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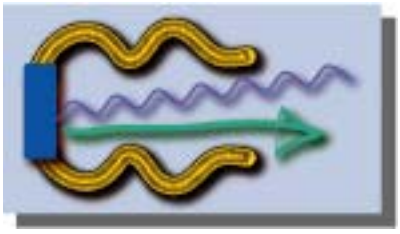

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PRODUCTION OF TEMPORALLY FLAT TOP UV LASER PULSES FOR SPARC PHOTOINJECTOR

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Abstract

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In the SPARC photoinjector, the amplified Ti:Sa laser system is conceived to produce an UV flat top pulse profile required to reduce the beam emittance by minimizing the non-linear space charge effects in the photoelectrons pulse. Beam dynamic simulations indicate that the optimal pulse distribution must be flat top in space and time with 10 ps FWHM duration, 1 ps of rise and fall time and a limited ripple on the plateau. In a previous work [1] it was demonstrated the possibility to use a programmable dispersive acousto-optics (AO) filter to achieve pulse profile close to the optimal one. In this paper we report the characterization of the effects of harmonics conversion on the pulse temporal profile. A technique to overcome the harmonics conversion distortions on the laser pulses at the fundamental wavelength in order to obtain the target pulse profile is explained too. Measurements and simulations in the temporal and spectral domain at the fundamental laser wavelength and at the second and third harmonics are presented in order to validate our work. It is also described a time diagnostic device for the UV pulses.

INTRODUCTION

The SPARC project (Sorgente Pulsata Autoamplificata di Radiazione Coerente) is a $150\ MeV$ advanced photoinjector designed to drive a SASE-FEL in the visible ($\sim 300 - 500\ nm$) [4]. The photoinjector, that is being developed at LNF, is conceived to explore the emittance correction technique and high current production with the preservation of the transverse emittance in order to obtain high brightness electron beam. This is an important requirement for the good development of the SPARC SASE FEL and in particular for its future upgrade to reach the soft x-ray. The accelerator consists of a Ti:Sa laser to illuminate a metal photocathode, an rf-gun and 3 SLAC s-band accelerating sections. As it has been demonstrated [3, 4], the generation of high energy laser pulses with a few picoseconds time width, center wavelength at $266\ nm$, flat top temporal profile with fast rise and fall time, is required to start the photo-emission process from metal cathodes in order to achieve electron bunches characterized by low transverse emittance $\sim 1\ mm{-}mrad$ and high current. In order to manipulate the Gaussian natural shape of the usual laser pulses and transform it into a uniform profile as required by SPARC, the following Ti:Sa laser chain has been chosen [4, 5]. A Ti:Sa oscillator generates $100\ fs$ pulses with a repetition rate (r.r.) of $79.3\ MHz$. An acousto-optic programmable dispersive filter called "DAZZLER" [6], used to modify the spectral amplitude and phase function is placed between the oscillator and the amplifier to obtain the target temporal profile. The amplifier is based on the well known "chirp pulse amplification" (CPA) process [7] and it is composed by a regenerative and a multipass amplifier. It delivers pulses at $\lambda = 800\ nm$ with energy of $\sim 50\ mJ$ and r.r. of $10\ Hz$. The pulses get into the harmonic conversion box (HGCB) where UV pulses with an energy up to $\sim 4\ mJ$ are produced. The HGCB is characterized by two type-I BBO (Beta Barium Borate) crystals of $0.5\ mm$ and $0.3\ mm$ used to produce respectively the second harmonic generation signal (SHG) and the third harmonic generation signal.

At the end of the laser chain there is a grating stretcher used to broaden temporally the pulses up to $(8 - 12)\ ps$. In this paper we present some pulse shape measurements going through the evolution from the fundamental towards the third harmonic generation and we show how to operate to obtain the target pulse shape. At the end we show how the UV pulse shape is retrieved.

PULSE SHAPING

In the previous work [8], we showed that by using the DAZZLER to introduce a proper spectral phase and amplitude modulation in the initial IR pulses, it is possible to manipulate their natural Gaussian shape to obtain the flat top profile with the right features required from SPARC. The obtained pulses profile is no more maintained as soon as the pulses go into the SHG and THG crystals to produce UV light. The reasons for these are fully explained in [9, 10] and briefly reported in the following for the simplest case of Type-I SH generation. In the situation of "non depletion" condition [11] and perfect phase-matching, the SH signal is given by:

$$\tilde{I}_2 \propto sinc^2\left(\beta\omega d\right) d^2 \left|\left[\tilde{A}_1 \otimes \tilde{A}_1\right]\right|^2 \qquad (1)$$

where: β is a factor that takes into account the group velocities of the pulses inside the crystal, d is the crystal length and the dispersion factor is neglected due to the short crystal length ($500\ \mu m$). Being the signal proportional to the convolution product of the power spectrum $\tilde{A}_1(\omega)$, it

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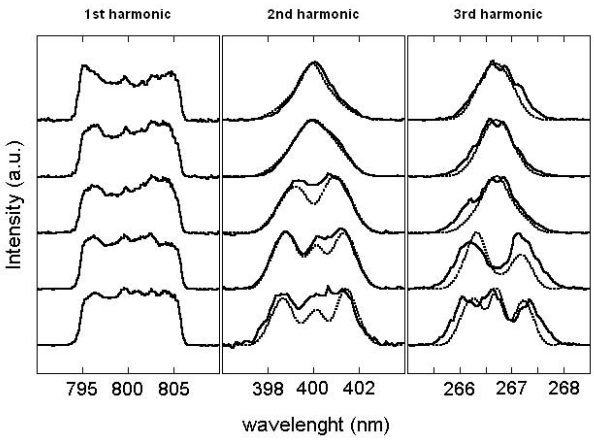

Figure 1: From the left to the right: measured IR, BLUE and UV spectra are reported in solid line; simulated spectra for second and third harmonic, (dashed line) are also shown. The chirp increases from the top to the bottom.

is clear that it is not possible to obtain a SH rectangular spectrum starting by just a first harmonic rectangular one, in fact the convolution product will yield a triangle. On the contrary by introducing a chirp into the fundamental signal, the initial rectangular shape can be preserved. In fact, considering $A_1(\omega) = S(\omega)e^{i\phi(\omega)}$ with $S(\omega)$ real and $\phi(\omega) = \alpha\omega^2/2$, where the α parameter is the chirp strength introduced by the DAZZLER, we obtain:

$$\tilde{A_1} \otimes \tilde{A_1}(\omega) = \int S(\omega-\Omega)S(\Omega)e^{i(\phi(\omega-\Omega)+\phi(\Omega))}d\Omega \quad (2)$$

Since in the phase factor, $\phi(\omega - \Omega) + \phi(\Omega)$ is a parabolic function centered at $\Omega = \omega/2$, the dominant contribution comes for Ω close to $\omega/2$ when enough chirp is applied. Thus we can write:

$$\int S(\omega-\Omega)S(\Omega)e^{i(\phi(\omega-\Omega)+\phi(\Omega))}d\Omega \sim S^2(\omega/2)e^{2i\phi(\omega/2)} \quad (3)$$

Therefore in the fundamental beam, the leading behavior of the SH spectral intensity is given by the square of the fundamental with twice the spectral width and the SH spectrum changes its shape from triangular to rectangular. Moreover, being the SH spectrum proportional to the square of the initial one, the increasing of the ripple in the higher harmonic is explained too. The above considerations can be extended to the third harmonic generation. The results of this discussion is that it is necessary to introduce a large enough chirp factor on the $800nm$ pulse in order to produce a UV rectangular spectrum. The amount of this chirp has to be determined accurately because a large value can reduce too much the conversion efficiency. These considerations are in good agreement with the experimental data reported in Fig. (1).

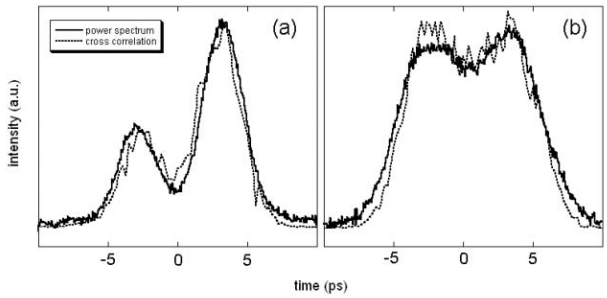

Figure 2: Comparison between the spectral, solid line, and temporal profile, dashed line, in two cases.

SPECTRUM TRANSFERRED IN TIME

In the previous section we demonstrate that by using the Dazzler to introduce proper spectral phase and amplitude modulation in the fundamental beam, it is possible to produce flat top UV spectra. Now we show that it is possible to have the same produced spectra profiles but in the time domain. In this way, once the correct flat top spectrum profile is obtained for the TH signal, the desired temporal shape is almost obtained too [10]. This is achieved by introducing enough temporal linear chirp into the TH signal by sending the pulse trough the UV stretcher. In Fig. (2) two examples are shown: we compare the spectral profile, solid line, and the time profile, dashed line. In both cases we obtained a good superposition between the spectrum and the temporal profile. These two profiles, have been produced by introducing with the Dazzler a proper phase and amplitude modulations in the fundamental. In Fig. (2), the spectral x-axis has been converted in the time coordinate using the relation $\Delta t = a \cdot \Delta\omega$ (in our case $a = 0.3\ ps^2$) between angular frequencies and time delay which is introduced by the stretcher and that will be discussed later on. In these two cases we have a strong pulse stretching, in fact the UV pulse length before the stretcher is about $300\ fs$ while the final pulse length is about $10\ ps$. The temporal profile has been traced by a UV-IR cross correlator that has been built, studied and characterized [12, 13] and briefly described later on. For completeness we report here the relation between the time profile and its spectrum. Let us consider a pulse with complex amplitude $A(\omega)$ and a quadratic phase function given by $\exp[i \cdot a\omega^2/2]$; the a parameter takes into account the chirp introduced by the stretcher. The time intensity profile, given by the square modulus of the inverse Fourier transform, turns out to be:

$$I(t) = \left| \int A(\omega)e^{i(\frac{a\omega^2}{2}-\omega t)}d\omega \right|^2 \sim \mathcal{I}(\omega = t/a) \quad (4)$$

where $\mathcal{I}(\omega) = |A(\omega)|^2$ is the power spectrum. In fact, since the phase function is a parabola centered at $\omega = t/a$, when the stretched pulse has a temporal width much longer than the input one, the leading contribution to the integral

comes from the angular frequencies near the minimum of the phase. Therefore the spectral profile can be used as a time profile diagnostic. Moreover the temporal coordinate can be obtained by the relation $\Delta t = a \cdot \Delta\omega$.

TIME DIAGNOSTIC

To measure the UV time pulse length a cross-correlator device based on the difference frequency generation (DFG) process is made using a BBO crystal by mixing a part of the IR pulses at frequency ω with the UV pulses at frequency 3ω [12, 13]. Since the IR pulses of intensity I_{IR} have a temporal width much shorter $\sim 100 fs$ (thus are called reference pulses) than the UV pulses $\sim 10ps$ of intensity I_{UV}, the signal produced at frequency $3\omega - \omega$ is proportional to the cross correlation function of the UV pulses:

$$I(3\omega - \omega, \tau) \propto \int I_{UV}(3\omega, t) I_{IR}(\omega, t - \tau) dt \quad (5)$$

The device is capable to measure $\sim 100 fs$ UV full width half maximum pulses. A complete and more detailed description of the device and of the physics behind it, is reported in [12, 13] where it is analyzed and discussed the presence of the spatial chirp in the UV beam and it is pointed out the importance of the crystal angle alignment. In fact changing the crystal phase matching angle, the temporal shape of the harmonic signal generated as well as its efficiency changes. The changes of the temporal shape due to the crystal angle mismatching have been observed. To overcome this problem the following procedure has been adopted: we first generated a two peaks spectrum profile and then we aligned the crystal angle in order to have the same shape in the time domain. This is possible once again because in our case the spectrum shape is transferred in the time domain.

CONCLUSION

In this paper we have presented a technique to produce the desired UV flat top laser pulses required from the SPARC project to achieve high brightness electron beam through the photoemission process form e metal photocathode. The whole technique is based on the Dazzler. Using this device it is possible to introduce the proper spectral phase and amplitude modulation in the initial IR pulses in order to manipulate their spectral shape and to obtain the target UV spectrum profile. A way to eliminate the distortions introduced by the SH and TH crystals is explained. This is done by introducing trough the Dazzler a chirp factor in the fundamental beam. We also showed that the UV spectrum shape can be transferred to time profile by introducing a large enough chirp factor in the UV beam. So that once the desired UV spectrum is achieved, the temporal shape is obtained too. As it is shown in Fig. (2), the desired rise and fall time of the pulses are longer ($\sim 2.5\ ps$) than the required one $< 1\ ps$. This will be the subject of further studies.

A time diagnostic device necessary to study the time profile of UV pulses has been presented: the UV-IR cross correlator.

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