Visible-to-near-Infrared Octave Spanning Supercontinuum Generation in a Partially Underetched Silicon Nitride Waveguide

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Abstract: The generation of an octave spanning supercontinuum covering most of the visible spectrum is demonstrated for the first time in a Si_3N_4 waveguide. This result is achieved by dispersion engineering through partially underetching a waveguide.

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1. Introduction

Supercontinuum generation on an integrated CMOS compatible platform is attracting significant attention since it has the potential to provide a compact broadband source for spectroscopy [1], optical coherence tomography [2] and precise frequency metrology [3]. While supercontinuum generation has been demonstrated in a silicon nanowire [4] and in a silicon nitride waveguide [5], they are mostly centered in the near- or mid-infrared. However, an on-chip intense broadband source in the optical window of cells and tissues (0.6 μm-1.2 μm) would offer several advantages to biomedical applications such as *in vivo* imaging [6] and Raman spectroscopy [7]. A major challenge of pushing supercontinuum generation to the visible spectral region is the strong normal material dispersion of materials such as silicon nitride in that wavelength region. Although a visible supercontinuum could be generated by up-converting an infrared supercontinuum [8], direct generation in a waveguide having small anomalous dispersion at visible spectral range is preferred but has not been demonstrated until now. In this paper, we dispersion engineer the cross-section of a silicon nitride waveguide and the key in making the dispersion anomalous in the visible spectral region is partially underetching the waveguide. This dispersion engineering allows us to generate an octave spanning supercontinuum ranging from 488 nm to 978 nm with a pump centered at 795 nm. To the best of our knowledge, this is the first demonstration of an octave spanning supercontinuum extending to sub-500 nm on an integrated platform.

2. Experimental results

The waveguide used in the experiment is fabricated in a silicon nitride layer deposited by low-pressure chemical vapor deposition (LPCVD) in a CMOS pilot line at imec [9]. The air-clad waveguide rests on a 1.6 μm oxide layer (BOX). The waveguide is 300 nm high and 500 nm wide and 1 cm long. The waveguide is partially underetched to tune the waveguide dispersion. A schematical cross-section is shown in Fig. 1.(b) while a SEM picture is shown in Fig. 1.(c). The increased index-contrast which is obtained by removing the oxide allows for increased confinement and anomalous dispersion at visible wavelengths. Fig. 1.(b) shows the group velocity dispersion D for the engineered waveguide. The dispersion is anomalous between its two zero diseprsion wavelengths 740 nm and 910 nm.

For the superconintuum generation experiment, we use a pulse train generated by a Ti:Sapphire laser operating at 795 nm. The pulses have a nominal squared hyperbolic secant shape in the temporal domain with FWHM $\sim$ 100 fs and a repetition rate of 80 MHz. To excite the quasi-TE mode of the waveguide we use a half-wave plate and a polarizing beam splitter. The pump is then coupled into the waveguide using a microscope objective and the generated spectrum is coupled out using a lensed fiber. The coupling loss at the input is 8.5 dB.

We use an optical spectrum analyzer with a bandwidth extending from 450 nm to 1600 nm to record the spectrum. Fig. 1.(a) shows the measured spectra at various coupled powers. With peak powers up to 324 W, spectral broadening

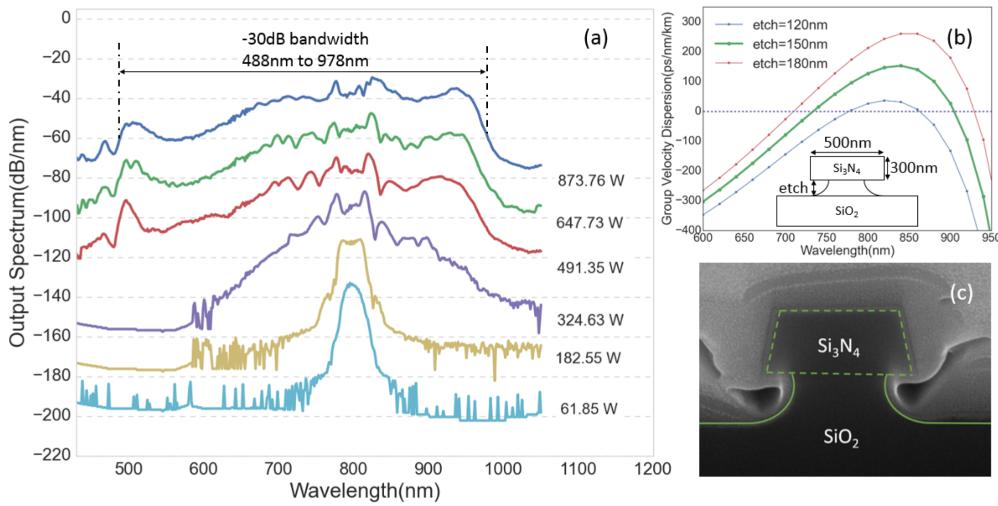

Fig. 1. (a) Generated supercontinuum at various coupled powers. (b) Schematic cross-section of waveguide and group velocity dispersion at various etching depth. In experiment we use waveguide with green dispersion curve. (c) SEM picture of the engineered waveguide

is mainly the result of self-phase modulation (SPM), which can be observed through the multiple small ripples in the central peak. With increasing pump power, two prominent peaks appear at 492 nm and 937 nm. At the maximal available coupled power 873.76 W, the -30 dB bandwidth spans 490 nm from 488 nm to 978 nm, which is just an octave. To understand the mechanisms of spectral broadening, we calculate various characteristic length scales. Because $L_{\mathrm{fiss}} = \sqrt{L_{\mathrm{D}} L_{\mathrm{NL}}} \approx 0.4$ cm$< L_{\mathrm{MI}} < L_{\mathrm{waveguide}} = 1$ cm, where L_{D} is the dispersion length, L_{MI} is the characteristic distance of modulation instability and L_{NL} is the nonlinear length, soliton fission should have significant contribution to spectral broadening. Additionally, since the peaks at 492 nm and 978 nm appear in the normal dispersion region they can be understood as dispersive waves.

3. Conclusion

We proposed a method to tune the zero-dispersion wavelength of a Si_3N_4 waveguide to the visible wavelengths by partially underetching the SiO_2 undercladding of 150 nm. With this dispersion engineered waveguide, we demonstrate for the first time a supercontinuum extending from 988 nm down to 488 nm on the Si_3N_4 platform.

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