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10 GHz Frequency Comb Spectral Broadening in AlGaAs-On-Insulator Nano-Waveguide with Ultra-Low Pump Power

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Abstract: We experimentally demonstrated 10 GHz frequency comb spectral broadening with a 30-dB bandwidth of 238 nm in an 11-mm long AlGaAsOI nano-waveguide. The 10-GHz 230-fs pump pulse has an average power of only 12 mW.
OCIS codes: (320.6629) Supercontinuum generation; (190.4390) Nonlinear optics, integrated optics; (230.7370) Waveguide.

1. Introduction

Optical frequency comb has many applications, such as spectroscopy, metrology, molecular fingerprinting, astronomy, atomic clocks, microwave photonics, and optical communications. There are mainly two ways to generate a broad-band optical frequency comb. One method is to launch a continuous wave (CW) light into a micro-resonator and a frequency comb can be generated through parametric oscillation [1-6]. However, it suffers from the thermal resonance shift and the absolute frequencies of the generated frequency comb are compromise between Kerr-nonlinear and thermal resonance shifts, therefore a feedback control and a reference laser are usually needed in order to achieve fully frequency stabilization. In addition, the frequency spacing between the generated comb lines is dependent on the free spectral range of the cavity, which has limited accuracy (at MHz scale); therefore, it's challenging to achieve a frequency comb with exact frequency spacing.

Another way to generate a broad-band optical frequency comb is to spectrally broaden a narrower frequency comb from a pulse laser in a highly nonlinear medium (such as highly nonlinear fibers or photonic crystal fibers) based on self-phase modulation (SPM) and soliton effects [7-9]. Recently, frequency comb spectral broadening (or supercontinuum generation) has also been demonstrated in planar integrated waveguides using different material platforms including silicon [10], chalcogenide [11], silicon nitride [12], and lithium niobate [13]. However, most of the supercontinuum generation in the integrated waveguides have small frequency spacing (usually less than 1 GHz), which is difficult to be spectrally resolved in a straight-forward manner. It would be advantageous to achieve frequency comb spectral broadening in an integrated waveguide with the frequency spacing between 10 GHz and 40 GHz, which can be both spectrally resolved by a diffraction grating and within electronic bandwidth. One of the main challenges is that the pulses with high repetition rate have low peak power, which is usually not enough to generate broad-band spectral broadening.

Very recently, we have demonstrated AlGaAs-on-insulator (AlGaAsOI) platform as an ultra-efficient nonlinear platform [6, 14-16]. It combines high intrinsic material nonlinearity (on the order of 10^{-17} W/m^2), large index contrast between AlGaAs (3.3) and silica cladding (1.5), and low linear and nonlinear losses **Error! Reference source not found.**. The bandgap of AlGaAs can also be engineered by changing the Al concentration to avoid TPA in the telecom wavelength. In this paper, we achieved 10 GHz frequency comb spectral broadening with a 30-dB bandwidth of 238 nm (from 1411 nm to 1649 nm) in an 11-mm long AlGaAsOI nano-waveguide. The pump pulse has a pulsewidth of 230 fs and the launched average power is only 12 mW (peak power of 5.2 W). The covered spectral range is more than C+L band, which can be potentially used for optical communication as multi-wavelength light sources.

2. 10 GHz frequency comb spectral broadening characterization for AlGaAsOI nano-waveguides

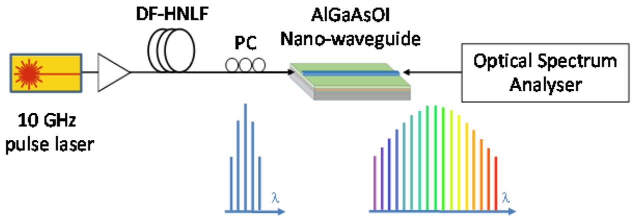

Fig.1 Experimental setup for spectral broadening in an AlGaAsOI nano-waveguide with a cross-section of 290×450 (or 500) nm^2.

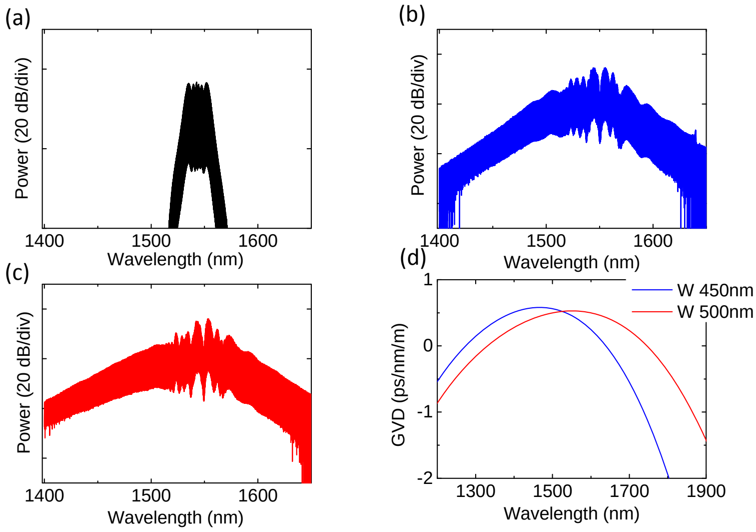

Fig. 2. Measured optical spectra at the input (a) and output of the AlGaAsOI nano-waveguide with the height of 290 nm and width of 450 nm (b) and 500 nm (c); the calculated group velocity dispersion (GVD) for the height of 290 nm and widths of 450 nm and 500 nm.

Fig. 1 shows the schematic drawing of the characterization setup for spectral broadening in an AlGaAsOI nano-waveguide. An erbium glass oscillator (ERGO) generates a 10 GHz pulse train at 1550 nm with picosecond pulse width. The 10 GHz modulation frequency is dependent of a microwave oscillator with an accuracy of ~Hz and the absolute frequency of the pulse can be fine-tuned without the need of external reference laser. After amplification in an erbium-doped fiber amplifier (EDFA), the pulses are launched into a dispersion flattened, highly nonlinear fiber (DF-HNLF) to compress the pulses to femto-second pulses (230-fs FWHM). Polarization controller is used to align the pulses to the transverse electric (TE) mode of the waveguide and optical spectrum analyzer (OSA) is used to record the output spectrum. A 290-nm thick $Al_{0.17}Ga_{0.83}As$ film is fabricated on an insulator layer (SiO_2) through wafer bonding and substrate removal. The width (450 nm or 500 nm) of waveguide is defined using electron-beam lithography and dry etching. The propagation loss of the waveguide is ~2 dB/cm. The waveguide under test is 11-mm long and is tapered to 120 nm at both sample facets for efficient fiber-to-chip coupling **Error! Reference source not found.**. Tapered fibers are used at both facets and the coupling loss is ~3 dB/facet.

Fig.2 (a) shows the spectrum of the 230-fs pump pulse at the input of AlGaAsOI nano-waveguide. Fig.2 (b) and (c) show the spectra at the output of the waveguide with an average pump power of only 12 mW (peak power of 5.2 W), for the waveguide dimension of 290-nm height and 450-nm or 500-nm width, which can be clearly spectral resolved. Fig. 2 (d) shows the calculated group velocity dispersion (GVD) for the 290-nm height and 450-nm or 500-nm width, and both of them exhibits anomalous dispersion at pump wavelength (1550 nm). For the width of 450 nm, 10 GHz frequency comb spectral broadening with a 30-dB bandwidth of 209 nm (from 1434 nm to 1643 nm) is achieved. For the width of 500 nm, the 30-dB bandwidth of 238 nm (from 1411 nm to 1649 nm) is achieved. Both dimensions of the waveguide have similar performance, showing a good fabrication tolerance.

3. Conclusion

We experimentally demonstrated 10 GHz frequency comb spectral broadening with a 30-dB bandwidth of 238 nm in an 11-mm long AlGaAsOI nano-waveguide with a cross-section of $290 \times 500\ nm^2$ by launching a 230-fs pulse train with an average pump power of only 12 mW (peak power of 5.2 W).

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