Real-Time Measurements of Ultrafast Instabilities in Nonlinear Fiber Optics: Recent Advances

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ABSTRACT

Recent years have seen renewed interest in the study of nonlinear fibre laser and propagation dynamics through the use of real-time measurement techniques for non-repetitive ultrafast optical signals. In this paper we review our recent work in this field using dispersive Fourier Transform and Time Lens techniques.

1. INTRODUCTION

The past few years have seen spectacular progress in the field of real-time measurement of non-repetitive ultrafast optical signals. Consequently, new light has been shed on the fundamental processes at play [1,2]. Though impressive, earlier studies have mostly consisted in either one of two approaches: (1) real-time spectral characterization via dispersive Fourier transform (DFT) or (2) real-time temporal characterization by time lensing at sub-picosecond resolution. Concerning nonlinear fiber optics specifically, these tools have been successfully applied to assessing supercontinuum generation, modulation instability and optical turbulence, to the point that such real-time techniques are rapidly becoming standard in studying the influence of noise with respect to several nonlinear propagation phenomena [3-8]. This communication proposes a review of our recent work in the field (described in detail in Ref. 8), specifically the simultaneous combination of time lens and DFT in the study of instabilities occurring during dissipative soliton structure build-up in a mode-locked fiber laser.

2. METHODOLOGY AND RESULTS

The experimental techniques that we have used provide real-time characterization in both the frequency and time domains. In the frequency domain, the DFT technique is based on the principle that a picosecond pulse propagating under large linear (group velocity) dispersion broadens to nanosecond duration, with the intensity profile of the nanosecond pulse taking on the functional form of its spectrum. In the time domain, the principle is based on transposing the action of a magnifying lens in space to temporally stretch picosecond pulses to the nanosecond domain whilst maintaining their intensity profile. Since nanosecond pulses can be readily measured using ~10's of GHz bandwidth detectors and ultrafast oscilloscopes, it is now possible to conveniently perform real time measurements under a wide range of experimental conditions. Our experiments characterized a passively mode-locked fiber laser emitting "dissipative solitons" shaped by a combination of nonlinearity and dispersion with gain, loss and a saturable absorber. We used real-time techniques to characterise a variety of laser dynamics, particularly the startup regime displaying instability characteristics.

Full details of our experimental setup are to be found in Ref. 8, and a particular feature of our approach is that we are able to simultaneously measure the spectral and temporal intensity of a pulse as it builds up from noise inside a laser cavity after the pump current is switched on. In particular, during laser startup, we observe an instability phase (quasi Q-switched regime) consisting of a series of large relaxation oscillation envelopes under which mode-locked pulses at the cavity repetition rate are observed. Over a series of several 100's of round trips in the cavity, these modelocked pulses (dissipative solitons) show complex evolution behaviour consisting of multi-pulse interactions, collisions and decay. Typical experimental results are shown in Fig. 1. Here we have plotted a selection of measurements examining different examples of instabilities observed. Figures 1(a)-(c) show unstable multipulse behaviour, Fig. 1(d) shows the onset of stabilisation with only one single pulse in the cavity but with fluctuating energy, while Fig. 1(e) shows stable dissipative soliton operation. Obtaining both time and frequency domain characteristics also allowed us to perform phase retrieval, enabling full field reconstruction (complex amplitude envelope). This in turn permits computing the complex nonlinear eigenvalue spectrum.

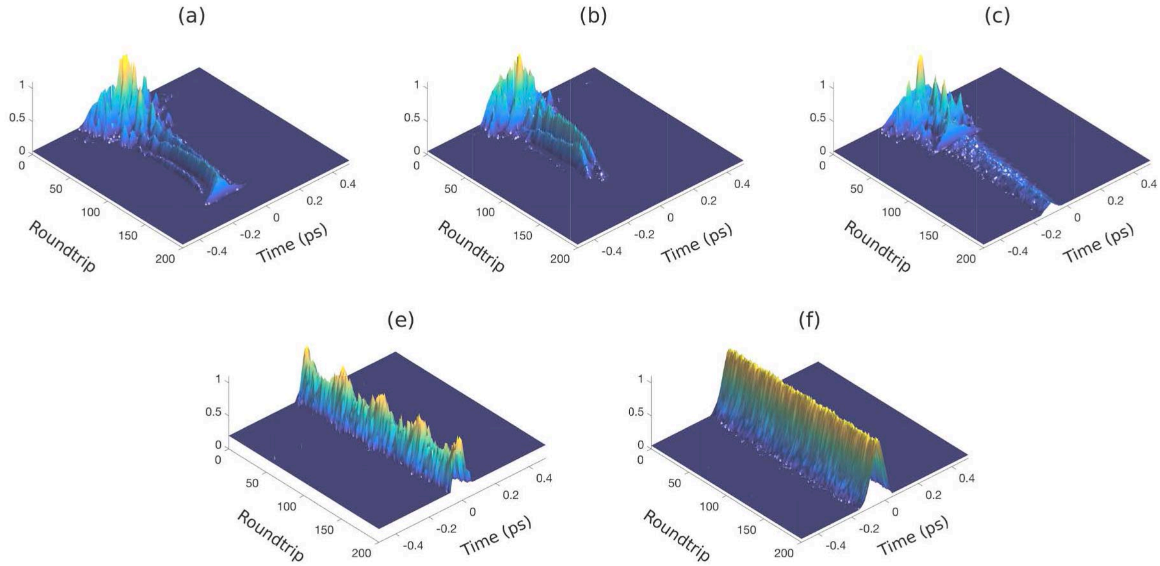

Figure 1. Real time intensity measurements using a time-lens technique to characterize different regimes of start-up dynamics in a passively-modelocked laser.

The ability to characterize dissipative solitons in real time is a major experimental advance. Such solitons are examples of a rich class of localized states appearing in far from equilibrium systems in many different scientific fields outside physics, including chemistry and biology. Studying these structures in laser systems has attracted significant attention but has been limited by available measurement techniques. Our results have overcome these limitations and we are now able to provide a more complete picture of their dynamics, even in the presence of complex evolution and multi-pulse interactions. In addition to their fundamental interest, we expect that this approach will provide a key tool in the development of high-performance, high-stability laser sources.

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