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PRELIMINARY RESULTS USING AN ACOUSTO-OPTIC DISPERSIVE FILTER FOR LASER PULSE SHAPING

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Abstract

In this note we summarize the preliminary results obtained using an acousto-optic crystal (DAZZLER by FASTLITE [1,2]) for the generation of ps-long laser pulses with flat-top time profile. The target was actually a 10 ps FWHM flat top pulse, which is predicted to be the optimum profile for emittance compensation in S-band advanced photoinjectors such as SPARC. This application requires also very short rise and fall times (defined as 10 to 90% of the maximum of intensity), definitely shorter than 1 ps. The development of a numerical code to simulate the effects of spectral amplitude and phase manipulation was carried out as prerequisite to conduct the experiment.

1 INTRODUCTION

According to simulations, the flat top pulse can be obtained starting from a gaussian or a hyperbolic secant intensity profile, as far as a spectral modulation is applied to both amplitude and phase of the pulse. The simulations showed that the required pulse should have a supergaussian spectral amplitude and a S-like group velocity. The group velocity is defined as the derivative of the spectral phase with respect to the frequency. Figure 1 shows the amplitude modulation (red curve) and group velocity delay (black line) obtained by numerical simulations in a typical case. The group delay was calculated as a polynomial Taylor expansion around the central wavelength of the laser pulse at 790 nm. The dashed blue line is the measured input spectrum of the DAZZLER, while the solid line is the theoretical supergaussian output spectrum.

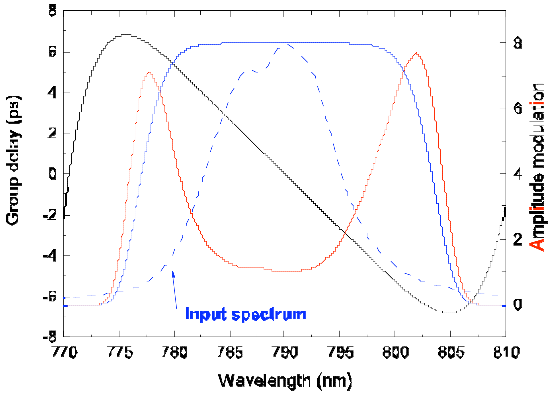

FIG. 1: Input spectrum (dashed blue curve) and theoretical output supergaussian spectrum (solid blue line). The theoretical DAZZLER amplitude and group velocity dispersion modulation are also plotted (red and black curves).

Figure 2 shows the calculated time intensity output using the modulation reported in figure 1.

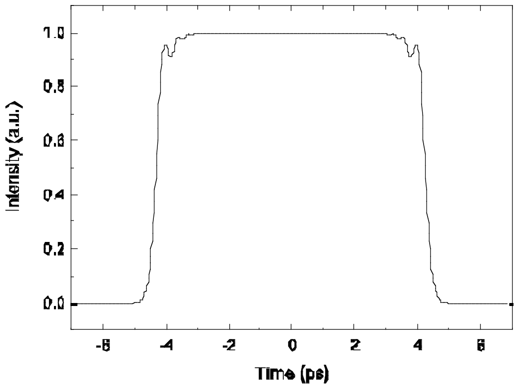

FIG. 2: Calculated pulse shape imposing the modulations shown in figure 1.

2 EXPERIMENTAL SETUP

The sketch of the experimental setup is reported in figure 3. The amplified Ti:Sapphire laser system delivered 20 fs FHWM, 500 mJ pulses at 1 kHz repetition rate with the central wavelength at 800 nm, in horizontal linear polarization. A small fraction of the laser beam (20 mJ) was sent to the experimental setup; here the beam was divided in two arms by a 50% beam splitter. In the SPARC laser system the pulse shaping device will be placed after the laser oscillator where the energy per pulse is in order of tens of nJ. The lower level of energy should not have influence on the DAZZLER operation.

In the first arm the beam was sent through a 10-nm band pass spectral filter, to obtain 100 fs FWHM pulses, and then through the DAZZLER crystal. The band pass filter was used to create a spectrum similar to the one expected by the SPARC laser system under development. The laser pulse went through the acousto-optics filter two times. In fact the acoustic-optics crystal can introduce a stretching up to 6 ps in a single passing. This limitation is due to the finite length of the crystal.

The second pulse (gate pulse) was sent to a delay line controlled by a 100 nm linear resolution stepper motor. For the measurement the shaped pulse and the gate signal overlapped in a non linear BBO crystal. The emerging double frequency pulse was proportional to the cross-correlation of the two pulses, and was measured by a photodiode. The measurement was based on the lock-in technique using a chopper for the shaped pulse. A computer was used to acquire the intensity profile as a function of the delay. The cross-correlation corresponded in our case to the temporal intensity measurement of the shaped pulses, because the gate pulse was much shorter than the DAZZLER pulse. The resolution was about the duration of the gate optical signal (20 fs).

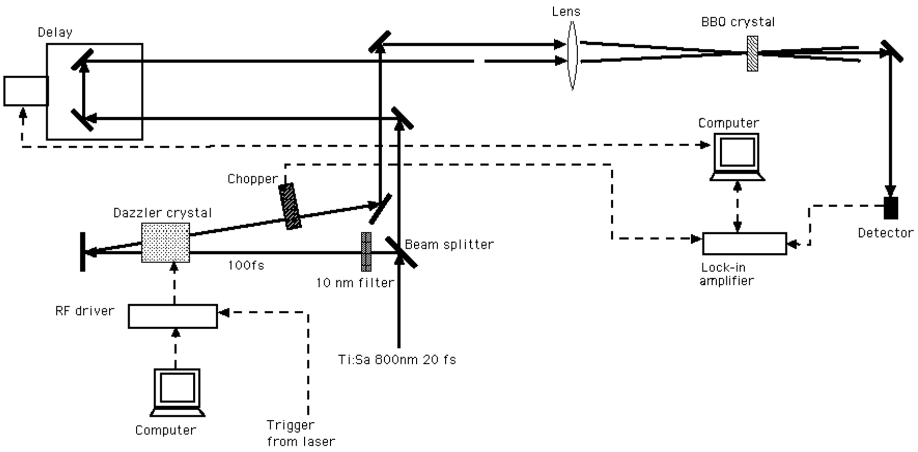

FIG .3: Sketch of the experimental setup

The RF generator driving the DAZZLER was controlled by a computer and could produce an arbitrary acoustic waveform inside the DAZZLER crystal. The DAZZLER control software provided the synchronization between the acoustic and the optical signals using the trigger signal from the laser system. The amplitude and phase modulation could be either imposed by the control software developed by FASTLITE or calculated by an external software or both. The default DAZZLER control software allows to introduce a Gaussian spectral modulation and to suppress some spectral components by introducing a valley in the spectrum. The phase modulation could be entered as a polynomial expansion up to the 4th order.

We developed a numerical code based on the FFT manipulation, to calculate in real time the optimal amplitude and phase modulation. The real spectrum of the pulse after the interferometric filter was included in the code. The code developed in Labview environment produces a supergaussian amplitude filtering with center, width and order freely tunable. The phase modulation is determined by a Taylor expansion up to 8^{th} order (only even terms). This tool generated an input for the DAZZLER software control. The FASTLITE control software was used for fine adjustments of the pulse shaping.

3 DAZZLER ALIGNMENT

To be sure that the acousto-optic crystal worked properly it was necessary to follow the alignment procedures reported below.

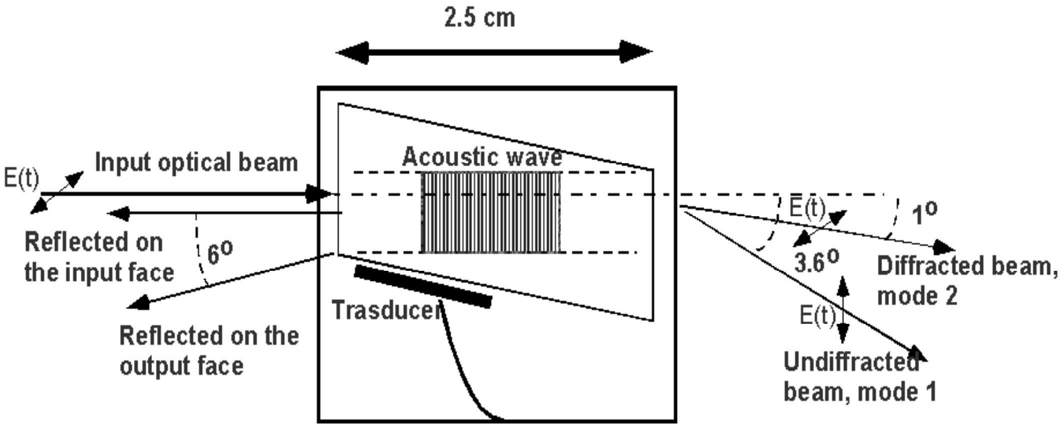

FIG. 4: Conceptual drawing of the DAZZLER crystal and the optical beam in a single passage.

3.1 DAZZLER in single pass configuration

1) For the first step we set an arbitrary group velocity dispersion, while the RF power had to be limited below 50% of its maximum. At the exit of the crystal (see figure 4) two cross polarized signals could be observed at different angles: the diffracted and the direct beam. The beam diffracted by the acoustic wave, the useful one, was sent to a spectrometer.

2) To adjust the filter we imposed a Gaussian spectral amplitude filtering with a valley in the software control panel (we used for instance a valley at 790 nm, with width 2 nm and deep 0.5 of the maximum).

3) At this point it was possible to align the crystal looking at the spectrometer. The right position was reached when the valley in the measured spectrum coincided with the imposed one.

3.2 DAZZLER in double passes configuration

1) To obtain a double passage in the crystal a mirror was mounted very close to the DAZZLER. It is possible to remove the crystal in order to facilitate the positioning of the mirror; the mirror is then adjusted in order to reflect back the beam towards the original propagation direction. It is important to keep the orientation of the DAZZLER crystal in the diffracted beam polarization plane, the vertical one in our case.

2) At the exit there were many beams (reflected on the input face, reflected on the exit face, the beam un-diffracted in the first pass, the diffracted and undiffracted beam on the second pass). As one can deduce by figure 4, the useful beam was very close to the input beam. We observed two beams near the input position, the higher was the useful one.

3) After that we could work on the mirror position to bring the right beam at the same height, at the side of the input. A correct alignment of the beam in the diffraction plane is very important; such operation can be monitored by a spectrometer: in case of misalignment of the second pass, the optical pulse experiences a different acoustic grating profile, so that two valleys appear in the beam spectrum at different optical wavelength.

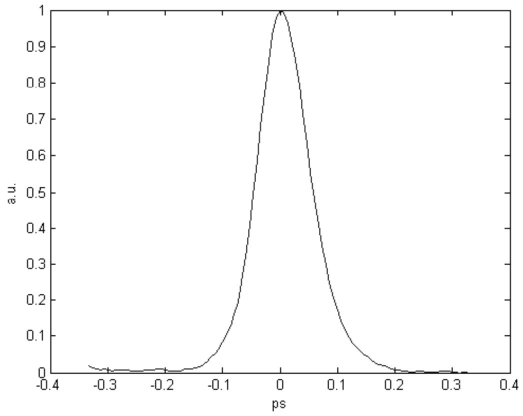

FIG. 5: Cross-correlation measurements imposing only compensation of the intrinsic dispersion of the TeO_2 crystal.

4 CROSS-CORRELATION MEASUREMENTS

Before starting the measurements, the intrinsic dispersion of the crystal had to be compensated. In fact the 2.5 cm TeO_2 crystal has a group velocity dispersion of 12000 fs^2 and a third order dispersion of 8000 fs^3. The cross correlation profile between the DAZZLER pulse and the gate optical signal is reported in figure 5. This profile has been produced by imposing only the compensation of the dispersive effect of the crystal. The duration of the pulse is 100 fs, like the input one. This measurement demonstrated that the crystal dispersion was completely compensated.

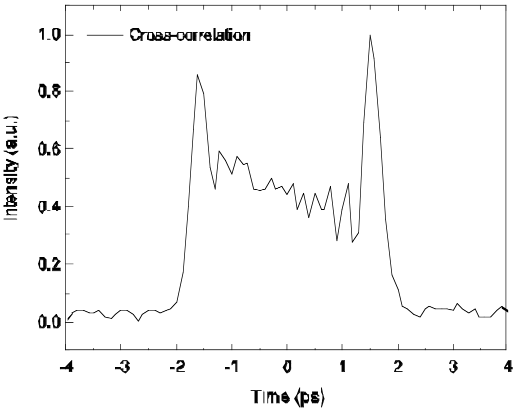

FIG. 6: Cross-correlation measurement of a pulse shaped with only FASTILITE control software.

The measured temporal profile obtained using only the software control by FASTLITE is reported in figure 6. The shaped pulse shows two high overshoots on the rise and fall edges: the pulse displays also a very jagged top. In order to obtain better results we had to use the amplitude and phase modulation generated by an external simulation code. In that way one can impose a more general filtering waveform by applying higher order terms in the phase modulation and a more complex amplitude modulation.

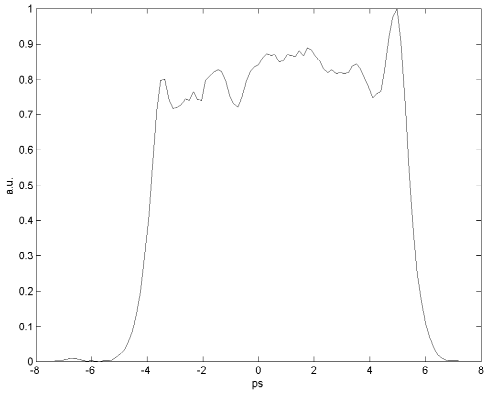

FIG. 7: Cross-correlation measurement of a pulse shaped with FASTLITE control software and external simulation code.

Figure 7 shows the measured pulse with the acoustic wave generated applying our simulation code as well as the FASTLITE control tool. The simulation code was used to calculate the best amplitude and phase modulation. The control software was used to refine the modulation waveform. The result approaches the required time pulse shape for SPARC photoinjector. As shown in the plot, the pulse rise and fall time is less than 0.7 ps and the ripples peak to peak are around 25%. The pulse duration is thereabouts 10 ps FWHM. The overshoot on the right edge come from the not completely optimization of the acoustic wave.

The duration of the pulse could be extended up to 12 ps, that is the theoretical limitation of the crystal in double passage configuration. In this case the pulse ripple was worse and the rise fall edge overshoot were bigger, as shown in figure 8.

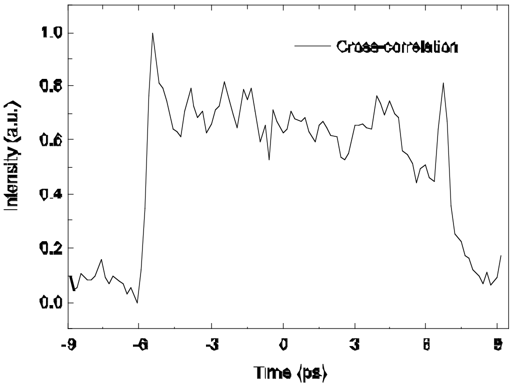

FIG. 8: Cross-correlation measurement of a 12 ps shaped pulse.

5 CONCLUSION

The experiment conducted was conceived as proof of principle of the flat top pulse production by acousto optics crystal.

The preliminary measurements conducted indicate the DAZZLER as a promising technique to produce flat top laser pulses up to 12 ps FWHM in double passage configuration. It is clear that, as the Dazzler is placed ahead of the laser amplifier, the final temporal profile of the pulse on the cathode is determined by the successive processes that the pulse undergoes. The effects of amplification, UV conversion and propagation through the optical transfer line are to be investigated. The flexibility of the DAZZLER device could be used to compensate some of these effects, as gain narrowing in the amplifier. We foresee also to conduct a more systematic set of measurements to test the long-term stability of the shaper.

Better results on the pulse shape can be achieved with a careful control of the acoustic modulation; this task can be accomplished by improving the control code in order to take into account both the real characteristic of the input laser pulse and the real performances of the DAZZLER.

6 REFERENCE

[1] Fastlite Ultrafast Scientific Instrumentation Campus de l'Ecole Polytechnique 91128 Palaseau, France.

[2] F. Verluise and al, Opt. Lett. **25**, 572 (2000).