Giant pulses generation with all-fibre Raman laser

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Abstract: We report on the giant pulse operation of a Raman fibre laser. Pulses with peak power up to 1kW and duration down to 1ns were obtained with a 10km long all-fibre cavity configuration pumped by a 2.4W continuous wave fibre laser source.

1. Introduction

Pulsed fibre lasers are attractive for many applications because they offer a large scale of the peak power, compact size, air-cooling and a high beam quality [1]. They find applications in many technological areas including material processing. Because of the versatility in the output wavelength choice and the possibility to tune this wavelength over a wide spectral range [2], Raman fibre lasers (RFLs) are of great interest. The realization of the giant pulse operation of RFL is very promising. However, traditional Q-switching techniques have not yet proven to be efficiently applicable to RFL, in particular because of the short lifetime of the optical phonons involved in the Raman process and of the large length of fibre required to provide sufficient gain in the cavity. Here, we present the experimental demonstration of a pulsed RFL that operates in passively Q-switched regime, employing laser dynamics associated with nonlinear effects. The principle of operation is based on Rayleigh scattering (RS) and stimulated Brillouin scattering (SBS) cascaded process that provide a dynamical feedback in the fibre cavity. Although the idea of the RS-SBS mirror has already been demonstrated with rare-earth-doped fibre lasers [3-5], it had never been realized with a RFL. Specifically for RFL, the RS-SBS process initiating Q-switching is strongly coupled with stimulated Raman scattering (SRS), which also contributes to the pulse formation process by providing dynamical amplification in the cavity. Here, we report our experimental results with a giant pulse RFL, demonstrating that RS, SBS and SRS are all involved in the pulse generation process.

2. Experimental set-up

Our experimental configuration is shown in Fig. 1. Thanks to a 1455 nm unpolarised CW laser with 1 nm linewidth, we pump a 10 km long single mode optical fibre. The pump provides Raman amplification in the fibre within the spectral band centred around $\lambda_{SRS} \approx 1555$ nm that corresponds to the 13 THz SRS shift in silica. The pump linear loss coefficient α_P and the Raman gain efficiency G_R of the fibre are estimated to be 0.2 dB/km and 0.75 $W^{-1}km^{-1}$ respectively. The pumping light is coupled into the fibre through a wavelength division multiplexer (Mux) and filtered at the end of the fibre by the Demux used as a demultiplexer. At the pumping end, the Mux is spliced with a broadband fibre loop mirror (FLM) that reflects $R \approx 80\%$ of the Stokes power back into the fibre. A 1% Tap coupler allows to monitor this power. Thanks to an optical isolator, we prevent Fresnel backreflection from the far fibre end. Thus, the distributed RS mirror formed by the fibre provides feedback and allows the laser to operate. Power at both fibre ends is monitored by high speed photodetectors (PD).

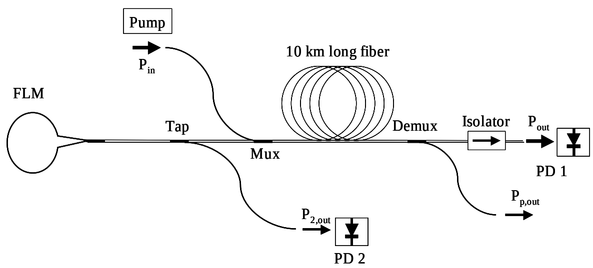


Fig. 1. Experimental set-up with pump multiplexer (Mux) and demultiplexer (Demux).

3. Results and discussion

Because the input pump power P_{in} used in the experiment is below the threshold power $P_{SRS}^{th} \approx K\left[16 - \ln R\right]/2G_R L_{eff} \approx 2.7$ W [6] (where $L_{eff} = (1-\exp(-\alpha_P L))/\alpha_P \approx 8$ km is the effective length of the fibre and $K = 2$ is the depolarisation factor) of classical SRS in the double-pass fibre configuration, the laser operation must rely on the distributed RS mirror. In Fig. 2, we show power characteristics of the RFL. The laser output power and the residual pump power are presented as functions of the input pump power P_{in}. When P_{in} is under the lasing threshold power $P_L^{th} \approx 1.6$ W, the Raman amplification in the fibre cavity is too small to compensate for linear losses and hence to cause significant power conversion from the pump to the Stokes wave. SBS is also prohibited for this broadband pump excitation. Therefore, the pumping light propagating through the fibre suffers only linear losses and the output pump power increases linearly with the input pump power until P_L^{th} is reached. Above the threshold, the Stokes power grows almost linearly with the input pump power leading to effective pump depletion inside the fibre. At an input pump power of 2.4 W, the average laser output power exceeds 700 mW, demonstrating a ~30 % conversion efficiency.

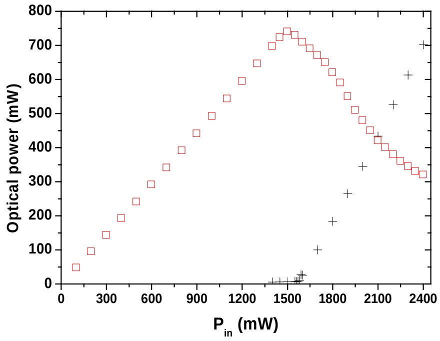


Fig. 2 : Output power (+) and residual pump power (□)

Above the lasing threshold, the RFL shows up a pulsed behaviour. Two typical traces synchronously recorded from both fibre cavity ends are shown in Fig 3a and b. The wide low power pulse (a) at the mirror side is dynamically amplified by SRS providing giant narrow pulses (b) at the output. We present histograms describing the statistics of the giant pulses duration (Fig 3c) and repetition rate (Fig 3d). The most frequent giant pulses last less than 1 ns. The pulses are produced with an average repetition rate of 180 kHz, which corresponds approximately to the inverse of the time that light takes to travel through the effective amplification length $L_a = \dfrac{1}{G_R / K . P_0} \approx 1.1$ km. The peak power of the giant pulses generated by the laser is of the order of 1 kW.

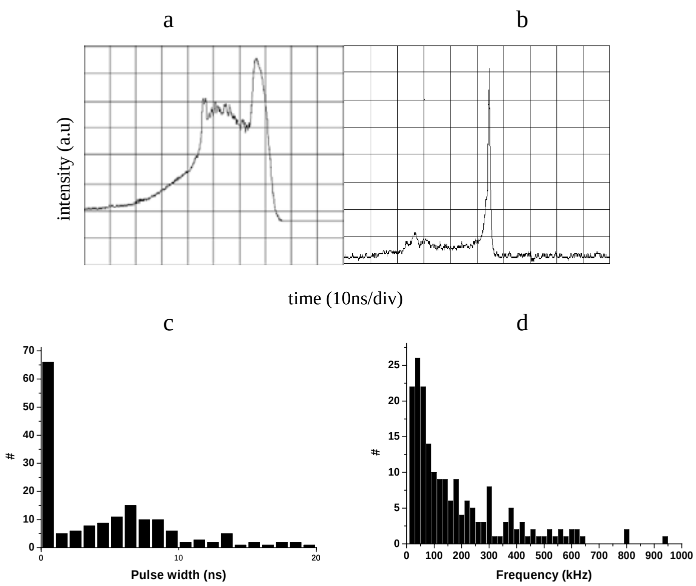


Fig. 3 : Pulse shape at mirror side (a) and output (b). Statistics of the duration (c) and repetition rate (d) of the pulses.

Experimental spectra of the laser confirm that RS-SBS cascaded mechanism is responsible for pulse generation in the laser. The RF spectrum shown in Fig. 4 has pronounced peaks at ~11 GHz and ~22 GHz. Since the SBS shift in silica optical fibre is ~11 GHz, these peaks correspond to the beating between cascaded SBS components generated in the fibre cavity. The broadband dynamical amplification provided by SRS and the effective line narrowing of the laser radiation associated with RS [7] both support multi-cascaded SBS process in the fibre cavity.

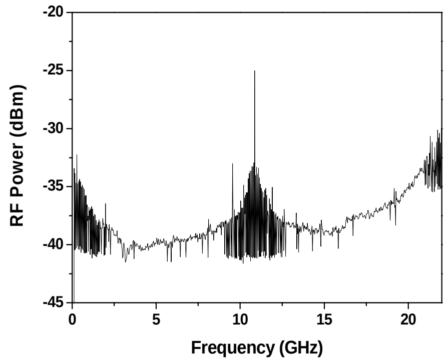
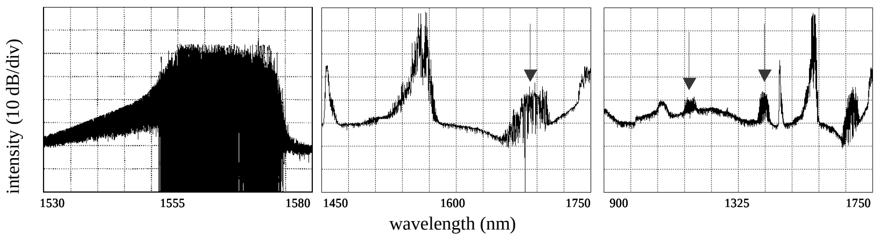


Fig. 4: radio-frequency spectrum

The optical spectrum of the output radiation shown in Fig. 5a is typical for the multi-cascaded RS-SBS generation in the fibre cavity [8]. Specifically, it exhibits multiplicity of narrow SBS components filling a 30 nm wide spectral band on the Stokes side of the central Raman wavelength at 1555 nm. The very high peak power of the pulse generates other nonlinear effects such as second order SRS (Fig 5b) and four wave mixing (FWM) lines with respect to the zero dispersion wavelength of 1310nm (Fig 5c).



a b c

Fig. 5 : Optical spectra exhibiting cascaded SBS lines (a), second order SRS (b) and FWM (c)

4. Conclusions

We have experimentally demonstrated the Q-switching operation of an all-fibre RFL. Giant pulses with a peak power of 1 kW and duration of 1 ns has been generated thanks to a laser configuration based on distributed RS feedback. Experimental results clearly indicate that RS-SBS cascaded mechanism is responsible for Q-switching in the RFL.

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