Energy-managed soliton fiber laser for efficient flexible picosecond pulse generation

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To upscale the pulse energy directly output from a single ultrafast fiber laser oscillator, scientists commonly resort to stretching the pulse inside of the cavity. This strategy, which is linked to the proven advantages of chirped-pulse amplification, is generally implemented through propagation within a normal-dispersion fiber. However, this results in strong pulse distortions, in addition to the need to de-chirp the output pulses [1,2].

In the present work, we revisit the search of higher pulse energy with the goal of generating neat pulse waveforms with reduced frequency chirping. We leverage the degrees of freedom of the cavity architecture, emphasizing on a large degree of energy management, to delineate high and low energy soliton propagation regions separated by strong nonlinear losses and spectral filtering, as illustrated in Fig. 1(a). For the present proof of concept, we restrict to the usage of standard fiber components and build an erbium-doped fiber laser cavity that generates pulses in the 1535-1590 nm range, sketched in Fig. 1(b). We employ nonlinear polarization evolution to obtain an effective saturable absorption for laser mode locking, while the laser pulses experience anomalous dispersion propagation all along the cavity. Therefore, our approach contrasts with the soliton-similariton laser developed earlier [3], which employed spectral filtering and dispersion management to delineate parabolic (normal dispersion) and (anomalous) soliton pulses propagation regions within the cavity. Here, we utilize an original blend of conventional and dissipative soliton dynamics inside the laser cavity [4]. The strong dissipation (more than 90% of the pulse energy is extracted from the main output, followed by spectral filtering) enables the generation of multi-nJ bell-shaped few-ps pulses having a limited frequency chirping.

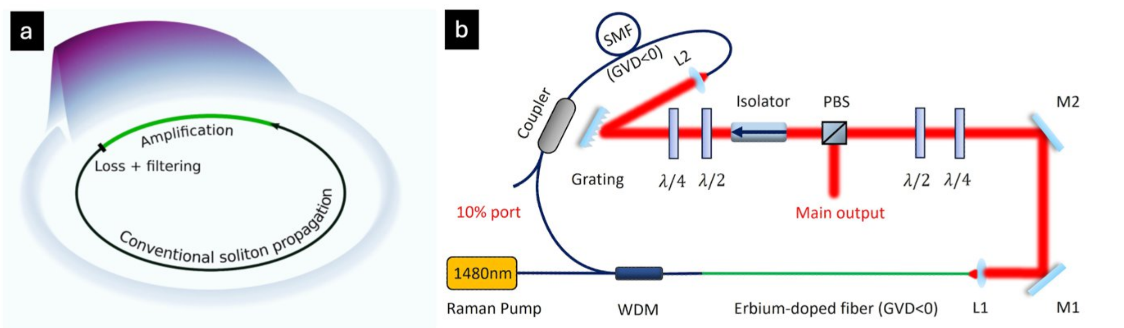

Fig.1. a) Conceptual figure of the intracavity laser dynamics. b) Schematic of the mode-locked fiber laser experiment. SMF: standard single mode fiber. PBS: polarization beam splitter. WDM: wavelength division multiplexer. M1,2: mirrors. l/2, l/4: waveplates.

The subsequent propagation in the passive SMF takes place at a reduced optical peak power, which is comparable to the conventional fundamental (N=1) soliton power, as checked through a 10% output coupler located by the end of the SMF. An example of laser operation is shown in Fig. 2. The main output yields an average power of 105 mW, which corresponds to a pulse energy of ∼ 3 nJ at the fundamental 34.9-MHz repetition rate. Such pulse energy is about two orders of magnitude higher than the conventional soliton energy ∼ 30 pJ that would be supported by the standard anomalous optical fibers used in the fiber laser, assuming the same 2-ps pulse duration. Fig. 2 also displays a bell-shaped pulse profile devoid of any radiation peak in the spectral domain.

Furthermore, the present laser architecture features an exceptional flexibility, in terms of pulse repetition rate and pulse duration. Since the propagation in the passive SMF section is undertaken at the low energy of a conventional soliton, the SMF length can be modified quite arbitrarily. We illustrate this feature by varying the cavity repetition rate over more than an order of magnitude, keeping the same pulse energy level, whereas the pump power is advantageously scaled down when the repetition rate is decreased. Concerning the flexibility of the pulse duration, we show that the pulse duration can be freely adjusted in the picosecond range, according to the setting of the spectral filter bandwidth, with the benefit of scaling up the pulse energy when the pulse duration is increased, and we demonstrate an output pulse energy up to 0.3 μJ.

To conclude, the present fiber laser architecture combines the possibilities of generating energetic ultrashort pulses enabled by dissipative soliton dynamics with the neat waveforms and contained frequency chirping that are characteristic of the conventional fiber soliton. As a benefit of such combination, the ultrafast fiber laser is highly flexible in terms of pulse repetition rate and pulse duration.

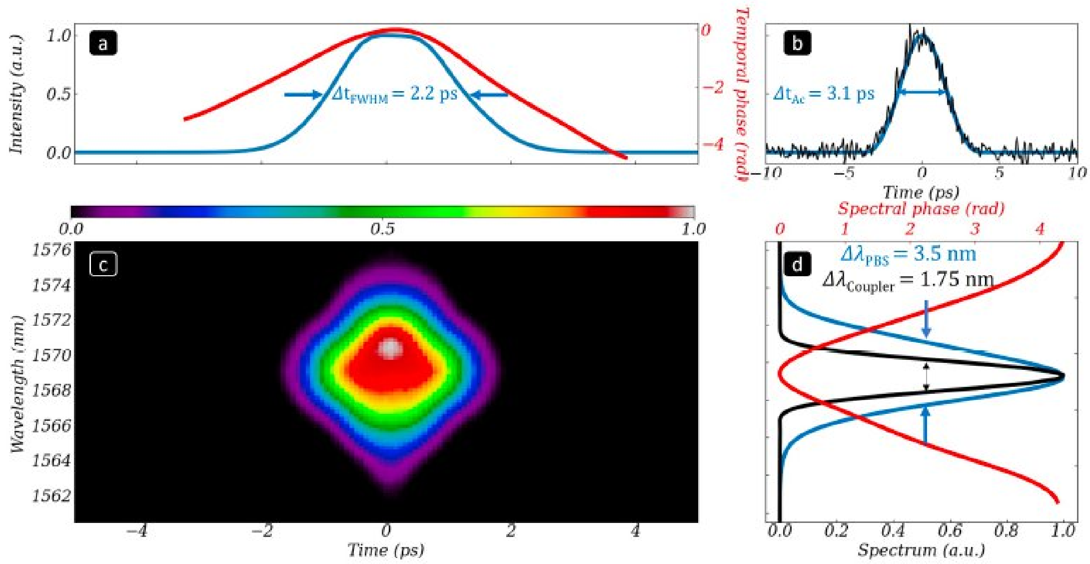

Fig. 2. Characterization of a 3-nJ output pulse. (a) Retrieved pulse intensity (blue) and phase (red); (b) Autocorrelation (blue curve); (c) FROG spectrogram; (d) Optical spectrum (in blue) and spectral phase (red curve). For the same laser regime, the secondary output (10% port) delivers 18-pJ pulses, whose autocorrelation and optical spectrum are displayed as black curves in (b) and (d), respectively.

References

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