STUDY OF COHERENT RADIATION FROM AN ELECTRON BEAM PREBUNCHED AT THE PHOTOCATHODE

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Abstract

Controlling the longitudinal distribution in an electron beam traveling through an accelerator can enhance system performance in various ways. Prebunching an electron beam in an accelerator can lead to enhanced radiation production from various emitters. Smoothing the shape of the electron beam pulse may suppress instabilities that result in beam breakup. This work, a collaboration between the University of Maryland and the Source Development Laboratory at Brookhaven National Laboratory, uses a Ti:Sapphire drive laser modulated at terahertz frequencies to extract a prebunched beam directly from the photocathode prior to acceleration in a linear RF accelerator. We have demonstrated that prebunched terahertz structure can be maintained after leaving the photocathode and through acceleration to high energy. Through the use of simulation and experiment, this work further explores the characteristics of an electron beam produced in this manner and examines the possibility of using this technology to develop a compact, powerful, narrowband terahertz emitter.

1 INTRODUCTION

During the last year, the University of Maryland has been working with the Source Development Laboratory at Brookhaven National Laboratory to develop a new terahertz light source. In 2002, high-power broadband terahertz radiation at an average power of 20 W was recorded at the Free Electron Laser Facility at Jefferson Laboratory [1]. In contrast, the goal of this collaboration is to develop technology that will lead to a compact, high-power, narrow-band terahertz source. In this case, the photocathode drive laser (a Ti:Sapphire laser frequency tripled to 266 nm) is used as an optical switch to turn the electron beam on and off at terahertz frequencies. The fast switching of the drive laser results in a pre-bunched electron beam. This prebunched electron beam is then accelerated from low energy near the cathode to relativistic velocities and caused to radiate. When an electron beam is prebunched, the radiation emitted near the bunching frequency will be coherent, and the energy will be enhanced by a factor of the number of electrons in the beam above the incoherent energy [2].

A preliminary experiment modulated the 266-nm drive laser at terahertz frequencies by using pulseshaping techniques [3] based on a modified chirped-pulse amplification system. The drive laser was incident on a copper photocathode, which produced a 50-pC electron beam that was also modulated in the terahertz regime. The incident drive laser pulse was measured with a scanning cross-correlator [4] (Fig. 1).

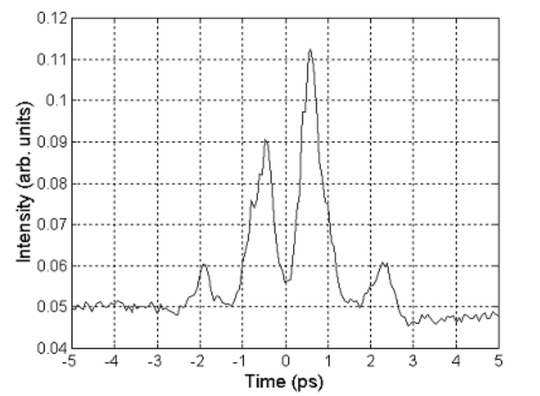

Figure 1: Cross-correlation measurement of 266-nm drive laser pulse incident on photocathode (Head of pulse on right).

The time profile of the electron beam that was generated with the drive laser pulse shown in Fig. 1 was measured using the RF-zero phasing technique (Fig. 2).

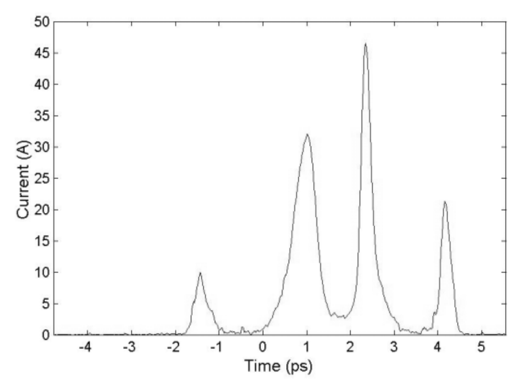

Figure 2: RF-zero phasing measurement of electron beam generated by laser pulse in Fig. 1. (Head of bunch on left).

Currently, a mirror is inserted into the beamline to generate transition radiation. The diagnostic system to

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measure the energy and spectrum of the light generated by the beam is still being improved. Future experiments will use this system in order to verify coherent radiation production, and demonstrate that the terahertz light is easily tunable by changing the bunching frequency. In order to achieve this goal, terahertz filters are being produced to assist with diagnostics and additional PARMELA simulations help predict the expected high-frequency and high-charge limits of this technique.

2 DIAGNOSTIC IMPROVEMENTS

Spectral information for terahertz radiation can currently be measured using a step-scan Michelson interferometer with a bolometric detector. While the interferometer can be used to collect detailed data, rough spectral content can be measured quickly using various band-pass filters.

The filters were constructed using stainless steel shim stock (each filter is a few hundred micrometers thick) that is chemically etched to produce holes that are fractions of a millimeter in diameter. An example of one of these filters is shown in Fig. 3. When this steel etch is mounted on a fluorogold substrate, reasonable band-pass performance at terahertz frequencies is achieved.

Figure 3: Etched steel terahertz filter.

The frequency characteristics of one filter, tested at the U12IR at the National Synchrotron Light Source, are shown in Fig. 4.

The additional filters still need to be characterized, but the center frequency of each one will be shifted so that various filters could be used in order to estimate the nature of the spectral content of the emitted radiation.

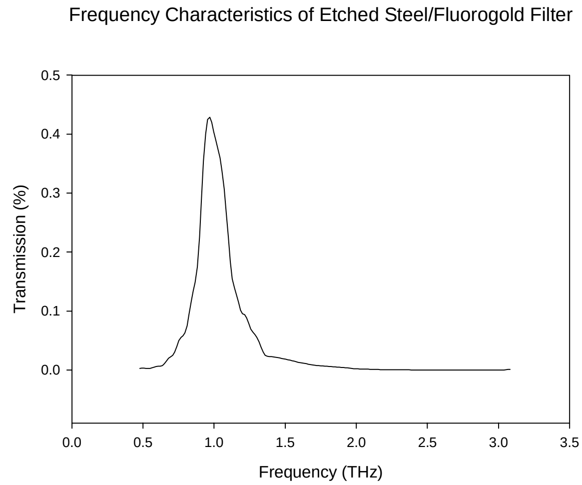

Figure 4: Terahertz band-pass filter.

3 PARMELA SIMULATIONS

The electron beam modulation is introduced at the cathode by modulating the drive laser at terahertz frequencies. Since the electron beam is prebunched at extremely low energies, space charge forces will play a large role in beam dynamics before it is accelerated to relativistic energy. Therefore, it is likely that the modulation on the electron beam will become less pronounced as the frequency of modulation and bunch charge increase.

The acceleration from cathode to gun exit was modeled using the code PARMELA. The input particle distribution at the cathode was considered to be identical to a simulated laser beam envelope because emission at a copper cathode like the one at the Source Development Laboratory is considered to be prompt [5]. For example, one input distribution included four equally sized bunches separated at ~1 THz.

The electron density distribution was examined at the exit of the gun as a function of total charge and frequency of modulation. The degree of modulation, or contrast, is a good measure of how much energy will be radiated by the beam, and is given by

$$Contrast = \frac{N_{\max} - N_{\min}}{N_{\max} + N_{\min}} \qquad (1)$$

where N_{max} is the maximum electron density and N_{min} is the minimum electron density in the bunch. The frequency of the density modulation was also obtained at the gun exit.

The Source Development Laboratory is able to produce electron beams that contain up to 1 nC of charge. Although approximately 0.8 THz modulation on a 50 pC electron beam was achieved in previous experiments, future experiments should explore a broader frequency range and higher charges per bunch. Therefore, the simulations were designed to explore the frequency range between 1 and 4 THz, and at varying charges up to 1 nC. Figure 5 shows preliminary results for the contrast between 1 and 4 THz at 100 pC, 500 pC, and 1 nC.

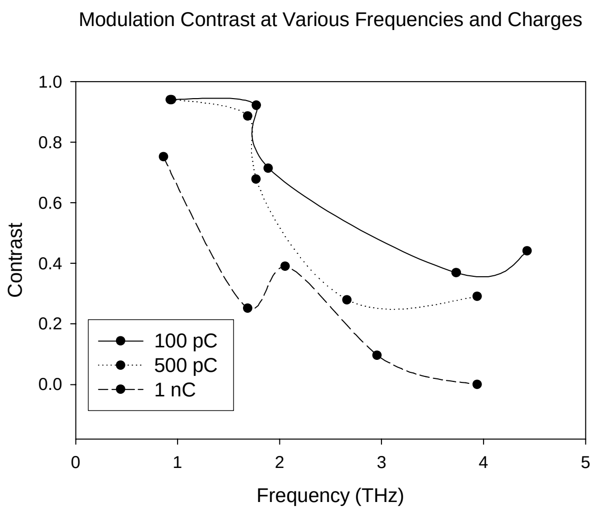

Figure 5: Degree of electron beam modulation as a function of charge and frequency.

The degrading effect of space charge on the modulation contrast at the injector exit is clear in Figure 5. It seems that modulation of the electron beam at the photocathode as a method of prebunching would at least be moderately effective up to a few terahertz at 500 pC and below. As expected, at low charge (~100 pC) and low frequencies, the degree of modulation at the injector exit remains the highest. In contrast, at high charge (~1 nC), or high frequencies there is degradation of the beam envelope even at relatively low frequencies.

4 CONCLUSION

In previous experiments, we were able to demonstrate that modulating the envelope of the drive laser appropriately can modulate an electron beam at terahertz frequencies. The prebunched electron beam can then be used to radiate coherently. Changing the frequency of drive laser modulation will also cause the electron beam modulation frequency to shift. The frequency content of radiation emitted by the electron beam will also shift. Therefore, this method could be used to build a compact, high-power, accelerator based terahertz radiation source.

To proceed toward that goal, we can use terahertz filters to quickly identify the spectral content of radiated light, and can use the PARMELA simulations to help us illuminate some of the limitations of this technique. Further work will also include additional experiments at the Source Development Laboratory to verify the predictions made by the PARMELA simulations.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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