PRELIMINARY RESULTS ON THE RESONANT EXCITATION OF THz WAKEFIELD IN A MULTI-MODE DIELECTRIC LOADED WAVEGUIDE BY BUNCH TRAIN*

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Abstract

We report the preliminary experimental results on the resonant excitation of THz wakefield in a multi-mode dielectric loaded waveguide (DLW) by electron bunch train at the Tsinghua University accelerator beamline. The bunch train with certain longitudinal periodicity was generated based on nonlinear longitudinal space charge oscillation [1]. By passing such bunch train through a multi-mode DLW, we observed selective excitation of the fifth longitudinal mode (TM05 mode) was resonantly excited. Future experiment plan is to tune the bunch train interval with a chicane in the beamline in order to selectively excite arbitrary mode for tunable THz radiation source with multi-mode DLWs.

INTRODUCTION

Dielectric Loaded Waveguides (DLWs) have long been studied as sources of narrow-band, coherent THz radiation [2]. Preliminary experiments demonstrated single-mode excitation of the fundamental mode at different frequencies by applying different waveguides [3, 4]. Follow-on experiments showed the potential of frequency-tunable THz sources with DLWs by exciting not only the fundamental mode but also the higher order longitudinal modes [5]. The selective excitation of different modes by use of the appropriate spaced electron bunch train has been demonstrated [6, 7].

We also designed experiment on the resonant excitation of arbitrary mode of THz wakefield in a multi-mode dielectric loaded waveguide (DLW) by tunable electron bunch train at the Tsinghua University accelerator beamline. The bunch train was generated based on nonlinear longitudinal space charge oscillation. The bunch train interval will be tunable when the chicane in the beamline is used in future. Our preliminary results shows the fifth longitudinal mode (TM05 mode $f_0 = 747\,GHz$) was resonantly excited by the bunch train with 400 µm spacing.

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PARAMETERS OF THE MULTI-MODE DIELECTRIC LOADED WAVEGUIDE

Selective Excitation of Wakefield in Multi-Mode DLW by Electron Bunch Train

The total power spectrum of wakefield radiation exctied by relative beam (or bunch train) $P_b(f)$ can be calculated by the equation $P_b(f) \approx N.^2 \cdot P_e(f) \cdot F(f)$, where N is the number of the total particles in the beam, and $P_e(f)$ is the wakefield spectrum excited by a single particle, which is also the intrinsic modes distributions of the DLW, F(f) is the bunch form factor which is defined as $F(f) = \int_{-\infty}^{\infty} \rho(z) e^{-ikz} dz$, with ρ(z) is the longitudinal distribution function of the drive beam, k is the wave number and c is light velocity in vacuum.

It is possible to design the total power spectrum when manipulating $P_e(f)$ and together with the drive bunch train distributions ρ(z). As shown in Figure 1 (a), we firstly choose a multi-mode DLW whose spectrum has different intrinsic frequencies, by choosing the bunch train with 1 ps spacing (interval) as an example, the spectrum of $F(f)$ peaks at 1 THz as shown in Figure 1 (b). Then the product in Figure 1 (c) gives the final results as shown in Figure 1 (d), the 1 THz mode are resonantly excited by 1 ps interval bunch train.

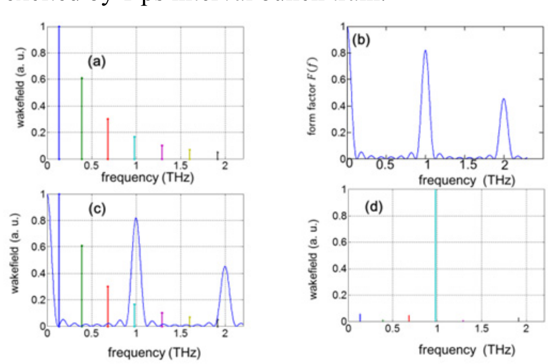

Figure 1: Sketch of selective excitation of wakefield in multi-mode DLW with electron bunch train. (a) the wakefield spectrum excited by a single particle $P_e(f)$; (b) the spectrum of electron bunch train $F(f)$ with 1 ps interval for example; (3) the product of $P_e(f)$ and $F(f)$; (d) the total power spectrum $P_b(f)$ in which the 1 THz mode is selectively excited.

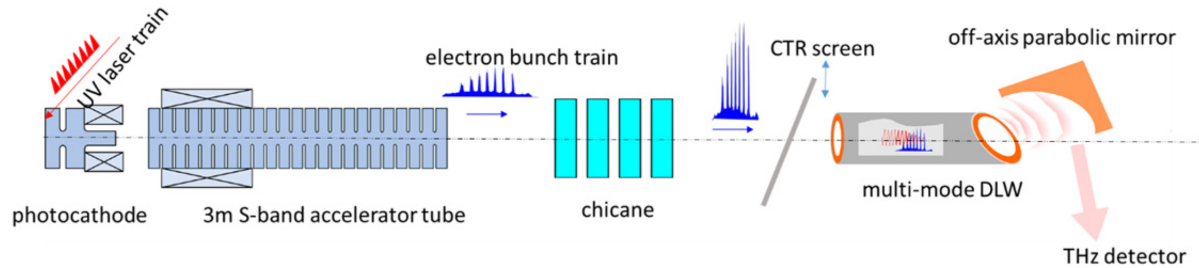

Figure 3: Schematic of the experimental setup

Parameters of the DLW

The sketch of the multi-mode DLW we used in the experiment is shown in Figure 2 (a). It's a quartz capillary tube (dielectric constant 3.8) plated with copper. The inner diameter a = 1 mm and the outer diameter of the dielectric capillaryb = 2 mm, and the total length of the structure is 40 mm. We have cut the end of the DLW at an angle to extract the wakefield out of the tube efficiently [8].

Figure 2 (b) shows the spectrum of the DLW with different modes. There are many modes in the tube due to the relatively thick dielectric layer. The frequency of first five modes is $f_{TM_{01}} = 0.091$ THz, $f_{TM_{02}} = 0.244$ THz, $f_{TM_{03}} = 0.406$ THz, $f_{TM_{04}} = 0.575$ THz, $f_{TM_{05}} = 0.747$ THz respectively.

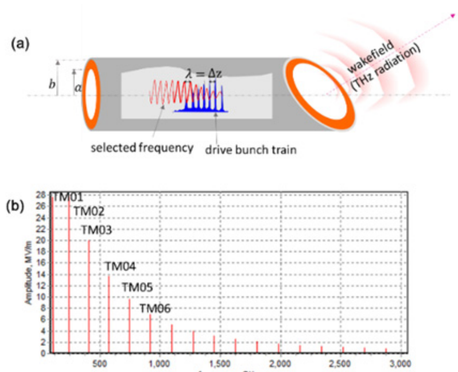

Figure 2: The multi-mode DLW (a) and its spectrum (b)

EXPERIMENTAL MEASUREMENT

Beamline Setup

The experiment was performed at the Tsinghua University Accelerator Laboratory [9]. Figure 3 shows the layout of the experiment. A ~40 MeV electron bunch train was generated based on the space charge oscillation [1] and employed to excite the multi-mode DLW. The chicane in front of the DLW has not been commissioned yet. It will be used to adjust the bunch train spacing in the future. A CTR screen which can be placed in and out was used to measure the bunch train form factor in front of the DLW. The generated Terahertz radiation was measured with a calibrated Golay Cell directly. Finally, a Michelson interferometer is with the Golay Cell detector was used to measure the frequency spectrum of THz pulse extracted from the DLW.

CTR Spectrum of the Bunch Train

When a bunch train strikes a metal plate it produces transition radiation with the same time structure as the electron beam. This coherent transition radiation (CTR) signal is measured with an interferometer. This measurement give a spectral content of the electron beam. Experimental results are shown in Figure 4. The spectrum of the bunch train peaked at 0.75 GHz, which indicate the interval of the drive bunch train is 400 μm.

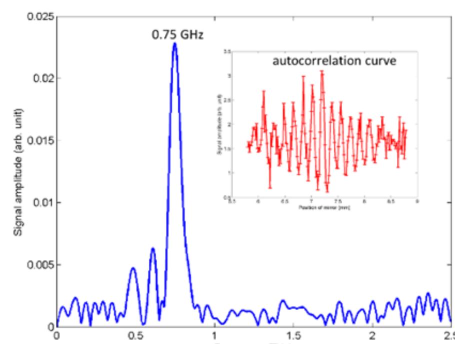

Figure 4: Measured CTR spectrum of the drive bunch train.

Spectrum of DLW THz Excited by a Single Bunch and by the Bunch Train

The THz spectrum of the DLW wake generated by an electron beam in the DLW is measured with the interferometer. The measured autocorrelation curves and the corresponding spectrums are shown in Figure 5. Initially, we used a single bunch to excite the wakefield in the DLW. In this case all modes are excited in the structure as shown in Figure 5 (a).

However when a bunch train is used with spectral content measured on Figure 4, it mostly excite the TM05 mode because its frequency ($f_0 \approx 750\,GHz$), matches that of the bunch train frequency. The measurement result is shown in Figure 5 (b), which demonstrates a selective excitation in the multi-mode DLW with bunch train as the theory predicted.

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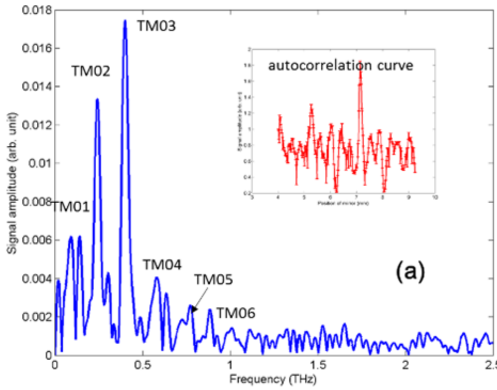

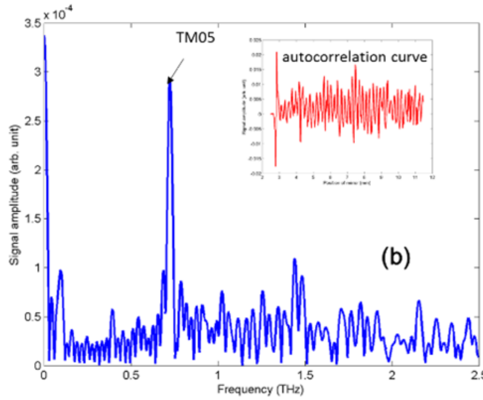

Figure 5: The THz spectrum of the DLW when excited by a single bunch (a) and by the bunch train with 400 μm interval (b).

CONCLUSION

We have performed the experiment of the resonant excitation of THz wakefield in a multi-mode DLW by electron bunch train from the space charge oscillation at Tsinghua University beamline. The preliminary results shown a selective excitation of the TM05 mode from the multI-mode DLW. Our plan is to tune the bunch train interval with a chicane in the beamline to selectively excite other modes in the multi-mode DLWs, which would yield a fast-tunable THz radiation source.

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