Nonlinear Management of Fiber Oscillator with Multiple Gain Segments

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Strong nonlinear effects typically dominate the dynamics of mode-locked fiber oscillators. These effects are simultaneously sources of fascinatingly rich dynamics and a technological limitation. While most approaches involve reduction of the nonlinear effects through larger chirping of the pulses or use of large-mode-area fibers, alternative approaches, such as seeking out new mode-locking regimes [1] or even direct compensation of nonlinear effects [2] have been proposed. However, the latter has not been fully realized experimentally.

Here, we demonstrate an oscillator cavity with two gain segments to effectively manage the magnitude and distribution of nonlinearity through the cavity. To perform experiments as controlled as possible, we keep the total pump (TP) constant. In Fig. 1, we summarize how this variation changes pump power distribution and the corresponding pulse duration (CPD) of output-coupled pulses, dechirped in external DDL. We increased pump of first gain segment from 98 mW to 400 mW, while decreasing pump on the other from 950 mW to 660 mW. Spectral bandwidth (SW) was observed to change from 17 nm to 21 nm, whereas CPD of the output varies between 140 fs to 215 fs as a result of PP variations. Fig.1f shows the SW is larger for pulses with less nonlinearity and Fig.1g shows SW is larger for shorter CPD. The longer pulse can be re-compressed to 140 fs using substantially smaller (30%) dispersion, which implies that we are effectively compensating positive GVD with SPM [3]. These expectations have been tested numerically, as shown in Fig. 1h-j.

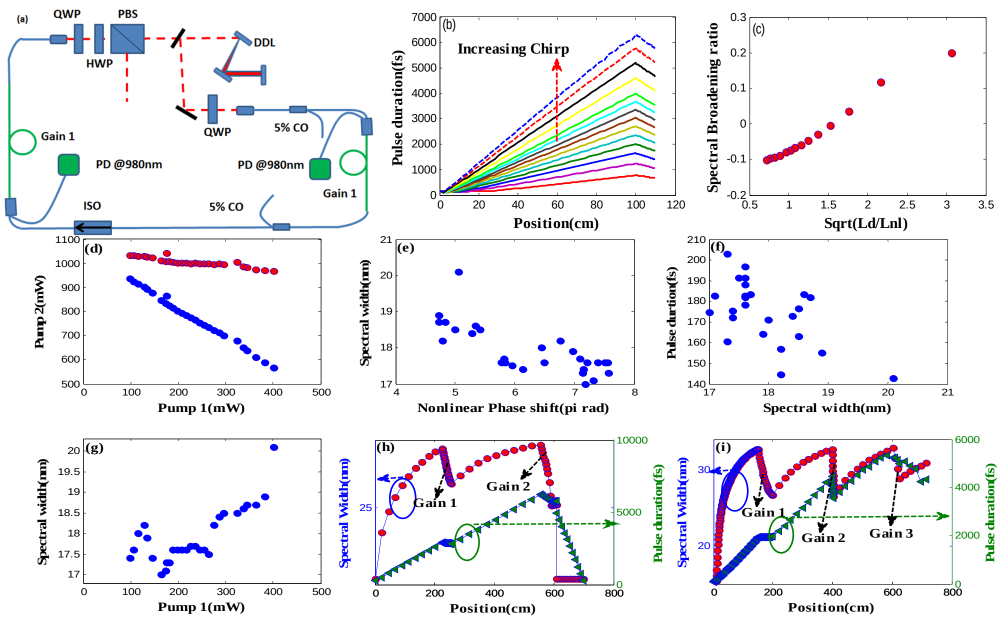

Fig. 1 (a) Schematic of the laser. (b), (c) Two-segment simulation showing the effect of chirp on spectral compression in Yb-gain fiber. Experiment (d-g) showing relationship between, (d). Two PP. and TP (Red) in the cavity. NLPS with (e). SW, (f). CPD, (g). SW with PP1. Simulation(h and i) (h). Dynamics of double gain oscillator and, (i). Dynamics of a cascade of gain and passive fiber.

In conclusion, we show through simulations and experiments that pulse evolution can be controlled to a certain extend through the distribution of nonlinear phase accumulation inside the oscillator. We observe that pulses with large chirp can undergo spectral compression in the gain fiber (Fig.1(b) and 1(c)) and collective action of sequentially arranged active and passive fibers can initiate spectral compression as shown in Fig 1(h) (oscillator) and Fig 1(i) (cascade of gain and passive fiber) by managing distribution of nonlinear phase accumulated in each segment. This is a result of the complex interaction between large pulse chirp, gain filtering, dispersion and SPM. Thus, one can have an *effective* negative nonlinear refractive index by artificial arrangement of gain and passive fibers, akin to metamaterials controloing the linear refractive index. The dynamics explored here, while preliminary, have exciting implications for energy scaling and limitations to pulse durations of mode-locked oscillators.

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