Generation of dissipative solitons in normal-dispersion Raman fiber laser

U. Tegin[1], P. Elahi[1], C. Senel[2], E. Ergecen[3] and F. Ömer Ilday[1, 4]
[1] Department of Physics, Bilkent University, 06800 Ankara, Turkey
[2] TUBITAK National Metrology Institute (UME), PO 54, TR-41470, Gebze, Kocaeli, Turkey
[3] Department of Electrical and Electronics Engineering, METU Ankara, 06800, Turkey
[4] Department of Electrical and Electronics Engineering, Bilkent University, 06800 Ankara, Turkey

Dissipative soliton pulses in a synchronously pumped all-normal-dispersion Raman fiber laser is presented theoretically and experimentally. The laser generates 7.1 nJ intra-cavity pulses at 1.12 µm and is compressed to 136 fs.

Stolen, et al. introduced synchronously pumped oscillators based on stimulated Raman scattering (SRS) in 1977 [1]. Raman lasers generate wavelengths outside of the limited range covered by the conventional laser gain media. Generally, Raman lasers are pumped by another laser source to generate a frequency-shifted Stokes (or anti Stokes) wave. Raman solitons, which are generated by this technique, require km-long cavities possess anomalous-dispersion fibers and usually are limited to generate high energy pulses [2]. Self-similar pulse evolution has been generated in km-long fibers to achieve picosecond-long pulses [3].

Here, we present a new type of Raman oscillator, which supports dissipative solitons in all-normal-dispersion regime. The dynamic of the system is governed by the complex Ginzburg-Landau equation which can support dissipative soliton.

The experimental setup shown in Fig. 1 and comprises of a pump laser source to generate highly positively chirped pulses centered at 1065 nm, an amplifier and Raman oscillator. When the Stokes pulse, generated in Raman oscillator, is band-pass filtered and re-launch into the oscillator, the strong Raman pulses are generated.

In this experiment, the pump laser is a mode-locked oscillator, which generates 6.5 ps long pulses with 37 MHz repetition rate at 1065 nm. The output from oscillator then amplified to 215 mW.

The chirped pulses from amplifier are led into the all-polarization-maintaining Yb-doped fiber Raman oscillator and amplified to 760 mW to generate the first Stokes wave. The Stokes component is fed back into the Raman oscillator while the pump is filtering out. We employed a precise translation stage to synchronize pump and Stokes and confirmed it by time-domain measurement.

When temporal pump-Raman overlap is achieved, the amplified spectrum is modified dramatically and most of the energy being transferred to the Stokes wave at 1120 nm (Fig. 2.b). By using of diffraction gratings, the pulses are compressed to 136 fs (Fig. 2.c) which is the shortest achieved dissipative soliton Raman pulse to the best of our knowledge.

Numerical simulation is employed to investigate the pulse dynamic through the system starting from mode-locked oscillator, amplifier and Raman oscillator. The output from each stage serves as the initial condition for the next one. The pulse propagation is modeled by generalized nonlinear Schrödinger equation (GNLSE) including gain saturation and Raman scattering and solved by using fourth-order Runge-Kutta in the interaction picture method [5].

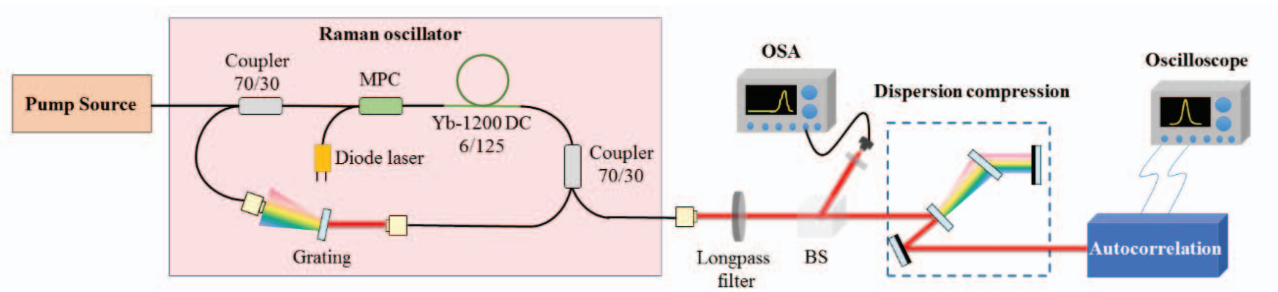

Fig. 1. Schematic experimental setup. MPC, multi-pump signal combiner; DC, double clad; BS, beam splitter

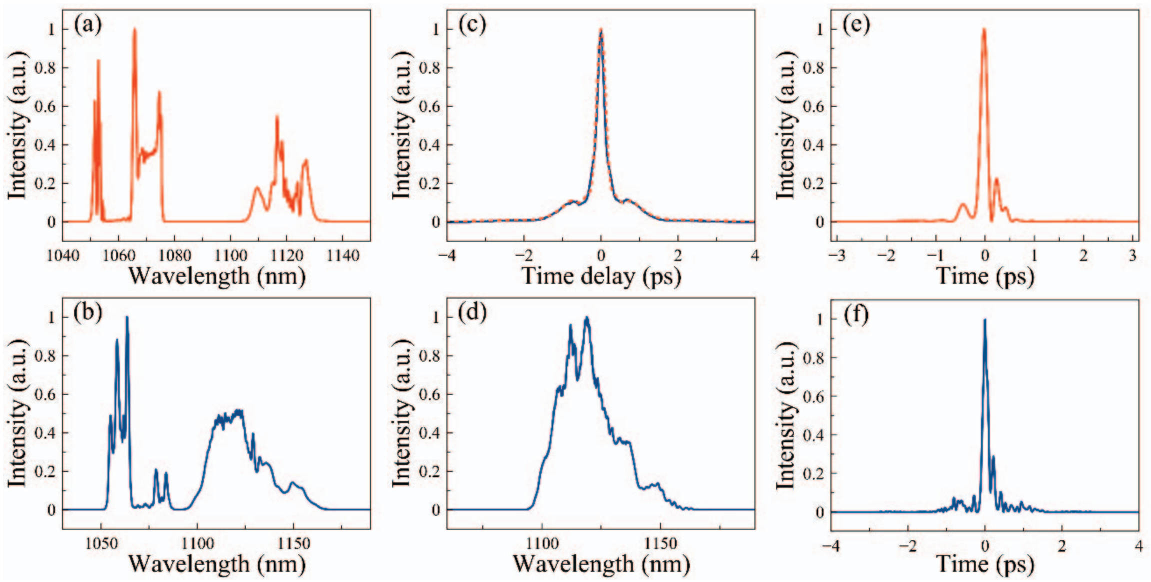

Fig. 2. (a) Numerical simulation and (b) measured spectra of Raman laser with internal feedback. (c) Measured autocorrelation trace of the dechirped pulse (blue solid-line) and calculated autocorrelation trace of dechirped pulse using PICASO algorithm (red dashed-line). (d) Measured output Stokes spectrum after longpass filtering. (e) Numerical simulation and (f) retrieved pulse using PICASO algorithm

Stimulated Raman scattering was modeled using the analytical model presented in [6]. Gain was modeled by solving rate-equations using experimentally measured emission and absorption cross-sections of ytterbium, ignoring amplified spontaneous emission [7]. Figs 2(a) and 2(e) show the simulatied optical spectra and pulse shape, respectively.

PICASO algorithm [8] was used to infer the pulse shape from the measured autocorrelation and spectrum. The measured pulse width for the Raman pulse is 136 fs with Gaussian-shape time-bandwidth product. The PICASO-retrieved pulse shapes duration is 154 fs, as shown in Fig. 2f.

In conclusion, we have demonstrated the first synchronously pumped dissipative soliton Raman laser. The pump laser comprises of an oscillator and an amplifier to generate highly-chirp pulses centered at 1060 nm. By leading the pulses into Raman oscillator (the same length as pump oscillator), after generating Stokes pulses and re-launching it, we generated strong Raman pulses. The intra-cavity energy of Raman pulse is 7.1 nJ and after compressing, 136 fs long pulses is achieved. The Raman oscillator can be modeled by complex Ginzburg-Landau equation, which support dissipative Raman solitons.

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