DRIVE LASER SYSTEM FOR THE ADVANCED PHOTON-INJECTOR EXPERIMENT AT THE LBNL*

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Abstract

The electron photo-gun of the Advanced Photo-injector EXperiment project (APEX) at the LBNL will be driven by a compact fiber laser for different photo-cathode experiments during the initial phase of the project. The fiber laser, developed at the Lawrence Livermore National Laboratory, is designed to deliver µJ/pulse at 1064 nm system that is frequency doubled to deliver light at 532nm with 1MHz repetition rate and 1ps pulse length optimized for photo-emission with multi-alkali antimonide cathodes. For Cs_2Te and diamond amplifier cathodes, the 4th harmonic will be generated by doubling frequency again in a non-linear crystal. Due to the requirement of small emittance for the electron beam, the laser pulse will be shaped in space and time for 532nm and UV lights, in general with a constant intensity in cross section with a sharp radial cutoff, and elliptical or rectangular distribution in the longitudinal plane. Diagnostics of the laser beam itself and of the cathode will be integrated with techniques such as cross-correlation, streak camera, and virtual cathode imaging, not only to monitor the laser pulse but also to provide automated feedbacks. The present status and the plan for future activities of the drive laser system are presented.

INTRODUCTION

In the framework of the Advanced photo-injector experiment (APEX) at the Lawrence Berkeley National Laboratory (LBNL), a laser–driven electron normal-conducting constant-wave photo-injector is in the active design and construction stage [1,2]. The APEX photo-injector will provide high brightness electron beams with charge ranging from few pC to up to ~ 1 nC at ~ MHz repetition rates with the reliability required to operate in a user facility [3,4,5]. The gun of the APEX photo-injector is a normal-conducting copper RF cavity resonating at 187 MHz in the VHF band with extremely low vacuum pressures down into the 10^{-11} Torr. The APEX photo-injector will also serve as a platform for studying various cathode materials such as diamond amplifier [6], metal and semiconductor cathodes under VHF fields. The choice of the laser system is critical for the APEX photo-injector. In addition to the technical specifications in terms of power, energy and pulse duration, other quantities such as reliability, stability, and reproducibility, are important characteristics.

*Work supported by the Director of the Office of Science of the US Department of Energy under Contract no. DEAC02-05CH11231
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Since modern linear accelerators are able to preserve the electron beam emittance throughout acceleration [7], it becomes important to extract electrons from a cathode with the lowest possible emittance [8]. The work function of the photocathode material determines the energy of the photons and its quantum efficiency (QE) determines the laser pulse energy for a given charge per electron bunch, and the laser power for a given repetition rate.

The laser source delivers pulses of different duration and shape, determined by the bandwidth of the seed laser and the alignment of the amplifier and compressor. The Ti:Sapphire or fiber laser source deliver nearly transform limited, sech^{2}-type pulses, which can fitted by Gaussian function. In order to minimize the emittance growth due to the space charge forces in the electron bunch, the control of the laser pulse shape at sub-ps level, and of the transverse profile at the cathode are necessary. 6-D ellipsoidal distributions are preferred (because they linearize space charge forces), but more realistic rectangular distributions in all the planes are equally acceptable and are typically pursued in photo-injector lasers.

In this paper, we describe the laser system under development for the APEX photon-injector by the LLNL/LBNL collaboration. The present status of the laser and the plan for future activities are presented.

FIBER LASER SYSTEM

The laser for the photoinjector is a fundamental element in all FEL designs. The pulse and electron beam quality of this system is crucial to the overall FEL performance, as it is directly imprinted on the emittance of the generated electron bunch. For the APEX photoinjector, a fiber laser [9,10] is chosen for the following reasons:

a) Fiber lasers have optimum performance in terms of timing and energy jitter.
b) They can be efficiently pumped by the diode lasers.
c) They have the capability of delivering high average power at a MHz repetition rate.
d) The use of an active medium such as Yb3+ assures a gain bandwidth large enough to support sub-picosecond pulse durations.

In Table 1 the laser parameters required at the cathode plane for APEX are shown for the different photocathode materials.

Table 1: Laser Requirements for Different Photocathodes for High Brightness Bunches at High Repetition Rate

Laser parameters	K2CsSb	Cs2Te
Wavelength(nm)	532	266
Energy (nJ)	up to 100	up to 200
Transverse distribution	Quasi-uniform hard edge	
Longitudinal distribution	trapezoidal with ~10% rise and fall time	
Flat-top width (ps)	from ~1 to ~60	
Repetition rate (MHz)	up to 1	

The fiber laser has been developed by the Lawrence Livermore National Laboratory (LLNL) and was delivered in November, 2010. It consists of a fiber oscillator, pre-amplifier and final amplifier. Both oscillator and amplifier are pumped by diode lasers. At present, the output power at 1064nm is measured to be about 500mW at 1MHz. Figure 1 shows the picture of current optical layout of the system. The green box in the picture is the final amplifier. The red lines represent the optical path of 1064nm beam. The blue lines represent the 532nm beam and the purple beam represents the 266nm beam.

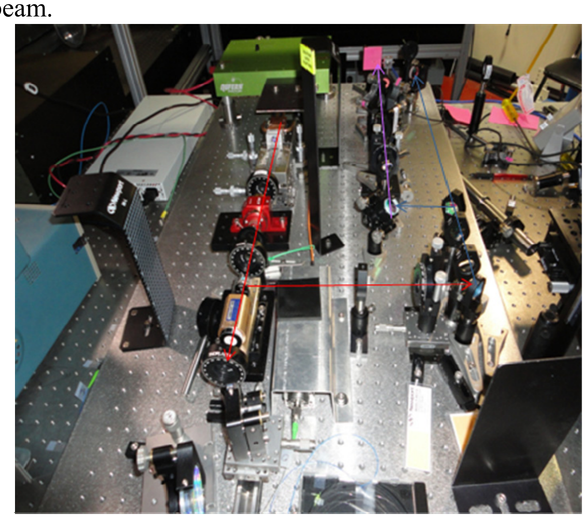

Figure 1: Optical layout of the laser system.

Precise electron beam generation requires the laser arrival time at the photocathode to be synchronized with the phase of the accelerating RF in the photoinjector gun cavity. The laser oscillator cavity needs to be tuned at 37MHz, the fifth sub-harmonics of the photoinjector RF frequency. The LLNL fiber laser oscillator cavity is equipped with a pico-motor driven and a piezo-driven stages to precisely synchronize with the RF of the photo-injector. These stages will be under control of a feedback, part of the low-level-rf control of APEX.

The 1064nm pulse time intensity from the fiber laser, as measured by a signal-shot auto-correlator, is shown in figure 2. The full-width half maximum is 607fs. A non-Gaussian long tail is found in the distribution. This long tail is probably due to imperfect control of the polarization in the final amplifier. Such a tail reduces the 2^{nd} harmonics conversion efficiency in the crystal. A new more powerful final amplifier is under development at LLNL.

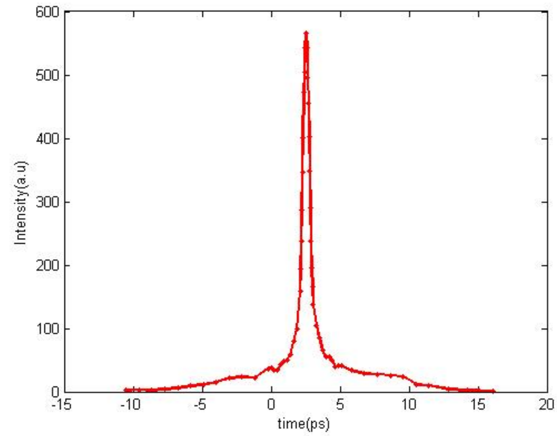

Figure 2: Auto-correlation measurement of the 1064nm pulse.

HARMONIC GENERATION

Starting from 1064nm wavelength from the fiber laser, frequency doubling and quadrupling are used to generate the 532nm and 266nm photons required by different photocathode materials. Type I BBO crystals are chosen for harmonics generation due to their stability and high conversion efficiency. Figure 3 shows the harmonic generation spectra. It can be seen that the mixture of fundamental pump beams can be completely removed in our system. A power of 100mW at 532nm light and of 40mW at 266nm light has been demonstrated. The overall conversion efficiency from 1064nm to 266nm is about 8%. The relatively low 2^{nd} harmonic efficiency is probably associated with the presence of the non-Gaussian tail mentioned above.

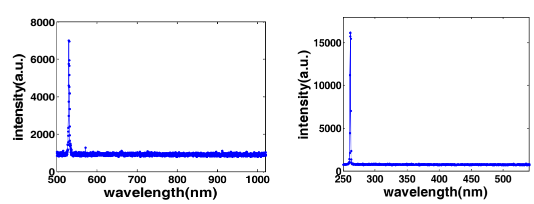

Figure 3: Harmonics generation spectra measured by a spectrometer at 532nm and 266nm demonstrating removal of the pump wavelength.

BEAM SHAPING

Due to the requirement of small emittance for the electron beam, the laser pulse will be shaped in space and time for both the 532nm and 266nm lights. A cylindrical distribution with a flat top and relative sharp drop-off will be pursued in the transverse plane, and a rectangular distribution with ps rise and fall times in the longitudinal plane. The uniform "hard-edge" transverse distribution can be achieved by different means of pulse-conditioning optical systems. An example of practical and flexible layout consists of a telescope system followed by an aperture. The telescope expands the beam transversely, overfilling the aperture, thereby selecting the pulse's central quasi-uniform region. Alternative schemes are to use commercial products [11] based on asperic lenses [12]. These schemes benefit from high efficiency, but require an accurate and stable alignment and rely on the Gaussian transverse beam profiles. We are pursuing both the options to evaluate the best solution for our case.

The required temporal laser beam shaping can be achieved, for example, by a pulse-stacking scheme which has been demonstrated to be both reliable and efficient [13]. In such a system, a single pulse is split into a pair of pulses with orthogonal polarization by a BBO crystal; this pair of pulses then passes through another BBO crystal, with each pulse forming a pair of daughter pulses, forming 2^n pulses for n crystals; these pulse replicas can be arranged to partially overlap in time, forming a quasi-flat-top beam. The rise and fall times of the shaped pulse depend on the original length. A longitudinal shaper based on such scheme will be developed for APEX.

BEAM TRANSPORT AND IMAGING

The location of the laser system is on the top of the shielding area of APEX. The distance from the laser system to the photo-injector cathode is about 12m. The beam transport system must propagate the beam from the laser room to the photocathode without distorting its spatial and temporal shape. Figure 4 shows the schematic of the laser beam transport and imaging system, , where three lenses, respectively 276, 100 and 150 cm focal lengths are used. The scheme has the capability of a 1:1/3 imaging, transporting the beam from a variable aperture plane to the photo-injector cathode. The aperture will be placed in the laser room, and the optics will guide the laser beam from there to an optical table in accelerator cave and to the cathode plane. All optics will be enclosed in shielding pipe to reduce environmental light and air temperature variation perturbations. During the transportation path, beam position will be monitored by CCD camera and controlled by steering mirror.

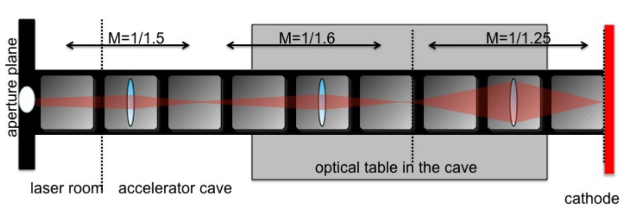

Figure 4: Schematic of the laser beam transport and imaging.

FUTURE PLANS

The fiber laser system for APEX is now installed in a temporary laboratory for testing purposes. In the near future the laser system will be moved to its final destination and the experimental activity will start. In the initial phase of the APEX program several different photocathodes with different work functions will be tested and characterized for defining the best system suitable for the operation of in a high repetition rate X-ray free electron laser. The capability of the laser of generating light in both the visible and UV provides the flexibility required to test such different photocathodes.

The present power performance of the laser will allow us to perform the majority of the cathode experimental program of APEX. A notable exception to that, is the demonstration of the capability of generating high charge bunches (1 nC) at high repetition rate (1 MHz), as this requires about a factor 2 higher power in the IR and the removal of the non-Gaussian tail in the laser pulse. The new amplifier under development at LLNL should resolve these two issues.

REFERENCES

[1] F. Sannibale et al., Proceedings of FEL2010, p. 475, Sweden ; http://www.JACoW.org.
[2] C. Papadopoulos et al., Proceedings of FEL2010, p. 479, Sweden; http://www.JACoW.org.
[3] K. Baptiste et al., NIM A 599 (2009) 9.
[4] K. Baptiste et al., Status of the LBNL normal-conducting CW VHF photo-injector, Proceedings of PAC09, Vancouver, Canada, May 2009, MO6RFP007, p. 551 (2010); http://www.JACoW.org.
[5] J. Staples, F. Sannibale and S. Virostek, "VHF-band Photoinjector," CBP Tech Note 366, Oct. 2006.
[6] T. Rao, J. Smedley, I. Benz-Vi, private communications.
[7] Y. Ding et al., "Measurements and Simulations of Ultralow Emittance and Ultrashort Electron Beams in the Linac Coherent Light Source," Phys. Rev. Lett. 102 (2009) 254801.
[8] See, for example, C. Vicario et al., Proceedings of FEL2010, p. 425, Sweden; http://www.JACoW.org.
[9] D.J. Gibson et al., Proceedings of PAC09, Vancouver, Canada, May 2009, TU6RFP047, p. 1653 (2010); http://www.JACoW.org.
[10] J. An et al., Opt. Lett. 32 (2007) 0146-9529.
[11] See, for example, http://www.pishaper.com
[12] A.K. Sharma et al., Phys. Rev. ST Accel. Beams 12 (2009) 033501.
[13] S. Zhou et al., Appl. Optics 46 (2007) 8488.