from a transparency window spanning from the visible to the mid-infrared wavelengths. It combines a high linear and nonlinear refractive index with negligible group velocity beyond 950 nm. Therefore, recent experimental studies have confirmed these features and reported the spectral broadening of a femtosecond pulse [1], the parametric wavelength conversion of a continuous wave [2] as well as the efficient generation of third harmonic [3].

TO$_2$ WAVEGUIDE DESIGN AND FABRICATION

We start from anatase TiO$_2$ layers with a thickness of 450 nm that are deposited on a 2" silicon wafer.

2.2 cm-long ridge waveguides with different widths are patterned thanks to an UV lithography.

After the reactive ion etching, the residual mask is stripped from the waveguides.

Propagation losses around 5 dB/cm are obtained.

Reduction of the losses can be reached in the near future.

The high contrast between the TiO$_2$ (n = 2.35) and the silica layer (n = 1.44) in the surrounding air is highly beneficial for a strong light confinement.

The TE$_{01}$ mode has an effective area of 0.54 µm$^2$, leading to a nonlinear coefficient of 1.2 W/m.

The TM$_{01}$ mode remains strongly normal.

Optical modes can be sustained.

In order to optimize the coupling of light, two 1-mm long layers have been included in the device.

EXPERIMENTAL DEMONSTRATION

The first experimental demonstration of an active spanning supercontinuum in TiO$_2$.

Third-harmonic generation in the visible due to the existence of phase-matched higher-order modes.

The central part of the supercontinuum is bounded by a self-frequency shifted soliton.

Dispersive waves bound the lower part.

Supercontinuum is only achieved in the TE mode thanks to the anomalous dispersion regime.

Optical supercontinuum measured at the output of the TiO$_2$ waveguide for various coupled energy conditions.

NUMERICAL SIMULATIONS

The experimental results are qualitatively reproducible by numerical simulations of the generalized nonlinear Schrödinger equation taking into account the full dispersion profile and the Raman contribution.

The nonlinear dynamics is mainly driven by Raman soliton self-frequency shift and generation of dispersive waves induced by the two zero dispersion wavelengths.

REFERENCE

1. Kamal HAMMANI, Laurent MARKEY, Manon LAMY, Bertrand KIBLER, Juan AROCAS, Julien FATOMÉ, Alain DEREUX, Jean-Claude WEEBER and Christophe FINOT


