MEASUREMENT OF HIGH POWER TERAHERTZ WITH DIELECTRIC LOADED WAVEGUIDE AT TSINGHUA UNIVERSITY*

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Abstract

We have measured an intense THz radiation produced by a sub-picosecond, relativistic electron bunch passing through a dielectric loaded waveguide (DLW) at Tsinghua University accelerator beamline. The DLW was 3 cm long quartz tube with 900 μm inner diameter and 100 μm wall thickness metallized on the outside. Radiated energy of the THz pulse was measured to be proportional to the square of the effective charge. The end of the DLW was cut at an angle for efficient THz pulse extraction. Tens of μJ THz energy per pulse were measured outside the vacuum chamber with a calibrated Golay cell in the experiment.

INTRODUCTION

Dielectric loaded waveguides (DLWs) have long been studied as sources of narrow-band, coherent THz radiation [1, 2]. A simple approach to efficiently extract the THz radiation out of the DLW is to cut the end of tube with a certain angle, such antenna converts the TM_{01} mode excited in the waveguide into a free-space at an angle with respect to the electron beam trajectory [3]. Here we report the experiment of intense THz radiation generation and measurement at Tsinghua University accelerator beamline with an angle-cut DLW. About 20 μJ energy per pulse of 0.3 THz radiation were measured with a calibrated Golay cell in the experiment.

PARAMETERS OF THE DIELECTRIC LOADED WAVEGUIDE

We used a 0.3 THz (TM_{01} mode) DLW in the experiment, which is a quartz capillary tube metallized via gold sputtering on the outer surface. The dielectric constant of quartz is 3.8, and the dimensions of the tube are: 900 μm inner diameter, 1100 μm outer diameter, 30 mm total length.

The coupling method for the fundamental TM_{01} mode with an angle cut at the end of the DLW was developed and demonstrated in Ref [3]. This simple approach approved to be quite effective for (i) high efficiency extraction of the radiation from the tube to free space; (ii) improving the signal-to-noise ratio by avoiding unwanted coherent transition radiation (CTR) produced on THz collection optics. Here we use the same approach to study the coupling of the second order mode with the angle cut at the end of DLW.

CST simulations code [4] is used to get the electric field and the far-field distribution of the TM_{01} mode at the end of the DWLs with angle-cut, and also the ones without angle-cut for comparison. Results are shown in Figure 1. The angle-cut at the end of the DLW breaks the symmetry that the far-field distribution in such antenna convert the TM_{01} mode excited in the waveguide into free-space mode propagating at an angle $\theta > 0^0$ with respect to the electron beam trajectory. With angle cut more than 90% of power is extracted, compared to <10% extraction from the open waveguide without any matching section. Thus most energy of the THz radiation extracted can be collected with a large aperture off-axis paraboloid mirror.

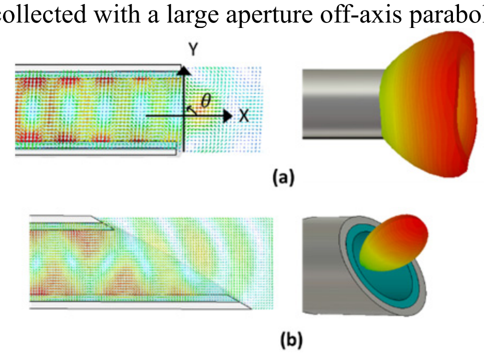

Figure 1: The electric field and the far-field distribution of TM_{01} mode at the end of the DLW without angle cut, and as well as the ones in the DLW with an angle cut.

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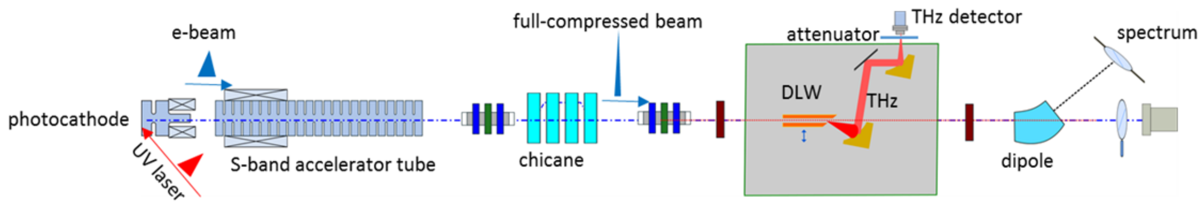

Figure 2: Schematic of the experimental setup.

EXPERIMENTAL MEASUREMENT

Beamline Setup

The experiment was performed at the Tsinghua Accelerator Laboratory [5]. Figure 2 shows the layout of the experiment. A 31 MeV chirped beam was generated and used to generate wake in the DLW with angle-cut . The chicane in front of the DLW worked at the full-compression mode to produce a short, high peak current electron bunch. The bunch charge was measured both before (Q_{before}) and after the DLW (Q_{after}).. The generated Terahertz radiation was was transported out of the vacuum chamber and measured with a calibrated Golay cell. When the power generation was optimized we had to use a 10% attenuator as the Golay cell signal saturated. We also use a Michelson interferometer to measure spectral properties of the THz signal. Electron beam energy spectrometer was used to measure particle energy loss due to wake generation.

Optimized the THz Signal Via Compression of the Electron Beam

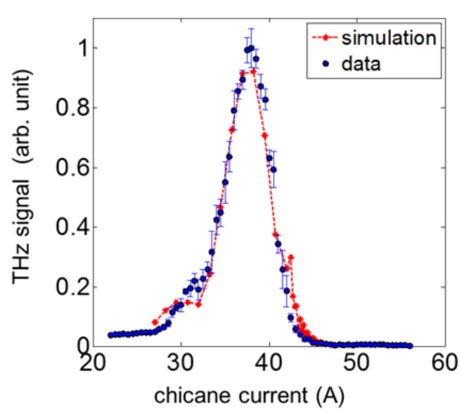

Figure 3: THz energy varies as the chicane current.

Generation of the THz pulse strongly depends on the bunch length of electron beam. We optimized the compression of electron beam to produce a high energy THz pulse. As shown in Figure 3, the measured THz signal varies with the chicane current (i.e. bunch compression), which also agree well with the simulations with ASTRA [6] and CST. The chicane compresses the chirped beam so that the tail of the drive beam catches up with its head forming an optimized short beam (full compressed beam) which corresponds to a maximum THz signal. If chicane current is not high enough, the beam is under compressed, i.e. the tail of the beam is still behind its head. Alternatively, the beam can be over-compressed when the tail passes its head forming a longer beam when chicane current is too strong. By measuring the wakefield pulse energy with the Golay cell, an optimal beam compression point can be determined (Figure 3). In our experiment the chicane current was set around 38 A based on the results in Figure 3.

Measurement of the Radiation Energy

The generated Terahertz radiation was measured with a calibrated Golay Cell as a function of the effective charge as shown in Figure 4. Here we define the effective charge as the charge contributed to the wakefield, which is in between the charge before (incident into) and the charge after (transmitted after) the DLW. Because the THz radiation energy is proportional to the charge square and the travel length of the charge, not only the charge Q_{after} but also other parts of the charge that lost in the DLW contribute to the wakefield energy. The total THz energy E_t can be written as $E_t \propto \sum_{n=1}^{n}((Q_{before} * t_n)^2 * L_n = Q_{before}^2 \sum_{n=1}^{n} t_n^2 * L_n = (Q_{before} * \eta).^2$ Where t_n and η are percent ratio numbers no greater than 1. As shown in Figure 4, compared with the coherent radiation curve ($y = x^2$), the effective charge in the experiment is $Q_{before} * 0.85$ or $Q_{after} * 1.2$.

We have measured more than 20 μJ THz energy per pulse outside the beamline when the effective charge is more than 350 pC.

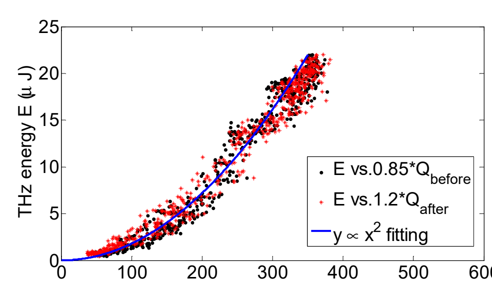

Figure 4: Measured THz energy varies as the effective charge. The definition of the effective charge ($0.85*Q_{before}$ or $1.2*Q_{after}$) depends on the measurement of THz energy versus the charge compared with the coherent radiation curve ($y \propto x^2$).

Spectrum Measurement

The THz spectrum of the wakefield generated in the DLW was measured with a Michelson interferometer and Golay cell detector. The measured autocorrelations curves

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and its Fourier transformed spectrums are shown in Figure 5. The measured THz pulse is narrowband signal with 0.3 THz frequency. This corresponds to the TM01 mode. The autocorrelation curve in Figure 5 is a long range scan to demonstrate the narrow band property of the wakefield generation in the DLW. Theoretical band width of the signal is about 1%. The measurement is limited by an interferometer mirror scan range.

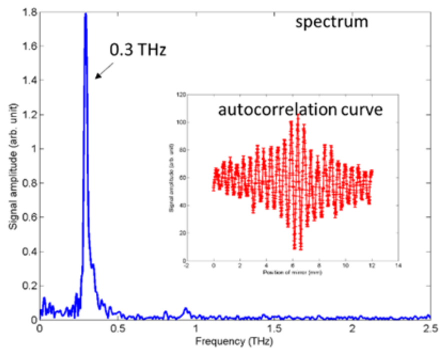

Figure 5: The autocorrelation curve from the interferometer and the spectrum of the 300 GHz DLW.

CONCLUSION

We have measured an intense THz radiation at the Tsinghua University accelerator beamline with fully-compressed 350 pC electron beam generating wakefield in a 3 cm long dielectric loaded waveguide. The DLW had a matching section (an angle cut) for efficient extraction of THz energy. More than 20 uJ energy of a narrowband 0.3 THz pulse was measured outside the vacuum chamber.

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