Bragg soliton dynamics in ultra-silicon-rich nitride devices

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Abstract— We present recent progress in ultra-silicon-rich nitride nonlinear photonics. Observations of Bragg soliton dynamics unveil their ability to bring about Bragg-soliton effect compression, soliton fission and enhanced and thermally tunable spectral broadening.

1. Introduction

The ultra-silicon-rich nitride (USRN) platform possesses a large linear and nonlinear refractive index of 3.1 and 2.8 x 10^{-13} cm^2/W respectively [1,2], while possessing a bandgap of 2.1eV. Consequently, two-photon absorption is absent at a wavelength of 1550 nm. The nonlinear parameter of USRN waveguides is 500x larger than that in stoichiometric silicon waveguides, significantly reducing the powers required for the observation of nonlinear optical phenomena. Bragg gratings on the other hand are prime candidates for the observation of nonlinear optical phenomena, allowing strong dispersion and elevated group indices to exist on the band edges. Recent advances in USRN-based nonlinear photonics span from high gain optical parametric amplifiers [3], soliton-effect compression [4] and Bragg soliton dynamics [5,6]. In this manuscript, Bragg soliton phenomena including Bragg-soliton effect compression, fission and thermo-optic tunable spectral broadening is discussed.

2. Nonlinear Bragg soliton dynamics in USRN

Photonic crystal waveguides have been shown to allow strong anomalous dispersion and flat-band slow light to be engineered on the band edge. One-dimension photonic crystals, also known as Bragg gratings possess a similar characteristic. The interaction of the forward and backward propagating fields arising from the artificial bandgap leads to a decreased group velocity at wavelengths close to the grating stopband. On the blue-side of the stopband, dispersion is anomalous, and has been shown to be three orders of magnitude larger than that in photonic waveguides [5]. The use of Bragg gratings for temporal compression were previously predicted both theoretically [7] and experimentally [8] in fiber-based Bragg gratings.

Cladding modulated Bragg gratings (CMBGs) in USRN are prime devices for the observation and application of Bragg soliton dynamics. CMBGs utilize pillars periodically placed a distance, *G* from a central waveguide, allowing apodization to be effectively applied by varying *G* as a function of the *z*-coordinate of the CMBG. Figure 1 (a) shows the schematic of the CMBG. Fabrication is undertaken using electron-beam lithography, reactive ion etching and plasma enhanced chemical vapor deposition of the SiO2 overcladding. The transmission, group delay and group velocity dispersion spectrum of the CMBG is shown in Fig. 1 (b) and (c). Notably, the group velocity dispersion of CMBG is anomalous with three orders of magnitude larger dispersion than that in a USRN waveguide [5]. It is further observed through time resolved frequency resolved electrical gating measurements that the temporal compression achieved in the CMBGs is dependent on the pump-stopband detuning. Figure 1 (d) shows the compression factor 1.37 ps pulses as a function of pulse wavelength, where it is observed that compression increases with the wavelength. This temporal dependence on wavelength is a characteristic feature of Bragg solitons. Next, the wavelength of 4.9 ps pulses is fixed and the peak power is increased to coincide with a soliton order, *N* of 4.65 and 8.75. When *N* = 4.65, 5.7× temporal compression is observed (Fig. 1 (f) top). Increasing the soliton order to 8.75 triggers soliton fission (Fig. 1 (f) bottom), brought on by the strong third order dispersion experienced by the optical pulse.

The strong wavelength dependence of the observed Bragg soliton dynamics could potentially be combined with thermo-optic tuning for tunable soliton-based phenomena. USRN possesses a thermo-optic coefficient of 2.48×10^{-4}°C^{-1}, an order of magnitude larger than that in stoichiometric silicon nitride [6]. The strong thermo-optic coefficient may therefore be combined with the strong wavelength dependence of the Bragg soliton behavior. Using a CMBG with a length of 3 mm concatenated with a 7 mm long USRN waveguide, the extent of temporal compression occurring in the CMBG may be thermally tuned prior to undergoing spectral broadening in the USRN waveguide, thus achieving varying extents of spectral enhancement. Using this device, we demonstrate tuning from 69 nm to 106 nm in the 30 dB bandwidth of the output as the temperature is decreased from 70 to 25ºC, in good agreement with simulations using the nonlinear Schrödinger equation. This new method allows laser pulses to be spectrally tuned in a wide dynamic range without losses in pulse energy.

3. Conclusion

The high nonlinear figure of merit of USRN has enabled Bragg soliton dynamics to be observed, including phenomena such as temporal compression, Bragg soliton fission and thermo-optic tuning of pulse spectra and enhanced supercontinuum generation [5].

Nonlinear optics based on USRN Bragg gratings could be applied towards new methods for laser pulse tuning, low power broadband light sources and coherent supercontinuum generation.

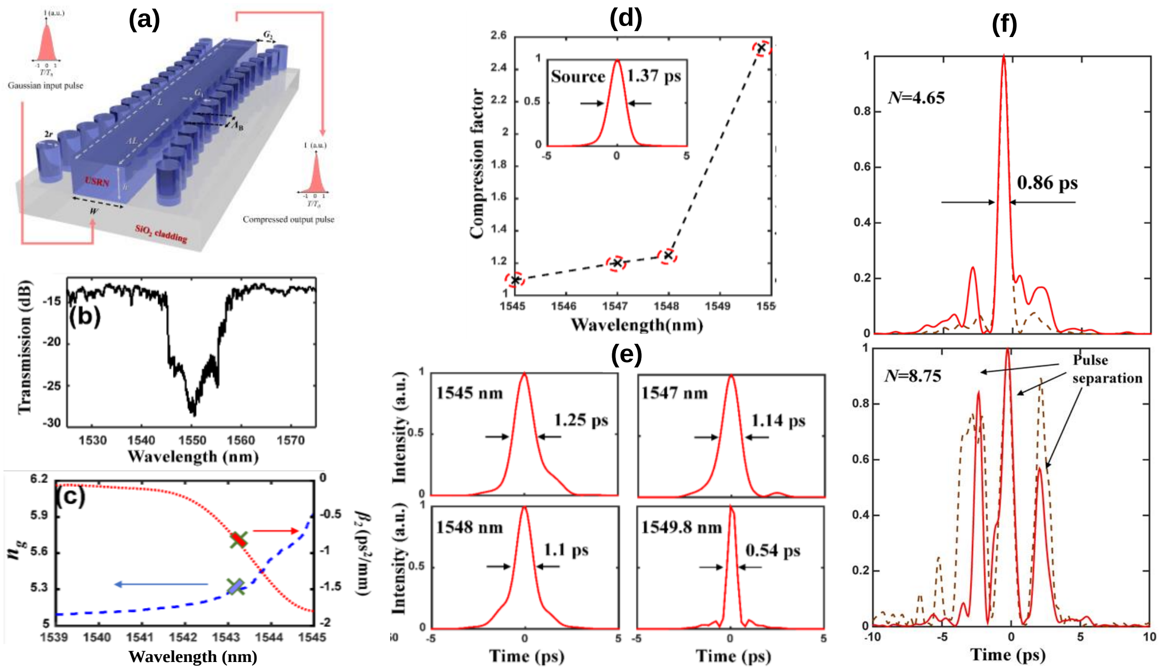

Figure 1. (a) Schematic, (b) transmission spectrum, (c) group index and group velocity dispersion spectrum for the nonlinear USRN CMBG. (e) Temporal compression as a function of pulse wavelength. (f) 5.7× temporal compression and observation of soliton fission of 4.9 ps input pulses.

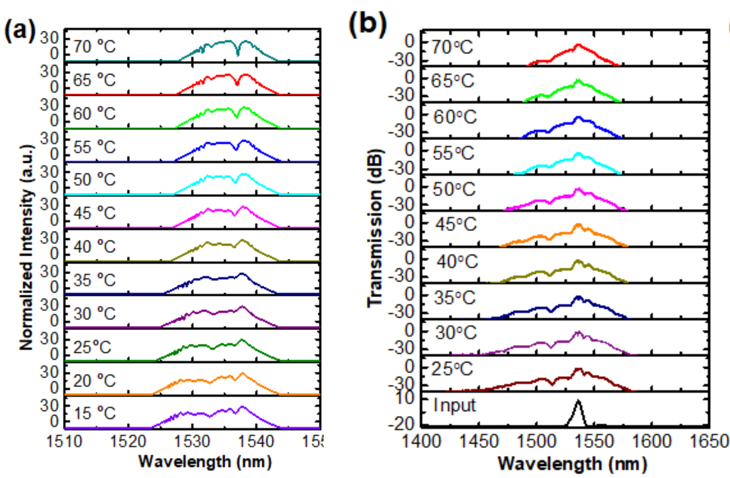

Figure 2. (a) Simulated and (b) measured output spectrum of a 3 mm CMBG concatenated with a 7 mm USRN waveguide as a function of temperature. (c) Experimentally measured 30 dB bandwidth as a function of temperature.

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4. References

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