Kerr optical frequency combs generated around 2-µm in a dual–pumped Brillouin fiber ring resonator

M. Deroh[1,2], G. Xu[2], H. Maillotte[1], T. Sylvestre[1], J-C. Beugnot[1], and B. Kibler[2]

[1]Institut FEMTO-ST, UMR 6174 CNRS, Université Bourgogne Franche-Comté, Besançon, France
[2]Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR 6303 CNRS, Université Bourgogne Franche-Comté, Dijon, France

Broadband coherent light sources consisting of equally-spaced discrete lines in the frequency domain, also called optical frequency combs (OFCs), constitute a very powerful tool in a vast number of applications such as optical frequency metrology, biology, and astronomical spectrograph calibration, optical fiber wavelength division multiplexing (WDM), microwave generation and molecular spectroscopy [1–4]. The latter application has attracted significant interest especially in the mid-infrared range (from 2-µm to 16-µm) where various relevant molecules, such as carbon dioxide and ammonia, exhibit vibration fingerprints. Various OFCs generated at 2-µm wavelengths have recently been reported based on different configurations [3,5].

In this communication, we demonstrate a simple and reconfigurable all-fibered system that generates symmetric optical frequency combs based on a dual-wavelength-pumped fiber ring cavity. More specifically, more than 20 symmetrical and stable optical frequency comb lines, with tunable frequency spacing and center wavelength, have been generated by exploiting both stimulated Brillouin scattering (SBS) and cascaded four-wave-mixing (FWM) in the 2-µm wavelength region.

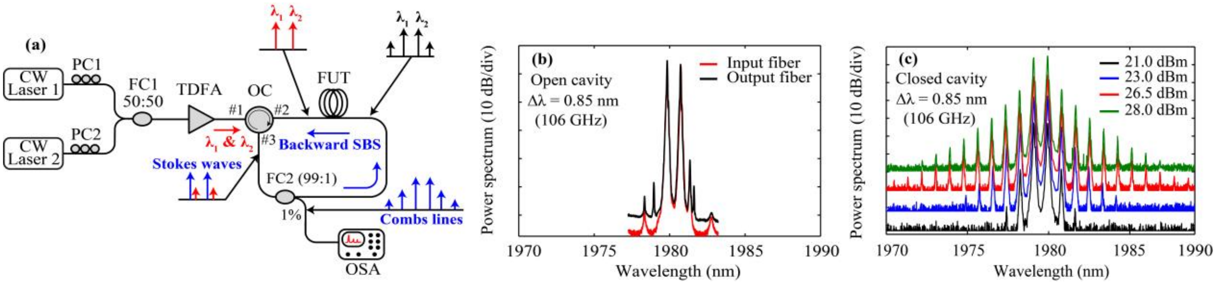

Fig. 1 (a) Experimental setup for optical frequency comb generation in a hybrid Brillouin-Kerr fiber resonator. CW: Continuous wave, PC: Polarization controller, FC: Fiber coupler, TDFA: Thulium-doped fiber amplifier, OC: Optical circulator, FUT: Fiber under test, OSA: Optical spectrum analyzer. (b) Open cavity configuration: Input and output fiber FWM spectra at a fixed frequency spacing of 106 GHz and for an injected power of 23 dBm (measured at OC port 2). (c) Closed cavity: Experimental results of the dependence of the Brillouin/Kerr output spectrum on the injected optical power.

Figure 1(a) shows the experimental setup based on fiber cavity made of a commercially available 350-m-long highly nonlinear fiber (HNLF) which exhibits anomalous group-velocity dispersion at 2-µm. This bi-chromatic pumping configuration allows the free propagation of the Brillouin Stokes waves, which perform multiple roundtrips in the backward direction and then undergo cascaded FWM, while the two injected optical pumps interact only over a single loop in the forward direction [6]. In Fig. 1(b), we present the input and output fiber spectra in the open cavity configuration, where the cascaded FWM process are clearly inefficient for an injected pump power of 23 dBm. By contrast, with the same pump power, the closed cavity system can easily generate more than 20 frequency comb lines, as shown in Fig. 1(c). We present here some results obtained with a fixed frequency spacing of 106 GHz (0.85 nm) and an increasing power varying from 21 dBm to 28 dBm. The stable Kerr combs raise remarkably up to 22 lines when the power is increased to about 26.5 dBm.

A more complete investigation of such hybrid Brillouin/Kerr optical frequency combs was also performed around 1550 nm to benefit from a wider range of available fiber dispersion properties, laser tunability, and ultrafast characterization devices. Benefits and limitations of this hybrid configuration will be discussed as well as numerical modelling.

References

1. T. Udem, R. Holzwarth, and T. W. Hänsch, "Optical frequency metrology," Nature **416**, 233–237 (2002).
2. L. Talaverano, S. Abad, S. Jarabo, and M. Lopez-Amo, "Multiwavelength fiber laser sources with Bragg-grating sensor multiplexing capability," Journal of Lightwave Technology **19**(4), 553–558 (2001).
3. C. Y. Wang, T. Herr, P. Del'Haye, A. Schliesser, J. Hofer, R. Holzwarth, T. W. Hänsch, N. Picqué, and T. J. Kippenberg, "Mid-infrared optical frequency combs at 2.5 µm based on crystalline microresonators," Nature Communications **4**, 1345 (2013).
4. J. Fatome, S. Pitois, C. Fortier, B. Kibler, C. Finot, G. Millot, C. Courde, M. Lintz, and E. Samain, "Multiple four-wave mixing in optical fibers: 1.5–3.4-THz femtosecond pulse sources and real-time monitoring of a 20-GHz picosecond source," Optics Communications **283**(11), 2425–2429 (2010).
5. K. Hu, I. V. Kabakova, S. Lefrancois, D. D. Hudson, S. He, and B. J. Eggleton, "Hybrid Brillouin/thulium multiwavelength fiber laser with switchable single- and double-Brillouin-frequency spacing," Optics Express **22**(26), 31884–31892 (2014).
6. Q. Li, Z. Jia, Z. Li, Y. Yang, J. Xiao, S. Chen, G. Qin, Y. Huang, and W. Qin, "Optical frequency combs generated by four-wave mixing in a dual wavelength Brillouin laser cavity," AIP Advances **7**(7), 075215 (2017).