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Talk Invited | Invited Talk

Spectrally breathing pulses in a mode-locked fiber laser: self-similar and soliton-like propagation in alternate parts of the resonator

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We report a mode-locked fiber laser incorporating dispersion-managed fiber sections and a narrow-bandpass filter. Modelocked operation corresponds to Kruglov-type self-similar pulse propagation in the normal-dispersion section (with amplification) and soliton-like pulse propagation in the anomalous-dispersion section (without amplification) of the resonator. Pulses circulating in the laser resonator exhibit periodic spectral broadening and reduction by 7 times, as a result of the optical Kerr nonlinearity. This is to our knowledge by far the highest of any laser reported. Given that spectral broadening is strictly a nonlinear process, the laser can be considered to be the "most nonlinear laser" demonstrated. The observed stability of the pulse formation in the presence of such strong nonlinear effects has profound implications on the pulse shaping mechanisms in a mode-locked laser.

Although a wide range of pulse shaping schemes have been reported for ultrafast lasers, including soliton, stretched-pulse, similariton and all-normal dispersion regimes, in all of these cases spectral modification of the pulse remain minor. Here, we report a laser containing a narrow-band optical filter, with the spectral width of the pulse changing by as much as 7-8 times within a single roundtrip. Remarkably, the laser operation is very stable. Experimentally, the cavity consists of 3.5 m of single-mode fiber (SMF) with negative dispersion and 1 m of highly doped Er-doped fiber with positive dispersion. The net dispersion of the laser cavity is $0.01ps^2$. We measured bandwidths of 12 nm and 85 nm for the optical spectra at different points within the cavity. The laser generates chirped pulses, which are compressed externally to 110 fs.

We seek maximal understanding of this mode of operation using numerical simulations. The model is based on a nonlinearch Schrodinger equation, generalized to include higher-order dispersion, Raman scattering, gain with saturation and bandwidth filtering, saturable absorption and the bandpass filter. Experimentally observed behavior is reproduced well with the simulations. A simple picture of how the pulse evolves emerges: upon filtering, the pulses enter the SMF, where they are of too low power to regenerate the lost spectral width. The broadening takes place predominantly within the normal-GVD Er-fiber, exhibiting an extreme case of similariton propagation maintained without pulse break-up owing to beginning the evolution with a particularly narrow spectrum. The pulse shape evolves into the parabolic shape, which is characteristic of similaritons. Note that, all previous observations of similaritons in a laser cavity exhibited mild changes in the spectral width.

In conclusion, we report a novel mode of operation of an ultrafast fiber laser, corresponding to extremely strong nonlinear shaping of the pulse, with spectral width breathing by a factor of 7. In analogy to the stretched-pulse laser, this laser could be regarded as a “stretched-spectrum” laser.