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Unexpected phase-locked Brillouin Kerr Frequency comb in fiber Fabry Perot resonators

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Stimulated Brillouin scattering (SBS) is the first nonlinear effect to be triggered when a powerful continuous wave laser interacts with a nonlinear waveguide. This effect is further exacerbated in resonators due to the multiple round trips in the cavity. SBS has proven to be extremely interesting for building ultra-stable microwave photonic synthesizers [1], to trigger broadband cavity solitons [2], or to balance thermo-optical effects to obtain ultra-stable sources [3]. Whatever the cavity architecture, the only requirement is to obtain a spectral overlap between the SBS gain ($\nu_B = 10$ GHz, $\Delta\nu = 50$ MHz), and the cavity resonances. This condition is automatically verified in fiber ring cavities, which have free spectral ranges (FSRs) typically between 1 and 100 MHz, or can be met by fine-tuning the cavity lengths in microresonators with FSRs in the GHz range [2-3]. In this paper we evidence an original mode-locking phenomena to generate a stable Brillouin Kerr frequency comb in fiber Fabry Perot resonators. The surprising feature of our work is illustrated in Fig. 1 (a). While there is a spectral overlap between the 8th cavity resonance (dashed lines) and the SBS gain curve (red curve) at 9.416 GHz, we observed a Brillouin Kerr frequency comb with a line-to-line spacing equals to 10.593 GHz (exactly 9 times the cavity FSR, blue line in Fig. 1 (a)) where there is no spectral overlap. The cavity is pumped by an ultra-narrow CW laser of 1.3 W. It is swept from blue to red to reach a cavity detuning of $\Delta = -0.0891$ rad, highly nonlinear fiber with group velocity dispersion $\beta_2 = +0.38$ ps$^2$ km$^{-1}$ and nonlinearity $\gamma = 10.6$ W$^{-1}$ km$^{-1}$, and a Q factor of 65 millions. Spectra had been recorded with a high resolution (20 MHz) optical spectrum analyser and time traces with a high bandpass (700 GHz) optical sampling oscilloscope.

blue to red to reach a cavity detuning of $\Delta = -0.0891$ rad, in order to jump onto the upper branch of the cavity CW response. In the early steps of the process, a Stokes band at 10.593 GHz (9 times the cavity FSR) is generated, and many others through four-wave mixing processes cascade (Fig. 1 (c)). Finally, a broadband frequency comb of 2 THz (Fig. 1 (b) and (c)) is obtained corresponding to a stable pulse train (Fig. 1 (d)). Numerical simulations, including forward and backward fields [5], without any fitting parameters reproduce perfectly these experimental observations (Fig. 1 (e)-(g)). We explain this unexpected feature by performing a linear stability analysis of a mean-field reduction of the governing equations. We found a maximum of the parametric gain exactly at 10.593 GHz, revealing the parametric origin of the Stokes band at this unexpected position.

To conclude, we discovered and explained a new nonlinear mechanism in fiber Fabry Perot cavities. It enables the generation of phase-locked stable Brillouin Kerr frequency combs which could find great interest in microwave photonic synthesizers.

References