THE PHOTOCATHODE LASER SYSTEM FOR THE APEX HIGH REPETITION RATE PHOTOINJECTOR*

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Abstract

The APEX photoinjector has been built and commissioned at LBNL. A CW-RF Gun accelerates electron bunches to 750 keV with MHz repetition rate. High quantum efficiency photocathodes are being tested with the help of a load lock system, with different work functions. The photocathode drive laser is thus conceived to provide up to 50 nJ per pulse in the UV and 250 nJ per pulse in the green at 1 MHz, with transverse and longitudinal shaping (flat top, 60 ps FWHM). A transfer line of about 12 meters has been designed and optimized to optimize position jitters. Remote control of repetition rate, energy and position have been implemented on the system, together with offline and online diagnostic for beam monitoring. Here we present the laser system setup as well as the first measurements on longitudinal pulse shaping and jitter characterization.

INTRODUCTION

The Next Generation Light Source (NGLS) is an high repetition rate Soft X-ray Free Electron Laser recently proposed at LBNL. It is conceived as a seeded machine, delivering to the user end stations fully coherent X-ray pulses at MHz repetition rate, with pulse duration ranging from 100 down to the single femtosecond [1]. The unprecedented average brightness will open the way to a series of new experiments and new techniques in all the fields of natural sciences, from chemistry to biology, to material science and condensed matter.

Among the various challenging aspects of the machine, the development of the photoinjector is of great importance as it directly impacts the FEL performances (and strongly affects the total cost). An R&D effort on high repetition rate photoinjectors has lead LBNL to the design and construction of the Advanced Photoinjector Experiment (APEX), a CW normal conducting electron gun, operating at 186 MHz. The accelerating electric field is 20 MV/m and the electron beam is accelerated to 750 keV energy in a 4 cm gap. The beam properties are then measured in the subsequent diagnostic beam line [2].

A load-lock system allows cathode replacement without exposing them to air. This feature, together with a vacuum pressure in the low 10^{-11}torr, makes APEX a perfect candidate for testing high quantum efficiency photocathode materials in rf environment, where surface contamination is a concern (e.g. multi-alkali [5]). The photocathode drive laser needs to be able to produce MHz pulses at different wavelengths (from 532 nm down to 213 nm) for cathode physics, with enough energy per pulse to produce the hundreds of pC needed by the NGLS, and with longitudinal and transverse pulse shape optimized for electron beam dynamics. The 12 meters transport line takes the pulses to the final laser table where most of the diagnostic for pulse shape, energy and position is hosted. In what follows we give a detailed description of the different laser subsystems.

THE LASER SYSTEM

The fiber laser oscillator and amplification stage were provided by the Lawrence Livermore National Laboratory (LLNL), in november 2010. The Yb-doped fiber oscillator is pumped with a 980 nm CW diode, producing output pulses at 37.14 MHz, with ∼mW output power around 1030-1070 nm. The mode locking is achieved via non-linear polarization rotation in the fiber, and the dispersion is controlled by the presence of a grating pair in the cavity. A chain of 4 pre-amplifiers gets the seed from the oscillator. After the first two pre-amplifiers, the repetition rate is decreased to 1 MHz by a acousto-optic kicker (AOM), driven by a 2 W 100 MHz pulsed rf signal synchronous with the oscillator. The AOM's rise and fall time are at the 20-30 ns level. A 100 m fiber is then used to stretch the pulse to around 100 ps, the bandwidth around 1064 nm is selected by an interferometric filter, and then sent in the last 2 pre-amplifiers and the final amplifier. The laser energy at the end of the chain is around 1.5 μJ, but it lowers down to 0.8 after re-compression with a grating pair. A KDP pockels cell (PC) is inserted at this point together with a half wave plate and a polarizing beam splitter, and it is used for low repetition rate operations (from 10 KHz down to 1 Hz). The HV power supply for the PC produces 3 KV pulses with 5 ns duration, in order to efficiently separate pulses. Despite its low non-linearity, KDP has been chosen to maximize the PC extinction rate. The final pulse, with a FWHM duration of 700 fs (Fig. 1), is used for second (SHG) and fourth (4HG) harmonic generation. A 3 mm non critically phase matched LBO crystal was used for SHG. The crystal is heated to 160 deg, and produces 270 mW output energy at 530 nm. The green pulse is then used in 4HG to get 50 mW UV in a 1.75 mm BBO crystal, via type I phase matching.

Laser Longitudinal Shaping

One of the laser requirements for the NGLS is a 60 ps longitudinally flat top beam. This is required for op-

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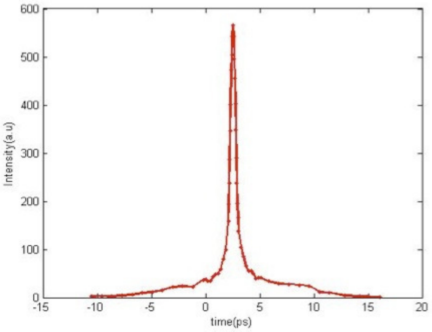

Figure 1: Longitudinal pulse shape.

timum emittance compensation downstream the electron source.Among many techniques used in time and or in frequency domain for longitudinal shaping, we implemented the pulse stacking [3]. This is a proven technique, easy to implement and with very low insertion losses (around 4% per crystal): a single pulse is split into a pair of pulses with orthogonal polarization by a BBO crystal, with a time distance equal to the crystal thickness times the group velocityy difference between ordinary and extra-ordinary axes. This pair of pulses then passes through another BBO crystal with 45 degrees rotation respect to the previous one, each pulse forming a pair of daughter pulses, with a total of 2n pulses for n crystals. The crystal thicknesses can be chosen to to partially overlap the pulses in time, forming a quasi-flat-top beam. The rise and fall times of the shaped pulse depend on the original length. A UV pulse shaper with 6 crystals has been designed and implemented at APEX. Figure 2 shows the setup. The longitudinal profile was measured after each crystal via a streak camera (visible in the picture), and Fig. 3 reports such measurements for 1, 2 and 6 crystals. Because the streak camera lens absorbs in the UV, green pulses (SH) have been used characterize the crystals, fitting the results to find the exact crystal thicknesses. The group velocity difference in BBO between ordinary and extraordinary axes is considerably less at 530 nm, so the measured green pulse was 32 ps FWHM. The corresponding UV pulse with the measured crystal thicknesses would be 58 ps. The streak camera was used in synchroscan mode to minimize time jitters. We generated a 125 MHz signal from the FPGA board, synchronous with the laser oscillator frequency. This signal was then amplified by the streak electronics and used as streak voltage. To increase further the resolution, single shot images were recorded by gating the MCP, and then averaged offline.

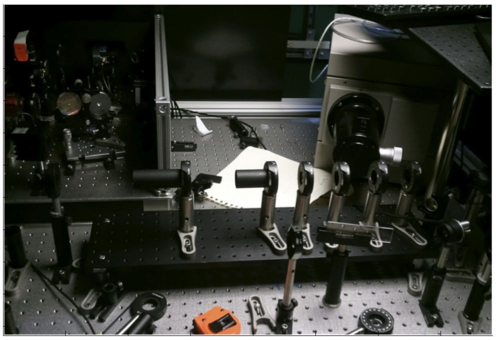

Figure 2: Picture of the UV pulse shaper installed on the laser table. Also the streak camera used for measurements in the green is visible on the right.

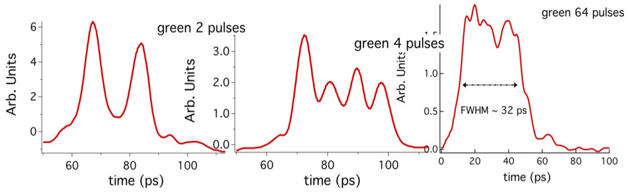

Figure 3: Laser pulses measured with the streak camera after the passage in the crystal stack. One, two and six crystals were used for this measurements. The measured pulse length is in very good agreement with the calculations.

In order to directly measure the UV pulse we are building a cross-correlator, where the short green pulse is opportunely delayed and interacts with the shaped UV pulse in a 1.5 mm BBO crystal (Type I phase matching). This is a particular case of difference harmonic generation (DHG), and the resulting green pulse should be proportional to the UV electric field at the time of the interaction. The DHG output is polarization dependent, so the 2 orthogonal polarizations creating the flat top UV pulse will be measured separately and superimposed offline.

We also foresee pulse stacking and transport of the the green pulse to the cathode area. YVO_4 crystals of the right thickness, have already been bought and will be installed and tested by the end of the year.

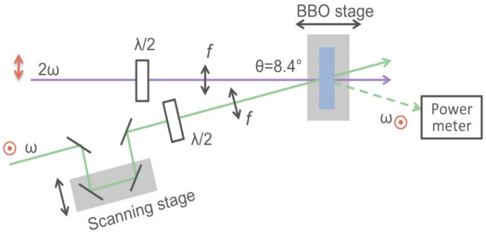

Figure 4: Schematics of the cross-correlator that is being installed. It would allow direct measurement of UV pulses. The orthogonal polarizations coming out from the pulse stacking will be recorded separately.

Beam Transport and Imaging

After the longitudinal shaping, the beam is transported from the laser room to the APEX gun, with a 12 meter long beamline, We use 3 lenses to relay imaging the pulse on the final table in the vicinity of the gun.

A schematic of the final table is provided in Fig. 5. A linear attenuator mounted on a remotely controlled stage is used to control the amount of energy sent to the cathode. The two axes of the following mirror are also motorized for beam centering to the cathode. Such motors are used in low bandwidth feedback loops to keep the laser energy and position at the cathode stable over time. A wedged glass after the last mirror samples a small fraction of the beam, which is then used for power control and cathode imaging (virtual cathode). A UV-to-visible converter and a CCD camera create an image of the laser on the cathode.

When running in high current mode (300 pC/ 1 MHz) a system for equipment protection (EPS) must be in operation to avoid damaging from excessive beam power. Intercepting screens, faraday cups, but also the vacuum chamber itself, must be protected against human errors and system failures. As part of this system, a shutter placed at the end of the laser path allows to switch off and on the electron emission.

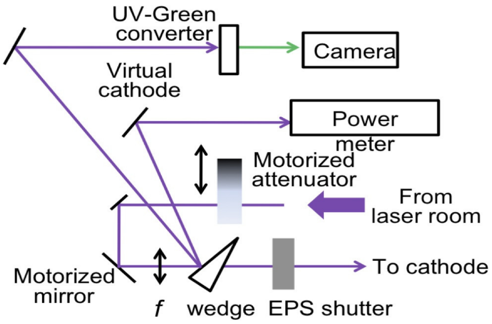

Figure 5: Final Table layout.

Laser Performances

Machine jitters can seriously impact FELs performances. Laser jitters are one of the major sources of noise, and need to be carefully studied and cured. Feedback loops are very effective in reducing the noise in the systems, but in existing FELs the bandwidth is limited to the low repetition rate of the sampling (tens of Hz), while most of the environment noise extends up to the few KHz. This can in principle be greatly improved in CW machines like NGLS. First measurements of time and energy jitters have been carried out at APEX (Fig. 6 and Fig. 7). For time jitters we used the FPGA board and extract a 1.3 seconds trace of the phase difference between the oscillator frequency and the reference oscillator. This has been then converted in time and plotted, showing roughly 2 ps RMS time jitter. Energy measurements where taken at the end of the amplification chain, by acquiring a photodiode signal in a single 0.5 s oscilloscope trace. The peak and the total area of each pulse in the trace were then extracted, and the noise power spectra calculated. Figure 7 reports the power spectrum of the energy noise using the pulse area, but the 2 spectra are in full agreement. Two spikes at high frequencies (78 kHz and its second harmonics at 156 kHz), are clearly visible. The origin of those is presently under investigation, and power supplies of CW pumps are the first candidates. Once online measurements with the required bandwidth are in place, our plan is to start developing feedbacks with KHz bandwidth for energy, time and position.

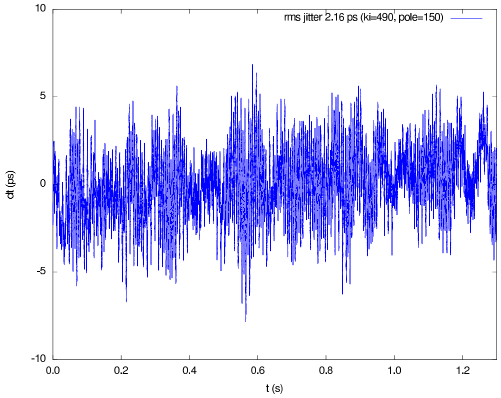

Figure 6: Oscillator time jitter measurements by using the FPGA electronics.

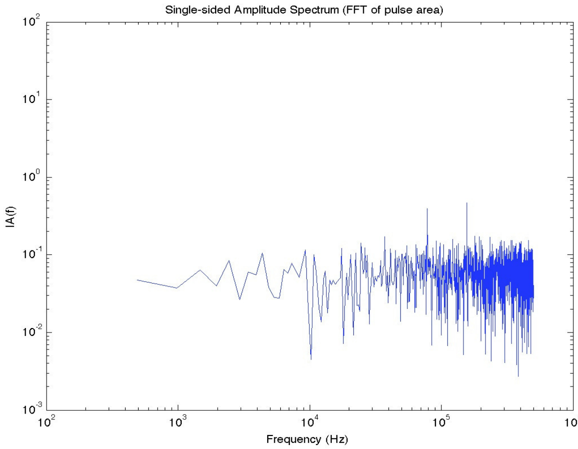

Figure 7: Energy jitter spectrum of the amplified laser pulse.

FUTURE PLANS

In the next future we plan to install a second fiber laser from Calmar [4]. This would have an increased output of 1.6 W with MHz repetition rate, an improved stability in energy and a cleaner time profile, allowing for more efficient harmonic generation. Also, we are upgrading our laser room with an external enclosure, that would allow a better control of the ambient temperature (within ±1°C). The 3D design is completed and we are now in the procurement phase. We will continue the characterization of noise in the system, implementing fast feedback loops for energy, time and position. Finally, the full beamline and pulse shaping for green laser pulses will be installed in the next months. This will allow the test in rf environment of multi alkali cathodes as CsK_2Sb [5].

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