DEMONSTRATION OF A COMPACT HIGH AVERAGE POWER THz LIGHT SOURCE AT THE IDAHO ACCELERATOR CENTER

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Abstract

The Idaho Accelerator Center (IAC) has been operating nine low energy accelerators for THz and X-ray light sources, nuclear physics, and medical isotope productions. In November 2012, the IAC and RadiaBeam collaborated to upgrade an IAC 44 MeV L-band RF linac with a chicane bunch compressor and a THz radiator with numerous periodic gratings for the resonant Cherenkov radiation. By using the THz radiator and the re-optimized L-band linac with a new operational energy of 5 MeV, we could demonstrate a THz resonant Cherenkov radiation with a high average power of about 17 W in an RF macropulse without using any sub-ps laser or undulator. In this paper, we describe our upgrades and accelerator optimization experiences to perform the proof-of-principle experiments at the IAC.

INTRODUCTION

As various user applications such as diagnosis of early stage cancers, 3D imaging of teeth, security and weapon scanning, and quality control of commercial products have been developing, recently, THz users strongly request coherent THz light source which can supply a high average power ($\geq$ 1 mW). Jefferson Lab and several other laboratories have demonstrated accelerator-based high average power THz light sources by using the Continuous Wave (CW) or Energy Recovery Linac (ERL) technology. However, we need a big budget to construct such an ERL based THz light source facility. To realize a compact and cheap high average THz light source facility, we have developed a resonant Cherenkov radiation based THz radiator [1–3], and performed its proof-of-principle experiments at the Idaho Accelerator Center (IAC) by upgrading an IAC 44 MeV L-band RF linac [4–6]. The parameters of the 44 MeV linac and the THz radiator are summarized in Table 1, and the layout of the upgraded IAC 44 MeV L-band linac is shown in Fig. 1. The upgraded linac has a 85 kV DC gun instead of an RF photoinjector and a THz radiator instead of a undulator as shown in Fig. 1. To perform the proof-of-principle experiments of narrow-bandwidth resonant Cherenkov radiation with a specially designed THz radiator, RF phases and gradients of the 44 MeV linac structures were re-optimized to have a new operational beam energy of 5 MeV and to have the shortest bunch length of about 500 fs (rms). It is well confirmed that the multi-bunch beam loading effects or the long-range longitudinal wakefields can be used to generate coherent narrow-bandwidth resonant Cherenkov radiation [1, 2, 7, 8]. In our experiments, we used a 85 kV DC gun to generate a long bunch train with 2600 short single bunches in a 2 μs long RF macropulse. By sending the 2600 short bunches with a single bunch charge of about 30 pC into the THz radiator, we could get strong multi-bunch beam loading effects to generate a high average power THz radiation at 0.316 THz. In this paper, we describe upgrades of the IAC L-band linac, the THz radiator, and linac optimization experiences to generate a high average power THz radiation at 0.316 THz with the compact THz radiator.

Table 1: Parameters of Linac and THz Radiator

Parameter	Value	Unit
Maximum beam energy	44	MeV
Minimum beam energy	5	MeV
RF frequency	1300	MHz
Repetition rate of RF macropulse	30	Hz
Length of RF macropulse	2	μs
Bunches in a macropulse	2600	·
Single bunch charge	30	pC
R_{56} of bunch compressor	13.7	mm
Minimum rms bunch length	500	fs
Resonance frequency of radiator	0.316	THz
Grating period	234	μm
Grating groove depth	80.86	μm
Grating structure length	30.4	mm
Grating structure width	6.3	mm
Grating structure gap	1.256	mm
Phase advance per period	88	deg
Quality factor	2150	·
Gap-averaged shunt impedance	4.3	MΩ/m
Nomalized group velocity	0.8	·
Average THz power per macropulse	17	W
Bandwidth of THz radiation	10	%

UPGRADES FOR EXPERIMENTS

For the THz experiments, as shown in Fig. 1, we installed a THz radiator, which had been fabricated with the conventional CNC milling, a chicane bunch com-

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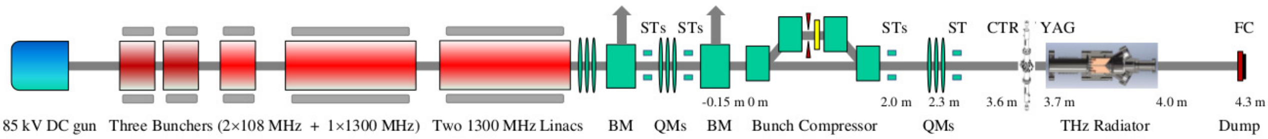

Figure 1: Layout of the IAC 44 MeV linac for the IAC-RadiaBeam THz project.

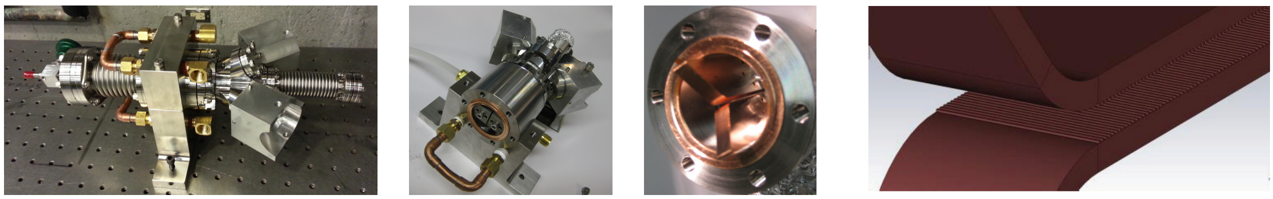

Figure 2: THz radiator: (first) entire THz radiator, (second) disassembled molybdenum collimator with a 1.2 mm wide gap, (third) copper side-open planar horn antenna with numorous gratings, (fourth) 3D images of the planar horn antenna.

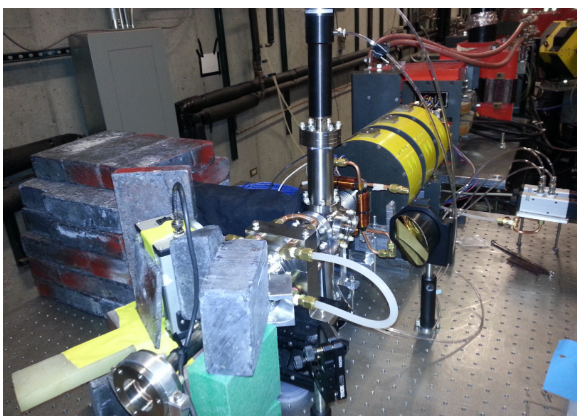

Figure 3: Upgraded beamline of the IAC 44 MeV linac for the IAC-RadiaBeam THz project.

pressor to compress electron bunch length, a quadrupole triplet (QMs) to change beam shape and to adjust focusing strength at the THz radiator, four horizontal and vertical steering magnets (STs) to adjust beam orbit along the beamline, a Coherent Transition Radiation (CTR) based interferometer to measure femtosecond long electron bunch length after the bunch compressor, an OTR screen to check the beam position and shape in front of the chicane bunch compressor, a YAG screen to check beam position and beam shape in front of the THz radiator, two Prosilica GigE CCD cameras to acquire beam shapes and positions at the OTR and YAG screens, a Faraday cup at the end of the beamline to measure electron beam charge going through the THz radiator [1, 5, 6]. In addition, as shown in Figs. 2 and 3, we had installed a homemade THz antenna in front of the left output-coupling Sapphire window of the THz radiator, and a GenTec QS-I-TEST SDX-1065 pyrodetector was installed in front of the right output-coupling Sapphire window of the THz radiator [1]. To acquire weak signals from the homemade antenna, we connected a Tektronix MSO72004 fast oscilloscope to the antenna with a 1.0 m long low loss copper coaxial cable. Since the cable length is only 1.0 m, we had to leave the oscilloscope in the linac tunnel with sufficient lead shielding. To control the oscilloscope from the linac control room, we used the remote desktop function of Windows XP. Since the cable is short and low loss one, it was very effective to find initial signals from the radiator [1]. The GenTec SDX-1065 pyrodetector was connected to a Tektronix TDS2014 slow oscilloscope with a 50 m long coaxial cable. Since the cable is long enough, the oscilloscope could be controlled at the control room directly.

To control newly installed magnets and Prosilica GigE CCD cameras remotely, we had installed EPICS accelerator control system. More details on the EPICS accelerator control system, the dipole magnets for the chicane and three quadrupoles for the triplet, and the Prosilica GigE CCD camera based beam imaging system can be found from references [4–6]. As shown in Fig. 1, the new 4.3 m long beamline for the THz experiments starts from the second 90 degree bending magnet (BM), which is located at right before the first 7 degree dipole magnet for the chicane bunch compressor. After installation of all components, the upgraded beamline is busy as shown in Fig 3. The 0.3 m long THz radiator consists of a molybdenum collimator set, cooling channels, two connecting flanges, and a pair of planar, side-open, copper gratings with symmetrical meander profile as shown in Fig. 2. Since the collimator has a 1.2 mm wide gap, good beam orbit steering is required to send electron beams through the THz radiator. Detailed design concepts of our THz radiator can be found from references [1, 2] and its parameters and performance are summarized in Table 1.

EXPERIMENTAL RESULTS

To detect THz signals from the THz radiator, first of all, we optimized the beam shape and orbit with steering magnets and the quadrupole triplet to get a weak transmission down to the Faraday cup. Then, we adjusted bunch length by optimizing RF phases of linac structures and chicane

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strength. After the bunch length optimization, we tried to improve beam transmission down to the Faraday cup with steering magnets and the quadrupole triplet. However, we could not get any THz signal from the GenTec SDX-1065 pyrodetector with 8 MeV electron beam, and the single bunch charge at the Faraday cup is much smaller than 1 pC. To overcome the high RF background noises, we installed a homemade THz antenna in front of the left output-coupling Sapphire window, and a Tektronix MSO72004 fast oscilloscope was connected to the antenna with a 1.0 m long low loss copper coaxial cable. Then, to improve the velocity bunching of the electron beam, we reduced beam energy from 8 MeV to 5 MeV. However, we could not get any signal from both the pyrodetector and the antenna either. In addition, the beam transmission to the Faraday cup was dramatically dropped at 5 MeV due to strong space charge forces at the THz radiator region when the beam was horizontally focused and longitudinally compressed at 5 MeV [1,6]. Therefore, we had to modify transverse beam shape from horizontally focused strip like one into uniformly distributed round one to reduce the beam spreading due to strong space charge forces in the THz radiator [1].

After the transverse beam shape modification, we could improve the beam transmission, and we could detect a weak cm-wavelength signal from the homemade THz antenna as shown in Fig. 4. The longer cm-wavelength radiation is generated by the wakefield induced at the 2 cm long horn antenna openings when the bunch length is longer than the grating period of 234 μm [1]. By adjusting RF phases for the velocity bunching, chicane strength for the magnetic compression, beam orbit, and beam uniformity against strong space charge forces, we could get good beam transmission down to the Faraday cup as well as the strong cm-wavelength signal from the homemade antenna as shown in Fig. 4. In that case, the single bunch charge at the Faraday cup was increased up to 30 pC. By compressing bunch length down to the grating period range, we could get a strong cm-wavelength signal from the homemade antenna and a strong THz signal from the pyrodetector as shown in Figs. 4 and 5. By analyzing signals from the pyrodetector, we found the fact that the average THz power of the RF macropulse with 2600 single bunches is about 17 W in the radiator [1]. We also got a similar power level by analyzing cm-wavelength signals from the homemade antenna. This is about two orders of magnitude higher average power than that was obtained with RF photoinjector based THz sources at low beam energies [8].

SUMMARY

Successfully, at 5 MeV, without any gun driving laser or undulator, we have demonstrated that a high average power THz radiation can be generated with a compact and cheap resonant Cherenkov radiation based THz radiator. The average THz power of an RF macropulse is about 17 W, which is is about two orders of magnitude higher average power than that was obtained with RF photoinjector based THz sources at low beam energies. We expect that the average power can be further increased by improving electron beam quality and by increasing RF macropulse length. By directly connecting the THz radiator to a multi-cell thermionic RF gun and an alpha magnet, we expect that the total length of the THz facility can be reduced down to several meters. By measuring average THz power from the THz radiator, hence the form factor of electron beam, we can also use the radiator to measure the femtosecond long bunch length of electron beams [1]. This work was supported by the U.S. Department of Energy (award No. DE-SC-FOA-0000760 and DE-FG02-07ER84877).

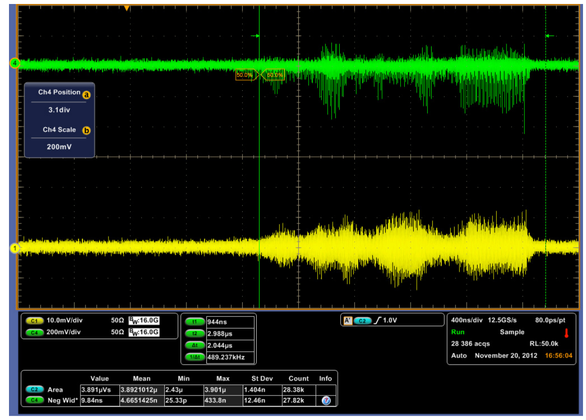

Figure 4: Tektronix MSO72004 oscilloscope signals at 5 MeV with a round beam shape: (top and green) signal from a Faraday cup, (bottom and yellow) signal from a THz antenna.

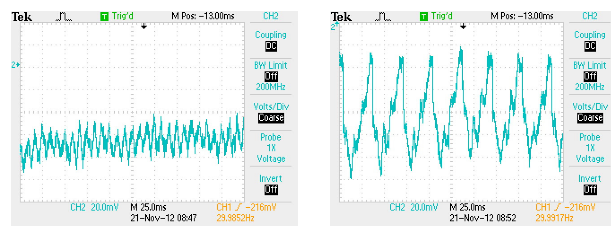

Figure 5: Tektronix TDS2014 oscilloscope signals from a GenTec pyrodetector at 5 MeV with a round beam shape: (left) when beam was off and (right) when the single bunch charge at the Faraday cup was about 30 pC, and the signal from THz antenna was strong as shown in Fig. 4.

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