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Self-pulsing of Brillouin-Raman distributed feedback fiber lasers

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Abstract: We report on self-pulsing in distributed-feedback single-frequency Raman fibre lasers. We see a periodic reduction in intra-cavity power associated with each pulse and propose that this self-pulsing arises from parasitic Brillouin scattering cavity dumping the Raman. © 2021 The Author(s)

1. Introduction

Recently there has been much interest and progress in developing single-frequency distributed feedback (DFB) Raman fibre lasers, as they provide a simple and compact means of achieving lasing at wavelengths outside the rare-earth ion bands [1–4]. There have been reports on stimulated Brillouin scattering (SBS) of the Raman cavity [5, 6], as well as one report on an active ”Q-switching bursting regime” when a Raman DFB is driven by a piezo actuator [7]. Here, we report the demonstration of 1119 nm DFB Raman lasers in small core high-NA fibre and observe passive self-pulsing. By measuring 1064 nm pump depletion as a proxy for intra-cavity Raman power we are able to describe the pulsing process and state that this can be modelled with Lotka-Volterra predatory-prey theory.

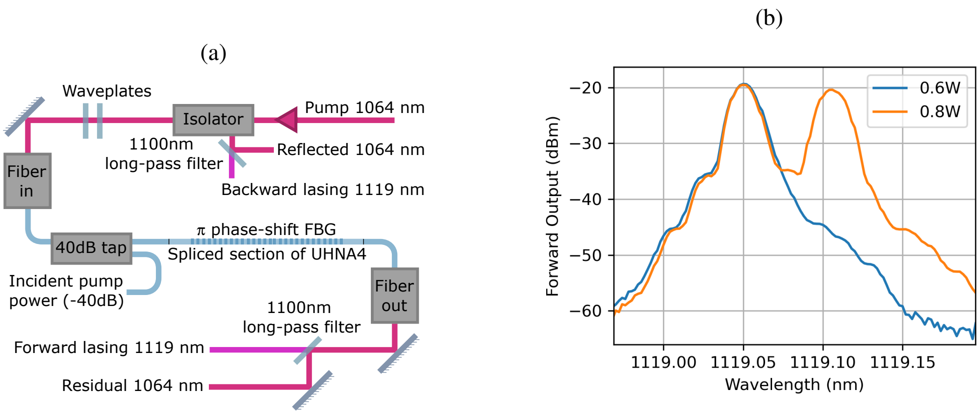

Fig. 1: (a) A schematic diagram of the laser setup. (b) OSA spectra of of the Raman just above the Raman lasing threshold and the Raman Brillouin just above the Brillouin threshold.

2. Results and Discussion

The DFB gratings were fabricated using the small spot direct UV writing [8], an interferometric technique using an EOM with feedback from air-bearing stages and a 244 nm frequency-doubled argon ion laser. Similarly to Shi *et al.* [5] ultra-high numerical aperture fibre (UHNA3) was used for its germania content and small mode area which both improve Raman gain, with the latter also increasing Brillouin gain. For this work, all gratings are 25 cm long with uniform apodisation and centrally located π phase-shifts and κ values of 30 m^{-1}. The DFBs were mounted on a copper bar with an induced small bow (3 m radius of curvature) to constrain the fibre to the bar with a thermal compound applied to the bar. The laser was pumped using a 10 W linear polarised fibre laser from IPG, with pre- and post-grating filtering done in free space as per Fig. 1a, with polarisation aligned to optimise lasing threshold. Pure Raman lasing was seen in all lasers just above the laser threshold, with SBS appearing a few hundred milliwatts above the Raman threshold. An example is shown in Fig. 1b. As others have reported, we

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found that the SBS dominates the laser output and clamps the Raman with increasing pump power only producing small increases in Raman as compared to the Brillouin.

(a) (b)

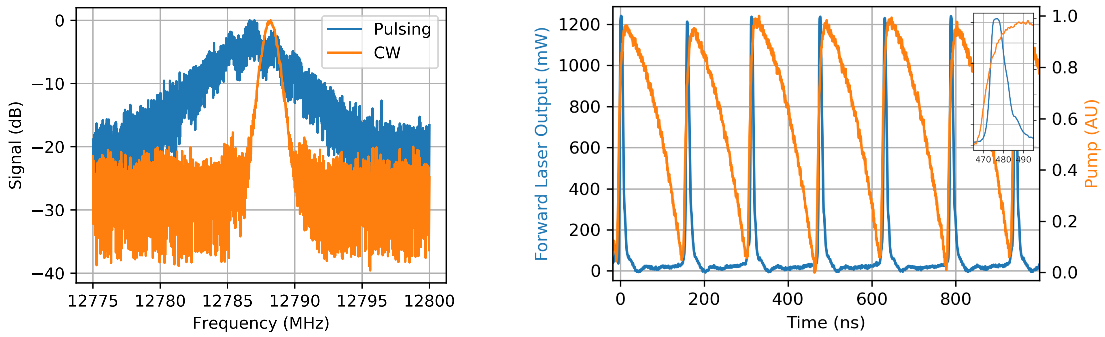

Fig. 2: (a) ESA spectra of the Raman-Brillouin beat frequency for both CW and pulsed regimes. b) Oscilloscope data of laser and pump output for the highest peak power observed with regular pulsing and an inset showing a magnified single pulse.

At powers slightly higher than SBS emergence, pulsing starts to be seen for all lasers tested. The pulse-pump behaviour is similar to that of Q switching, where repetition rates started low at 3 MHz increasing with pump power up to 7 MHz with pulse duration decreasing from 25 ns to 8 ns. A maximum peak power achieved of 1.2 W achieved at 4 W of pump. The highest average power was 1.2 W in the forward propagating output with a pump power of 4.5 W but with chaotic pulsing. An electrical spectrum analyser (ESA) with a fast InGaAs detector was used to directly measure the 12.8 GHz beatnote of the Raman and Brillouin for both pulsing and CW behaviours, with the CW measurement bandwidth limited by the response time of the ESA. As can be seen in Fig. 2a, the pulsing has a narrow linewidth of <5 MHz, which is less than the expected gain bandwidth of the SBS. Pump depletion can also here be used as a proxy for intra-cavity Raman power. As shown in Fig. 2b, it can be seen that the intra-cavity power rapidly depletes during a pulse and then slowly builds back up before the SBS threshold is reached and a new pulse initiates. The pulsing behaviour is similar to Q-switching but as there is no solid-state energy storage, ”cavity dumping” is the more appropriate term. We have found this behaviour can be modelled with rate equations for the pump, Raman and Brillouin; we later realsied this was identical to the famous Lotka-Volterra predatory-prey equations.

3. Conclusion

We have demonstrated SBS based self-pulsing of a single frequency Raman fibre laser at 1119 nm using a 25 cm long DFB grating in UHNA3. The lasers produce 8-30 ns pulses and 3-7 MHz repetition rates. Based on our measurements, we have proposed a potential mechanism for the pulsing and note that Lotka-Volterra predatory-prey equations can be used to model the pulsing.

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