Cs_2Te PHOTOCATHODE RESPONSE TIME MEASUREMENTS AND FEMTOSECOND COMB ELECTRON BEAM GENERATION AS A MILESTONE TOWARDS PRE-BUNCHED THz FEL REALIZATION

A. Aryshev[#,1], Y. Honda[1,2], K. Lekomtsev[1], M. Shevelev[1], N. Terunuma[1,2], and J. Urakawa[1],
[1] High Energy Accelerator Research Organization, Tsukuba, Japan
[2] SOKENDAI: The Graduate University for Advanced Studies, Tsukuba, Japan

Abstract

Currently there is a rapidly growing demand to increase the brightness of electron beams generated by conventional RF guns as well as to decrease the cost of the injector accelerator system for many research facilities worldwide. To address this demand we investigate one of the most important parameter of the high Q.E. conventional semiconductor Cs_2Te photocathode, its response time. It sets the principle limitation for generated bunch length and hence maximum achievable beam brightness of electron diffraction and pre-bunched THz FEL facility's injectors. The experimental investigation was done at KEK: LUCX facility. The Cs_2Te photocathode response time better than 250 fs was demonstrated. The generation of 4 micro-bunch comb electron beam with variable time separation as a crucial technology for pre-bunched THz FEL realization was achieved.

INTRODUCTION

The recent interest in high-brightness coherent THz light source (0.3 – 5 THz) radiation is associated with its ability to penetrate deep into many organic materials without the damage produced by ionizing radiation such as X-rays. In the last decade electromagnetic radiation in the terahertz frequency range is widely used in time-domain spectroscopy to understand biological processes, chemical reactions and for THz imaging [1]. Usual expectation from THz users community is a high brightness (high photon flux, density and short duration), wide spectrum tunability and compactness as well as low cost of the system. There are a few effective ways to construct such a THz source using particle accelerators [2]. One of the approach is to generate short electron bunches directly illuminating an RF gun photocathode with femtosecond laser pulses. To address this demand we investigate one of the most important parameter of the high Q.E. conventional semiconductor Cs_2Te photocathode, its response time. It sets the principle limitation for generated bunch length and hence maximum achievable beam brightness of electron diffraction and pre-bunched THz FEL facility's injectors.

It is also possible to construct tabletop THz FEL where a femtosecond comb beam is accelerated by a RF accelerating field with gradient of the order of 50 MV/m while carried on a single RF accelerating field cycle enabling it to be accelerated to 5 MeV in a 7.5 cm RF gun. When such a comb beam is passed in the vicinity of a periodical structure or through short edge-focusing wiggler [3] it generates Coherent Smith-Purcell Radiation (CSPR) [4] or Undulator radiation (UR) in "super-radiant'' regime if micro-bunch spacing becomes comparable with radiation wavelength which is comparable to the grating or undulator period.

Our plan is to develop and apply an accelerator based ultra-compact high-brightness coherent THz light source, with short pulses of ~10 MW peak power, variable frequency range from 0.3 to 5 THz, and typical energy 10 uJ/pulse [5]. It was decided to investigate the CSPR and UR as a potential candidate for generating intense broad-band radiation in THz frequency range as a part of a larger THz program launched at KEK: LUCX (Laser Undulator Compact X-ray project) facility. The program is aiming to investigate various mechanisms of EM radiation generation including Undulator radiation, Smith-Purcell and other special cases of Polarization Radiation. In this report the status of the experiment, LUCX RF Gun Ti:Sa laser system and comb beam generation will be presented.

LUCX is a multipurpose linear electron accelerator facility initially constructed as a RF gun test bench and later extended to facilitate Compton scattering and coherent radiation generation experiments. It consists of a high mode separation 3.6 cell RF gun, which was designed to produce a multi-bunch high quality electron beam with up to 1000 bunches, a 0.5 nC bunch charge, and 10 MeV beam energy. This beam can be then accelerated to 30 MeV by the normal conductivity 1 m 12–cell mode–separated linac booster. Table 1 summarizes electron beam parameters usually obtained in femtosecond operation mode of the LUCX. Figure 1 shows LUCX beamline schematics.

Table 1: LUCX Parameters in fs Operation Mode

Parameter	Values
Beam energy, typ.	8 MeV
Intensity/4 micro-bunches	10pC
Bunch length, max	1 ps
Bunch length, min	250 fs
Repetition rate, typ	3.13 train/s
Normalized emittance, ε_x x ε_y	4.7x6.5 πmm mrad

[#] alar@post.kek.jp

ISBN 978-3-95450-147-2

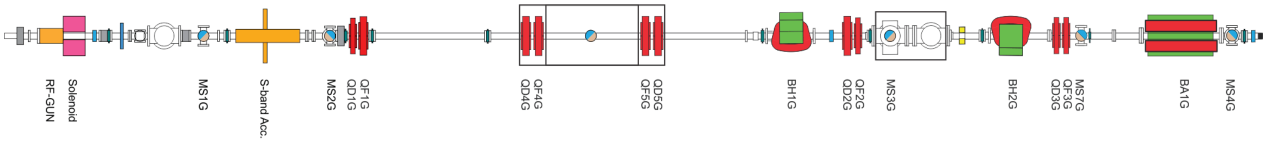

Figure 1: LUCX accelerator schematics.

To generate a sequence of femtosecond micro-bunches the well-established Titanium-Sapphire Chirped Pulse Amplification (CPA) technique laser system was chosen (Fig. 2).

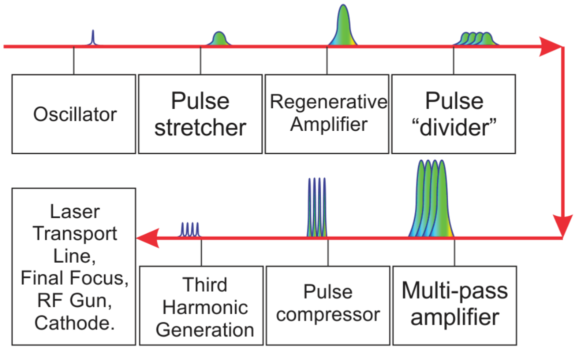

Figure 2: CPA technique: the pulse from the oscillator is stretched, amplified and recompressed to its original duration.

Laser pulses of a few tens femtoseconds from the oscillator are temporarily stretched to a picosecond level before they are amplified in Regenerative Amplifier (RGA). The "pulse divider" was installed right after the RGA so pulses are splitted and recombined with controllable delay by the double–pass Michelson interferometer. This modification allows generating sequence of a spectrally chirped picosecond pulses with variable time separation at the output of the Ti:Sa multi-pass amplifier. After that they are re-compressed back to a few tens femtoseconds. This is possible due to the same micro–pulses polarizations after multi–pass amplifier. As a result sufficient amount of laser energy was obtained at the laser system output allowing for third harmonic generation needed for Cs_2Te photocathode illumination.

To confirm electron beam parameters the quasi–ballistic electron beam optics was designed. This optics makes 250 mm horizontal dispersion at the MS3G 300 µm–thick YAG screen which is located beyond BH1G bending magnet after the linac booster. Calibrating transverse scale of the screen by BH1G dipole magnet current change we have measured initial electron beam kinetic energy is equal to E = 8.25 ± 0.002 MeV and energy spread is dE = 18.8 ± 0.2 keV, i.e. dE/E ~ 0.2%.

The rms electron bunch length was confirmed by the zero- phasing technique [6]. To estimate bunch length the correlation of the RF phase with image centroid shift on MS3G screen was measured. The linear approximation of this correlation effectively gives scale of the horizontal image size in RF degrees, what in turn can be recalculated to the time scale as follows. The linear slope of the calibration is 6.03 ± 0.32 mm/deg. what is 6.2 ± 0.3 µm/fs or 0.161 ± 0.008 fs/µm assuming 1deg. S-band (2856 MHz) RF is 972.6 fs. The evaluation of the real rms bunch length can be done assuming that compression and decompression rates C_r are equal at 0 deg. and 180 deg. RF phases as: $\sigma_z = X^-_{rms} \cdot C_r = X^+_{rms}/C_r$ or $\sigma_z = \sqrt{X^-_{rms} \cdot X^+_{rms}}$. Substituting the measured electron distribution width from Fig. 3 *b* and *d*, the rms electron bunch length can be found as 1467.57 ±119.43 µm or 236.28±22.52 fs. This approach gives only preliminary estimate of the sub-ps time response of the Cs_2Te photocathode and further detailed study is required.

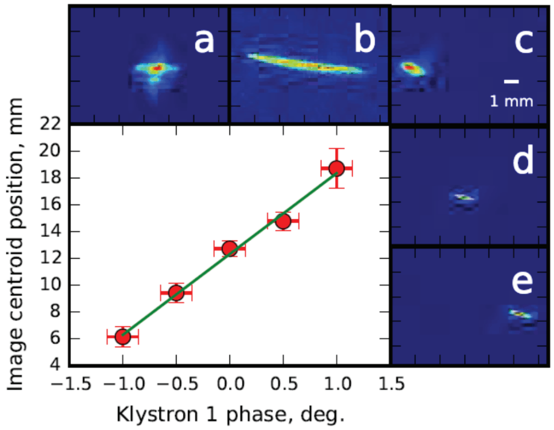

Figure 3: Electron density distribution measured for a RF power off - (a), 180-degree RF crossing - (b), −1deg. accelerating phase - (c), 0deg. accelerating phase - (d), +1deg. accelerating phase - (e). Bottom left: Beam image centroid position plotted as a function of RF phase.

To utilize femtosecond electron beam for THz radiation generation the experimental setup for the observation and investigation of the different types of polarization radiations was constructed at LUCX facility in KEK.

CONCLUSION

Our result further widens the potential of designing a table-top tunable THz FEL based on super-radiant coherent radiation. With no doubts space-charge effects play a fundamental role in preservation of the temporal structure of the comb electron beam and limits the maximum achievable beam charge. The further work on higher charge per bunch is desired for strong THz radiation generation. It can be done by increasing of the RF gun acceleration gradient and optimization of the laser spot size at the photocathode. Also detailed comparison of zero-phasing measurements with these based on THz spectral measurement system (Michelson interferometer for spectrometry of intense broadband radiation in THz frequency range and bunch shape reconstruction [7]) is foreseen in nearest future. The work on super-radiant undulator radiation [8] properties simulation and its comparison with CSPR is also ongoing. Right now repetition rate of this comb beam is limited by Ti:Sa laser system and cannot be faster than 10 Hz. In order to overcome current limitation one needs to consider new CPA laser system (presumably fiber-based) with micro-bunching capability.

Further details on the project progress will be published in successive papers.

ACKNOWLEDGEMENTS

Authors would like to thank S. Araki and M. Fukuda for valuable help, useful discussions and support of the LUCX accelerator operation and maintenance. The work was supported by Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sports, Science and Technology, Japan and JSPS KAKENHI: 23226020 and 24654076.

REFERENCES

[1] J.L. LaRue, T. Katayama, A. Lindenberg, et.al. *Phys. Rev. Lett.* 115, 036103 (2015).

[2] Y. Ding, A. Brachmann, F.J. Decker, D. Dowell, P.Emma, J. Frisch, S. Gilevich, G. Hays, Ph. Hering, Z. Huang, et al., *Phys. Rev. Lett.* 102, 254801 (2009).

[3] S. Kashiwagi, et.al., *Phys. Rev. ST Accel. Beams* 12, 120703 (2009).

[4] H. Harrison, A. J. Lancaster, G. Doucas, I. V. Konoplev, et.al, in *Proc. of the IPAC16,* SUPSS069.

[5] A. Aryshev et al., "Development of Advanced THz Generation Schemes at KEK LUCX Facility," in *Proc. 10th Annual Meeting of Particle Accelerator Society of Japan (PASJ'13),* Nagoya, Japan, Aug. 2013, pp. 873–876.

[6] D. X. Wang, G.A. Krafft, C.K. Sinclair, *Phys. Rev. E* 57, 2283 (1998).

[7] M. Shevelev, A. Aryshev, et. al., *Nucl. Instr. and Methods in Phys. Res. section A,* 771, 126 (2014).

[8] D. Li, K. Imasaki, et.al, in *Proc. FEL2006 Conf.* TUPPH049, 2006.