Real-time pulse dynamics in bidirectional mode-locked fibre lasers

I. Kudelin[1], **S. Sugavanam**[1], **M. Chernysheva**[2,*]

[1]*Aston Institute of Photonic Technologies, Aston University*

[2]*Leibniz Institute of Photonic Technology*

[*]*E-mail: Maria.Chernysheva@leibniz-ipht.de*

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Real-time observation of the emergence of coherent structures from noise via instabilities is of particular interest across disciplines ranging from biology to astrophysics. In the context of photonics, ultrafast fibre lasers provide an ideal test-bed for an experimental observation of dynamical instabilities and generation of coherent structures of ultrashort pulses.

The availability of real-time measurement techniques like spatio-temporal dynamics, time lenses [1], Dispersive Fourier Transform (DFT) [2] and others have enabled the observation of self-organisation of such coherent features [3] and their complexes [4], soliton interactions and soliton explosions [5]. Such real-time approaches also enable observation of build-up dynamics of various ultrashort pulses, *e.g.* employing DFT technique [3,6], which confirm the origination of ultrashort pulses from intensity fluctuations on the noise floor, shaped further via modulation instabilities [3] or Q-switched dynamics [7]. All this works substantially increase the knowledge of soliton behaviour and dynamics in nonlinear systems.

Bidirectional ultrafast fibre lasers present an attractive solution, enabling the generation of two mutually coherent ultrashort pulse trains in a simple and turnkey system [8]. Still, the lack of a comprehensive numerical model describing steady-state bidirectional generation, and even less ultrafast soliton breakdowns and collisions, is obstructing the achievement of the performance compared with unidirectional lasers.

In the current presentation, real-time build-up dynamics of counter-propagating solitons in ultrafast ring Er-doped fibre laser, recorded via the dispersive Fourier transform methodology, will be discussed [9]. Even though the counter-propagating pulses experience independent build-up dynamics from modulation instability, undergoing breathing dynamics, diverging sub-ordinate pulse structures formation and annihilation, and Q-swtuch instabilities, etc. to a stable bidirectional pulse train. Yet, the interaction of pulses in the cavity presents the key underlying phenomenon driving formation evolution distinct from unidirectional pulse build-up. These observations open up a great avenue towards versatile manipulation of the nonlinear soliton dynamics. Our findings will provide physical foundations for bidirectional ultrafast fibre laser design to carry forward their applications, including dual-comb spectroscopy and gyroscopy.

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