LASER SYSTEM OF PHOTOCATHODE RF GUN AT POHANG ACCELERATOR LABORATORY

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Abstract

A photocathode RF gun has been installed at the photo-injector test facility for the X-ray free electron laser in the Pohang Accelerator Laboratory. The photocathode RF gun will provide electron bunches which have a high charge (1 nC) and short bunch length (10 ps). For this purpose, a new laser system was installed and it can provide laser pulses of 2 mJ energy, 110 fs pulse width at 800 nm wavelength. A third harmonic generator and an ultraviolet stretcher system were added to generate UV laser pulses with controllable pulse widths which can be increased up to 10 ps. In this article, we introduce our laser system and report recent progresses of electron beam generations under the various laser conditions.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has started its X-ray free electron laser (PAL-XFEL) project from 2004 [1]. This will be a 4^{th} generation radiation facility by using the self-amplified spontaneous emission (SASE) for X-ray generation [2]. For this project, 2.5 GeV electron linac of the Pohang Light Source (PLS) will be used after an upgrade in its energy and performance. Besides the upgrade of the existing linac, we have to solve some challenging problems, such as the generation of low emittance electron beams from a photocathode RF gun, bunch compressions to make an ultra short electron beam, maintaining the low emittnace beam to the end of the linac, and keeping the straight orbit in the undulator. None of them can be ignored but should be fulfilled to the state of arts for the success of the project so that several research programs are on going in parallel.

Especially for the low emittance electron beam from the photocathode RF gun, a gun test stand (GTS) is constructed and a gun development program has been pursued [3]. Significant resources were put into the GTS construction with the support of the PAL. They include a radiation shielding tunnel, a full set of RF system, a photocathode RF gun and its stand, and a high power laser system with a clean room facility. Recently, the electron beam generation was performed successfully and the GTS shows promising results for the success of the PAL-XFEL project.

In this paper, we introduce the Ti:Sapphire laser system for the GTS. It starts from the configuration of the laser system and explains the special features of the ultra violet (UV) stretcher. The details of synchronization with RF and laser transport line are described. Some preliminary results of the electron generation are presented as well.

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LASER SYSTEM

System Configuration

In 2005, a Ti:Sapphire laser system (Spectra Physics) was installed for the photocathode RF gun in GTS. This laser system consists of an oscillator, a regenerative amplifier, a third harmonic generator (THG), and a custom designed UV stretcher system. The laser system is installed in a clean room which temperature is controlled within 0.5° C for stable operations. Figure 1 shows whole system of GTS laser. From the oscillator, 105 fs pulse width, 800 nm wavelength infrared (IR) laser pulses are generated with 80 MHz repetition rate. These laser pulses come into the regenerative amplifier to be amplified up to 2.5 mJ energy laser pulses with 1 kHz repetition rate. During the amplification, the chirped pulse amplification (CPA) method is used to prevent a damage of the gain medium [4]. The 2.5 mJ energy of the IR laser is designed to obtain 1 nC charge. We need 125 μJ UV laser pulse when 10^{-5} quantum efficiency of the copper cathode is considered. In addition, we assumed about 50% loss during the transport of the UV laser pulse and 10% efficiency of the third harmonic generation. Thus the required energy for the IR laser was calculated to 2.5 mJ.

THG and UV Stretcher

After the regenerative amplifier, the laser pulse comes into the THG to produce 266 nm wavelength laser pulse. The UV laser pulse still has an ultra short pulse width so that a UV pulse stretcher is installed to reduce the space charge effect in a generated electron beam. In addition, the UV pulse stretcher has a capability to change the pulse width form 1 to 10 ps and we can find an optimum pulse width to produce a low emittance high charge electron beam. To increase the UV laser pulse width, two prism pairs are used in the UV stretcher. When the laser pulse passes through the prism pair, each wavelength

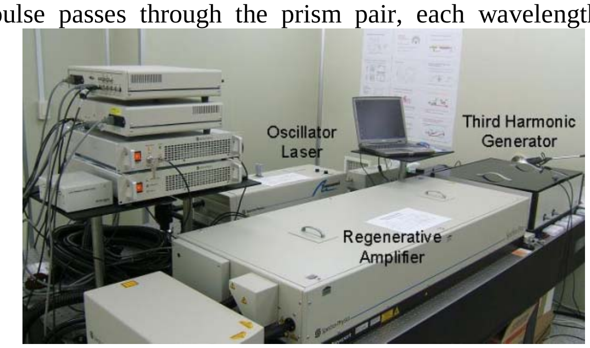

Figure 1: Picture of Ti:sapphire laser system. It shows the oscillator, the regenerative amplifier, and the third harmonic generator.

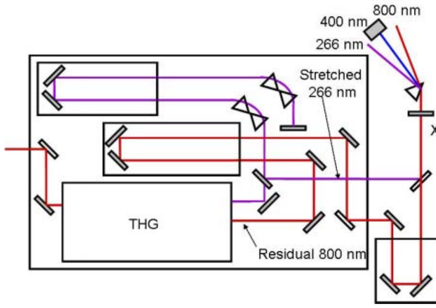

Figure 2: Schematic of UV pulse stretcher. The UV pulse width is determined by the distance between two prism pairs. Next to the UV stretcher, a cross correlator is installed to measure the UV pulse width.

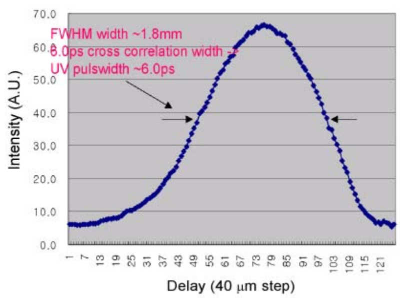

Figure 3: Measurement result of a 400 nm signal from the cross correlator. The FWHM of the 400 nm profile is 1.8 mm which is corresponding to 6.0 ps pulse width.

travels a different optical path so that one can increase the pulse width. In addition, one can control the UV pulse width by changing the distance between two prism pairs. Figure 2 is the schematic of the UV stretcher. The violet line represents UV laser path of the UV stretcher and red one is that of the residual IR laser for UV pulse width measurement.

Next to the UV stretcher, a cross correlator is installed to measure the UV pulse width. If the stretched 266 nm and the short 800 nm lasers are overlapped in the nonlinear crystal (BBO), the 400 nm signal can be observed by the difference frequency generation. In addition, one can obtain the intensity profile of the 400 nm signal by scanning the optical delay of 800 nm laser. Figure 3 is the measurement result of the 400 nm profile and this profile represents the UV pulse width. The intensity profile of 400 nm signal is measured in every 40 μm delay and the full width at half maximum (FWHM) is 1.8 mm which means that the UV pulse width is 6.0 ps.

Synchronization with RF

To generate and accelerate an electron beam from the photocathode RF gun, one has to make a synchronization between the laser and RF system. To do that, let us consider the timing system of the laser first. Laser pulses from the oscillator and the pump laser go into the regenerative amplifier. At the same time, photodiode signals of two lasers are sent to the timing and delay generator. The timing and delay generator opens or closes

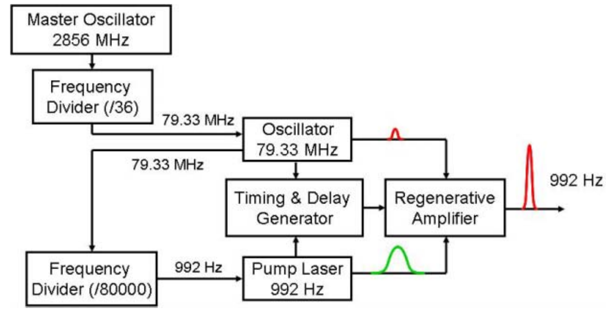

Figure 4: Schematic of synchronization system. The oscillator and pump laser are locked with the master oscillator by using two frequency dividers. In this way, the energy spread of the laser pulse is reduced to 1%.

the gate of the regenerative amplifier to send the oscillator laser pulse into the amplifier cavity. In this way, the timing and delay generator decides which oscillator laser pulses should be amplified. The amplified laser pulse comes out from the regenerative amplifier with 1 kHz repetition rate which is equal to the pump laser repetition rate.

The synchronization between the laser and RF is made with two frequency dividers. First of all, we made 79.33 MHz from 2856 MHz RF frequency by using a frequency divider (/36) and oscillator laser is locked with this 79.33 MHz frequency. Next, another frequency divider (/80000) is installed to make 992 Hz frequency from the 79.33 MHz. This frequency triggers the pump laser so that the pump laser is synchronized with the RF system as well (see Fig. 4). The measured timing jitter and energy stability are 130 fs and 1%, respectively.

Laser Transport Line

There are two ways of laser incidence into photo cathode RF gun: the oblique and normal incidence. In case of the oblique incidence, there is an angle between the laser propagation direction and the cathode normal, so that the circular laser profile is changed to an elliptical one on the cathode surface. In addition, because of the angle, photons in a wave front do not arrive the cathode surface simultaneously and this makes a time slew in the laser pulse from the view point of the cathode surface. However, all optics in a laser transport line is installed outside vacuum chamber and one can approach them easily. On the other hand, in the normal incidence, the laser pulse comes into the normal direction of the cathode surface so that there are no profile change and time slew. However, some optics should be installed inside the vacuum chamber and it is difficult to handle after installation. Moreover, if distances between the electron beam and the optics are too close then one can experience the charge accumulation in the optics which can cause an electrical breakdown in the optics.

The laser transport line is shown in Fig. 5. There are two focusing lens to reduce the transverse size and a special filter to improve the transverse profile. Next, the laser pulse is reflected with a remote controlled steering mirror to make a fine tuning of the laser spot position.

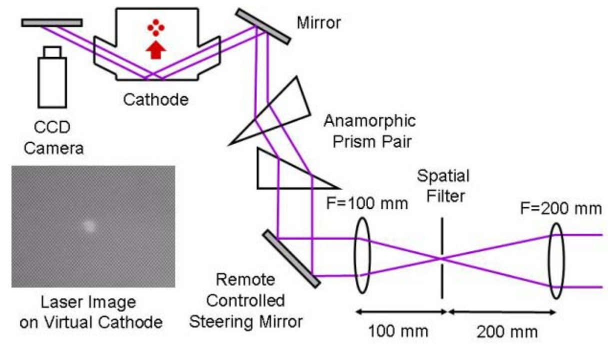

Figure 5: Schematic of laser transport line. In the laser transport line, there are two lenses for the laser size control, a remote controlled mirror for fine alignment, and an anamorphic prism pair for the laser profile correction. After the electron beam generation, the laser pulse is reflected to the virtual cathode.

The laser can be aligned to the mechanical centre of the gun cavity. However, the RF centre is usually mismatched with the mechanical centre so that the remote controlled mirror is needed for a fine alignment of the laser spot position. After the steering mirror, the laser pulse passes through an anamorphic prism pair to make a circular laser profile on the cathode surface. The anamorphic prism pair is used to decrease or increase the beam size in one direction only. In our case, the beam size is reduced to the horizontal direction and the laser profile is changed to an ellipsoid. If this ellipsoid laser goes into the cathode, the laser profile comes back to the circular one because of the laser incidence angle. The residual laser pulse after the electron beam generation is reflected from the cathode surface and makes laser spot image on a virtual cathode. The virtual cathode is installed in parallel to the cathode surface so that one can obtain a one to one image of the laser profile of the cathode.

Electron Beam Generation

The electron beam is successfully generated from the photocathode RF gun and its charge and size are measured. We installed an integrate charge transformer (ICT) and a phosphor screen at 40 and 50 cm distance from the cathode, respectively. The charge coupled device (CCD) camera is synchronized with 10 Hz repetition rate of RF and the electron beam is focused on the phosphor screen by using a solenoid magnet. Figure 6 shows images of electron beams under various RF phases. It is observed that the beam size is changed according to the RF phase and the measured RMS radius is 500 μm at 50 degree RF phase. Measured beam charges under various RF phases and laser energies are plotted in Fig. 7. The electron beam is observed from 0 to 120 degree RF phase and the maximum charge is measured at 70 degree. In addition, measured charge of the electron beam is increased as the laser energy increases and the maximum charge is 530 pC when the laser energy is 95 mJ at the cathode surface.

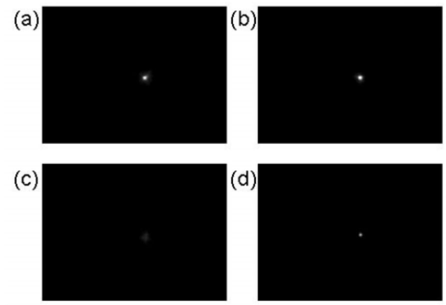

Figure 6: Images of electron beam under various RF phases. Used RF phase are (a) 30, (b) 50, (c) 70, and (d) 90 degree, respectively. The distance from the cathode to the phosphor screen is 50 cm and the solenoid current is 54.33 A. The UV laser energy is 47 μJ.

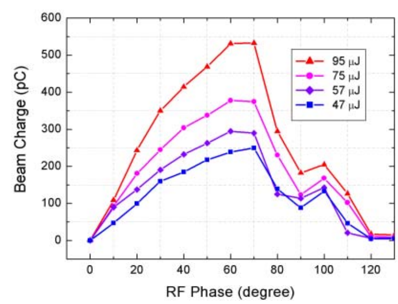

Figure 7: Measured beam charge under various RF phases and laser energies. Electron charges are measured in the range of 120 degree and the maximum charge is obtained at 70 degree. In addition, the beam charge is increased according to the energy increase of the UV laser pulse.

SUMMARY

A Ti:Sapphire laser system is installed for the photocathode RF gun study in PAL XFEL project. The laser shows 1% energy stability and 200 fs timing jitter. A UV stretcher is developed and the stretched UV laser pulse width can be changed from 1 to 10 ps. The stretched UV pulse width is measured by cross correlator. Laser transport line is under installation and an oblique incidence is tried. Some preliminary results of electron beam generation are successfully obtained.

ACKNOWLEDGMENTS

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REFERENCES

[1] T.-Y. Lee et al, J. Korean Phys. Soc. 48, 791 (2006).
[2] R. Bonifacio, C. Pellegrini and L. Narducci, Opt. Commun. **50**, 373 (1984).
[3] S. J. Park et al., in Proc. of 27th Int. Conf. on FEL (Palo Alto, USA, August 21-26, 2005), pp. 600-603.
[4] D. Strickland and G. Mourou, Opt. Comm. **56**, 219 (1985).