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Scalable, Autonomous On-Chip Picosecond Pulse-Shaping Enabled by Smart Optimization

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Abstract: We demonstrate a scalable, autonomous on-chip pulse shaping system based on temporal coherence synthesis. The inclusion of smart optimization algorithms enables robust, and reconfigurable pulse-shaping over a wide range of input and target durations. © 2021 The Author(s)

1. Introduction

The use of machine-learning and guided optimization approaches, such as genetic algorithms, with photonic systems is revolutionizing the field, enabling novel device functionalities beyond traditional designs [1]. A key prerequisite towards the successful implementation of such systems lies in overcoming three major challenges: i) the implementation of reconfigurable elements within the optical system; ii) the adoption of efficient learning algorithms with reduced complexity; and iii) the implementation of fast and efficient optical-to-electronic feedback schemes. The majority of implementations thus far rely on the use of relatively slow spatial-light-modulators and electronic polarization controllers as reconfigurable optical elements, as used in e.g., ‘smart lasers’ [2]. In order to advance system compactness, robustness, and speed, photonic integrated circuits (PICs) are an attractive alternative for achieving peak performance in a compact and mass-producible platform. Recently, PICs have enabled reconfigurable ‘smart’ devices, such as photonic field programmable gate arrays [3], intelligent telecommunications processors [4], and widely tailorable nonlinear broadband light sources [5].

An unexplored area for this technology is optical pulse-shaping, especially in the picosecond domain (∼1-100 ps), which is of great relevance for controlling nonlinear dynamics [6] and for information encoding in telecommunications [7]. However, to date, the narrow linewidth of sub-nanosecond sources has inhibited any demonstration of an efficient and adaptable scheme, which combines user-friendly, reconfigurable picosecond pulse-shaping with an efficient monitoring solution for on-the-fly flexibility and scalability.

In our work [8], we demonstrate that the combination of integrated photonic platforms, all-optical sampling, and smart-optimization algorithms allows for the robust generation and control of user-defined waveforms, based on temporal coherence synthesis. We further demonstrate the scalability of the approach, covering the picosecond range from 3 ps to over 150 ps, and compare the impact of different optimization algorithms on performance.

2. Results and Discussion

In our implementation, the chip is based on a silicon-oxy-nitride glass that offers exceptionally low linear and nonlinear losses, and is coupled to standard single-mode fibers for ease of use [5, 8]. The platform consists of an on-chip chain of interferometers with bit-wise increasing delays with a resolution of 1 ps. The concept of the temporal coherence synthesis and the experimental implementation is illustrated in Fig.1ab.

An incoming Gaussian pulse (≈20 ps duration) is split with a given amplitude ratio at the first electrically tunable coupler and one part of the pulse is delayed while the other part travels a fixed delay. Subsequently, the split pulse is coherently re-combined at the next coupler, and may split again to undergo a different delay. At the end of the interferometer chain, the new waveform is obtained as a result of a chosen selection of amplitude ratios. The second major part of the setup consists of an all-optical sampling scheme [9]. In particular, we exploited degenerate four-wave mixing a highly-nonlinear fiber as an optical AND-gate, which only generates an idler signal when the stronger pump (i.e., the shaped signal) and a seed (i.e., the sampling source, here a spectrally-filtered frequency comb, ≈4.4 ps duration) overlaps in time. Owing to a slight desynchronization of the repetition rates of both lasers, the generated idler is passively scanning across the shaped pulse over multiple repetitions (∼kHz rate) and can thus be detected using low-bandwidth detection equipment. Finally, a software-based algorithm evaluates the detected sampling signal, retrieves the signal envelope and calculates the deviation between the targeted and the detected waveforms (using cosine similarity as a metric). A particle swarm optimization algorithm is used to
mediate the update of the individual amplitude ratios of the on-chip interferometers to minimize this deviation. Figure 1c-d show the results of our autonomous pulse-shaper. In all cases, we limited the available delays to five (1 ps to 16 ps). The experimental results of the platform are depicted in Fig. 1c-d for a positive sawtooth and a flattop pulse. In our approach, we optimized the waveform for the best target coverage, regardless of the achieved full-width at half maximum (FWHM), i.e., the best overlap between target and returned waveform. As a result, the returned waveforms feature a FWHM of 39.1 ps and 53.6 ps for the sawtooth and flattop, respectively. Fig. 1e illustrates the scalability of our approach. In detail, we simulated the pulse-shaping for three different input pulse durations (3 ps, 20 ps, 50 ps), optimized for 30 random target FWHMs within a given range, and evaluated the returned FWHMs to assess the performance. The sawtooth deviates more from the ideal performance (slope = 1) as the target width increases. One reason for this behavior is the modulation of the waveform that arises from the lack of phase control for each delay as well as the delay configuration of the chip. The flattop pulse, on the other hand, shows a better behavior compared to the sawtooth. The reason for the increased performance is partly due to the evaluation criteria, where the FWHM in most cases shows very good overlap, while key features (i.e., the flatness of the top part) deteriorate for larger target widths (i.e., returning super gaussians rather than flattops).

3. Conclusion

In conclusion, we have demonstrated a novel approach for on-chip pulse shaping, which benefits from a straightforward, low-bandwidth optical readout, and smart-optimization algorithms to generate a reconfigurable and scalable waveform output.

References