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Methods and Applications for Amplified Bursts of Picosecond-Spaced Ultrashort Pulses

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Abstract: Generating packages of picosecond-spaced ultrashort pulses yields various advantages in their application in nonlinear spectroscopy, micromachining, and plasma generation. We outline methods of burst amplification, with a focus on recent advancements in the generation and application of amplified pulse bursts.

1. Introduction

The field of ultrashort pulse shaping expands the challenge to generate an isolated single pulse to also control its spatial properties, temporal waveform, or spectrum in various forms. One particular task is the generation of a finite number of equidistant ultrashort pulses, called finite pulse train or burst, that is especially for picosecond (ps) interpulse spacings and strongly amplified energies a non-trivial task. Such a pulse format shows interesting properties, including the formation of only a few spectral intensity peaks formed by interference, or the preservation of a high temporal peak intensity while keeping the energy of the whole waveform constant. In such a case, it combines the best of both worlds of long nanosecond pulses with narrow spectral bandwidth and ultrashort, highly intense femtosecond pulses that are broadband. In contrast to continuous pulse trains, such as frequency combs, it allows amplifying a finite number of pulses to millijoule (mJ) energies. In this contribution, we will give an overview of this topic with a focus on recent advances in burst-mode chirped-pulse amplification (CPA), as it was developed in the previous years in our group to a mature technological state.

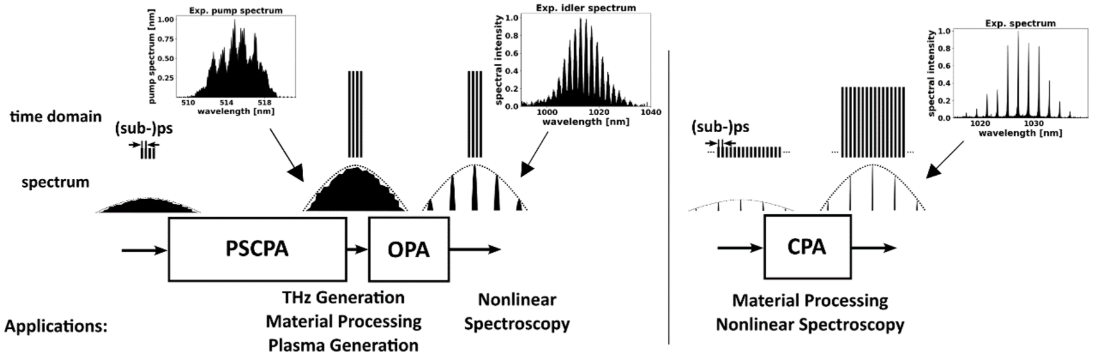

Fig. 1. CPA of ps-spaced burst pulses in two regimes. Left: Low pulse number (less than a few dozens of pulses). PSCPA is required to suppress spectral peaks. Subsequently, the spectral peaks are recovered in an OPA. Right: High pulse number (more than a few dozen pulses) and CPA works comparable as with a single pulse. Experimental spectra are shown as inlay (250 fs pulse durations. Left: 6 pulses, ≤ 2 ps spacing, 140 µJ pump burst energy, few µJ idler burst energy; Right: 40 pulses, 1.8 ps spacing, 10 µJ burst energy)

2. Technological overview

The most prominent techniques to generate a burst with ps interpulse spacings are: Applying spectral filters directly in the seed-pulse generating mode-locked oscillator [1], splitting an isolated pulse into multiple copies with a spectral pulse shaper [2], applying an interferometer for pulse splitting and recombination [3], stacking the pulses with a constant spacing in a controlled time-delay loop (Vernier effect) [4,5], or any combination of these techniques [6]. However, for systems providing mJ energies or higher, the burst formation needs to be done prior to amplification, because otherwise, only interferometric burst generation of an amplified pulse is available due to the damage thresholds of pulse shapers, being only useful for a very low number of pulses. Previously, we discovered that the CPA of ps-spaced burst pulses is governed by two separate pulse regimes [7] (See Fig. 1), which are low- and high-pulse numbers (low-/high-N). In the low-N regime, the overlapping of the chirped burst pulses is sufficient to build up temporal interference spikes given the fact that the pulses have a constant pulse-to-pulse phase slip. This requires individual burst-pulse phase modulation to form a quasi-continuous burst spectrum [5] (Phase-Scrambled CPA, PSCPA), and subsequent phase demodulation in case of applications where the spectral peaks need to be recovered after amplification [8]. The high-N regime, however, shows that the CPA approach is recovered by temporal smearing of the intensity spikes in the chirped waveform because the chirped burst becomes sufficiently long due to the high pulse number.

3. Applications

In the low-N regime, mJ bursts need to be amplified by PSCPA and can, in the near-infrared, be directly used as drivers for the generation of THz radiation [5], as a high repetition rate source for micromachining [9], or plasma generation [10]. These are applications, where the waveform envelope is of primary interest, and thus, phase-scrambled pulses are an acceptable format. Even though the pulse spacing is only slightly larger than the individual burst pulse duration, the pulses act individually in various nonlinear processes, such as sum-frequency generation (SFG), difference-frequency generation (DFG) or white-light generation (WLG). Thus, burst CPA systems can also be used as drivers for optical-parametric amplifier (OPA) systems. This includes applying passive carrier-envelope phase (CEP) stable OPAs, where the CEP of the idler is set to a constant value for all pulses within the burst and spectral peaks are recovered [8]. Thus, it is possible to achieve versatile frequency ranges by frequency conversion due to high individual pulse intensities in the low-N regime. In the high-N regime, the burst is highly useful for nonlinear spectroscopy, such as Stimulated Raman Spectroscopy (SRS) [11] or Resonantly Enhanced Multi-Photon Ionization (REMPI) [12], due to its narrow spectral lines. We give an overview of applications of ps-spaced burst pulses performed over the past years, and on ongoing efforts, such as an increased capability of bursts in plasma generation (See Fig. 2), and an improved performance in SRS where theoretical investigations were performed [11] that are currently translated into experimental works.

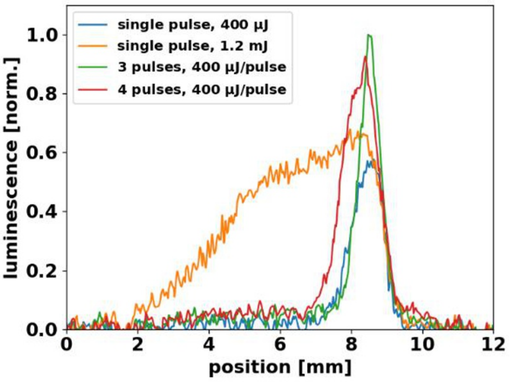

Fig.2. Luminescence curves of recorded plasma distributions for a single pulse (blue: 0.4 mJ, orange: 1.2 mJ) and for a burst of 3 pulses (green) and 4 pulses (red) with 0.4 mJ per pulse.

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