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A HIGH BRIGHTNESS ELECTRON BEAM RESEARCH AND APPLICATION BEAMLINE AT TSINGHUA UNIVERSITY

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Abstract

In this paper we report on the status and performance of a newly commissioned high brightness electron beamline at Tsinghua University. The beamline is dedicated to research on the physics and technologies of multi-MeV, low charge, high brightness electron beams, as well as applications including MeV ultrafast electron diffraction and imaging. The layout, simulation and measurement results of the beam parameters and the stability performance of the facility will be discussed. A liquid-phase UED sample delivery system and experiment methodology have recently been commissioned and established. Near-term upgrade to a variety of key components, including the high power rf source, laser-to-rf timing system, electro-optic lenses will also be presented.

INTRODUCTION

The physics, technology and application of generating high brightness electron beam through photo-emission source rise great interests. We nearly commissioned the Tsinghua Ultrafast Electron Diffraction beamline (THU-UED) facility, aiming at generating high brightness, low charge multi-MeV beam.The overview of beamline is shown in Fig. 1. The beamline is designed accordingly.

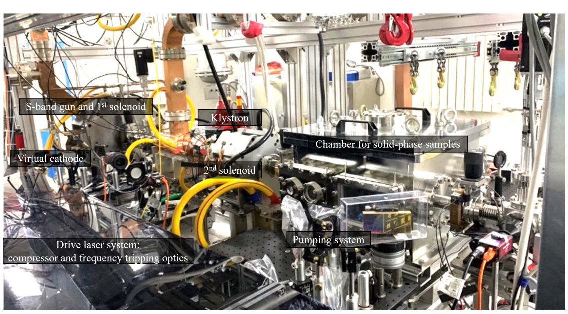

Figure 1: Overview of the THU-UED beamline.

The 50Hz repetition rate photoemission source of THU-UED is a 1.6 cell S-band RF gun [1], which accelerates the electrons rapidly to 3 MeV with a peak gradient of 70 MV/m.

Downstream the gun, two focusing solenoids give the capability to control the evolution of the beam spot size and angular divergence along the beamline. A vacuum chamber with a 5D sample stand (3D linear motion and yaw-pitch rotation) is installed right after the second solenoid. Recently, a new-dedicated vacuum chamber for liquid-phase experiments is installed and commissioned after the first chamber, together with a liquid sample delivery system and differential-pumping systems.

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BEAMLINE PERFORMANCE

To improve the stability and reproduciblility of the beamline, we construct effective monitoring system on laser, beam and the environment. During months of time, we evaluate the performance of beamline and introduce improvements continuously. The simulation and measurement results of beamline is listed as follows.

The drive laser with 266 nm wavelength is generated by frequency tripling of an IR source laser of 800 nm. The drive laser passes through a rotating iris with different apertures before it is imaged onto the cathode. A set of image transfer optics is placed after the iris so that the laser shaped by apertures can be presented directly on the cathode.

By employing iris and image-transfer system, the pointing jitter of the laser beam can be minimized, for the spot on the cathode depends on the image transfer of the apertures rather than its initial position. By employing a virtual cathode, we can measure the laser spot on the cathode. The typical position jitter of the spot is 1.5%. In general cases, the long-term UV energy jitter is 2%. The FWHM duration of the drive laser is measured to be 107 fs using autocorrelation method.

We employed a home-built high performance low level RF system [2] to monitor and feedback possible perturbations. A close-loop feedback system is used to narrowed down the input jitter on RF power and to fix the gun phase. The relative RF jitter and phase error is presented in Fig. 2. The rms close-loop RF amplitude jitter is 0.015%, while the rms phase error is lower than $\pm$ 0.08° as shown in Fig. 2.

In typical UED or other experiments when precise control on beam size is desired, we expect a tightly focused beam so that the beam passes through the sample with the same thickness. To achieve that goal, we introduce two movable apertures to cut the beam, whose size is 100 µm (upstream) and 300 µm (downstream). The downstream apertures are set to be larger so that they can be used to cut dark current without limiting the main beam. The rms beam size is presented in Fig. 3. Using the knife-edge method, the typical

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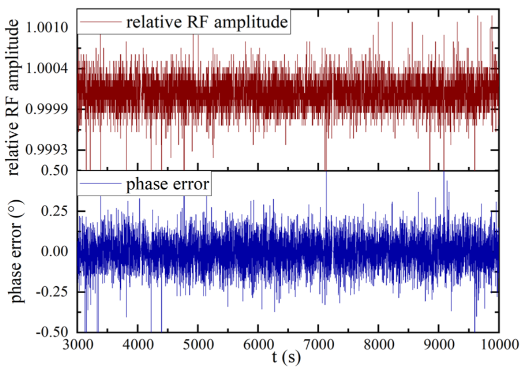

Figure 2: RF amplitude and phase error.

full beam width on the sample is 140 µm, which can be further fine-tuned by the strength of the second solenoid.

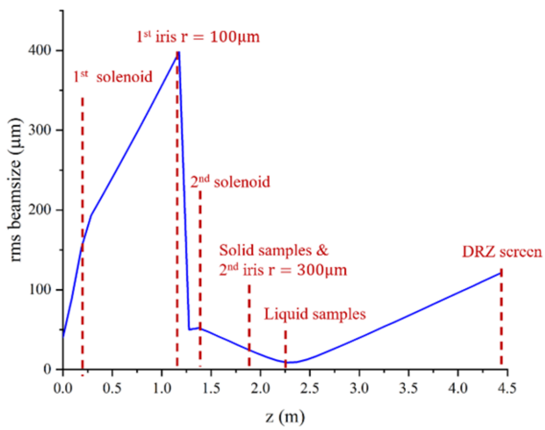

Figure 3: rms beam size in x direction.

At the end of the beamline, we use a DRZ screen to convert electrons to photons, which are then reflected by a metal mirror and collected by an EMCCD placed perpendicular to the beamline. The typical FWHM widths of the beam spot on the screen are 300 µm. The beam position fluctuation in a monitoring period of 15mins is presented in Fig. 4. Although the rms pointing jitter is no larger than 5 µrad (x direction) and 10 µrad (y direction), the long-term pointing drift in y direction is worse. In this example, the peak-to-peak position shifts are 30 µrad for y direction. This shifting will be reduced to a half after beamline warm-up of 5~6 hours. This large drift is probably caused by the undesirable vertical collimation of the gun and the first solenoid which results in a large beam steering along this direction. A quite strong vertical kicker is installed right downstream the gun, compensating for the height difference between the gun and the following beamline. The shift on power supply may then caused a much more severe beam shift in y direction compared with x direction.

LUED COMMISSIONING

Compared with solid-phase diffraction, liquid-phase UED experiments pose more technical challenges. Our UED

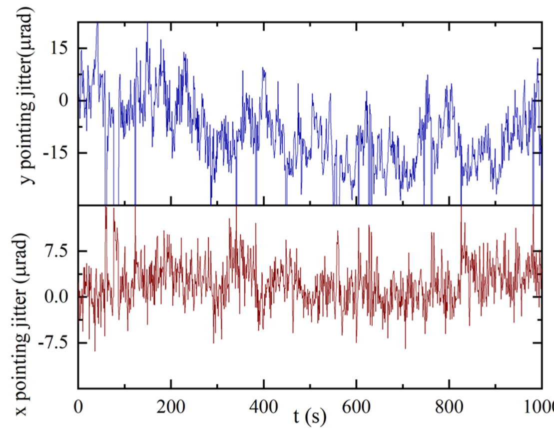

Figure 4: Beam position fluctuation for both direction on the screen.

beamline with high spatial resolution and deep penetration is suitable to investigate the structural information of molecules in liquid, denoted as LUED (liquid phase UED). The overview of vacuum chamber is shown in Fig. 5

Figure 5: Chamber for liquid-phase experiments and its sample stand under construction.

We designed and commissioned an in-vacuum substrate-free liquid delivery system for such diffraction schema, using a microfluidic chip and liquid-catching system [3]. A surface-tension-driven chip design is used to generate a big and thin liquid sheet. A typical liquid sheet in our experiment is > 2 mm long and >500 µm wide.

The biggest technical challenge in LUED experiments turns out to be maintaining a relatively high vacuum level for the upstream beamline. Because of the liquid flow of more than 4 ml/min, the vacuum level of the liquid chamber is no better than 0.1 Pa. However, the regular operation of the RF gun requires a vacuum level of 10^{-7} Pa. A four-stage differential pumping system is then installed to narrow down the influence of liquid fluid, and successfully make these huge vacuum differences a reality in the facility. We can now carry out continuous experiments for longer than 24 hours without vacuum incidents.

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With the improved performance of vacuum system, we have already verified the feasibility of our proposed LUED to successfully gather the diffraction patterns of liquid samples. A typical diffraction image is shown in Fig. 6. Isotropous property of liquid sample leads to the final results cannot be treated as a Bragg peak.

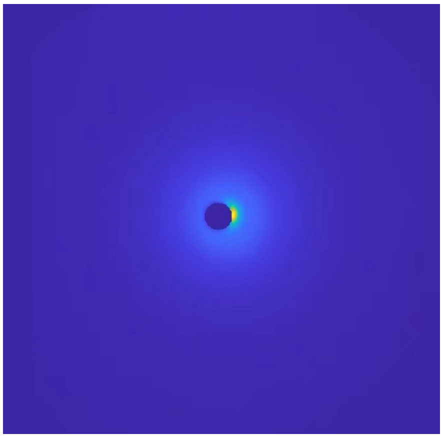

Figure 6: Typical diffraction image of LUED.

NEAR-TERM UPGRADES

Based on the performance of existing beamline and ongoing experiments, a series of upgrades are being implemented in a new facility under construction . Such upgrades are expected to considerably enhance the stability and precision of beam control for accelerator R&D and UED science experiments.

To begin with, a new bunker with temperature control system has already been built. Equipped with a high-performance clean room, the new experimental site ensures a much more stable and controllable environment of this facility. The layout of new bunker and beamline is shown in Fig. 7.

The recent development of an ultrahigh-vacuum S-band gun compatible with advanced semiconductor photocathode [4] carried out by Tsinghua enables the generation of brighter beam. We plan to use a special designed load-lock to employ advanced semiconductor photocathode in the high gradient gun for exploring routes towards brighter electron beams.

By employing a new klystron along with a new-designed high-voltage systems, the RF source is able to give much higher output so that the gun and RF-buncher can be operated simultaneously. Powered by a solid-state modulator with voltage stability <30 ppm, the new RF source could minimize the timing jitter and the energy jitter of electron beam. By introducing beam compressor, the facility is expected to reach a temporal resolution of few femtoseconds. Based on the promising improvements on temporal resolution, the new beamline is designed for pump-probe methods, giving us the opportunities to study dynamic procedure in much more complex systems.

Also, a new laser-to-RF timing system is developed in the recent years. The timing system currently in use has a timing shift of 50 fs over 24h monitoring, and a phase-locking jitter of 60 fs. By employing new EOM bias voltage controlling method, the day-long timing shift is limited to 10.53 fs(peak to peak). Meanwhile, the phase-locking jitter is controlled to 3 fs rms.

To enable high-precision control of electron beam, new electro-optic lenses are being designed and fabricated. The new focus solenoid employs advanced reeling structure and external water-cooling plate, which optimizes its cross-layer errors and enables higher peak fields.

The new THU-UED beamline is scheduled to be commissioned by the end of this year. The current status is shown in Fig. 8. It will carry significant upgrades compared to the previous facility, and serves as a high performance facility for research and student training in accelerator and ultrafast sciences.

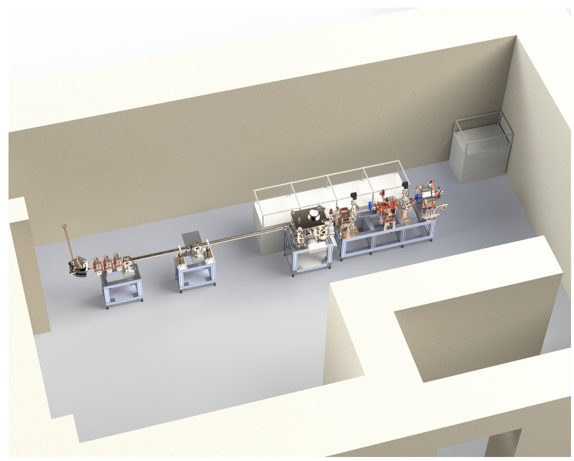

Figure 7: Layout of new THU-UED beamline.

Figure 8: New THU-UED beamline under construction.

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