Self-injection-locked dual-frequency Brillouin laser operating CW with a simple active feedback loop

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Abstract: A simple dual-frequency laser, employing a single ring fiber cavity for self-injection-locking of a semiconductor DFB-laser and generation of stimulated Brillouin scattering, features a 300-Hz-width RF spectrum recorded with the beating between two channels.

Linewidth narrowing and stabilization of semiconductor laser light generation is of great research interest governed by huge demand for compact cost-effective narrow-band laser sources for many potential applications. In 2012, we demonstrated a simple kHz-linewidth laser just splicing a standard distributed feedback (DFB) laser diode and a few passive telecommunication components [1]. The principle of operation employs the mechanism of self-injection locking that significantly improves DFB laser performance [2]. The main drawback of this technique is its high sensitivity to fluctuations of the configuration parameters and surroundings. Many efforts have been made to stabilize the laser operation in the self-injection locking regime.

Here, we introduce a simple dual-frequency laser based on a semiconductor DFB laser coupled with an external fiber ring cavity and working in self-injection-locking regime. Specifically, the same ring fiber cavity is exploited both for self-injection locking of the DFB laser and for generation of stimulated Brillouin scattering. To prevent mode-hopping, a low-cost USB-DAQ is used to stabilize the system [3]. Importantly, a stable laser operation at two mutually locked frequencies is provided by the self-injection locking, whereas the active feedback just helps the laser operate in this regime. Besides, the self-injection locking mechanism maintains permanent coupling between the DFB laser and the external fiber ring cavity enabling perfect resonant pumping for low-noise Brillouin lasing.

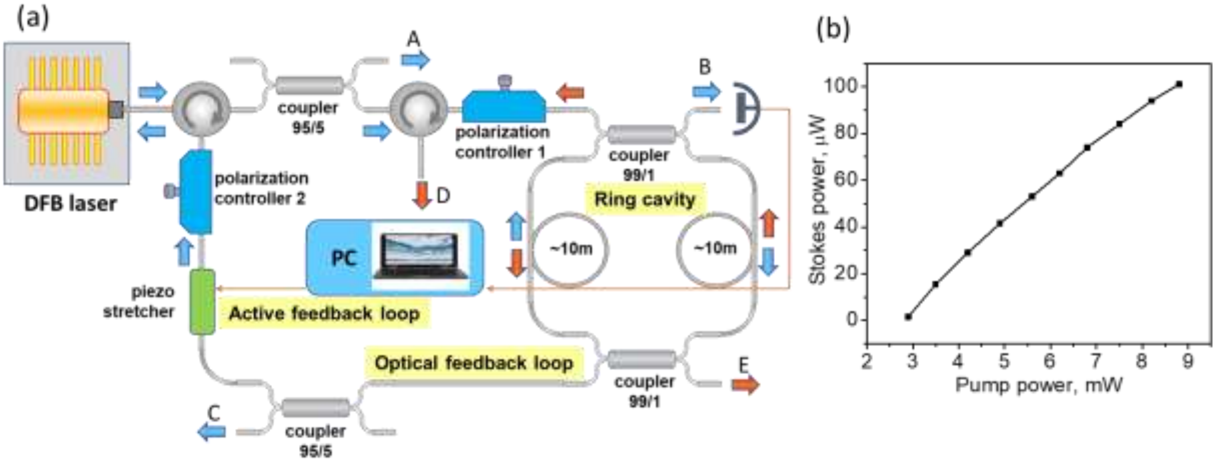

Fig. 1. (a) The experimental laser configuration; (b) Brillouin output power at port D as a function of the DFB laser power at port A.

The experimental laser configuration is shown in Fig. 1, a. The semiconductor laser we use is a commercial distributed feedback (DFB) laser diode (MITSUBISHI FU-68PDF-V520M27B) coupled with the fiber ring cavity through a circulator. The DFB laser delivering ~15 mW at ~1535.6 nm is equipped with a built-in optical isolator attenuating the power of backward radiation by -30 dB. The external high-Q 20-m-long ring cavity is spliced from two couplers (99/1) and (99/1). In order to implement the self-injection locking mechanism, the coupler redirects a part of the light circulating inside the cavity clockwise (CW) through the circulator (OC) back into the DFB laser thus providing passive feedback to the laser operation. The fiber configuration is spliced from standard telecom components and placed into a foam box to reduce the influence of the laboratory environment. No additional thermal control of the box is applied. The piezo-activator attached to the optical feedback fiber is driven by a low-cost USB Multifunction DAQ (National Instrument NI USB-6009) connected to a PC. The laser power detected at port B serves as an error signal. The DAQ manages to keep it as low as possible adjusting the DAQ output voltage applied to the piezo-activator. It maintains a continuous laser operation in self-injection locking regime keeping the matching between the laser generation frequency ν_L and the ring cavity resonance that, in its turn, slowly drifts due to environmental temperature. Specifically, we generate Brillouin lasing with the same fiber ring cavity that is already used for self-injection locking [4]. Inside the ring the DFB laser radiation at ν_L propagating CW is used to pump generation of a CCW Brillouin wave at $\nu_S = \nu_L - \Delta_{SBS}$, where Δ_{SBS} is the Brillouin frequency shift. The ring cavity length has been adjusted precisely with the single-cut technique [5] to get perfect matching between the Brillouin frequency shift and the ring cavity free spectrum range. With the perfectly adjusted fiber ring cavity active stabilization of lasing at the pump frequency ν_L ensures stabilization of lasing at the frequency ν_S.

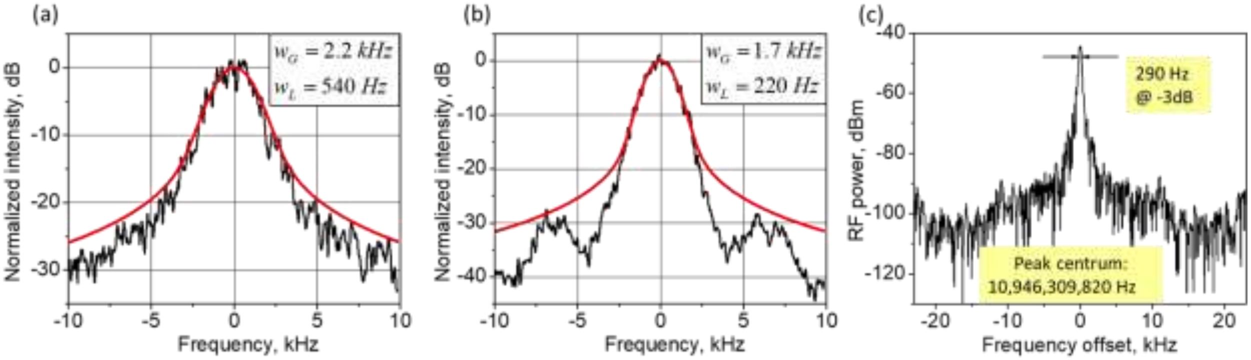

Fig. 2. Delayed self-heterodyne spectra recorded at pump (a, port A) and Stokes (b, port D) laser frequencies and RF spectrum recorded with beating of two channels. The measured spectra (black), their fitting Voigt profiles (red), w_G and w_L are the Gaussian and Lorentzian linewidths.

The dual-frequency laser performance is quite impressive considering that no significant attempt has been made to stabilize the set-up temperature [6]. The laser output powers are $\sim 9\ mW$ and $\sim 100\ \mu W$ for pump and Stokes outputs, respectively [Fig.1, b]. Further power scaling is still possible with external amplifiers. The pump laser power could be amplified with an Erbium-doped fiber amplifier (EDFA), while the use of an external Brillouin amplifier (built from the same fiber as the ring cavity and pumped by the laser power amplified in EDFA) is preferrable for narrow-band Stokes beam amplification. Figures 2, a, b show the delayed self-heterodyne laser spectra measured with an all-fiber unbalanced Mach–Zehnder interferometer comprising a 55 km delay fiber and 25 MHz phase modulator. Decompositions of these spectra into Gaussian and Lorentzian contributions allow to estimate the natural Lorentzian laser linewidths to be narrower than 270 Hz and 110 Hz for the pump and Stokes laser outputs, respectively. These results are in a good agreement with the direct measurements of the radio-frequency (RF) spectrum characterizing the beating between pump and Stokes laser outputs shown in Fig. 2, c. The spectrum exhibits a pronounced peak with the center at $\sim 10946.3098\ MHz$ and the width of $\sim 290\ Hz$. The peak frequency corresponds to the Brillouin frequency shift in the ring cavity fiber (SMF-28, Corning Inc.) at 1535 nm.

In summary, new ability to generate continuously two locked frequencies is attractive for many laser applications, including high-resolution spectroscopy, phase coherent optical communications, distributed fiber optics sensing, coherent optical spectrum analyzer, and microwave photonics. In particular, the reported laser characteristics are well superior to the requirements to the laser modules commonly used with Brillouin Optical Time Domain Analyzer (BOTDA). The work is supported by Russian Science Foundation (№18-12-00457) and Ministry of Science and Higher Education of the Russian Federation (Mega-grant program).

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