Reconfigurable Brillouin laser for linewidth narrowing and microwave-spaced frequency combs

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Narrow-linewidth frequency-stable sources are of interest for a diverse range of applications such as quantum computing and sensing, high-bandwidth communications, precision timekeeping and high-frequency (>10 GHz) radar. Brillouin lasers are promising practical sources of extremely narrow linewidths due to their narrow gain spectrum and ability to dissipate pump phase noise [1]. Though remarkable performance has been reported in terms of linewidth and power [1,2], progress in Brillouin lasers has been hampered by a lack of control of power into higher Stokes orders. Such control is an important requirement depending on applications for single narrow-linewidth output for coherent laser applications or Brillouin frequency combs for use in microwave photonics.

Here we report a novel approach to Brillouin laser design that enables reconfigurable operation between single-frequency narrow-linewidth and Brillouin comb output. The cavity length is tuned to either enhance or suppress second and higher-order Stokes. Shown in Fig. 1(a), the design uses a temperature-stabilized etalon with a transmission peak tuned to the pump frequency. In combination with the high gain Brillouin crystal paratellurite [3], laser action is achieved for singly- and multiply-resonant alignment of the cavity modes with the Brillouin gain peaks (Modes 1 and 2 in Fig. 1(a)).

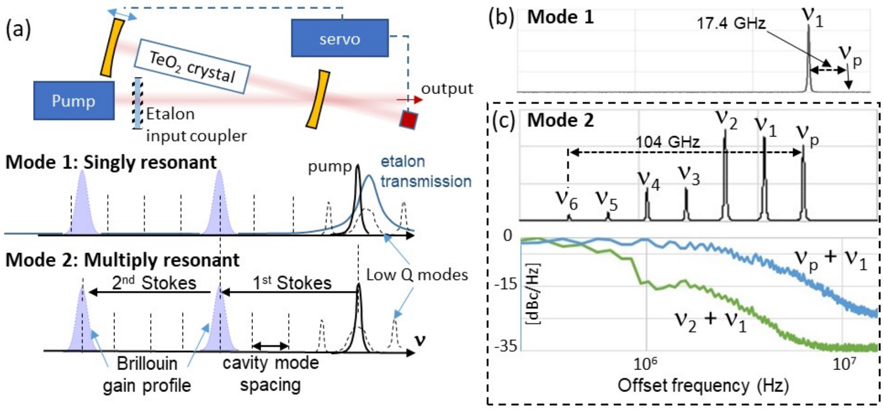

Fig. 1. (a) Layout of the Brillouin laser layout along with cavity resonance conditions for single Stokes (Mode 1) and Brillouin comb output (Mode 2). (b) Mode 1 output spectrum. (c) Mode 2 spectrum with measured frequency noise spectra for heterodyne signals of the pump with the first Stokes ($\nu_p+\nu_1$) and the first with second Stokes ($\nu_1+\nu_2$). Spectra measured using a 1-GHz resolution spectrometer (Light Machinery, Hyperfine).

Spectra obtained for Mode 1 and 2 resonance configurations using a 1064 nm pump laser of 2 MHz linewidth show the transition from single Stokes to frequency comb output (Figs. 1(b) and (c)). For single wavelength output, the threshold for laser action was 10 W with a maximum output beam power of 0.25 W at a frequency shift of 17.4 GHz and a measured reduction in the Lorentzian linewidth by a factor of 3. For comb output, we obtained up to 6 Stokes orders spanning frequencies over 104 GHz, with a combined output power of 0.4 W. Comparison of first and second Stokes photo-mixed signals on a 25 GHz detector showed an 18 dB reduction in phase noise at offset frequencies above 1 MHz compared with the pump and first Stokes photo-mixed signal (Fig 1(c)). We believe the design is amenable to a wide range of power, generation of ultra-narrow linewidths and synthesis of low-noise microwave and mm-Wave frequencies.

References

[1] D. Blumenthal, I. Kabakova, P.T. Rakich and K. Vahala. "Integrated Brillouin lasers and their applications." (Ch. 10) Semiconductors and Semimetals, **110**, 107 (2022),

[2] D. Jin, Z Bai, Z. Lu, R. Fan, Z. Zhao, X. Yang, Y. Wang, and R.P. Mildren, "22.5-W narrow-linewidth diamond Brillouin laser at 1064 nm", Opt. Lett. **47**, 5360 (2022).

[3] M.A. Dubinskii and L.D. Merkle," Ultrahigh-gain bulk solid-state stimulated Brillouin scattering phase-conjugation material" Opt. Lett. **29**, 992-994 (2004)