ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP032

SRF GUN AND SRF LINAC DRIVEN THz AT ELBE SUCCESSFULLY IN USER OPERATION

R. Xiang†, A. Arnold, P. Evtushenko, S. Kovalev, U. Lehnert, P. Lu[1], S. Ma, P. Murcek, P. Michel, A. Ryzhov, J. Schaber[2], C. Schneider, J. Teichert, H. Vennekate[3]
Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
I. Will, Max-Born-Institut, Berlin, Germany
[1]present address: KLA-Tencor, Shanghai, China
[2]also at Technische Universität Dresden, Dresden, Germany
[3]present address: RI Research Instruments GmbH, Bergisch Gladbach, Germany

Abstract

The first all-SRF accelerator driven THz source has been operated as a user facility since 2018 at ELBE radiation center. The CW electron beam is extracted from SRF gun II, accelerated to relativistic energies and compressed to sub-ps length in the ELBE SRF linac with a chicane. THz pulses are produced by passing the short electron bunches through a diffraction radiator (CDR) and an undulator. The coherent THz power increases quadratically with bunch charge. The pulse energy up to 10 µJ at 0.3 THz with 100 kHz has been generated.

INTRODUCTION

Benefit from the superconducting RF techniques, ELBE with SRF photoinjector and Linac has the unique feature to operate in continuous wave (CW) mode as a user facility open for the research work worldwide with electrons and the secondary radiation, including the lately demonstrated THz source. The success of SRF gun II at ELBE is meaningful for THz radiation production due to the higher bunch charge than the old thermionic DC gun. In this contribution, the experimental setting up for the THz generation will be introduced, including the operation of SRF gun II and the acceleration/compression concept in the linac, and also the parameters of THz radiation.

EXPERIMENTAL LAYOUT

Figure 1 shows the ELBE beamline layout for the THz radiation production with the SRF gun and Linac. The CW electron beam is extracted from SRF gun II, accelerated to relativistic energies in the ELBE SRF linac and compressed to required sub-ps length with a chicane. THz pulses are produced by passing the short electron bunches through a diffraction radiator (CDR) and an undulator.

Operation of SRF Gun II

The present SRF Gun-II is an updated version based on the experience of the first SRF Gun [1, 2]. Since 2014 SRF gun II has been installed as the second CW injector at ELBE centre.During the commissioning, the acceleration gradient of 8 MV/m (20.5 MV/m peak field on axis) has been achieved. With Mg cathode illuminated with 258nm laser the SRF gun II provides e- beam with bunch charge up to 300 pC, which is limited by the space charge effect on cathode surface. In last years, commissioning with further improvements and optimization of components as well as our operational experience has increased the performance and reliability so that the SRF Gun-II is now applied for user operation. Now SRF gun II is the standard injector for THz production at ELBE [3].

The design of the cryomodule of SRF gun II is shown in Fig. 2. The gun cryomodule holds a 3.5 cell gun cavity and a superconducting solenoid.

The photocathode consists of bulk magnesium with a quantum efficiency (QE) of 0.3 %. At the cathode, a laser pulse energy of about 0.3 µJ is needed to produce the 200 pC pulses. At the photocathode the laser spot size is about 4 mm in diameter. The temporal profile is Gaussian with an rms pulse length of about 2 ps. The beam parameters are shown in Table 1.

The CW electron beam extracted from SRF gun II has kinetic energy of 4 MeV. After focused with a SC solenoid the beam leaves the gun and passes through a quadrupole triplet and an achromatic dogleg structure, injecting into ELBE linac beam line.

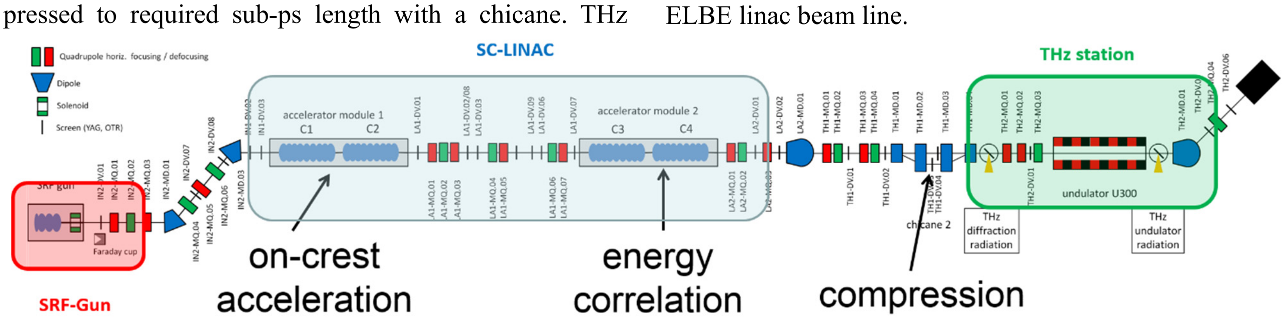

Figure 1: The ELBE beamline layout for the THz radiation production with the SRF gun and Linac.

† r.xiang@hzdr.de

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP032

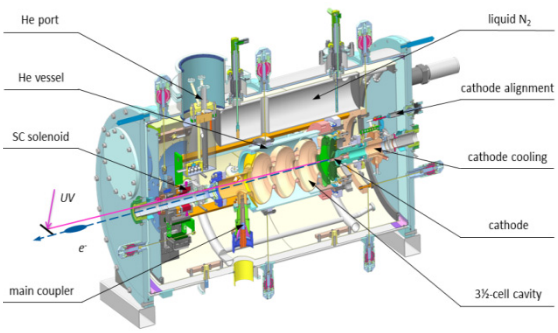

Figure 2: Cross section of the ELBE SRF gun II cryomodule, holding a 3.5 cell gun cavity and a superconducting solenoid.

Table 1: SRF Gun and Beam Parameter Values

Parameter	Value
E_{acc} / E_{peak}	8 MVm^{-1} / 20 MVm^{-1}
beam energy E_{kin}	4 MeV
Bunch charge	100 ~ 200 pC
Pulse repetition rate	100 kHz CW
Beam current	10 - 20 µA
Dark current	33 nA
Photocathode / QE	Mg / 0.1 -0.3 %
Laser spot on PC	ϕ 4 mm
Laser pulse length	2.6 ps rms

To be noticed, SRF gun with Mg cathode has no multipacting problem. Another important character of SRF gun II is the low dark current, which comes from field emitters on the cavity surface, little from cathode.

SRF Linac and Bunch Compression

In the first accelerator module with two 9-cell Tesla cavities the beam is accelerated on-crest to an energy of 16 MeV. Further acceleration happens in the second module with another two Tesla cavities, where the acceleration is off-crest with a phase of about 45° in order to produce the needed energy chirp of the bunch. The final beam energy amounts to 26 MeV. In the magnetic bunch compressor (chicane 2) the bunch is compressed to the required sub-ps length. The final bunch length is defined by the uncorrelated energy spread and phase space nonlinearities [4].

The mirror downstream sends the radiation towards the THz laboratory whereas the electron beam passes through a centred hole towards the undulator (U300 as shown in Fig. 1). In this electromagnetic undulator with 8 periods and a period length of 300 mm the super-radiant undulator radiation is produced with a designated range between 0.1 and 3 THz. It follows a second hole-punched THz mirror, a bending magnet and the dump for the electron beam. Near the beamline a broad-band power meter and with an insertable screen the bunch length can be determined from coherent transition radiation in a Martin-Puplett interferometer (see Fig.3).

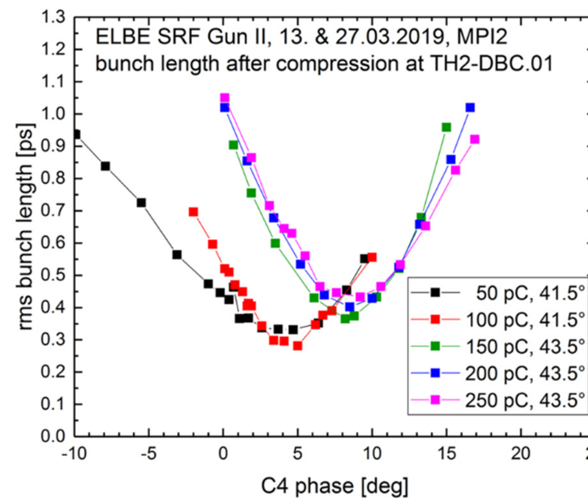

Figure 3: Bunch length measurement after compression with Martin-Puplett Interferometer (MPI). The optimized bunch length is about 300 fs.

THZ RADIATION FOR USERS

In the first season of 2019, 31 ELBE shifts for THz users were performed. And in the second season 17 shifts THz and ELBE machine development with SRF gun II are done. The main wavelengths are between 0.2 THz to 1.5 THz.

Figure 4 presents the measured THz power as the function of bunch charge for beam parameters optimized for 200 pC. As expected a quadratic dependency is obviously here, which means the compression concept successful.

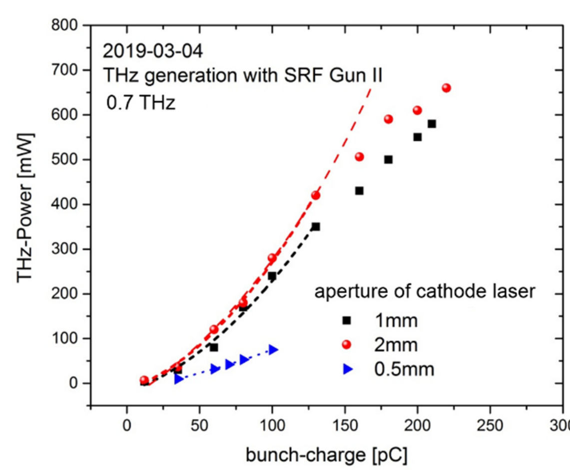

Figure 4: Measured THz power vs. bunch charge.

Because SRF Gun II can provide higher bunch charge than the old thermionic DC gun, the pulse energy of THz radiation has been improved in a large scale. Figure 5 shows the total THz power vs. THz wavelength, comparing the results with SRF Gun II and with thermionic DC gun. The

ISBN: 978-3-95450-211-0 doi:10.18429/JACoW-SRF2019-THP032

difference of 2018/2019 is due to the change of bunch compression situation. THz production at 0.3THz with 250 pC has been demonstrated, where 10 µJ @ 100 kHz CW has been produced.

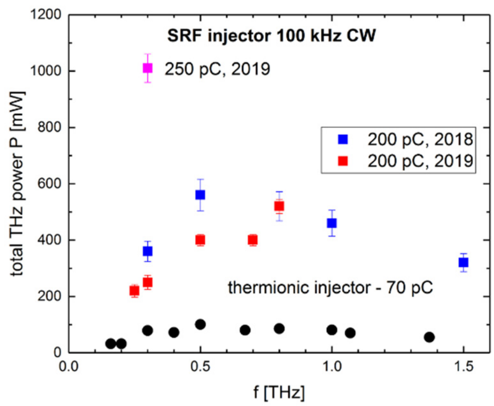

Figure 5: Total THz power vs. THz wavelength, comparing with SRF Gun II and with thermionic DC gun. The difference of 2018/2019 is due to the change of bunch compression situation. THz production at 0.3THz with 250 pC.

CONCLUSION

The first all-SRF accelerator driven THz source has been operated as a user facility at ELBE radiation centre. The SRF gun II has operated stably for a number of user experiment shifts without any shutoffs. The next step is to improve the stability and further increase the bunch charge, which is limited by the space charge effect in gun and the beam transport in the dog leg area.

The amplitude stability and timing jitter are measured by the THz user labor, showing at least a factor of two better than that with the thermionic injector. The timing jitter about 1 ps rms is mainly coursed by the RF phase stability of the accelerator and therefore rather independent of the injector used.

The stable high peak energy and high average power THz radiation have given out convincing results, attractive for the new scientific cases required ultrashort, high intensity THz sources with adjustable wavelengths.

ACKNOWLEDGEMENTS

We would like to thank the whole ELBE team for their help with this project. The work was partly supported by the European Community under FP7 program (EuCARD-2, contract No.312453, and LA^{3}NET, contract No. 289191), and the German Federal Ministry of Education and Research (BMBF) grant 05K12CR1, as well as Deutsche Forschungsgemeinschaft (DFG) project (XI 106/2-1).

REFERENCES

[1] A. Arnold *et al.*, "Development of a Superconducting Radio Frequency Photoelectron Injector", *Nucl. Instr. Meth. A*, vol. 577, pp. 440-454, 2007. Doi:10.1016/j.nima.2007.04.171.

[2] J. Teichert *et al.*, "Free-electron Laser Operation with a Superconducting Radio-frequency Photoinjector at ELBE", *Nucl. Instr. Meth. A*, vol. 743, pp. 114-120, 2014. Doi:10.1016/j.nima.2014.01.006

[3] B. Green *et al.*, "High-field High-repetition-rate Sources for the Coherent THz Control of Matter", *Sci. Rep.* 6, 22256 (2016). Doi: 10.1038/srep22256(2016)

[4] P. Lu, "Optimization of an SRF Gun for High Bunch Charge Applications at ELBE", PhD thesis, TU-Dresden, Germany, 2017.