Dispersion-scan Measurements of the Multiplate Continuum Process

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Abstract: Multiplate continuum (MPC) is a recent supercontinuum generation technique for spectral broadening of ultrashort laser pulses. In this work, we report the first direct temporal characterization of ultrashort laser pulses generated by the MPC process, without any further pulse manipulation apart from dispersion compensation, using the dispersion scan technique.

1 INTRODUCTION

The first reports on large spectral broadening of picosecond laser pulses - supercontinuum generation - were done in the 1970s (Alfano, 2013). This nonlinear optical phenomenon occurs in solids (bulk media, optical fibers, photonics crystal fibers), liquids and gases. It has major applications in ultrashort pulse compression, ultrafast laser spectroscopy (Lindfors et al., 2004), optical coherence tomography (Humbert et al., 2006), telecommunications (Takara et al., 2005), and application in carrier-envelope phase stabilization of mode-locked lasers (Dudley J.M., 2010).

Supercontinuum generation in bulk media has several practical advantages, but suffers from a major drawback, i.e., it cannot be used with high peak power pulses; the lower damage threshold in solids render them unattractive for high power applications. While the generation of supercontinuum in solids is readily available for peak powers of MW (Silva et al., 2012), no other method for the generation of high power supercontinuum in solids was available until the introduction of the multiplate continuum (MPC), which uses a set of thin slides of glass (e.g. fused silica). This enables spectral broadening in each plate, while avoiding damage to the medium due to self-focusing (Lu et al., 2014).

The dispersion-scan (d-scan) technique (Miranda et al., 2012) is a recent but well-established method for the measurement of ultrashort laser pulses. It relies on the manipulation of the total dispersion incurred by the pulse while traveling through a standard pulse compressor setup comprised of dispersion compensation mirrors (DCMs) and a pair of glass wedges. The amount of glass traversed by the pulse is an independent variable that can be controlled with the simple insertion of one of the wedges. While the DCMs impart negative dispersion, the variable positive dispersion introduced by the wedges will vary the total dispersion of the pulse to be measured. In the case of the second-harmonic variant of the d-scan (SHG d-scan), the measurement of the second-harmonic signal after the compressor results in a two-dimensional trace of the SHG spectrum versus glass insertion. With the measured trace, together with the linear spectrum of the light source, it is possible to retrieve the spectral phase of the pulse under test through a mathematical optimization algorithm, and thus, reconstruct its full temporal profile.

2 EXPERIMENTAL SETUP

Our laser system is composed of a Ti:Sapphire chirped pulse amplifier (Femtolasers FemtoPower Compact Pro CEP) seeded by pulses from a few-cycle, prismless Ti:Sa oscillator (Femtolasers Rainbow), with 0.8 mJ of pulse energy in sub-30-fs pulses at an repetition rate of 1 kHz. Only a fraction of this output power will be used for the present experiment. The experimental setup (Figure 1) comprises two main parts: the spectral broadening process, i.e., the MPC, and the ultrafast pulse measurement part, the d-scan. The MPC part begins with a f=1 m lens

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that focuses our input beam onto a stack of six unevenly spaced, thin (100 μm) slides of fused silica placed at Brewster's angle. The uneven spacing is motivated by simulations (Cheng et al., 2016), as well as by the criterion of obtaining the broadest spectrum as we place each individual slide in the setup while minimizing spatial wavefront distortions due to self-focusing. Both factors show that the spacing between successive slides gets shorter. The long focal length of the lens gives us a wide Rayleigh range that fully envelopes the slide stack, ensuring that the electric field strength is high enough to induce spectral broadening. The emerging beam, with its successively broadened spectrum is then collimated by a concave mirror and directed to a pair of dispersion compensation mirrors (DCMs) which impart negative dispersion to the pulse. We record the second-harmonic signal generated by a 5 μm thick nonlinear BBO crystal cut for type-I SHG as a function of wedge insertion, hence obtaining the d-scan trace of the pulses shown in Figure 2. The simplicity and performance of the d-scan setup was one of the deciding factors on the choice of this measurement method, compared with other conventional techniques like SPIDER (Anderson et al., 2008) and FROG (Trebino et al., 1997). Another convenient factor is the fact that after making the sweep and obtaining the d-scan trace we can immediately set the necessary amount of glass insertion, so that the pulse at the exit of the wedges is as compressed as possible for the given setup.

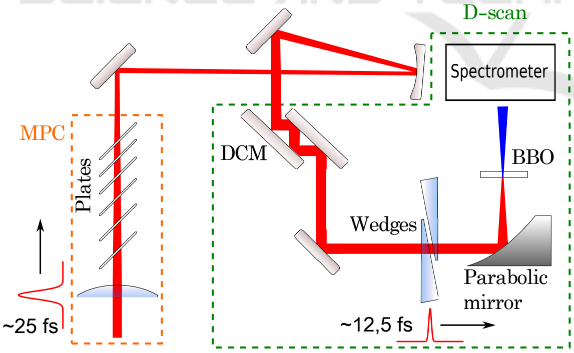

Figure 1: Experimental setup of the MPC and the d-scan.

3 RESULTS

As mentioned previously, the d-scan trace is a two-dimensional plot of the second harmonic spectrum as a function of glass insertion. As the total spectral phase of the pulse under test changes from negative to positive, it passes through a point where the pulse is well compressed, i.e, the second-harmonic signal achieves a maximum. This position is relabeled as the point of zero insertion, as shown in Figure 2, which contains the measured and numerically retrieved d-scan traces.

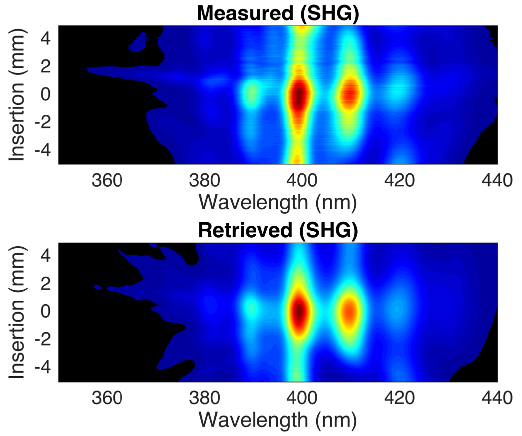

Figure 2: Measured and retrieved d-scan traces.

Even though the measured trace has a complex structure, we were able to get a retrieved trace that closely resembles the measured one, i.e., it is able to reproduce the main features of the measured trace.

The spectrum and retrieved spectral phase of the MPC pulse is shown in Figure 3.

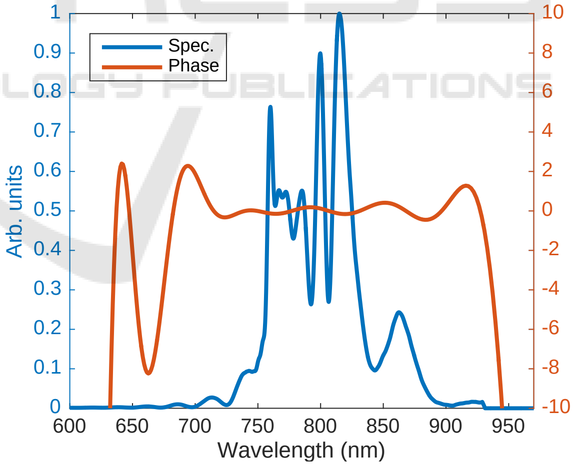

Figure 3: Spectrum and spectral phase of the measured pulse.

Although the broadest high power supercontinuum is currently generated in gas-filled hollow fiber compressors, e.g. (Silva et al., 2014; Böhle et al., 2014), the supercontinuum generated by MPC is still significant.

The measured linear spectrum and the retrieved spectral phase gives us full information to completely reconstruct the temporal profile of the pulse under test, as shown in Figure 4.

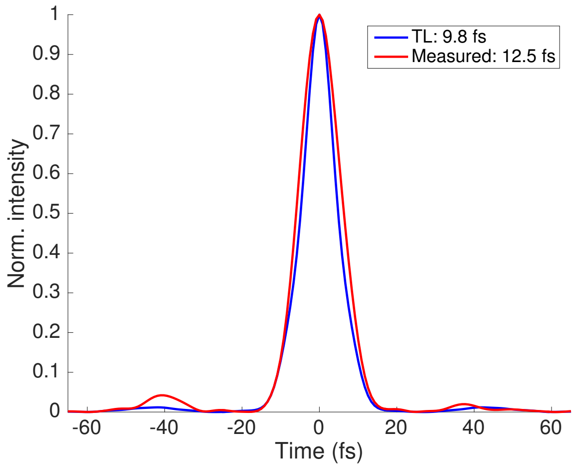

Figure 4: Retrieved pulse and transform-limited pulse.

We see that the retrieved pulse has twice the duration compared with the transform-limited (TL) pulse (ie., a pulse with same spectrum but with a flat spectral phase).

The pulses generated by MPC are longer than the pulses generated in a hollow-core fiber (Silva et al., 2014) by a factor of 3, but nonetheless this kind of setup has its own advantages, such as compactness (it occupies a small space), simplicity (can be implemented with off-the-shelf optical components), robustness (less dependent on alignment, whereas hollow-core fibers setups normally require feedback loops to keep a good alignment for a long period of time), high efficiency, and does not involve the handling of gases within a vaccuum system.

The output power of the MPC process is roughly 50 % of the 140 mW of input average power. The output beam profile is shown in Figure 5; it is homogeneous and most of the power is concentrated in the central part. Hence, the central part was spatially filtered by an iris (not shown in Figure 1) before being directed to the measurement setup (d-scan).

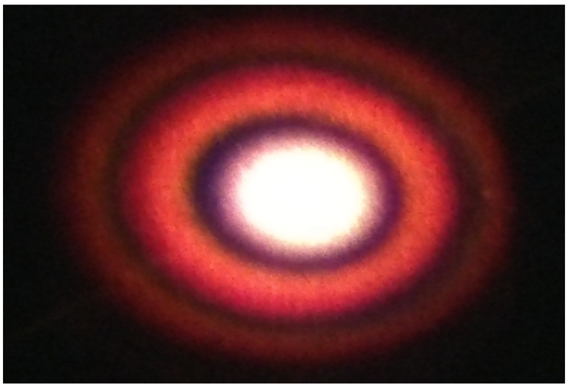

Figure 5: Spatial mode.

4 CONCLUSIONS

We successfully compressed and measured ultrashort laser pulses using the multiplate and dispersion-scan techniques. We were able to generate a broad spectrum capable of supporting transform-limited pulses down to 9.8 fs from a high peak power laser, which suggests that the output pulse can be further shortened if additional phase control or pulse shaping is used. The spatial mode is homogeneous and stable, and the MPC process has a good efficiency compared to traditional hollow-fiber compression setups. The compactness and simplicity of the setup makes the MPC a good candidate/alternative for application in high-harmonic generation (HHG), as was demonstrated recently (Huang et al., 2016).

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