

Highly coherent triple frequency comb generation in a tri-core fiber for four-wave-mixing experiments

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Optical Frequency Combs (OFC) are coherent light sources, emitting a broad spectrum of evenly spaced narrow frequency lines [1]. Dual-Comb Spectroscopy [2] relies on multiheterodyne beat note detection, accessing high spectral resolution, and fast acquisition. The interest of adding a third comb to the system is demonstrated, for example, in the case of four-wave mixing (FWM) [3], enabling to measure time-resolved non-linear spectra. The joint use of three frequency combs requires a high degree of coherence. The current solutions are either to phase-lock three mode-locked lasers [3-4], or to generate different modes in micro-resonators [5]. Here we demonstrate the generation of three mutually coherent frequency comb by spatial light multiplexing in a tri-core fiber (see Fig.1 (a-b)). We demonstrate the potential of this light source for four wave mixing (FWM) spectroscopy.

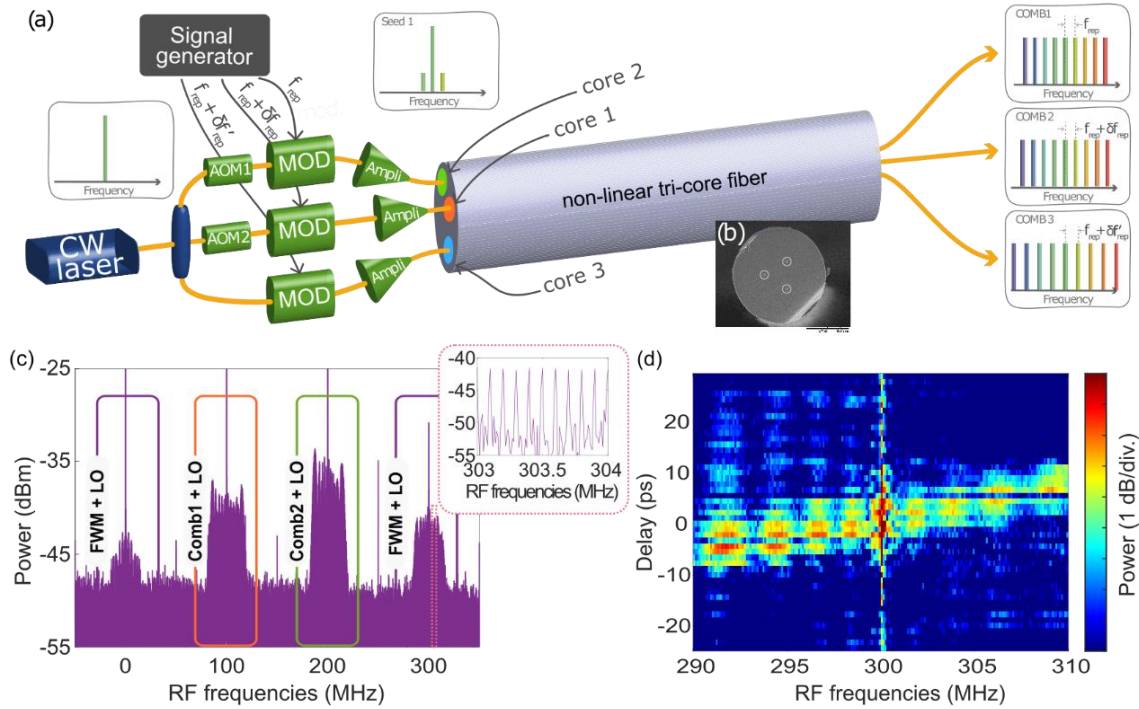


Fig. 1. (a) Simplified sketch of the experimental setup. (b) Scanning electron microscope image of the tri-core fiber. (c) RF spectrum. The inset is a zoom-in of the FWM spectrum around 300 MHz, and shows the comb structure (d) Spectrogram, showing the optical spectrum of the FWM signal as a function of the delay between the two pumps. Parameters: $f_{\text{AOM}1} = 100$ MHz and $f_{\text{AOM}2} = 200$ MHz, $\delta f_{\text{rep}} = 100$ kHz and $f_{\text{rep}} = 1.25$ GHz. CW = continuous wave, AOM = acousto-optic modulator, MOD = intensity modulator, Ampli = Erbium-doped fiber amplifier.

From a single continuous-wave laser, three combs are generated by electro-optical modulation, and then spectrally broadened by self-phase modulation in three cores of the same non-linear fiber (normal dispersion region). The high coherence between the three combs is demonstrated in a FWM experiment. Two combs, shifted in central frequencies, generate FWM harmonics. The output signal is optically sampled and down-converted in the RF domain (see Fig.1 (c)) with the use of a third comb at a different repetition rate. The inset shows the clear separation between the teeth of the FWM signal. Finally, we recorded its evolution as a function of the pump-probe delay (Fig. 1 (d)) to illustrate the interest of this light source for non-linear spectroscopy experiments.

References

- [1] S. T. Cundiff and J. Ye, Colloquium: Femtosecond optical frequency combs, *Reviews of Modern Physics* 75, 325 (2003).
- [2] N. Picqué and T. W. Hänsch, Frequency comb spectroscopy, *Nature Photonics* 13, 146 (2019).
- [3] B. Lomsadze, B. C. Smith, and S. T. Cundiff, Tri-comb spectroscopy, *Nature Photonics* 12, 676 (2018).
- [4] J. Kim, T. H. Yoon, and M. Cho, Time-Resolved Impulsive Stimulated Raman Spectroscopy with Synchronized Triple Mode-Locked Lasers, *The Journal of Physical Chemistry Letters* 11, 2864 (2020).
- [5] E. Lucas, G. Lihachev, R. Bouchand, N. G. Pavlov, A. S. Raja, M. Karpov, M. L. Gorodetsky, and T. J. Kippenberg, Spatial multiplexing of soliton microcombs, *Nature Photonics* 12, 699 (2018).