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On-chip temporal pulse pattern generation and fiber propagation: Multidimensional wave-packet control and characterization

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Abstract— We review recent work using integrated and fibered platforms for advanced optical processing. We show that machine learning in photonics systems can be leveraged to generate custom optical wave-packets relevant for targeted applications and further discuss the extension of this approach within multimode fibers.

Keywords—nonlinear optics, fiber optics, integrated photonics, supercontinuum, pulse shaping, machine learning, multimode fiber

I. INTRODUCTION

The fields of ultrafast and nonlinear photonics have brought about several recent research breakthroughs, for which machine learning (ML) has been a driving force at the core of numerous research efforts [1]. Among others, advances in so-called “smart” photonics have been enabled by photonic integrated circuits (PICs), which provide customizable and scalable functionalities highly sought-after for a wide variety of machine learning architectures [2]. In particular, systems based on cascaded interferometers allow to boost the accessible parameter space of optical systems required for multiple applications.

Fairly simple architectures can thus be leveraged for generating customized optical wave-packets, eventually taking advantage of hybrid platforms encompassing nonlinear fiber propagation for optimized spectral broadening [3]. Here, we provide a succinct overview of our recent results in this research area.

II. RESULTS

A. Supercontinuum optimization

Our implementations rely on a PIC, playing the role of an integrated pulse splitter, by means of concatenated balanced and unbalanced Mach-Zehnder interferometers [4,5]. The high-index glass platform of the chip exhibits low linear (< 0.06 dB/cm) and negligible nonlinear losses. The eight unbalanced interferometer structures of the chip feature bit-wise increasing delays (from 1 to 255 ps), which are readily adjusted by a micro-controller driving the pulse splitting via on-chip electric heaters. Fully fiber-coupled, the PIC can be effectively reconfigured with a > 20 Hz refresh rate, offering a good approach for versatile ML-based optical processing. For

instance, the short delays and weak dispersion of the PIC sample can be used to tailor femtosecond pulse patterns and subsequent nonlinear guided-propagation for optimized spectral broadening. This approach was demonstrated to drive conjoint broadening processes in highly-nonlinear fibers and yield spectrally-optimized supercontinuum (SC) generation [3], as illustrated in Fig. 1.

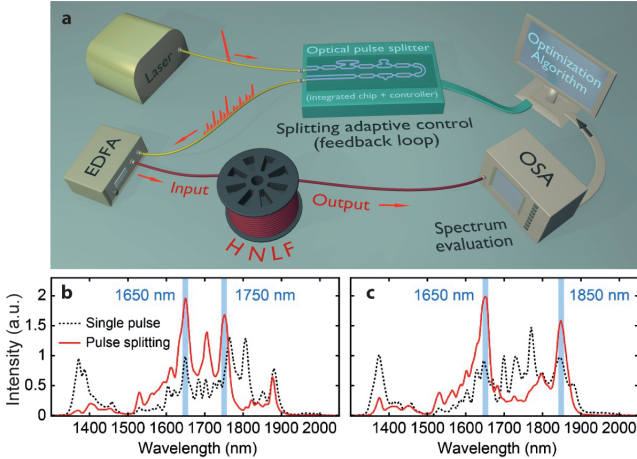


Fig. 1. Supercontinuum spectral optimization: (a) Experimental setup. (b-c) Example of optimized supercontinua (red) with spectral intensities enhanced at selected target wavelengths (blue shading).

B. Pulse shaping

Similar optical processing, paired with ML optimization, can yield autonomous picosecond pulse generation with arbitrary and reconfigurable shapes following the approach displayed in Fig. 2. In this case, the picosecond pulses are experimentally measured via asynchronous optical sampling based on fibered four-wave mixing [5]. Using the previously-demonstrated PIC femtosecond pulse pattern shaping [4], we numerically studied and showed that the spectrally-optimized SCs could be further tuned in the temporal domain [6], as to iteratively enhance multiphoton absorption relevant for various modalities of nonlinear microscopy [7].

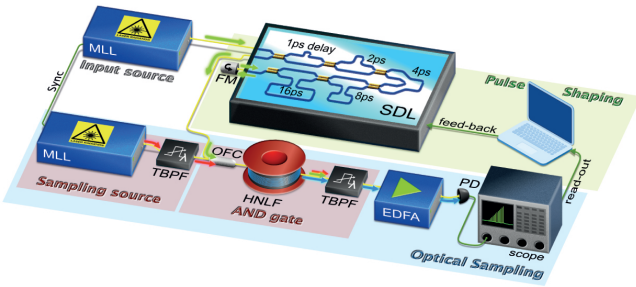


Fig. 2. Experimental setup used for autonomous picosecond pulse shaping.

III. DISCUSSION

More recently, we experimentally implemented a similar approach using (asynchronous) cross-correlated frequency-resolved optical gating (X-FROG) based on sum-frequency generation [8]. Experimental results, shown in Fig.3, illustrate how spectrograms obtained after nonlinear broadening can be

reconfigured to gain complete control for customizing the spectro-temporal properties of the SC, thus yielding optical signals directly relevant for applications such as multiphoton microscopy and spectroscopy [7].

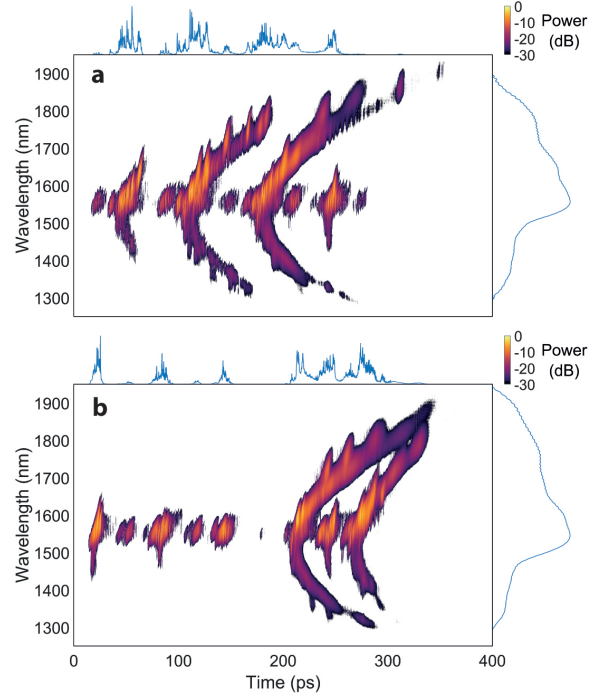


Fig. 3. (a,b) Experimental spectrograms retrieved from X-FROG measurements, illustrating the spectro-temporal reconfigurability of the SC. The different output spectrograms are obtained by adjusting the pulse patterns at the fiber input (via on-chip temporal reshaping).

In this paper, we review these numerical and experimental results while discussing the potential of such processing techniques in the framework of multidimensional wave-packet optimization. We also discuss the viability and the impact of these advanced characterization tools for tailoring pulse propagation dynamics in multimode fibers [9].

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