DRIVE LASER SYSTEM FOR SPARC PHOTOINJECTOR*

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Abstract

In this paper we report the status of the SPARC photocathode drive laser system. In the high brightness photoinjector the properties of the electron beam are directly related to the drive laser features. In fact the 3D distribution of the electron beam ant the time of emission are determined by the incoming laser pulse. The SPARC laser is a 10 Hz frequency-tripled TW-class Ti:Sa commercial system. A dedicated activity on the shape of the laser pulse has been performed in order to produce flat top and multi-peaks time profile. To achieve the required flat top shape we perform a manipulation of the laser spectrum at the fundamental wavelength and directly at the third harmonic. The production of multi peaks laser pulse have been studied and tested. Finally we present the key laser performances recorded for the SPARC FEL experiment.

INTRODUCTION

The SPARC project is an R&D photo-injector facility at LNF-INFN, devoted to the production of high brightness electron beam at 150-200 MeV for a SASE-FEL experiment [1]. SPARC will allow also investigations into the physics of ultra-short electron beams, laser plasma wakefield acceleration, and X-ray Compton back-scattering. In fact in the next future the SPARC photoinjector will be combined with 200 TW laser for the interaction of highly focused electron beam and extreme light intensity.

The SPARC photocathode drive laser is a 10 Hz frequency-tripled Ti:Sa. The laser pulse specifications are set in order to have the optimal photoelectron density and to determine the emission at the best RF phase. For beam operation the laser pulse length used is varied between 5 and 10 ps and the transverse diameter can be continuously changed between 1 and 2 mm diameter. The pulse energy can be increased between 40 to 200 µJ in order to achieve charge between 0.2 and 1 nC per bunch.

Challenging specifications are requested in terms of laser temporal pulse profile (flat top pulse with < 2 ps rise time and ripples within 30%) to minimize the e-beam emittance; in the following we present some new results [3, 4]. The possibility of generating different time shape such as multipeaks structures is under investigation. These shapes are interesting for the implementation for pump and probe scheme and for the efficient generation of THz radiation.

The laser performances should also meet the stringent requests of amplitude and pointing stability. Finally, precise synchronization between the laser and the accelerating wave is necessary for stable time-of-arrival of the photons on the cathode with respect of the phase of the 2856 MHz RF field. This condition is very important to guarantee high brightness and the shot-to-shot reproducibility of crucial beam parameters such as the beam charge, energy, emittance and energy spread.

In the following sections we first describe the laser system performances and then we report the activity on the temporal pulse shape.

LASER SYSTEM

The SPARC laser is a TW-class Ti:Sapphire system constructed by Coherent. The laser consists of a Ti:Sa oscillator that generates 100 fs, 12 nm BW pulses. The oscillator operates at a repetition rate of 79+1/3 MHz corresponding to the 36th of the RF frequency. An acousto-optic programmable filter called "DAZZLER," [3] between the oscillator and the amplifier, is used to modify the laser spectrum. The programmable acousto-optic filter is adjusted in order to obtain the target temporal profile on the cathode [5].

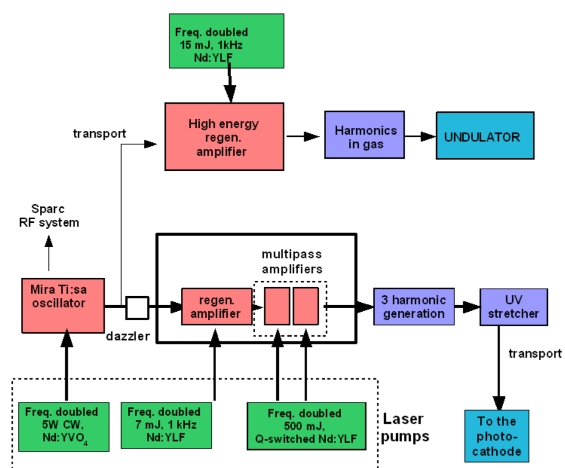

Figure 1: Conceptual drawing of the SPARC laser system.

A fraction of the oscillator's pulses is directed to a Ti:SA regenerative amplifier placed 15 meters away to have a synchronized additional laser source. This amplifier delivers up to 3 mJ pulse energy that will be focused in an noble gas jet in order to produce high order harmonics for seeded-FEL experiments.

The photocathode laser amplification process is carried out by one regenerative pre-amplifier and a two multipass stages, for details see Fig. 1. The whole system delivers sub-ps pulses with energy up to 50 mJ. At the output of the amplifier the IR pulses is frequency tripled and UV pulses hundreds fs long with an energy of up to 3 mJ can be available [3]. The harmonic generation is followed by an UV stretcher to lengthen the pulse up to 15 ps. This apparatus allows also the control of the time pulse shape and it will be described in the following [4].

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A 10 meters long optical transfer line is used to image the beam onto the cathode. The object plane consists of a circular iris selecting the central part of the laser beam to achieve an optimized transverse distribution. The optical system produces a faithful reconstruction of the laser distribution at iris plane. This optical transport mitigates the pointing instability of the laser source and allows a pointing jitter within 17 micron rms over several hours. The optical transport is equipped with a three lenses telescope which is useful to gradually vary the spot size at the cathode with an overall demagnification factor ranging from 3 to 6. A motorized variable neutral filter allows the precise control of laser energy on the cathode.

Dealing with laser system synchronization, challenging performances are requested to the system regarding laser to RF system time jitter. Within the first synchronization scheme, laser oscillator was enslaved to the RF clock as the global timing reference. Recently, a new synchronization scheme where the radio frequency master clock is driven by the laser has been implemented and tested. This modification allowed for a net improvement respect to the previous topology. Briefly: a fast photodiode (bandwidth > 10 GHz) is installed at the oscillator exit and it is used to form the RF signal in phase with the lasing. The photodiode output is amplified and using a band-pass filter the harmonic at 2856 MHz is selected. To prevent the slow frequency drift typical of the lasers, the optical cavity length is actively stabilized with a piezo and a stepper motor actuator. The deviation of the laser repetition rate respect to a local stable electronic reference is the error signal for the active feedback loop. To measure the relative time of arrival of the UV pulse respect to the RF accelerating electric field we developed a specific diagnostic [5]. The measured phase noise is used to compensate slow drifts of the laser time of arrival by acting on the RF phase shifters. The time of arrival monitor indicate the phase noise jitter of 0.5 ps rms when the laser is locked to the RF master clock. On the other side, the laser driven RF scheme demonstrated to be able to produce laser pulse at the cathode with a time jitter better than 0.25 ps rms.

SPECTRAL DOMAIN UV PULSE SHAPING

Previous measurements on our system indicated that the achievable rise time in the UV using the DAZZLER is not better than 3 ps [3]. In fact, due to the finite bandwidth of the non-linear crystals of the third harmonic generator, the steepness of the resulting UV flat-top pulses cannot be fully controlled through the DAZZLER. We found also that downstream the UV stretcher, there is a full correspondence between spectral and temporal profiles. This observation suggests that to improve the rise time the spectral tails needs to be sharply clipped.

To perform this manipulation we place a slit in the UV stretcher Fourier plane. The stretcher is a particular version of the 4f scheme with two transmission gratings and two lenses as shown in Fig. 2 [4]. The laser is sent onto a diffraction grating having 4500 lines/mm at an incidence angle of 49°. The dispersed wavelengths are then focused using f=500mm lens. On the lens focus, Fourier plane, each spectral component will be focused in a different transverse position. This allows any desired spectral amplitude modulation and in particular to cut the tails of the spectrum. The beam is then sent to another grating which is shifted from the symmetry position by a distance h. The beam is then retro-reflected by the fold mirror and at the exit the outgoing pulse length is proportional to h. After the second pass the fraction of the beam transmitted by the grating is focalized by a 30 cm lens onto the plane of a CCD camera. In this way an on-line high-resolution (≈ 0.03 nm) spectrometer is integrated in the shaping system.

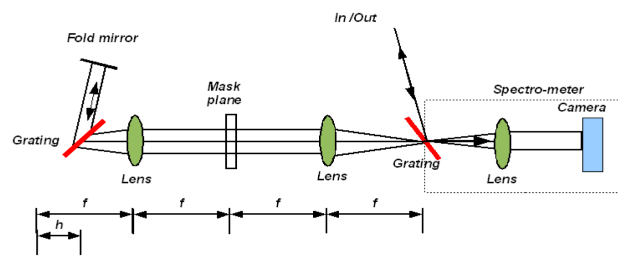

Figure 2: Schematic layout of the UV stretcher.

In the Fig. 3 we report two spectra (upper plots) and two corresponding cross-correlation traces obtained with and without the spectral filtering. The temporal profile has been reconstructed by a multishot UV-IR cross-correlator. In this device the UV pulse is gated by the amplified IR pulse which duration is about 0.5 ps FWHM. Programming the DAZZLER we were able to achieve the flat shape and spectrum on the left side. with a very long rise time. It should be noted that the pulse time profile is very similar to the spectral one.

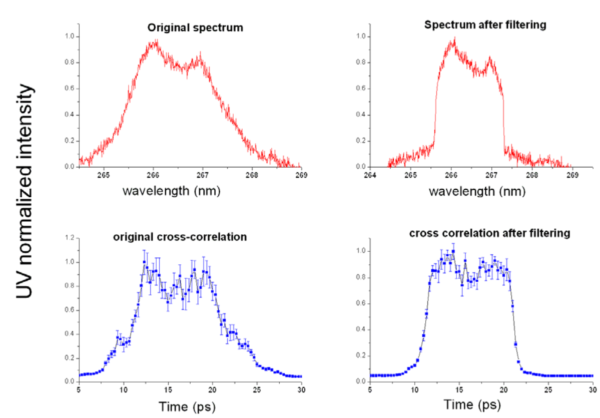

Figure 3: Spectral and time UV distribution obtained without and with the spectral filtering in the stretcher Fourier plane.

Properly cutting the spectral tails in the Fourier plane of the stretcher, top right plot, we observed a net reduction on the rise time, blue plot on the right. The resulted rise time is less than 1.4 ps and the ripple on the plateau is within 10 % rms.

The overall efficiency of the shaper is much higher respect to the case of reflection grating, but it is still limited to 60%. The additional energy losses due to the spectral filtering can be estimated by integration of the spectra and results to be about 20%.

TIME DOMAIN UV PULSE SHAPING

The flat top laser pulse can be obtained as superimposition of several sub-ps UV pulses delayed in time. The use of birefringent crystals for pulse shaping has been proposed and demonstrated elsewhere [6]. The crystals used in this measurement were a-cut BBO.

The α-BBO crystals are oriented with fast and slow axes at 45° to the incident optical polarizations, so that a temporally distinct pulse is split into two pulses with orthogonal polarizations traveling at different group velocities in each crystal, see Fig. 4. The lengths of the crystals, 10.353, 5.323, 2.661, and 1.331 mm determine the separation between the two output pulses, proportional to the thickness of the birefringent material.

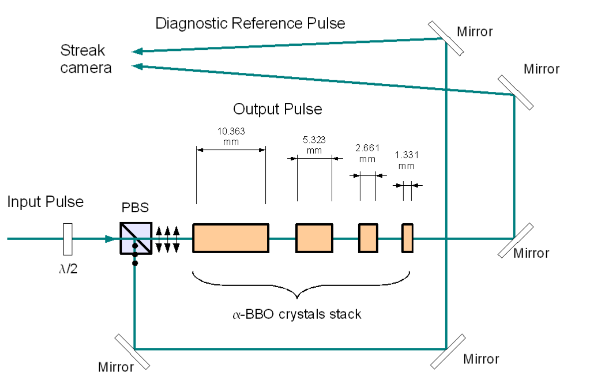

Figure 4: Schematic layout of the UV shaper based on the birefringent crystals.

The resulting temporal profile is a modulated flat-top with the rise and fall times of the original unshaped pulse. The pulse shape we obtained at the exit of each crystal is reported step-by-step in the Fig. 5. To measure the time profile we used a streak camera (Hamamatsu Fesca200) since this diagnostic is not polarization sensitive. To integrate the measurement over several pulses we sent to the streak a portion of the input single pulse and overlap the different image using this pulse as reference. The time frame used for the first two measurements was 100 ps and for the last two 50 ps. The resolution is 1 ps for the first case is limited to 0.5 ps for the second.

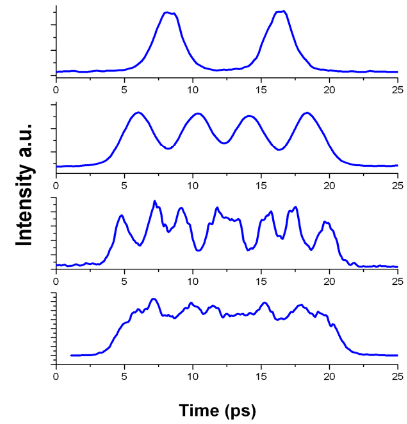

Figure 5: Step-by-step pulse shaping obtained with birefringent crystals.

As shown in the figure the exit of the first crystal we produced two pulses spaced by 8 ps, then we added the second crystals to produce 4 identical pulses and so forth up to 16 short partially overlapped pulses. The final rise and fall time pulse are 1.8 and 1.6 ps respectively. The rise time and the ripple on the plateau could be controlled by controlling with the DAZZLER the UV pulse length at the input of the birefringent crystals. In the present measurement we did not applied this fine tuning.

All BBO surfaces are antireflection coated and the overall transmission we measured is close to 95%.

CONCLUSIONS

We presented the most significant results and the recorded performances achieved with the SPARC photocathode drive laser. We reported also the time UV laser pulse shape achieved with time and spectral domain techniques. The pulse shaping based on birefringent crystals demonstrated to be ideal for multipeaks high efficiency generation. Further optimization is required to minimize the rise time and the ripple on the pulse plateau. The pulse shaping carried out with spectral manipulation demonstrate good reliability but still large energy losses.

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