# DESIGN OF A SOURCE TO SUPPLY ULTRA-FAST ELECTRON AND X-RAY PULSES

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*Abstract*

In this paper we report the preliminary design and considerations on a multi-discipline ultra-fast source, which is capable of providing the user community with femtosecond electron bunch and light pulses with the wavelength ranging from IR to X-ray. The facility is based on photocathode RF gun driven by a Ti:Sapphire laser system. The low emittance subpicosecond electron bunch at the gun exit can be used in femtosecond electron diffraction setup to visualize the ultrafast structural dynamics. After acceleration and compression, the electron beam with the energy of 50 MeV is further used to provide high peak brightness X-ray by inverse Compton scattering with TW laser. We also consider the possibility and reliability of storing the electron beam in a compact storage ring and the laser pulse in a super-cavity. Operating in this scheme may increase the average flux of the X-ray photons by orders of magnitude.

## INTRODUCTION

The ultra-fast electron beam and X-ray are important probes for structural dynamics on the atomic and molecular scale in a number of fields including solid state physics, material science, chemistry and biology. To meet the demands, several next-generation light sources and R&D projects are initiated in the world. A multi-discipline ultra-fast source is also proposed in Tsinghua University [1]. Based on the photocathode RF gun and inverse Compton scattering, the facility will provide ultra-fast electron beam and X-ray for the user community to investigate the scientific frontiers. We report in this paper the conceptual design and ongoing R&D for the multi-discipline ultra-fast source.

## SOURCE LAYOUT AND R&D

The source will be built in the experiment hall of our department. As shown in Figure 1, it consists of photocathode rf gun, linac, beam diagnostic equipments, compact storage ring, laser system, power source and control system. The photocathode RF gun will produce ~2.7 MeV subpicosecond electron bunch for electron diffraction experiment. With different working point, the electron bunch with energy of 5 MeV and bunch length of 10 ps could also be generated. The beam will be injected into the following S-band travelling wave (TW) tube for post acceleration and compression. At the exit of the linac, the electron bunch with energy of about 50 MeV will enter into the interaction chamber and collide with the TW laser pulse. The X-ray photons are generated in the velocity direction of the electron beam and will be detected with a microchannel plate (MCP). Even though this scheme can provide high peak brightness X-ray pulse, the average flux is relatively low due to the low repetition rate of TW laser system. To get high average flux X-ray pulse, a compact storage ring and super-cavity are used to store electron beam and laser, and then the scattering event rate between them is increased to several hundreds MHz.

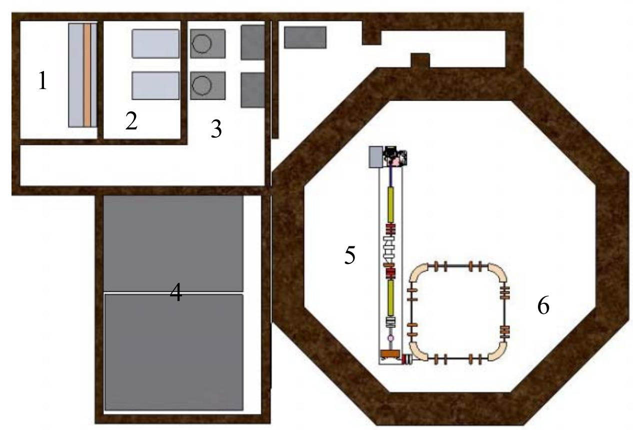


Figure 1: The schematic layout of ultra-fast source 1-control room 2-modulator 3-klystron 4-laser clean room 5-gun and linac 6-compact ring.

Table 1: Design parameters of ultra-fast source

| | |
|---|---|
| **Laser beam** | |
| Wavelength | 800 nm |
| Pulse energy | 600 mJ |
| Pulse duration | 30 fs |
| Focal spot radius | 0.05 mm |
| **Electron beam** | |
| Energy | 40~60 MeV |
| Bunch duration(rms) | 1~3 ps |
| Charge | 1.0 nC |
| Beam radius | 0.05 mm |
| **x-ray pulse** | |
| Photon energy | 16~72 keV |
| Pulse duration | 230~1000 fs |
| Number of photons | $3.5\times10^{6}$~$3.2\times10^{7}$ |

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Table 1 summarizes the design parameters. In the following we will give the detailed designs for different parts.

### *Phtocathode RF gun*

We have developed an S-band 1.6 cell BNL/KEK/SHI type photocathode RF gun with copper cathode [2-3]. When operated in low gradient condition, it can provide subpicosecond electron beam for UED (Ultrafast Electron Diffraction). The simulation results with Parmela indicate that with proper launching phase, the electron beam with energy of 2.7 MeV, bunch length of 130 fs and bunch charge of 0.08 pC can be produced [4]. This beam will finally provide a temporal resolution of 250 fs for the UED. The number of electrons is orders of magnitude larger than that used by conventional DC gun based UED and may enable a single shot imaging for the ultra-fast structural dynamics. When operated in high gradient condition, the photocathode rf gun will deliver 5 MeV electron bunch with bunch rms length of 3ps to the linac.

### *Linac*

The 5 MeV electron beam is space charge dominated. It will enter a drift section after exiting the gun where the emittance compensation occurs. At the end of the drift section, the beam is properly focused to form a waist and matched to the accelerating section. It consist of two S-band 1.5m TW tube separated by the 4 bend type chicane, diagnostic devices and scattering chamber. A 50MW klystron is used to feed the gun and two TW tube. The beam energy at the exit of the linac is about 50 MeV. In order to get ultra-short and high flux X-ray, the chicane will compress the beam rms length from 3 ps to 1 ps. Figure 2 gives the evolution of the bunch length and emittance along the linac with Parmela.

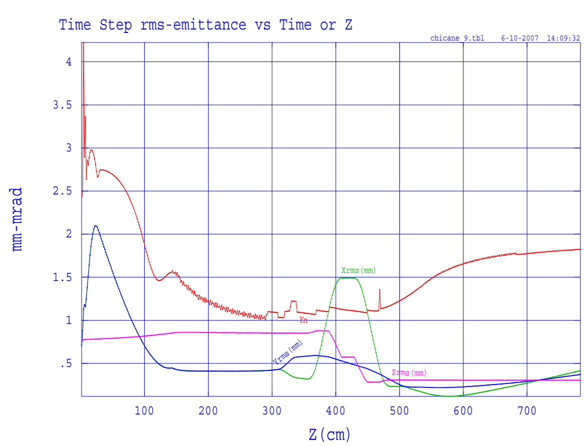


Figure 2: Bunch length and normalized transverse emittance along the linac.

### *Laser system*

There are two laser systems, one is the driving laser for the photocathode RF gun, the other is the TW laser for inverse Compton scattering. The driving laser system is a commercial product of Coherent Inc. As shown in the right part of Figure 3, a 800 nm, 110 fs FWHM laser pulse from diode-pumped Ti:Sapphire oscillator is sent to the regenerative amplifier, from which 1 kHz, 2 mJ IR pulse is produced. After three harmonic generator, we get 500 μJ, 110 fs UV pulse centered at 266 nm with 1 kHz repetition rate. The femtosecond UV pulse can directly illuminate the cathode and generate ultrashort electron bunch for UED applications. Alternatively, when the electron beam is used to drive the inverse Compton scattering X-ray source, the UV pulse can be stretched to 2-12 ps with a UV pulse stretcher. The relatively long pulse is a compromise between high charge and low emittance, which is essential to the development of high brightness pulsed X-ray source.

Some upgrade work is also shown in Figure 3, such as compensation for the temporal and spatial distortion due to grazing incidence, temporal and spatial pulse shaping. To measure the UV pulse length and test the temporal pulse shaping, a cross-correlator has been built [5].

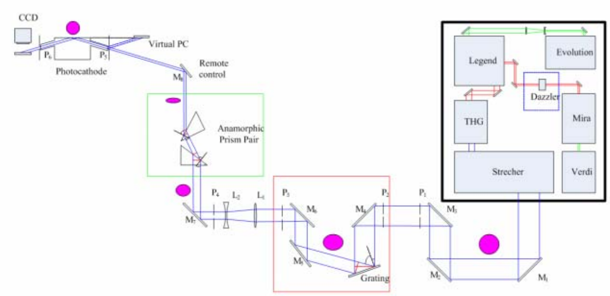


Figure 3: The schematic layout of driving laser system

In addition to the driving laser, a 20 TW Ti:Sapphire laser system is now being designed and constructed. The super-cavity that stores laser pulse to enhance the colliding event rate is also under design.

### *Synchronization*

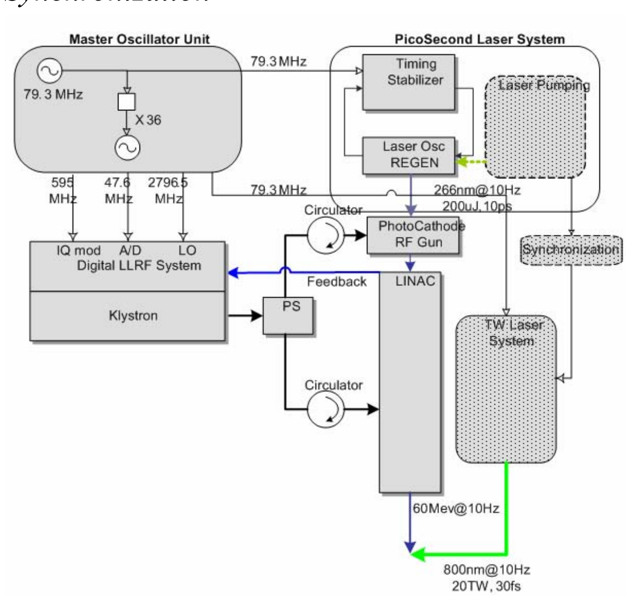


Figure 4: Conceptual design of synchronization



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Synchronization is one of the key issues in developing the source. The timing jitter between the driving laser and RF accelerating field, between the relativistic electron beam and the scattering laser should be less than 0.3 ps and 0.5 ps respectively. Figure 4 is the conceptual design of the synchronization system, it consists of RF-laser synchronization, laser-laser synchronization and LLRF.

We have achieved less than 0.2 ps timing jitter between RF oscillator and laser oscillator based on phase locking feedback loop frequency stabilization. The Laser-laser synchronization will be achieved by adopting optic cross correlation method.

### *Compact storage ring*

To increase the average flux of X-ray, a compact storage ring is considered. The scheme with non-steady-state parameters is be used[6,7]. The ring lattice structure consists of four 90 degree bending section, two long and two short straight sections. The interaction point is located inside one of long straight section and the axis of super-cavity is aligned to this straight section. Figure 5 shows the amplitude and dispersion functions.

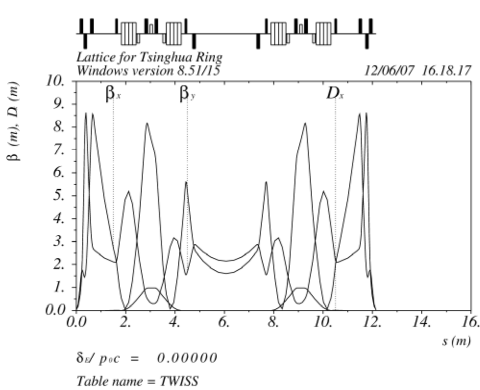


Figure 5: Lattice of compact storage ring

## SUMMARY

We presented the conceptual design of a multi-discipline ultra-fast source. The advantage of this source is that it can provide high property electron and X-ray with moderate cost and compact size. The key issue R&D, such as high brightness RF gun, synchronization technique, beam diagnostics, etc. are going on. TW laser system, pulse modulator, klystron and linac tube will be ready next year.

## ACKNOWLEDGEMENTS

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