OPERATION OF THE DRIVE LASER SYSTEM FOR THE 2998 MHz NSRRC PHOTOINJECTOR

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Abstract

A 266 nm ultra-violet (UV) laser system has been installed as the drive laser of the NSRRC 2998 MHz photocathode RF gun. A 2.3 MeV, 246 pC electron bunch is performed with this laser system. Synchronization between the high power microwave system and the UV laser system is achieved with a time jitter < 1 ps RMS. In order to make the photoinjector more user friendly, some beam monitor systems are being implemented.

INTRODUCTION

Laser driven photocathode RF gun is one of the brightest electron sources to date. It is a flexible system such that its beam properties and time structure are controllable by the drive laser. The high brightness injector project of NSRRC has been initiated since 2006 [1]. The injectors that comprised a laser-driven photocathode RF gun and a thermionic cathode RF gun using the same 2998 MHz linac system. According to beam dynamic studies for the photoinjector, a 10-ps uniform cylindrical electron beam will be generated at the copper (Cu) cathode to reduce emittance growth due to space charge and transverse RF fields in the photoinjector cavity. The main part of the photocathode RF gun is a 1.6-cell π-mode cavity structure with dimensions optimized for operation at 2998 MHz. The Cu cathode at the end-wall of the shorter cell is illuminated by a 266-nm picosecond UV laser, leading to intense photo-electrons emitted from the cathode surface are abruptly accelerated to relativistic energy by the high gradient accelerating RF field in the cavity. Two 35 MW, 2998 MHz THALES TH2100A klystron systems are installed as the microwave sources for the RF gun and linac sections. The timing jitter between laser and electron bunches is less than 250 fs RMS. The energy of the electron bunch will be up to 150 MeV after three linac sections that can be used for next generation light source development in the future.

In this proceeding we report the operation of the UV laser system to drive a photocathode RF gun. With an 8-ps UV laser of 100 µJ energy, a 2.3 MeV, 246 pC electron bunch is performed. The details of the 2998 MHz high power microwave system can be referred to the manuscript of “Operation of the NSRRC 2998 MHz photo-cathode RF gun” [2] in this conference. The contents of the drive laser system, the optical layout and diagnostics for monitoring the UV laser pulse will be described below.

DRIVE LASER SYSTEM

The ultrafast laser system was purchased from Coherent Corporation and it is a Ti:sapphire laser system based on the chirped-pulse amplification technique [3]. This system consists of an oscillator (Mira-900), an amplifier (Legend-F), a third harmonic generator (THG), and a UV stretcher. The layout of the laser system is shown in Fig. 1. The oscillator is an 85-fs passively mode-locked oscillator pumped by Verdi, a 5 W cw frequency-doubled Nd:YVO$_4$ laser. It delivers 16 nJ energy per pulse, 74.95 MHz repetition rate and a central wavelength of 797 nm. The seed laser from the oscillator is then conveyed into the Legend-F amplifier. It is composed of three essential elements, an optical pulse stretcher, a regenerative amplifier and an optical pulse compressor. Before entering the amplifier, the laser pulses are stretched with an Öffner-type all-reflective stretcher. After stretched, the laser pulses are amplified by a regenerative amplifier while the energy is raised from nJ to mJ level and meantime the repetition rate of the laser is modulated to 1 kHz by a frequency-doubled diode-pumped Nd:YLF laser (Evolution). The amplified laser pulse is further compressed with a grating compressor. Currently the IR laser output from the Legend is 3 mJ per pulse with energy stability <1% RMS, which is lower than that of factory specifications due to the degradation of optics such as the compressor grating.

In order to extract photoelectrons from the Cu photocathode RF gun efficiently, the photon energy of the laser pulse should be higher than the work function of Cu ~ 4 eV. For this reason the laser frequency from the Legend is tripled by a third harmonic generator (THG), which mainly consists of two nonlinear crystals. After the THG, a UV laser pulse with 266 nm, corresponding to photo energy of 4.5 eV, is generated. The UV laser pulse can be further stretched from 800 fs to 10 ps by a UV stretcher,

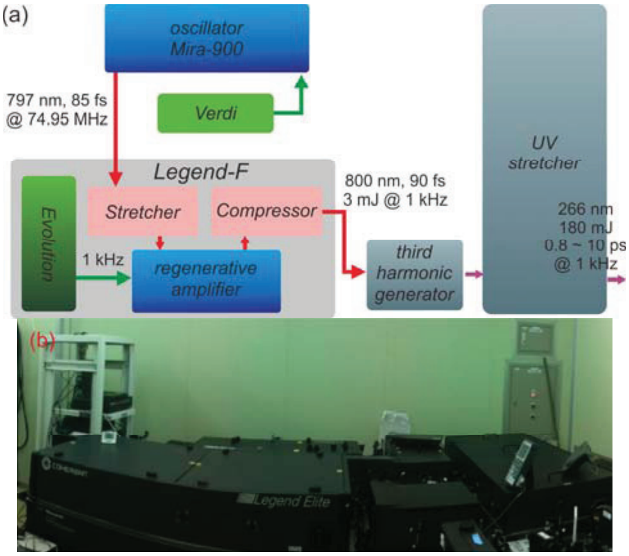

Figure 1: (a) Layout and (b) photo of the ultrafast laser system .

which is consisted of four fused silica prisms. We set the pulse duration of the UV laser at 8 ps for initial gun test. Similarly, the UV laser energy of 180 μJ at the exit of the UV stretcher is a little lower, compared to that of factory specifications due to the degradation of the nonlinear crystals and prisms. Although the UV energy attenuates to about 100 μJ after propagating to the Cu cathode due to mirror loss and absorption of the air, it is sufficient for gun test. Table 1 lists the specifications of current status of the laser system.

Table 1: Specifications of the Drive Laser System

Parameter	Spec.
IR wavelength	800 nm
IR pulse energy	3 mJ
IR pulse duration	90 fs
UV wavelength	266 nm
UV pulse energy	180 μJ (after UV stretcher)
UV pulse duration	0.8 – 10 ps (adjustable)
Rep. rate	1 kHz
Timing jitter	< 1 ps rms typical

OPTICAL LAYOUT OF UV LASER

In order to avoid exposing to the synchrotron radiation, the photocathode RF gun is installed in the gun test site whose location is about 15 meters far away from the laser hutch. The layout of UV beam line is shown in Fig. 2.

Since the UV pulse has slightly divergence after the THG, the beam size of the UV laser will become larger and larger after propagating a very long distance. We collimate the UV pulse by a 20-cm concave lens (L2) and a 30-cm convex lens (L1) after the exit of the UV stretcher. Then the laser pulse is propagated a little higher than the floor through a small hole drilled on the shielding wall. After that the UV pulse is focused with a convex lens (L3) of 2-m focal length. The focal size of the UV laser on the Cu cathode can be tuned by adjusting the position of L3. Figure 3 shows the beam profile of the focused UV laser on the Cu cathode. The beam size is about 2.1 mm in the horizontal direction and 1.9 mm in the vertical direction. There are two choices of laser incidence into the photocathode gun, normal incidence or grazing incidence. According to our vacuum system design, we adopted normal incidence. In this way we placed two tiny mirrors with a small gap inside the vacuum chamber to keep electron bunches passing through these two mirrors.

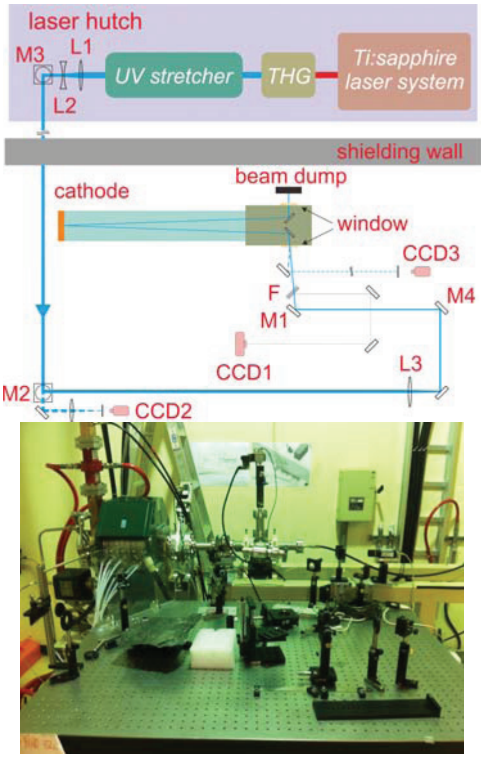

Figure 2: Layout and photo of the UV beam line.

In order to monitor the beam size and the focus position of the UV laser pulse on the Cu cathode, we installed the UV beam profile monitor and beam position monitors. As shown in Fig. 2, a flipper mirror (F) is installed between the window and the last mirror (M1) before the window. When the flipper moves up, the UV pulse is directed to CCD1. The distance between M1 and CCD1 equals that between M1 and the Cu cathode so that we can measure the UV beam size at any time as long as the flipper moves up. When operating the photocathode RF gun day to day, a crucial issue is how we can know if the UV laser irradiates at the center of the Cu cathode precisely or not. To solve out this problem, we implement two beam position monitors in the current layout. First, we monitor the beam position of the UV laser with CCD2 by collecting the UV leakage from M2. Once the UV laser is misaligned after passing through the shielding wall, we can correct the UV beam line to the right path through monitoring the mark on CCD2 by adjusting M3. Secondly, there is a small portion of the UV laser reflected by the window since the UV laser is obliquely incident into the vacuum system. We direct the reflective UV laser pulse to a virtual target and monitor the beam position by CCD3. The virtual target has a mark on the screen which is expected to the center of the Cu

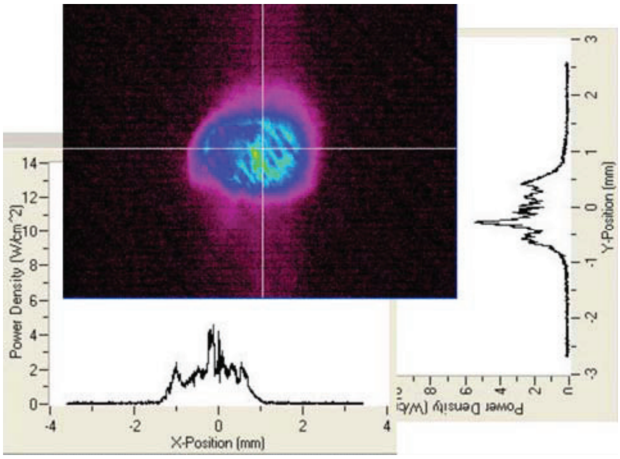

Figure 3: Beam profile of the focused UV laser on the Cu cathode.

cathode. We can align the UV laser to the right position by adjusting M4 which is mounted on a motorized mirror mount. However, the virtual target may not correspond to the position of the Cu cathode accurately. We can also optimize the quality of electron bunches by adjusting M4

SYNCHRONIZATION WITH RF

To generate and accelerate electron bunches from the photocathode RF gun, one has to make synchronization between the laser and the RF system. The fine synchronization with the RF reference can be carried out at the level of the laser oscillator. As shown in Fig. 4, a 2998 MHz signal generator is reduced 40 times to 74.95 MHz by a frequency divider. Then the Mira is locked with the signal generator by a Synchrolock which was also bought from Coherent. The signal generator also triggers the pump laser of regenerative amplifier with 1 kHz. The synchronization and delay generator (SDG) is designed to control the precise timing for the regen amplifier. In order to make sure that a single pulse is admitted to the resonator, the Pockels cells must be switched at the same time with respect to the seed pulse train every time. So switching is synchronized to the RF signal generated by the seed laser. Coherent specifies a time jitter is less than 250 fs RMS when the Synchrolock is used to lock two laser oscillators. Since the oscillator phase noise may have variations, in next step we will measure the time jitter when an external RF signal is used to drive the Synchrolock.

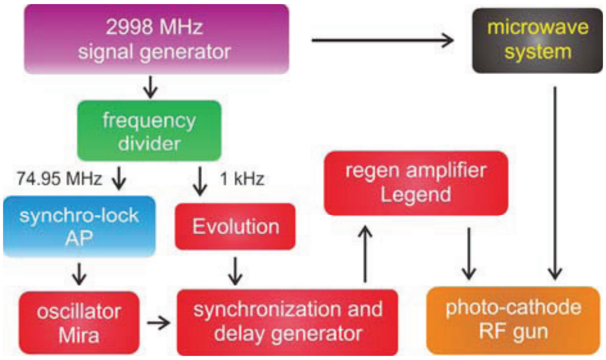

Figure 4: Layout of the synchronization units.

WORKS FOR IMPROVEMENT

To acquire the lower emittance electron bunches from the photocathode RF gun, it is important to produce a temporally and spatially flat-top intensity profile of the UV laser. Recently, many schemes of the pulse shaping were demonstrated at several groups. We will improve the quality of the electron bunches by spatial and temporal pulse shaping. For example, a refractive UV beam shaper may be used to spatial pulse shaping. Nevertheless, it will be a challenge since the optical path from the laser hutch to the photocathode is more than 15 meters. In contrast with spatial pulse shaping, the techniques of temporal pulse shaping are much more desirable, such as acousto-optic programmable dispersive filter (DAZZLER), frequency domain pulse shaping and pulse stacking [4][5]. Now we plan to use pulse stacking technique to achieve an electron beam with a transverse emittance smaller than 1 mm-mrad.

SUMMARY

In this proceeding, we report the operation of the UV laser system for driving the NSRRC 2998 MHz photocathode RF gun. A 2.3 MeV, 246 pC electron bunch is performed with this laser system. Beam position monitors are installed to help operating this photoinjector more reliable. Next we will figure out the time jitter of the system and improve the beam quality by the temporal and spatial pulse shaping of the UV laser.

REFERENCE

[1] W.K. Lau, J. Y. Hwang, G.Y. Hsiung, D.J. Wang, G.H. Luo, J. R. Chen, "Conceptual Design of a High Brightness Injector at NSRRC", NSRRC Technical Report, NSRRC-TR00022 (2006).

[2] A.P. Lee, P.Y. Chiu, W.K. Lau, M.C. Chou, H.Y. Hwang, "Operation of the NSRRC 2998 MHz Photo-Cathode RF Gun", this conference.

[3] D. Strickland, G. Mourou, "Compression of Amplified Chirped Optical Pulses", Opt. Comm. **56**, 219 (1985).

[4] C. Vicario *et al.*, "Laser Temporal pulse Shaping Experiment for SPARC Photoinjector", Proc. of EPAC04, Lucerne, Switzerland.

[5] I. Will, "Generation of flat-top picosecond pulses by means of a two-stage birefringent filter", Nucl. Instr. And Meth. A **594**, 119 (2008).