ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP030

AN UPDATED DESIGN OF THE NSRRC SEEDED VUV FREE ELECTRON LASER TEST FACILITY

W.K. Lau[1], C.K. Chan[1], C.C. Chang[1], C.H. Chang[1], L.H. Chang[1], C.H. Chen[1], M.C. Chou[1], P.J. Chou[1], F.Z. Hsiao[1], H.P. Hsueh[1], K.T. Hsu[1], K.H. Hu[1], C.S. Hwang[1], J.Y. Hwang[1], J.C. Jan[1], C.K. Kuan[1], A.P. Lee[1], M.C. Lin[1], G.H. Luo[1], S.Y. Teng[2], K.L. Tsai[1], J. Wu[3], A.W. Chao[3]
[1] NSRRC, Hsinchu, Taiwan
[2] Department of Physics, NTHU, Hsinchu, Taiwan
[3] SLAC National Accelerator Laboratory, Menlo Park, USA

Abstract

In this report, we present an updated design of the facility which is a 200 nm seeded, HGHG FEL driven by a 250 MeV high brightness electron linac system with dogleg bunch compressor for generation of ultrashort intense coherent radiation in the vacuum ultraviolet region. It employs a 10-periods helical undulator for enhancement of beam energy modulation and a helical undulator of 20 mm period length as the radiator (i.e. THU20) to produce hundreds of megawatts radiation with wavelength as short as 66.7 nm. An optional planar undulator can be added to generate odd harmonics (e.g. 22.2 nm, 13.3 nm etc.) of the fundamental. The facility layout and expected FEL output performance is reported.

INTRODUCTION

The Baseline design of the test facility is a VUV high-gain harmonic generation (HGHG) FEL seeded by a 200 nm laser. The seed laser is injected to a 10-periods helical undulator of 24 mm period length (i.e. THU24) for beam energy modulation. A small chicane located at downstream of THU24 provides the required dispersion for microbunching. In the first phase of the project, a THU20 undulator of length at about twice of gain length will be used as the radiator which allows generation of MW-level coherent radiation at 66.7 nm wavelength (i.e. the third harmonic of the seed). If the more segmented THU20 undulators are used, the radiation grows and saturates in ~6 m. In the initial stage, the facility has to be fitted into the existing 38 m × 5 m tunnel in the Accelerator Test Area (ATA). Since the total length of the accelerator system from the gun to beam modulator entrance is about 25.5 m, the length of the FEL section and its output diagnostics station is limited to 12.5 m. Future extension of the laboratory building will be necessary if more THU20 undulators are installed for FEL operation at saturation. Extra space will also be needed for photon beamlines and experimental stations if a practical user facility is under consideration. Nevertheless, a 1.5 m long THU20 undulator prototype will be used to demonstrate the concepts in the initial stage. A schematic of the overall layout is shown in Fig. 1.

Broad tunability of radiation wavelength of the VUV FEL can be achieved by using tunable seed laser. The klystron systems operate at 10 Hz pulse-prepetition-rate rate, and can be increased up to 50 Hz if demand arises.

ACCELERATOR SYSTEM

The facility is based on a recently built 2998 MHz laser driven photoinjector which delivers low emittance electron beam for the 250 MeV drive linac system. Since the beam brightness required for the seeded VUV FEL system located at downstream of the linac system is as high as $5x10^{13}$ A/m^2, bunch compressor with capability to linearize electron distribution in longitudinal phase space is therefore essential. Conventional four-dipole chicanes are usually equipped with harmonic rf linearizers to compensate the nonlinearities introduced into beam distribution by the rf curvature of chirper linac. However, harmonic rf linac as well as the corresponding pulsed klystron system do not fit into our budget plan, we therefore consider to exploit the concept of dogleg bunch compressor with linearization optics. After bunch compression, the sub-100 fs beam is then accelerated to designed beam energy by two rf linac sections that are powered by a single klystron with standard SLED cavity for rf pulse compression. A linear achromatic beam transport system delivers the beam to the FEL system and allows coupling seed laser collinearly with the beam in the beam energy modulator unit. Beam parameters are listed in Table 1.

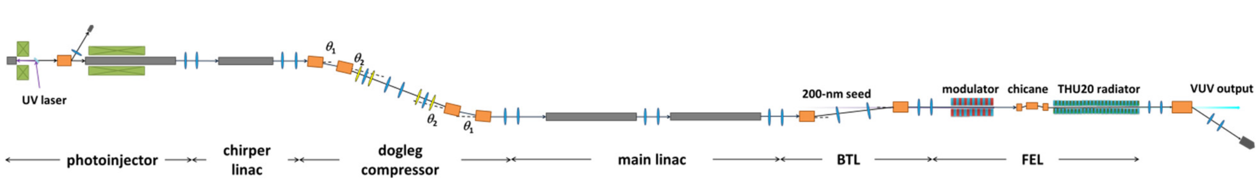

Figure 1: Layout of the NSRRC VUV FEL test facility.

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP030

Photoinjector

Operation of the 2998 MHz photo-cathode rf gun system (Fig. 2) has been successful in 2013 after high power microwave processing of the gun cavity up to ~70 MV/m. A 266 nm, 300 μJ laser system that consists of an ultrafast Ti:Sapphire regenerative amplifier and nonlinear optics has been used to drive the Cu photo-cathode. The system delivers regularly an electron beam with energy of 3.3 MeV at 250 pC bunch charge [1]. Beam transverse emittance of 2-3 mm-mrad is achievable. With a 5.2 m long rf linac section, the beam energy will be boosted to ~70 MeV. For operation at higher field gradient and 50 Hz pulse repetition rate, a new rf gun cavity is under development [2].

Figure 2: The NSRRC 2998 MHz photoinjector system.

Dogleg Bunch Compressor

A single stage nonlinear bunch compressor designed for the proposed facility is a double dog-leg configuration that provides a first order longitudinal dispersion function (i.e. R_{56}) with a sign opposite to that of a conventional four-dipole chicane. Variation in the bunch length or the peak current for various operation conditions can be done by tuning R_{56}. This can be realized by changing the longitudinal positions of the outside dipoles and by adjusting the quadrupoles and sextupoles settings for desired bunch compression [3].

Main Linac

After bunch compression, the beam is accelerated to higher energy by two 5.2 m rf linac sections. They are powered by a 35 MW pulsed klystron with standard SLED cavity for rf pulse compression. We expect a beam energy gain of 140 MeV from these two rf linac sections.

Dechirper

As revealed from ELEGANT simulation, a residual energy chirp of 41.7 keV/μm is left after bunch compression. It can be corrected by a capacitive dechirper structure when the bunch is slightly over-compressed. We tentatively use a 1 m long corrugated pipe to remove the residual energy chirp in our previous study [3]. However, we considered using dielectric-lined waveguide structures to simplify the mechanical design of the dechirper system and to save space [4,5].

Table 1: Nominal Beam Parameters of the Drive Linac used in Design Study

Beam energy [MeV]	250
Beam current [A]	500
Bunch length [fsec]	~50
Normalized sliced emittance [mm-mrad]	3
Sliced energy spread [keV]	200
Repetition rate [Hz]	10

FEL SYSTEM

The 200 nm seed laser is coupled into a 10-period helical undulator of 24 mm period length for beam energy modulation (see Fig. 3). With the dispersion provided by a small chicane after the modulator, the beam is slightly bunched at 200 nm spacing and radiate coherently at its harmonics when some resonant condition is met. In our case, we employ a THU20 helical undulator of 20 mm period length which is tuned to resonance at third harmonics as radiator which allows generation of intense coherent radiation at 66.7 nm wavelength. If the more segmented THU20 undulators are available, as can be shown from start-to-end simulation, the coherent undulator radiation grows exponentially and saturates within a few meters [6]. In the initial stage, the facility has to be fitted into the existing 38m x 5m tunnel in the Accelerator Test Area (ATA). Future extension of the laboratory building will be necessary if more THU20 undulators are installed for FEL operation at saturation. Extra space will also be needed for photon beamlines and experimental stations if a practical user facility is under consideration. Nevertheless, a 1.5 m long THU20 undulator prototype can be used to demonstrate the concepts in the initial stage. Design FEL parameters are listed in Table 2. An optional planar undulator can be added to generate odd harmonics of the fundamental.

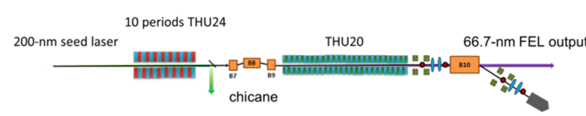

Figure 3: The VUV FEL system.

Table 2: Design Parameters of the NSRRC VUV FEL

Modulator	
Period length [mm]	24
Length [m]	0.24
Strength parameter K	1.73
Seed laser wavelength [nm]	200
Laser power [MW]	300
Energy modulation [%]	0.14
Radiator	
Period length [mm]	20
Strength parameter K	0.78
VUV radiation	
Wavelength [nm]	66.7
Peak power [MW]	200
Gain length [m]	0.69

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-THP030

Seed Laser

The 200 nm seed (Fig. 4) is produced from a fourth harmonic generator (FHG) which is driven by a 800 nm laser amplifier. This 800 nm laser amplifier shares the same master oscillator with the photo-cathode rf gun drive laser system. The seed laser will be coupled to the THU24 helical undulator via the achromatic beam transport section located upstream. Broad tunability of radiation wavelength of the VUV FEL can be achieved by using tunable seed laser.

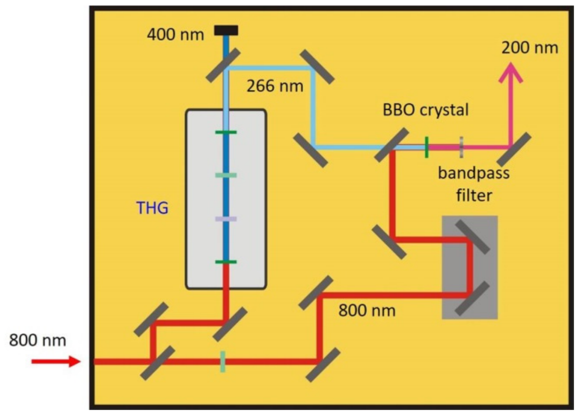

Figure 4: Schematic diagram of the 200-nm seed driven by a 800 nm laser.

Helical Undulators

A novel type twin-helix undulator (THU) with a short period length of 20 mm has been designed for the NSRRC VUV free electron laser test facility [7]. This undulator consists of two helical magnet arrays symmetrically arranged along a 1.5 m beam axis. The NdFeB permanent magnet with helical shaped poles is designed and optimized to generate a high helical field of 1.05 T in a 5.6 mm round gap along its axis. End pole design and shimming methods are considered to achieve a wider and very precise field performance in the small-bore diameter. Moreover, with a 0.5 mm space between two helical arrays, weak magnetic forces of only 1500 kgf are expected for the 1.5 meter long undulator. A simple and low-cost mechanical structure was designed for this horizontal open gap undulator. The modulator is a 10-period helical undulator of the same type except period length is 24 mm.

CONCLUSION

We presented a new design of the facility which is a 200 nm seeded, HGHG FEL driven by a 250 MeV high brightness electron linac system with dogleg bunch compressor for generation of ultrashort intense coherent radiation in the vacuum ultraviolet region. It employs novel helical undulator for enhancement of beam-wave interactions in modulator as well as the radiator. It is capable of producing 200 MW coherent VUV radiation with wavelength as short as 66.7 nm.

REFERENCES

[1] A. P. Lee *et al.*, "First beam test of the high brightness photo-injector at NSRRC", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 1800–1802. doi:10.18429/JACoW-IPAC2016-TUPOW025

[2] W. T. Chiu, "Design of a 2998 MHz laser-driven photocathode rf gun for EUV free electron laser operation at high repetition rate", National Tsing Hua University master thesis, 2019.

[3] W. K. Lau *et al.*, "Design of a dogleg bunch compressor with tunable first-order longitudinal dispersion", in *Proc. FEL'17*, Santa Fe, NM, USA, Aug. 2017, pp. 309-312. doi.org/10.18429/JACoW-FEL2017-TUP031

[4] L. Xiao, W. Gai and X. Sun, "Field analysis of a dielectric-loaded rectangular waveguide accelerating structure", *Phys. Rev. E*, vol. 65, p. 016505, 2001. doi:10.1103/PhysRevE.65.016505

[5] S. Antipov *et al.*, "Experimental observation of energy modulation in electron beams passing through terahertz dielectric wakefield structures", *Phys. Rev. Lett.*, vol. 112, p. 114801, 2014. doi:10.1103/PhysRevLett.112.114801

[6] S. Y. Teng *et al.*, "Start-to-end simulation of the NSRRC seeded VUV FEL", presented in the *39th Int. Free-Electron Laser Conf. (FEL'19)*, Hamburg, Germany, Aug. 2019, TUP091, this conference.

[7] T. Y. Chung *et al.*, "Twin-helix undulator for round beam-related light sources", *Synch. Rad. News*, vol. 31, no. 3, p. 14-17, 2018. doi:10.1080/08940886.2018.1460169