FIRST BEAM TEST OF THE HIGH BRIGHTNESS PHOTO-INJECTOR AT NSRRC

A.P. Lee , M.C. Chou, N. Y. Huang, J. Y. Hwang, W. K. Lau, C.C. Liang, M.T. Tsou,
NSRRC, Hsinchu 30076 Taiwan.
Polly Wang, Department of Engineering and System Science,
National Tsing Hua University, Hsinchu 30013 Taiwan

Abstract

A High brightness injector at NSRRC is built for a VUV/THz free electron laser (FEL) facility and light source R&D. This injector with a photocathode rf gun with a solenoid for emittance compensation, a UV laser system, a 5.2 m S-band linac as well as various beam diagnostic tools has been installed in the linac test laboratory. The main goal is to produce beams with emittance smaller than 1 mm-mrad at energy of ~100 MeV. The other goal is to compress bunches to ~100 fs with charge of 100 pc and energy of ~30 MeV. In this contribution, an overview of the commissioning results of the photocathode rf gun and the laser system will be given. The first beam observation downstream the lianc will be presented in this paper.

INTRODUCTION

A THz/VUV free electron laser facility was proposed at National Synchrotron Radiation Research Center in Taiwansince 2013. In January 2013, thefirst photocathode RF gun was test inside the booster ring of NSRRC andelectrons were produced. Then it was decided to install the photo injector at linac test laboratory of NSRRC since the TPS linac system was moved from linac test laboratory to the TPS ring area. The major goal of building the photo-injector is to develop and study an electron source for VUV free electron laser and THz coherent undulator radiation at NSRRC [1]. The first main works is to produce a 1mm-mrad normalized transverse emittance beam at a charge of about 100 pC. Experimentalanalysis of beams after the gun and the linac will be compared to the GPT simulation results. It will help us to benchmark the operation point of the injector system.Details of the components of photo-injectorand diagnostic tools aredescribes elsewhere [2].The schematic overview of the THz coherent undulate radiation system is presented in the Fig. 1.

PHOTO-INJECTOR TEST

Photocathode RF Gun Processing and Dark Current Measurement

In the beginning of developing the photo-injector, the photocathode RF gun was set up in the TLS booster room then it was moved to the linac test laboratory and leaved unused for a long time, so it need to do RF processing again. The RF gun was processed by varying the rf amplitude of the incident field with RF frequency 2998.55 MHz, pulse length 2 µs and 10 Hz repetition rate. The total processing time is about 100 hours. After the processing the gun can be operated at peak field of 60 MV/m with the input power 4.85 MW andthe vacuum pressure with the RF poweris up to 1.6x10^{-6} mbar. It seems that there is a vacuum leakage inside the system. But we do not find the leakage point until now.The measured forward, reflected and dark current signals during the RF processing are shown in Fig. 2. The time axis has not been corrected for cable length differences.

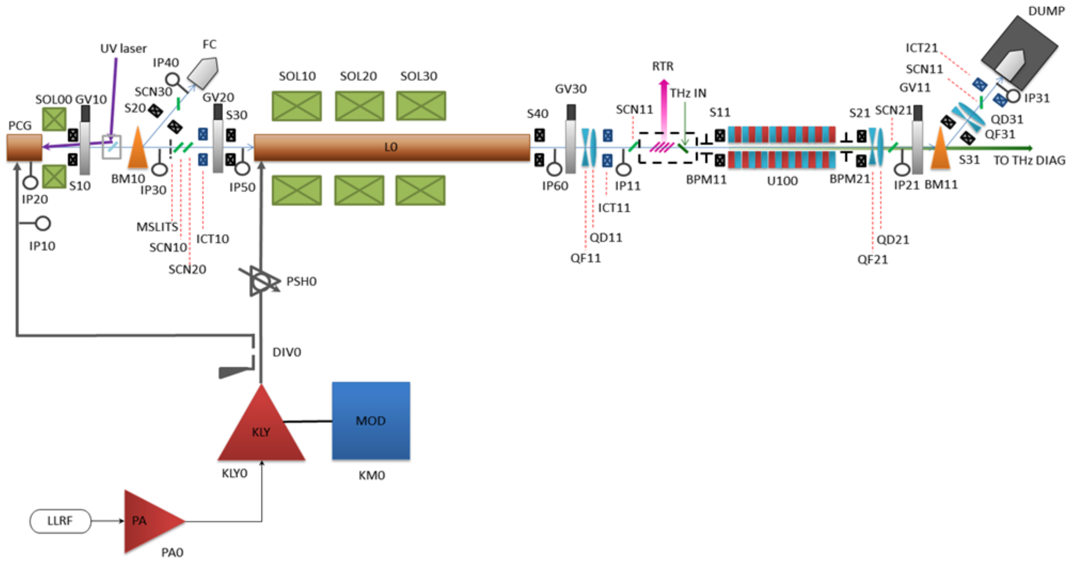

Figure 1: The layout of the THz coherent undulator radiation system.

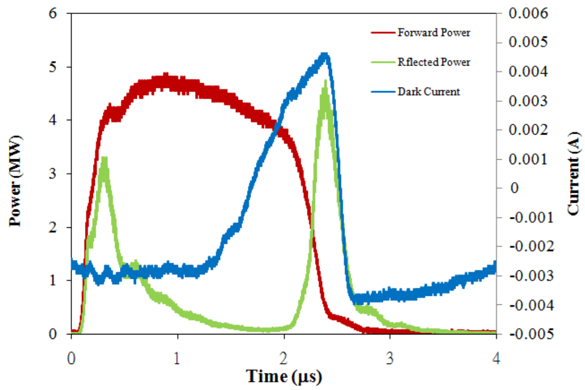

Figure 2: Forward power (red), reflected power (green) and dark current (blue) during rf processing.

The current exiting the gun is measured with a Bergoz ICT that was located at downstream of the solenoid magnet. The total charge is computed as the pulse area divided by the turn ratio 5.The magnetic field of the solenoid is set to maximize the beam charge passing through the ICT. The maximum dark charge is 1.1 nC at field strength 60MV/m. In addition the peak of the pulse divided by the turn ratio 5 is recorded as the peak current in order to plot the Fowler-Nordheim curves shown in Fig. 3. The field enhancement factor for the cathode is 97.5.

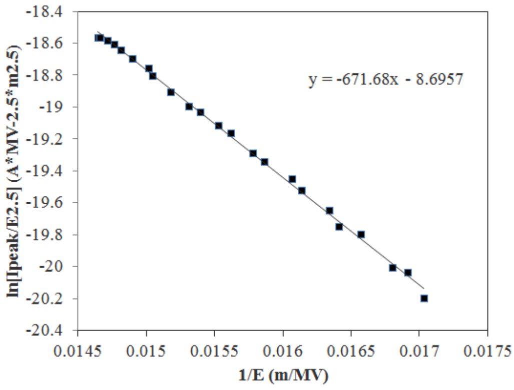

Figure 3: Fowler-Nordheim plot for the dark current measurement.

The Ultrafast Laser System

The NSRRC ultrafast laser system is a Ti:sapphire laser system based onthe chirped-pulse amplification technique. This system consists of an oscillator (Mira-900), an amplifier (Legend-F), a third harmonic generator (THG), and a UV stretcher. In 2013 this laser system was successfully used fordriving the NSRRC photocathode RF gun [3]. The system was moved to the linac test laboratory and installed in a temperature-humidity controlled clean room in the beginning of 2015. Currently the IR laseroutput from the Legend-F is 4mJ per pulse with energy stability 0.3% rms. After the THG and the UV stretcher, the UV laser pulse with 300 µJ and 0.8 – 10 ps adjustable pulse duration is used to drive the photocathode gun. We set the pulse duration of the UV laser at 3 ps for electron beam test. The photocathode RF gun is installed in the tunnel of the linac test laboratory whose location is about 30 metersaway from the laser room. Since the UV laser profile has slightly divergence and distortion after the UV stretcher, we collimate the UV pulse by a pair of convex lenseswith 5-m and 4-m focal length after the UV stretcher. After that, the UV laser pulse is focused to the size of 2.3 mm in the horizontal direction and 1.8 mm in the vertical direction by a convex lens of 2-m focal length, resulting in pointing stability of 8.6 µrad. However, the UV laser energy decreases to 180 µJ with energy stability <1.1% rms after propagating to the Cu cathode due to energy loss from optical components and absorption of the air. An energy tuner consisting of a half-wave plate and a polarizer is installed to adjust the UV energy on the cathode. A small portion of the UV laser reflected by the window of the laser chamber since the UV laser is obliquelyincident into the vacuum system.We direct the reflective UV laser to a virtual target and monitor the position of the UV laser. A mark on the screen of the virtual target is expected to the centre of the Cu cathode. We can control the UV laser to the right position by adjusting amirror 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 beam by adjusting that mirror.

Table 1: Specifications of the Drive Laser System

Parameter	Spec.
IR wavelength	800 nm
IR pulse energy	4mJ
IR pulse duration	100 fs
UV wavelength	266 nm
UV pulse energy	300 µJ (after UV stretcher) 180 µJ (@gun surface)
UV pulse duration	0.8 – 10 ps (adjustable)
Energy stability	1.1% rms
Pointing stability	8.6 µrad
Rep. rate	1 kHz– 10 Hz
Timing jitter	< 1 ps rms typical

High Power Microwave System

The high power microwave system includes a 35 MW pulsed klystron, ThalesTH2100A, which can deliver max peak power of 35MW at pulse duration of 4.5 µs. Adriver amplifier, ThalesTH2047 klystron, can provide one kilowatt to TH2100A klystron. Theoutput microwave is transmittedby vacuum waveguides. Thenthe powerfed to the gun and linac is adjusted by a high power hybrid. The phase of microwave fed to the linac is controlled using high power phase which is between the hybrid and the linac. The stability of the RF phase and amplitude of the high power microwave system is critical to photo-injector performance. In order to check the stability of the high power microwave system, an IQ demodulator was used to measure the RF amplitude and phase stability at the same time. The IQ demodulator from Polyphase Microwave Corporation. The IQ waveform are digitized using data acquisitioncard, ADLINK PCI 9820 digitizer with 14bit resolution and 60M/s sample rate. The amplitude and phase of RF pulses have been acquired and recorded for 1000 pulses.The standard deviation of the RF phase is σ_{phase}= 2°,at frequency 2998.55MHz. The relative standard deviation of the amplitude is 3.4%. These value do not meets the photo-injector requirements, and it may decreases the beam quality such as energy spread and transverse emittnce, so the RF stability needs to be further improved.

Quantum Efficiency

The quantum efficiency of the cathode is shown in Fig. 4. The injection phase of the laser was set on the maximum bunch charge location.The quantum efficiency was found to be $9\text{x}10^{-6}$ which is smaller than the quantum efficiency $1.5\text{x}10^{-5}$ measured in 2013 [4]. The pool vacuum of the RF gun may degrade the quantum efficiency.

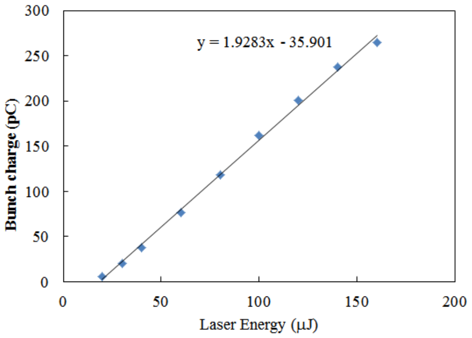

Figure 4: Bunch charge versus laser pulse energy.

Bunch ChargeMeasurement and Phase Scan

Bunchcharge was measured by the ICT. In Fig.5 the bunch charge is plotted as a function of different laser injection phase whilethe laser energy is 177μJ, RF field is 60MV/m. The maximum of bunch charge is 322pC at the RF gun phase that 75° behind the gun phase at zerocharge point.

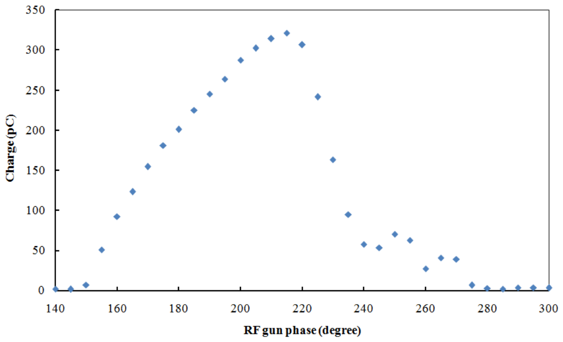

Figure 5: Bunch charge as a function of the RF gun phase

Initial Beam Test of the Photo-injector

After commissioning the 5.2 m, 2998MHz constant gradient linac to 5 MW (giving an estimated field of 7 MV/m), the beam test was started at the end of April,2016. A YAG:Ce screen downstream the linac is used to observe the beam profile. The electron beam profile is shown in the Fig. 6. The rms beam size is 1.3mm. The rmsbeam pointing stability is about 45μm horizontally and 57μm vertically.A quadruple has also been installed to measure the emiitance by quadruple scan method. The transverse geometric emiitance is about 0.83 μm. At the moment the energy spectrometer is not installed, so we cannot measure the beam energy and energy spread.

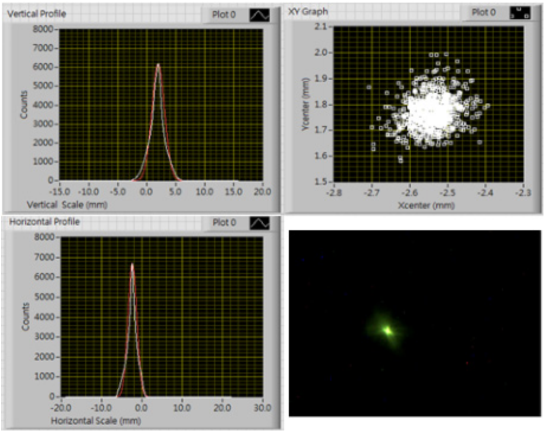

Figure 6: The electron beam profile and pointing stability downstream the linac.

SUMMARY

The photo- injector system for the THz/VUV FEL has been builtat NSRRC. The commissioning of the injector was finished at the beginning of April, 2015. The electron beam has been observed downstream the linac. The RF stability needsto be improved in order to match the requirement of the photo-injector next. The quadruple scan method will be used to measure the transverse emittance. The coherent transition radiation is under design for measuring the bunch length.

REFERENCE

[1]. N.Y. Huang et al., “Study of a THz/VUV Free Electron Laser Facility in Taiwan”, THPRO050, IPAC’14.

[2]. A.P. Lee et al., “The NSRRC Photo-injector Diagnostic Tools for Initial Beam Test”, MOPB055, IBIC’15.

[3]. M.C. Chou et al., “Operation of the drive laser system for the 2998MHz NSRRC photoinjector”, WEPWA059, IPAC’13.

[4]. A.P. Lee et al., “Operation of the NSRRC 2998 MHz photo-cathode RF gun”, WEPWA058, IPAC’13.