Supercontinuum generation in ultra-low loss silicon nitride waveguides

(Student paper)

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In this paper, we present the generation of supercontinuum in ultra-low loss silicon nitride waveguides fabricated in 200mm wafer. The waveguide was pumped at its maximum group velocity dispersion wavelength. Both experimental and simulation results are presented and compared. We observed a rather flat and symmetric spectrum expansion over 1.3 octave from visible to near IR wavelength range with a pump pulse energy lower than 65pJ.

Keywords: *silicon photonics, nonlinear optics, supercontinuum, integrated optics*

INTRODUCTION

Nonlinear optics has paved a way to many integrated photonics applications including optical communications, sensing and quantum technology. Among all nonlinear mechanisms, supercontinuum generation (SCG) taking advantage of third order nonlinearity (optical Kerr effect) is an interesting effect to largely expend the spectrum covering over one octave. Indeed, the wide spectrum expansion is essential for f-2f interferometry [1]. For applications like optical tomography and spectroscopy, we wish spectra to be as wide as possible [2]. In our research, we focus on SCG in ultra-low-loss silicon nitride waveguide. Silicon nitride is currently used for its good compatibility to silicon platform and low propagation loss behavior. Our SiN waveguides were fabricated by CEA Leti using a wafer-scale process to achieve ultra-low loss property, as low as a few dB/m [3]. Such low loss can compete with the performance obtained with Damascene process [4]. Besides, this material has a negligible nonlinear loss (two photon absorption, TPA) in visible and near IR wavelength range. We pumped the waveguide in anomalous dispersion area around its maximum group velocity dispersion (GVD) wavelength. We has obtained a relatively symmetric spectrum broadening over 1.3 octave due to its quasi-parabolic group velocity dispersion profile [5].

RESULTS

- WAVEGUIDE DESIGN

The device is implemented on the silicon nitride on insulator (SiNOI) platform with a geometry reported in Fig.1(a). The cross section has a 40° bevel on the corner attributed to encapsulation step in the fabrication process. The length of the waveguide is 2cm. We harness soliton fission and dispersion wave (DW) generation from dispersion engineering to largely extend bandwidth [6].

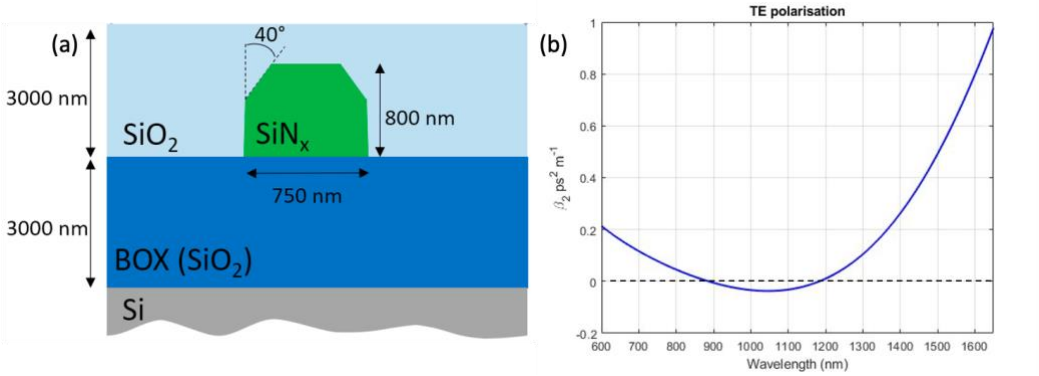

Fig. 1.(a) Waveguide cross section geometry. (b) Group velocity dispersion curve at TE polarization.

The waveguide presents a linear loss below 20dB/m and a group velocity dispersion (GVD) property showed in Fig.1(b). From the integrated dispersion curve reported in Fig.3(b), two dispersive waves are predicted around 645nm and 1465nm, which results in a spectrum expansion around 1.3 octave.

- CHARACTERSATION

To predict the spectrum of supercontinuum, numerical simulations have been investigated. In the simulation, we numerically solved the generalized nonlinear Schrodinger equation (GNLSE), see Eq.1, in which the noise has also been taken into account in simulations. We have neglected Raman effect in our simulations because of the short Raman shock time and short waveguide length. The material index dispersion of SiN_x was measured by ellipsometry method and has been taken into account in the simulations. A nonlinear refractive index of $n_2 = 2.4*10^{-19}$ m/W was used which is a common value for stoichiometric Si_3N_4.

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A + i\sum_{k\geq 2}\beta_k \frac{i^k}{k!}\frac{\partial^k A}{\partial t^k} + i\gamma(1 + i\tau_{shock}\frac{\partial}{\partial t})|A|^2 A \quad (1)$$

Experimental characterizations were carried out using a femtosecond laser (FWHM 190fs, repetition rate 1Mhz) which is tunable by using optical parametrical amplifier Fig.2.

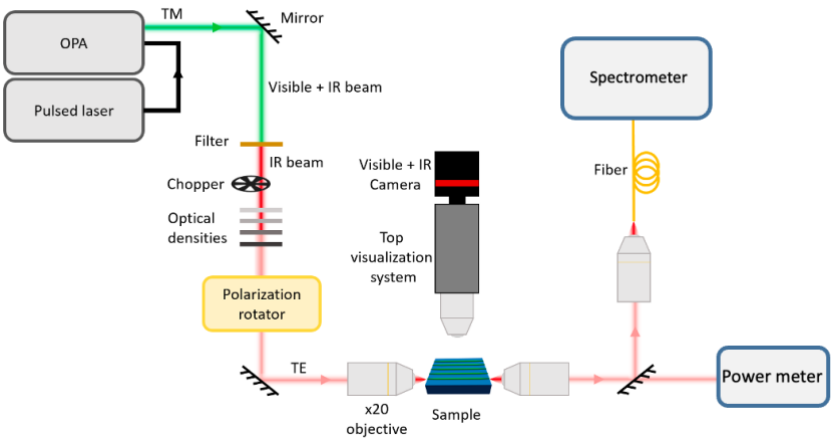

Fig. 2. Schematic view of our tunable femtosecond laser set-up.

We pumped the waveguide around its maximum GVD in the anomalous dispersion region. The coupled peak power varied from 69W to 695W for pump at a wavelength of 1060nm. The coupled powers are measured from a broadband power meter and are also determined from simulation results. The output spectra of the device exhibit an extensive broadening of the input pulse from 630nm to 1500nm at -30dB level with a pump peak power of about 300W (single pulse energy 65pJ). The spectra become quite flat if we continue increasing the pump power. The numerical simulations also show a good agreement with experimental results.

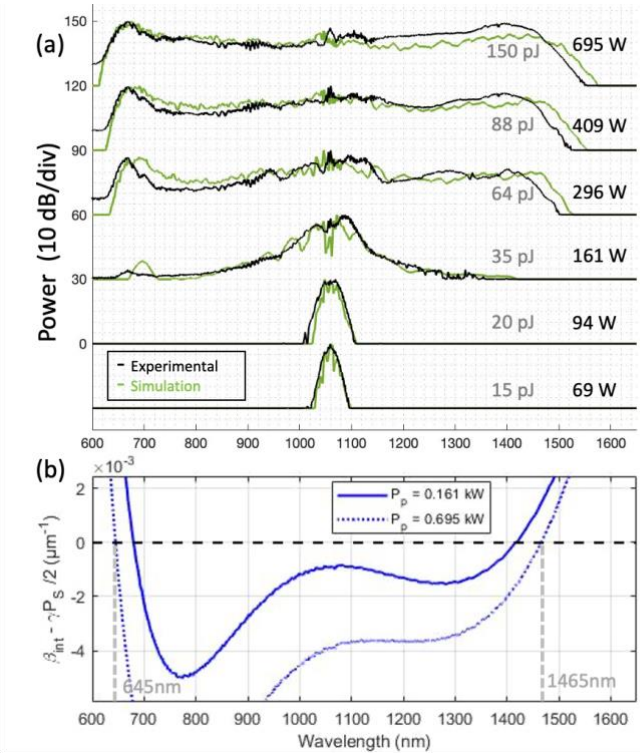

Fig. 3. (a) Experimental (black line) and simulation (green line) spectra of the waveguide in function of coupled peak power from femtosecond laser pumped at 1060nm. The pulse energies are also shown on the graph in grey. (b) . Dispersive waves phase-matching conditions are shown in two different peak pump power (161W and 695W). The positions of DW correspond well with experimental characterizations.

DISCUSSION

We used femtosecond pulses to generate supercontinuum in the soliton fission regime caused by higher order dispersion. Comparing to previous work on nitrogen-rich SiN waveguide [7] and Ge-rich graded SiGe waveguide [8], the experimental results show a rather symmetric and flat spectrum broadening. The depletion of pump power indicates a good conversion efficiency. The slight difference between experimental characterizations and simulations could origin from inaccuracy in dispersion simulation since supercontinuum is very sensitive to dispersion curve. We have proved that the wafer-scale ultra-low-loss SiN_x platform developed by CEA Leti is interesting for supercontinuum generation under low input power. The broadened spectrum from visible to near-IR is suitable for applications like optical tomography and sensing. More works in the future will be carried out to reduce the power demand toward using a compact on-chip source to trigger this complex nonlinear effect.

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