A birefringence-managed normal-dispersion fiber laser delivering energy-tunable chirp-free solitons

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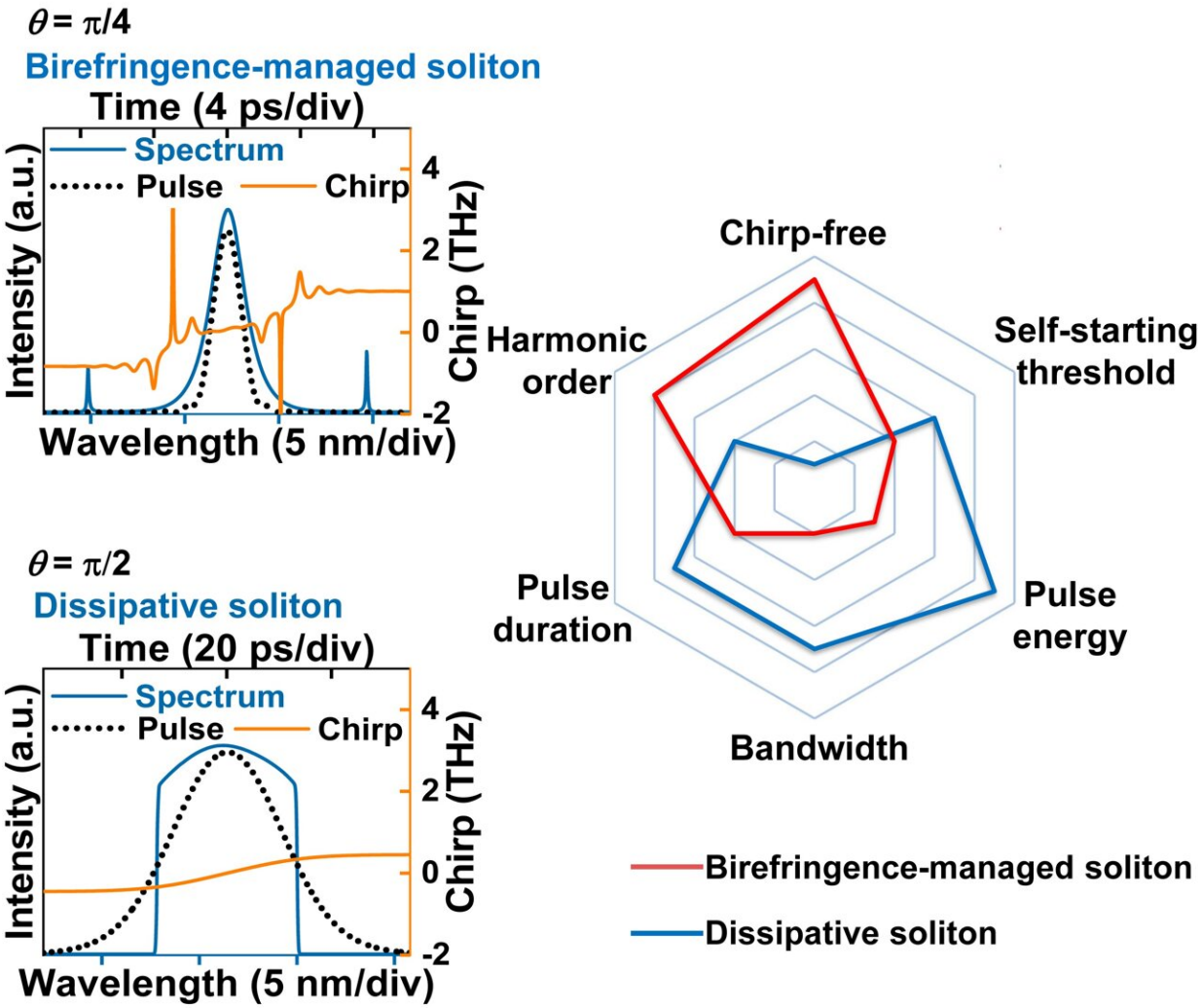

Comparison of birefringence-managed soliton and dissipative soliton in the same normal-dispersion fiber laser. Credit: *Ultrafast Science* (2022). DOI: 10.34133/2022/9760631

Over the past decades, researchers have demonstrated conventional solitons, stretched pulses, self-similar pulses, and dissipative solitons by managing the dispersion and nonlinearity of fiber lasers. However, new types of robust pulses were less discovered in mode-locked fiber lasers, since dissipative solitons were reported in ~2000s. On the other hand, chirp-free solitons are only achieved with anomalous-dispersion fiber lasers in the past, and the single-pulse energy is constrained within a relatively tight bound.

Recentlty, a joint research team led by Prof. Dong Mao and Jianlin Zhao from Northwestern Polytechnical University, together with Prof. Zhipei Sun from Aalto University, proposed a novel class of chirp-free pulse in net-normal-dispersion erbium-doped fiber lasers. The birefringence-related phase-matching effect dominates the formation of the chirp-free soliton, and hence it is termed as birefringence-managed soliton.

Controllable harmonic mode-locking from 5-order to 85-order can be achieved at the same pump level of ~10 mW with soliton energy fully tunable beyond ten folds, indicating a new birefringence-related energy law that intrinsically distinct from the energy theorem of conventional solitons.

For the normal-dispersion fiber laser containing a section of polarization-maintaining fiber, mode coupling between two orthogonal-polarized components occurs when the pulse propagates from single-mode fiber to

polarization-maintaining fiber. The laser operation mainly depends on the polarization state of the pulse in single-mode fiber.

When the θ (i.e., the angle between y-polarized component and fast axis of PMF) is ~0 or ~π/2, the laser emits dissipative solitons, while birefringence-managed soliton can be realized when θ varies between ~π/10 and ~2π/5. Compared with dissipative solitons, the birefringence-managed solitons possess smaller pulse duration, bandwidth, and pulse energy, as well as self-starting threshold, and are capable of assembling themselves into high-order harmonic mode-locking states.

By virtue of single-shot spectroscopy and electrically tunable polarization controller, the transition between dissipative soliton and birefringence-managed soliton can be visualized in real time. For both transition process, they exhibit degeneration of solitons, relaxation oscillation, and regeneration of solitons. These results further validate that birefringence-managed soliton is realized in normal-dispersion region.

Numerical simulations based on coupled Ginzburg-Landau equations well reproduce the experiment observations, corroborating that apart from the chromatic dispersion, nonlinearity, and saturable absorption effects, the birefringence can be exploited to manage the energy and propagation behavior of pulse, which may open new research directions in fields of optical solitons and ultrafast fiber lasers.

This work paves an avenue to directly generate chirp-free solitons in normal-dispersion cavities without external compression. Such flexible fiber laser is capable of producing tunable high-order harmonically mode-locked solitons at a relatively low pump power, providing a promising way for realizing high-repetition-rate pulse sources operating with low power consumption for optical communication and sensing.

The paper is published in the journal *Ultrafast Science*.

More information: Dong Mao et al, Birefringence-Managed Normal-Dispersion Fiber Laser Delivering Energy-Tunable Chirp-Free Solitons, *Ultrafast Science* (2022). DOI: 10.34133/2022/9760631

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