Fiber-Slab-Pumped OPCPA for XUV-Based Time-Resolved Photoelectron Spectroscopy at 500 kHz Repetition Rate

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Abstract: A passive optically-synchronized OPCPA based on a combination of fiber and slab pump lasers is presented. We demonstrate 30 µJ, sub-20 fs, 780 nm pulses at 500 kHz repetition rate, suitable for high harmonic generation.

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1. Introduction

Time- and angle-resolved photoelectron spectroscopy (trARPES) is a powerful tool to probe photo-induced processes and excited state dynamics at solid surfaces in the femtosecond range. Up to now, there have been two complementary approaches distinguished by the employed probe laser pulses: UV sources with 100s of kHz repetition rate provide sufficient counting statistics to allow for the investigation of transiently populated states [1], whereas high harmonic generation (HHG) based XUV sources provide spectroscopic access to the electronic structure in the full Brillouin zone but at limited repetition rate of up to 10 kHz [2]. We aim at bridging this technology gap by developing an efficient femtosecond XUV source with 500 kHz repetition rate.

The key component of this approach is an optical parametric chirped-pulse amplifier (OPCPA) providing tunable visible to the near-infrared ultra-short pulses. We report on hybrid fiber-slab Ytterbium-based laser system and a two-stage OPCPA providing 30 µJ pulses with sub-20 fs duration suitable for HHG at 500 kHz repetition rate.

2. Fiber oscillator and hybrid fiber- slab amplifier

A combination of fiber master oscillator and fiber-slab power amplifier system provides both pump and seed for the OPCPA (Fig. 1). A 25 MHz mode-locked Ytterbium fiber oscillator working in all normal dispersive regime [3] provides a spectral bandwidth of 10 nm full width half maximum (FWHM) at a central wavelength of 1030 nm.

The stretched output of the oscillator is coupled into a dual-stage fiber preamplifier including a fiber-coupled acousto-optical modulator for reducing the repetition rate to the range between 300 kHz and 1 MHz. These pulses are further amplified in an 80 cm long rod-type photonic crystal fiber (NKT, DC 285/100 PM-Yb-ROD) to more than 9 W average power. The system is typically operated at a repetition rate of 500 kHz. 65 % of the output is compressed to ~360 fs pulse duration and used for the first stage of the OPCPA.

The remaining output directly seeds a commercial Yb:YAG SLAB amplifier (Amphos 200). A seed power of 3.6 W is sufficient to reach saturated output exceeding 200 W average power. The gain-narrowed spectrum centered at 1030 nm output was compressed to ~1.25 ps pulse duration by a transmission grating compressor with 75 % efficiency.

3. OPCPA results and discussion

20 % of the compressed output of the fiber amplifier is used to generate a white light (WL) continuum in a 3 mm thick YAG crystal: the resulting 3.25 nJ pulses in the spectral range 540 nm–920 nm (-3 dBc) seed the OPCPA. The remaining output from the fiber amplifier compressor is frequency doubled in a 1 mm thick BBO crystal and used as a pump for the first OPCPA stage. The seed and the pump beams are overlapped non-collinearly in a 3 mm thick BBO crystal (θ=24.3°, internal angle 2.4°, Type I). An additional 6 mm thick fused silica (FS) stretches the WL to achieve a spectral bandwidth of 100 nm FWHM when the amplification is tuned at a central wavelength of 780 nm.

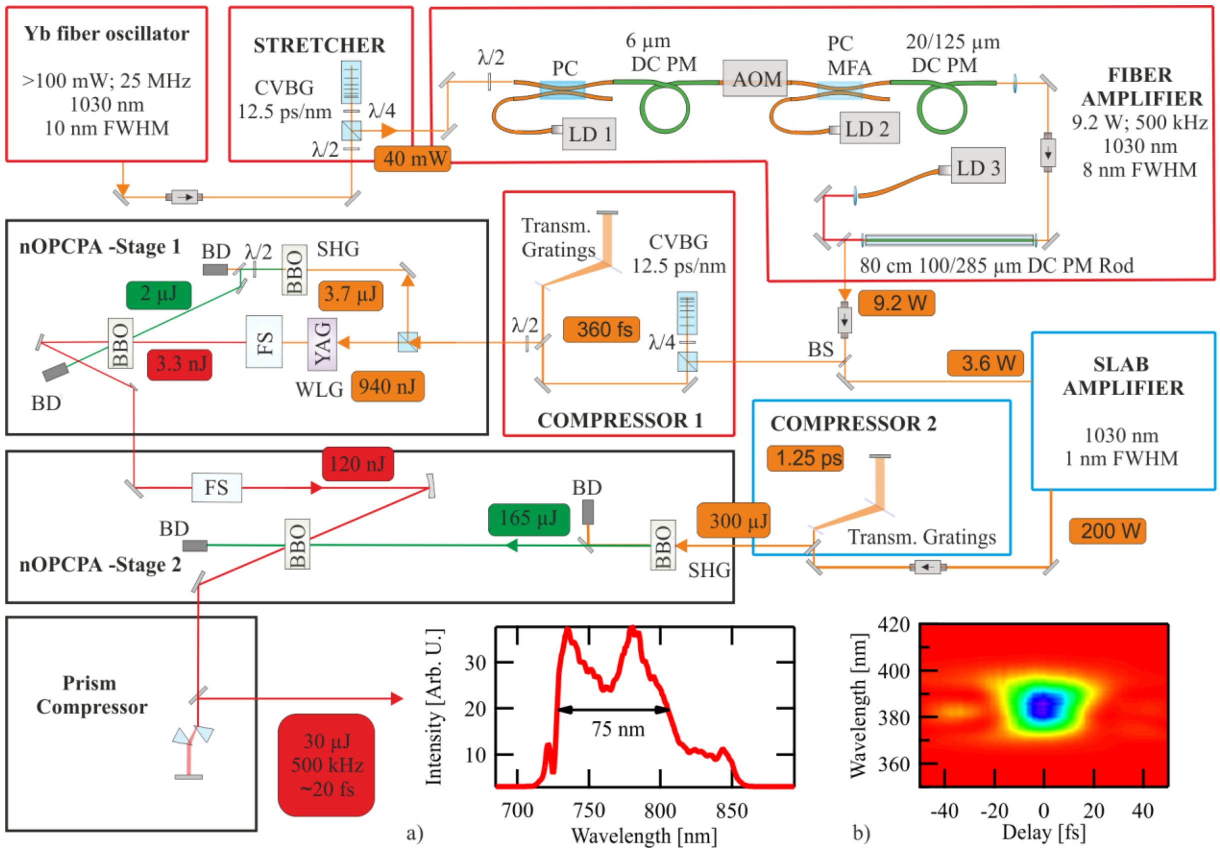

Fig. 1: OPCPA scheme. CVBG Chirped Volume Bragg Grating; LD laser diode; PC pump combiner; MFA mode field adapter; DC PM Double clad polarization maintaining; SHG second harmonic generation; WLG white light generation; FS fused silica. Insets a) Spectrum after the prism compressor b) SHG FROG for the given spectrum

An 82.5 W average power pump for the second OPCPA stage is generated by frequency doubling the slab amplifier output in a 2 mm thick BBO crystal. The 60 mW signal from the first stage is stretched by 60 mm FS and its mode size is matched to the 560 μm diameter pump spot: a 3 mm thick second stage BBO crystal (θ=24.3°, internal angle 2.4°, Type I) allows for amplification to 21 W average power. The parasitic second harmonic generation for the signal is below 400 mW and an upper boundary for amplified parametric superfluorescence of 560 mW is measured by blocking the WL seed in the first OPCPA stage.

The pulses are de-chirped in a Brewster cut fused silica prism compressor and characterized by SHG FROG: an 18 fs FWHM temporal envelope is reconstructed, starting from a measured 75 nm FWHM spectrum. We obtain a compressed power of 15 W with a pulse to pulse energy stability of 1.6 %. The white light seed pulses and the pump pulses amplified in the slab follow an optical path length of less than 10 m before interacting in the second OPCPA stage: the drift of the central wavelength is below 0.15 % over 1 hour without any active stabilization.

This novel light source is well suited for HHG in noble gases [3]. The OPCPA concept provides tunability in both central wavelength and spectral width of the output. As the energy resolution in trARPES is dictated by the spectral width of the XUV probe pulses, our approach will allow for optimization of the experimental energy and time resolution and represents a very attractive light source for HHG-based spectroscopies at high repetition rates.

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