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High-Energy Solitonic Source of High Harmonics

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Abstract: We report on high harmonics generation in zinc oxide thin-films driven by an all-solid fiber-based architecture. The laser delivers 41 nJ 70 fs solitonic pulses at 1764 nm and drives harmonics generation up to H7. © 2022 The Authors

1. Introduction

High-harmonics generation (HHG) in solid targets [1] such as small bandgap semiconductors (e.g. Si, ZnO) require high-energy few-cycle laser drivers at near- to mid-infrared wavelengths to avoid multiphoton absorption. High peak power and excellent beam quality are required to reach fluences of $\sim 10^{12}$ W/cm². An all-fiber architecture free from e.g. bulk compressor is interesting to optimize the quality of the output beam and ruggedize the whole system. Along this line, solitonic effects exacerbated in large mode area (LMA) silica-core singlemode fibers were already used to produce ultrashort (70 fs) pulses at remote wavelengths with tens of nJ energy from picosecond pulses in the telecom band [2,3], providing a new platform for driving HHG in solids. HHG was demonstrated already from fiber lasers albeit with a limited level of energy (~ 10 nJ) [4,5]. In this communication, we explore the potential of such soliton-based fiber driver for HHG in thin-films of zinc oxide. Using the same soliton-based driver, we propose an all-solid fiber architecture producing 1.4 MW peak power 20 fs pulses out of a standard telecom singlemode fiber by soliton self-compression, likely to enhance HHG.

2. High-harmonics generation in ZnO thin films

The proposed architecture is schematically depicted in Fig. 1a.

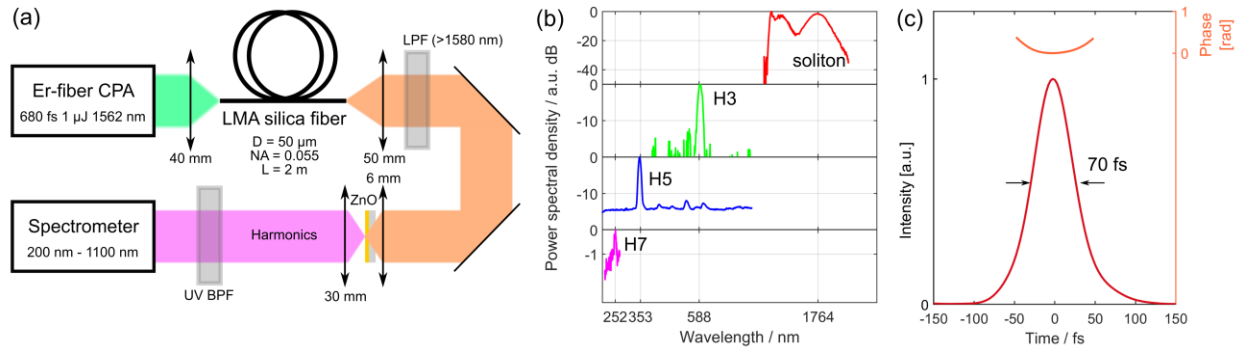


Fig. 1. (a) Schematic of the laser set-up. LPF: long-pass filter. BPF: band-pass filter. (b) Spectra of the solitonic pump and harmonics 3 to 7. (c) Temporal intensity and phase profiles of the solitonic pulse.

The front-end is composed of a chirped-pulse amplifier system delivering μ J energy 680 fs pulses at 1562 nm at 1 MHz repetition rate. It is followed by a 2 m long piece of large mode area silica fiber (core diameter $D = 50$ μ m, numerical aperture $NA = 0.055$) where the interplay between the anomalous dispersion and Kerr nonlinearity leads to multi-solitonic compression and fission followed by soliton self-frequency shift via intrapulse stimulated Raman scattering. The ejected solitonic pulse is centered at 1764 nm. The residual pump around 1562 nm is then filtered out by means of a long-pass filter at 1580 nm. The spectrum measured after the filter is shown in Fig. 1b (top). We measured an average power after the filter of 50 mW. Careful evaluation of the fraction of power contained in the soliton around 1764 nm indicated that the pulse carries an energy of 41 nJ. We have characterized the soliton by second-harmonic generation frequency-resolved optical gating (SHG-FROG) and displayed the temporal profile of the pulse in Fig. 1c. The full width at half maximum (FWHM) of the pulse is 70 fs, corresponding to 0.52 MW peak

power. The beam was then focused into thin-films of ZnO deposited by magnetron sputtering onto a silica substrate. The films are 400 nm in thickness. High harmonics generation was observed by focusing the pulses by means of a 6 mm focal length lens, corresponding to a beam waist at $1/e^2$ of 4.6 μm . The intensity onto the thin-film was evaluated to 3×10^{12} W/cm². As shown in Fig. 1b, we observed H3 and H5, while H7 was barely seen with our collection optics.

3. Post-compression

Since HHG depends on the instantaneous power of the driver, we studied the possibility to further compress the soliton. The radiation was then launched into a standard singlemode fiber for telecom applications ($D = 8 \mu\text{m}$, $NA = 0.12$). Numerical simulations show that multisolitonic self-compression occurs for centimeter-long piece of fiber for 0.5 MW peak power. The set-up used for post-compression is shown in Fig. 2a. We have tested several fiber lengths between 1.3 cm and 4 cm. Results obtained for 1.5 cm are shown in Fig. 2b. The FWHM of the spectrum is 400 nm. The reconstructed temporal profile confirms that the pulse is compressed down to 20 fs. The average power measured after the long-pass filter is 32 mW, indicating that the peak power reached 1.4 MW assuming a sech²-shaped pulse. For the moment, such compressed pulse did not allow us to observe harmonics beyond H3, likely due to un-optimized all-reflective focusing optics.

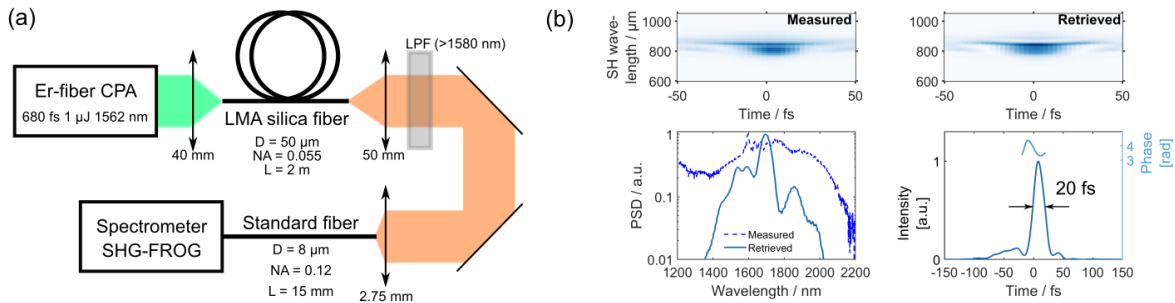


Fig. 2. (a) Schematic of the set-up used for post-compression. (b) Results of SHG-FROG characterization of the compressed pulse: measured (top left) and retrieved (top right) FROG traces. Spectra (bottom left) and temporal intensity and phase profiles (bottom right).

4. References

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