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Nonlinear Broadening of Electro-Optic Frequency Combs in All-Normal Dispersion Si_3N_4 Waveguides

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Dispersion-engineered silicon nitride waveguides are often used for broadening of frequency combs. Previous experiments have focused on anomalous dispersion waveguides pumped by femtosecond laser pulses, whereby coherent supercontinuum generation relies on soliton compression and dispersive wave emission (see e.g. [1]). This regime of operation does not work well with high-repetition rate sources, such as microcombs or electro-optic (EO) combs, because the pulse duration is not sufficiently short to drive coherent broadening in anomalous dispersion media. Indeed, octave-spanning coherent broadening of high-repetition rate sources has been attained in anomalous dispersion silicon nitride waveguides, but this required using a pre-broadening stage in a normal-dispersion highly nonlinear fiber (HNLF) [2]. Implementing this stage in a silicon nitride waveguide is the topic we address in this contribution.

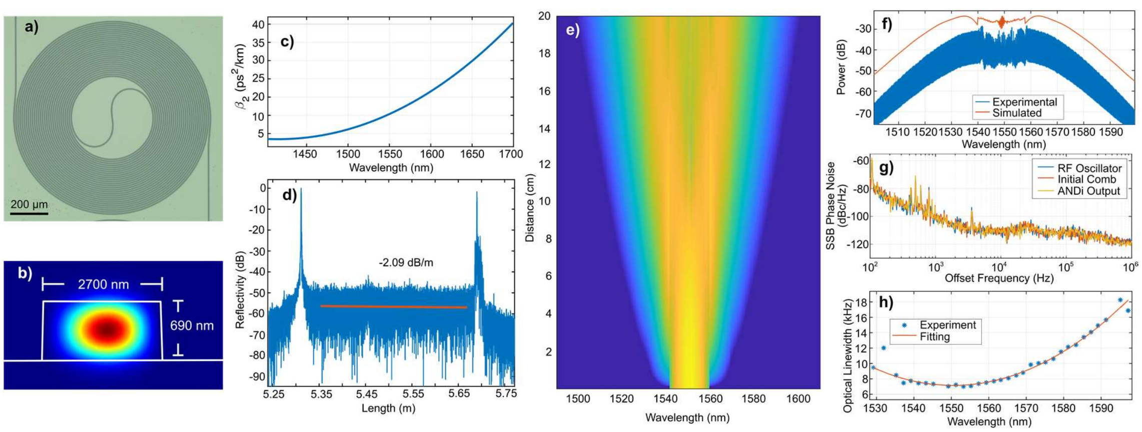

Fig. 1 All-normal dispersion waveguided designed (a, b). Simulated dispersion (c) and loss characterization(d). The output of the spectral evolution (e) is compared with the measured spectra (f). Measurements of the repetition rate single sideband (SSB) phase noise(g) and the optical linewidth of the comb lines (h) of the broadened spectrum.

Operating in the normal dispersion regime is a well-known strategy for nonlinear broadening of picosecond pulses, but to enable efficient broadening, the waveguide requires long length, low loss and flat dispersion. In this work, we design a waveguide wrapped in a sequence of spirals geometry to reach a total length of 20 cm (see picture of a spiral in Fig. 1a). The cross-section is designed to operate in the normal dispersion regime (Fig. 1b, c). The waveguide loss is measured with optical frequency domain reflectometry (Fig. 1d), resulting in 2.09 dB/m. Our source is an EO frequency comb implemented by one intensity modulator followed by four phase modulators, all driven by an amplified 25 GHz signal derived from a dielectric resonator oscillator. We shape and compress the pulse using a spectral pulse shaper to an approximately transform limited Gaussian of 450 fs. The pulse is amplified to an estimated peak power of 62W when coupled to the waveguide. Figure 1e presents a simulation of the pulse evolution, first dominated by self-phase modulation but around 15 cm, the broadening develops the characteristic shoulders akin to optical wave breaking. The resulting spectrum (Fig. 1f) matches well with simulations. The comb is broadened up to ~2.5 times, an amount comparable to the broadening obtained in commercial normal-dispersion HNLFs. We characterize the output spectrum in two ways. First, we analyze the phase noise of the photodetected repetition rate [3]. The results are presented in Fig. 1g and indicate that there is no degradation of the repetition rate stability within our measurement capabilities. Next, we measure the optical linewidth of the comb lines (Fig. 1h) with a self-heterodyne setup and a coherent receiver. The results follow the classical parabolic distribution as expected from nonlinear broadened EO combs [2].

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