Fiber-Integrated Supercontinuum with a 20 GHz Resonant Electro-Optic Frequency Comb

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Abstract: We employ an efficient 1550 nm resonant waveguide-type electro-optic comb generator with PM nonlinear fiber optics to generate 50 fs pulses and 500 nm broad supercontinuum at 20 GHz.

There is growing interest in developing broadband, low-noise optical frequency combs at high repetition rates (∼ 10 GHz) for many applications that require access to individual comb modes. We are particularly interested in simple and robust approaches to comb generation for astronomical spectrograph calibration. Recently, technologies like electro-optic modulation (EOM) [1], and microcombs [2] have been employed in generating astrocombs. However, both of these approaches require amplification and engineering nonlinear optics to generate broad supercontinuum that covers the spectrograph bandwidth. This is challenging due to the low pulse energy associated with high repetition rate combs.

Here, we report a robust approach to generating 20 GHz comb by employing EOM in a resonant waveguide Fabry-Perot cavity [3]. The so-called optical frequency comb generator (OFCG) has the advantages of highly

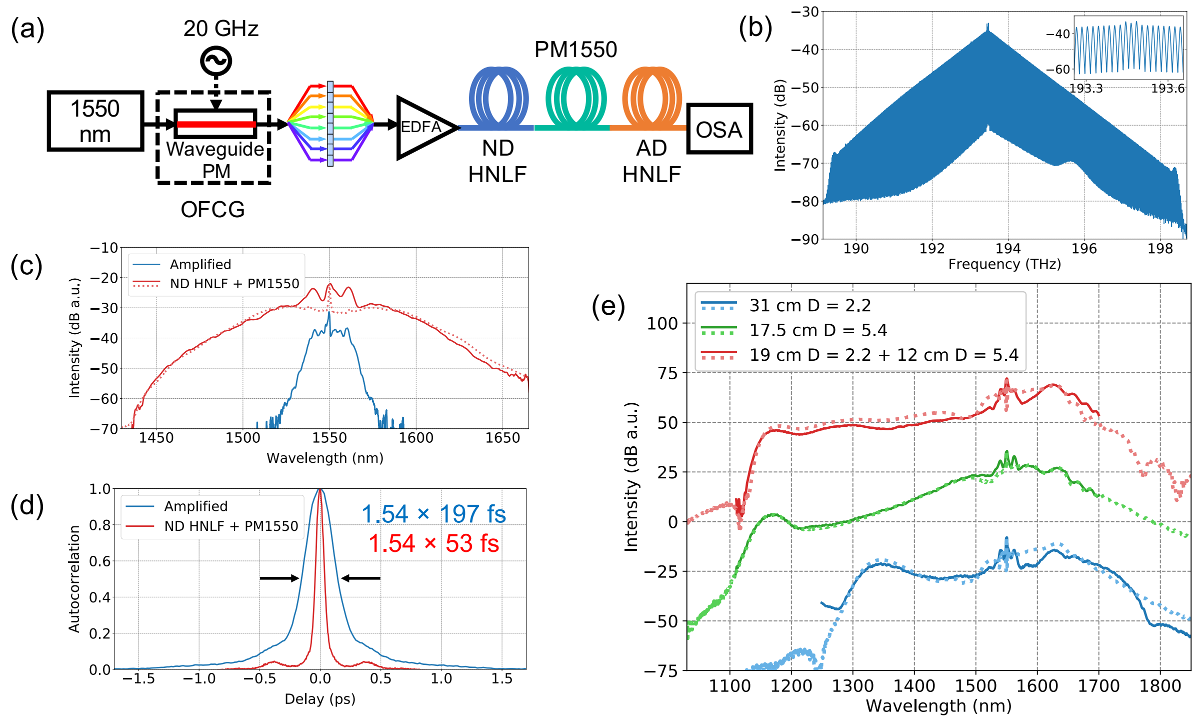

Fig. 1: (a) Experimental setup; (b) EOM comb spectrum and zoomed inset; (c) Optical spectra after amplification (blue trace), and propagation through ND HNLF and PM1550 (red trace); (d) Corresponding autocorrelation traces and pulse widths; (e) Supercontinuum spectra generated in AD HNLF of D = 2.2 ps/nm.km (blue), D = 5.4 ps/nm.km (green) and hybrid (red). Experimental and simulation results are shown as solid and dotted lines respectively.

efficient resonance modulation and built-in RF phase noise filtering [4]. We achieve temporal compression of 20 GHz pulses to $\sim$ 50 fs at 3.5 W deploying all PM fiber design, followed by supercontinuum generation in a multi-segment dispersion-tailored fiber. Pulse propagation through the entire nonlinear fiber system has been modelled and our simulation results show excellent agreement with the experiment. Our approach to nonlinear spectral broadening achieves simplicity and robustness that is applicable to other techniques of comb generation and can be extended to greater spectral broadening using nonlinear nanophotonics.

Fig. 1(a) shows the experimental setup. A continuous wave (CW) laser at 1550 nm is used to pump the comb generator. OFCG is driven by a 1 W microwave signal at 20 GHz that is a multiple of the Fabry-Perot cavity's free spectral range (FSR = 2.5 GHz for our system). Fig. 1(b) shows the optical spectra of the EOM comb. The comb pulses are then sent through a waveshaper for dispersion compensation and to apply group delay for overlapping the two interleaved pulse trains. The 20 GHz pulse train is then amplified to 3.5 W average power using an erbium-doped fiber amplifier (EDFA). Autocorrelation width of the amplified pulses is measured to be $\sim$ 300 fs [Fig. 1(d)]. After amplification, we propagate the pulse train through 1.2 m of normal-dispersion (ND) highly nonlinear fiber (HNLF) for spectral broadening through self-phase modulation (SPM). The specified dispersion parameters of the fiber at 1550 nm are D = -2.6 ps/(nm.km) and D_slope = 0.026 ps/(nm^2.km). To compensate for the SPM chirp, we propagate the pulses through 22.5 cm long PM1550. The measured autocorrelation width of the compressed pulse [red trace in Fig. 1(d)], corresponding to a 53 fs pulse, is approximately 81 fs. We performed the simulation for pulse propagation in nonlinear fibers by solving the nonlinear Schrodinger equation (NLSE) in PyNLO [5] taking the Fourier transform limit pulse of the amplified pulses as input. Assuming 80% of the measured average power (2.8 W) as input to account for the non-ideal conditions, simulation results on propagation through 1.2 m long ND HNLF and 18.4 cm PM1550 are in good agreement with the experiment as shown in Fig. 1(c).

The compressed pulse is then passed through anomalous dispersion (AD) HNLF for supercontinuum generation. The total splicing loss is measured to be $\sim$ 1.4 dB. We studied the supercontinuum generated in two AD HNLFs with different dispersion characteristics independently and observed that a flat broadband spectrum is generated on propagation through multi-segment AD HNLF. Fig. 1(e) shows the corresponding spectra obtained experimentally as well as in simulation. The blue trace corresponds to 31 cm long D = 2.2 ps/nm.km (D_slope = 0.026 ps/(nm^2.km)) fiber that generates dispersive wave (DW) around 1345 nm while 17.5 cm long D = 5.4 ps/nm.km (D_slope = 0.028 ps/(nm^2.km)) fiber generates DW around 1165 nm as shown in the green trace. On slightly tuning the dispersion parameters and input pulse energies to the respective fibers in simulations, spectra very close to the experiment are obtained as shown in Fig. 1(e). The corresponding dispersion parameters used in simulations are D = 2 ps/nm.km, D_slope = 0.034 ps/(nm^2.km) and D = 4.88 ps/nm.km, D_slope = 0.0228 ps/(nm^2.km). A flat supercontinuum spanning 1150 nm to 1700 nm as shown in red trace is generated in a hybrid HNLF consisting of 19 cm long D = 2.2 ps/nm/km and 12 cm long D = 5.4 ps/(nm.km). The length of the first AD HNLF is fixed at the point of soliton fission and then the pulse train is propagated through appropriate length of the second AD HNLF to obtain a flat spectrum.

In conclusion, we achieved 50 fs pulses and supercontinuum spanning over 500 nm at 20 GHz employing a 1550 nm resonant electro-optic comb generator. Octave-spanning spectra could be obtained with different fiber dispersion [6]. In future work, we will pursue additional spectral broadening in SiN waveguides [7]. It will also be important to study the coherence of the supercontinuum and understand the effect of electro-optic cavity filtering on the microwave thermal noise [4,6,7].

References

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