Generation of Subnanosecond Solitary Pulses by Backward Stimulated Raman Scattering in Hydrogen-filled Photonic Crystal Fibres

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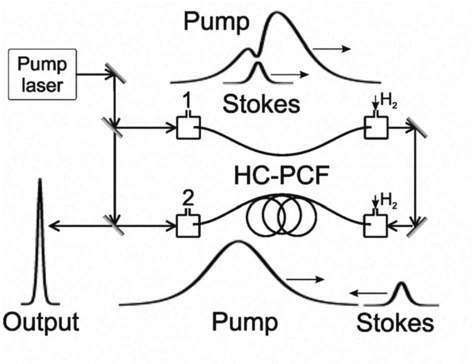
Backward stimulated Raman scattering (BSRS) has been widely used as an efficient method for generation of high energy short laser pulses [1]. In BSRS the Stokes field continuously encounters undepleted incoming pump light, and its front can be amplified to a value many times higher than the pump intensity, resulting in pulse compression. In the presence of linear loss this process can stabilize, giving rise to a solitary wave. This occurs because build-up of the stationary gain develops within a finite time determined by the phase relaxation time T_2 of the Raman transition. Therefore, solitary wave formation is directly related to the transient (coherent) Raman effects occurring at times $t < T_2$. So far, this phenomenon has been difficult to study because, in a focused geometry, BSRS is typically accompanied by laser beam self-focusing and competing forward SRS.

Here we report the observation of soliton-like pulses generated by BSRS in a gas-filled photonic crystal fiber (HC-PCF). The excellent performance of HC-PCF for SRS studies was shown recently in the quasi CW-regime [2]. In the present experiment, we have observed high energy pulses of duration (0.7 ns) significantly shorter than the irreversible phase relaxation time T_2 of the Raman transition. The fact that the pulse parameters (temporal shape, duration and energy) are insensitive to the temporal structure of the seed pulse (generated by forward SRS from noise) suggests that they are similar to solitary pulses generated in laser amplifiers.

Our experimental set-up has a two-stage configuration (see Fig.1), with a pump laser at λ=1.064 µm delivering 12 ns pulses of energy ≤ 100 µJ. The first stage (a 1.5 m long bandgap HC-PCF filled with H_2 at p= 3 bar) was used to generate a seed Stokes pulse by pure rotational forward SRS (Stokes shift 18 THz [3]). The seed pulse was amplified by BSRS in the second stage, comprising a 4 m-long HC-PCF filled with H_2 at p=1.5 bar. The second fibre length and pressure were chosen to maximize the gain factor for the seed, while keeping the pump energy below the threshold for SRS. For 20 µJ pump pulses, at the output of the second stage we observed stable generation of 0.7 ns pulses with a symmetric temporal envelope. Typical results from single-shot measurements are shown in Fig. 2. While the long trailing edge of the pulse fluctuates from shot to shot, the intense short spike at the leading edge shows remarkable stability and does not depend on fluctuations in the seed pulse. The symmetric $\mathrm{sech}^2(x)$ shape of the pulse is in a good agreement with our theoretical prediction (see inset in Fig.2), i.e., that in the presence of linear loss of 0.15 dB/m and Doppler broadening $\Delta\nu_D \approx 4$ GHz, the solitary pulse duration should be 5 times shorter than $T_2 \approx 3$ ns caused by collisions. Thus, the results suggest that pulse amplification and temporal shortening by BSRS is not limited by T_2 and can occur in the extremely transient regime.

Finally, we note that by minimizing the loss in a properly engineered HC-PCF and optimizing the configuration of the experiment, a compression factor with respect to the pump pulse duration much higher than 20×, as demonstrated here, can be achieved.

(a)



(b)

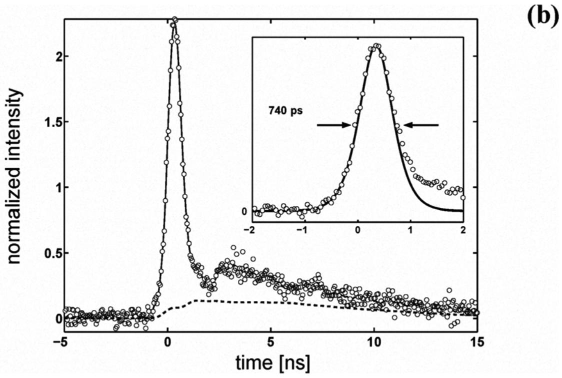


Fig. 1 (a): Sketch of the set-up for generation of sub-ns pulses by BSRS; **(b)** Temporal structure of the input (seed) Stokes pulse (dashed line) and the output amplified Stokes pulse (circles) measured after a 4 m-long HC-PCF filled with hydrogen at p=1.5 bar. The inset shows a fit of the Stokes pulse envelope to the $\mathrm{sech}^2(x)$ function predicted by theory; the agreement is excellent.

References

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