ULTRSHORT ELECTRON BUNCH TRAIN PRODUCTION BY UV LASER PULSE STACKING *

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Abstract

Ultrashort relativistic electron beam can be applied to produce high power coherent THz radiation by mechanisms such as FEL, CSR, CTR et al. The THz modulated electron beams, or THz-repetition-rate ultrashort electron pulse trains exhibit further enhancement of coherent THz radiation. This article will report the preliminary experimental results on the ultrashort electron beam train production via copper based photocathode RF gun by direct UV laser pulse stacking using birefringent α-BBO crystal serials at our laboratory. The temporal profile of the electron beam was measured by deflecting cavity. This shaping method of laser pulse by α-BBO crystals can also be applied to form quasi flattop UV laser pulse for reducing the initial emittance of the electron beam from the photocathode RF gun.

INTRODUCTION

The production of high power THz radiation has been demonstrated by ultrashort relativistic electron beams (<1ps, tens of MeV) from an accelerator[1]. The radiation enhancement comes from two effects: one is γ^4 dependence on the relativistic energy of a single electron; the other is the coherent superposition of radiation by multiple electrons in the ultrashort beam. However, ultrashort electron bunch train exhibits further THz radiation enhancement because of the coherent superposition effect between sub beamlets[2,3]. Such electron bunch trains can be directly initiated from a photocathode RF gun illuminated by stacked drive laser pulses. Due to the negligible emission time of the photocathode, the initial temporal distribution of the electron beam is the same as that of the laser pulse. Thus how to form THz-repetition-rate ultrashort laser pulse trains plays significant role in such electron bunch train production.

This article will focus on ultrashort electron bunch train generation by UV laser pulse stacking. Using the birefringent α-BBO crystal serials, we formed UV pulse train with ps time intervals between adjacent sub pulses. With such pulse train to illuminate the copper photocathode RF gun, THz-repetition-rate ultrashort electron bunch train was produced preliminarily at our laboratory. To measure the temporal distribution of the electron bunch train, a RF deflecting cavity was applied. We plan to produce THz radiation by CTR mechanism with this kind of bunch trains later at our laboratory. The bunch train also have important applications in time-resolved ultrafast electron diffraction, multi-pulse Thomson scattering and other areas. The shaping method of laser pulse by α-BBO crystals can also be applied to reduce the initial emittance of the electron beam from the photocathode RF gun.

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THZ ENHANCEMENT BY BUNCH TRAIN

The total radiation power from a group of electrons can be expressed as the following equation [4]:

$$\frac{d^2W}{d\omega d\Omega}=\frac{d^2W_1}{d\omega d\Omega}[N_e+N_e(N_e-1)f(\omega)] \qquad (1),$$

where $\frac{d^2W_1}{d\omega d\Omega}$ is the radiation power of a single electron, $f(\omega)$ is the form factor relative to the density distribution of the electron beam. It is described by equation (2):

$$f(\omega)=\left|\int d\vec{r}S(\vec{r})e^{i(\omega/c)\hat{n}\cdot\hat{r}}\right|^2 \qquad (2)$$

The form factor of the THz-repetition-rate ultrashort electron bunch train will be enhanced at THz radiation.

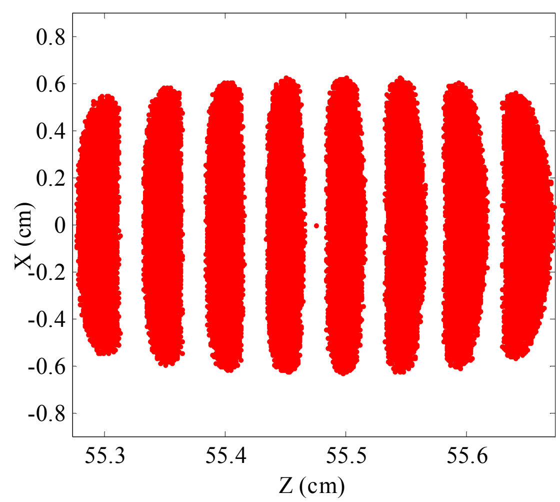

Figure1: Beam density distribution at 55.47cm

Here we simulate such a bunch train with eight sub beamlets produced for our photocathode RF gun. Charge of each beamlet is set to be 100pC. The transverse distribution of the drive laser on the cathode is tophatted and 3mm in diameter. The temporal profile of each sub-pulse is Gaussian with 0.3ps duration (FWHM). The interval of the adjacent sub-pulse is 2.0ps. The maximum electric field in the RF gun is 87MV/m. the launching phase of the first beamlet is 34.5degree. The maximum magnetic strength of the coil along z axis is 1530 Gauss. The simulation results at 55.47cm downstream the photochthode are shown as figure 2~4.

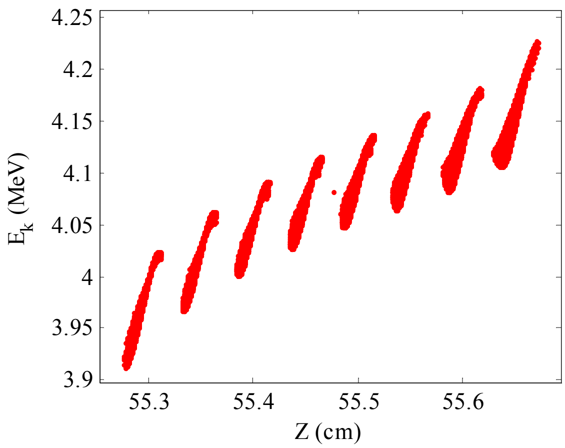

Figure 2: Z-Ek phase space at 55.47cm

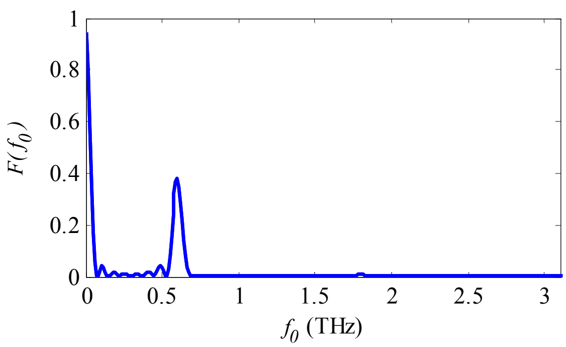

Figure 3: Form factor of the bunch train at 55.47cm

From the simulation, such a bunch train with 8 sub beamlets have large form factor in THz radiation region, thus considerable enhancement of THz radiation can be achieved with this kind of electron bunch train. Using UV pulse stacking we may directly produce such electron bunch trains.

PRINCIPLES OF UV STACKING

The α-BBO crystal has large birefringence over the broad transparency range from 190 to 3500nm, which makes it an excellent candidate material for linear optics[5]. The crystal is cut so that its extraordinary axis lies in its surface and perpendicular to the incident laser pulse. For the UV laser to drive copper photocathode RF gun at central wavelength 266.7 nm (triple of laser at wavelength 800 nm), the index of ordinary light and extraordinary light are n_o=1.758, n_e=1.612 respectively. The birefringence is 0.146. So the initially coincided such two types of polarized light centred at wavelength 266.7 nm will have relative retardation t (in ps) after propagation in the crystal for length l (in mm), which satisfies $l = ct/(n_o - n_e)$, where c=2.99792458×10^{-1}m/ps is the velocity of light in vacuum, as shown in fig.4. To make the delay time between ordinary light and extraordinary light to be 1 ps, the thickness of the crystal should be 2.058 mm (about 2 mm).

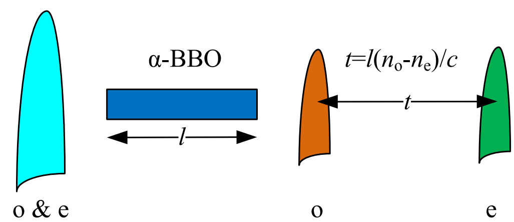

Figure 4: The principle of birefringent crystal

Now suppose there are four pieces of α-BBO crystals with thickness (16mm, 8mm, 4mm, 2mm) placed along z axis successfully. The extraordinary axis of the odd crystals is parallel with the original input pulse polarization direction, while the extraordinary axis of the even crystals is tuned to be 45 degree with that of adjacent crystals. Without consideration of dispersion induced by the crystals, with an initial input pulse with 0.5 ps duration (FWHM), one can obtain pulse train with 16 sub-pulses. The time interval of the adjacent sub pulses is about 1 ps, thus the THz-rep-rate pulse train with equal amplitude is formed. Because of the alternatively varied polarization, interference doesn't play considerable role in the pulse train formation.

EXPERIMENTS AND RESULTS

In our preliminary experiment, we use two pieces of α-BBO crystals to form UV pulse train with four sub-pulses (Figure 5 shows four pieces for 16 sub-pulses production). The initial UV pulse is stretched to about 0.6ps (FWHM) by prism pair made of fused silica, and then incident on the surfaces of the α-BBO serials. The stacked UV pulse is then transported to illuminate the photocathode RF gun by imaging relay technique.

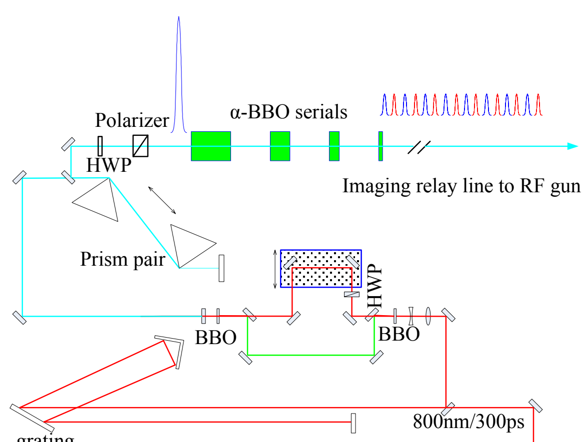

Figure 5: Schematic of pulse stacking layout

The temporal profile of the produced electron bunch train was measured by a 3-cell, S-band, standing wave, pi-mode RF deflecting cavity. Schematic of the experimental setup is show in figure 6. During the experiment, the maximum electric field on the cathode is 65MV/m, and the laser launching phase is 20degree. The rms laser spot size on the cathode is 0.4mm. The beam energy is 2.8MeV, and the total beam charge is 40~50pC. The microwave power distributed for the deflecting cavity is 4MW, corresponding to maximum electric field 3.4MV/m. The CCD in the detection system was calibrated to be 0.0118ps/pixel.

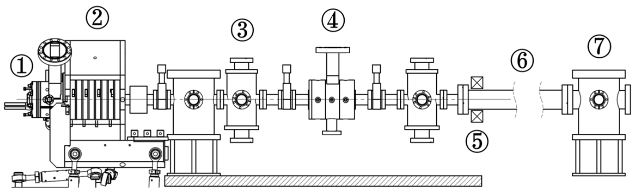

Figure 6: Schematic of the experimental layout. ① photocathode ② solenoid magnet ③ slit chamber ④ deflecting cavity ⑤beam diagnostic chamber ⑥1.5m drift tube ⑦detection chamber

In the experiment, three combinations of α-BBO crystals were tried to achieve pulse trains: 4mm+2mm; 8mm+4mm; 16mm+8mm. The measured temporal profiles of the electron bunch trains by the RF deflecting cavity are shown in figure 7~9.

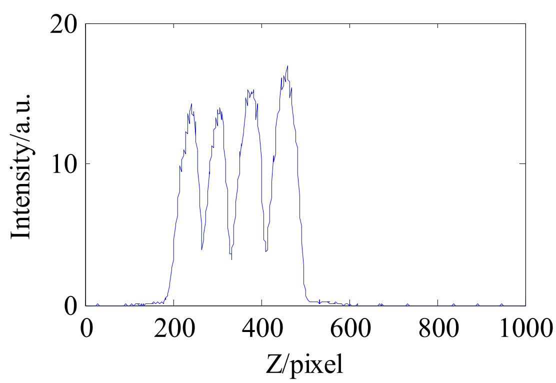

Figure 7: Results for 4mm+2mm α-BBO crystals.

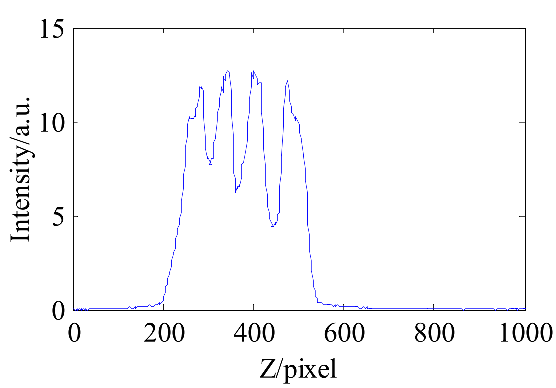

Figure 8: Results for 8mm+ 4mm α-BBO crystals

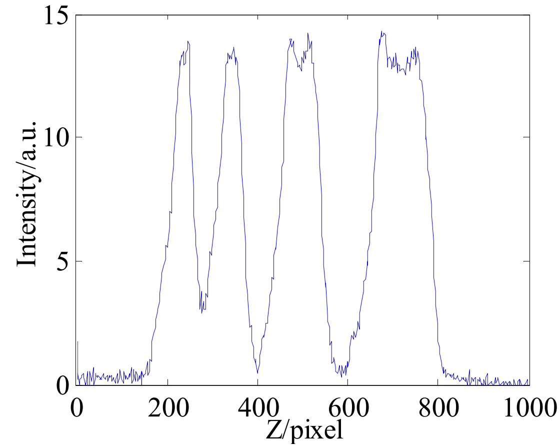

Figure 9: Results for 16mm+ 8mm α-BBO crystals

From the experimental results, we can see that using this kind of method, THz-repetition-rate ultrashort electron bunch train has been directly achieved by UV pulse stacking.

CONCLUSION

THz-repetition-rate ultrashort electron bunch train can be used to produce enhanced THz radiation by different mechanisms. Preliminary experiments have been demonstrated at our laboratory the direct production of such ultrashort electron bunch train with photocathode RF gun driven by UV laser pulse stacking with α-BBO crystal serials. Further efforts are to be taken to demonstrate bunch train with 16 sub beamlets by 4 pieces of α-BBO crystals and also to produce THz radiation by CTR mechanism.

REFERENCES

[1] G. L. Carr, M. C. Martin, W. R. Mckinney, et al, Nature, 420(2002)153.
[2] Gover A, Phys. Rev. ST Accel. Beams 8(2005)03701
[3] Gover A, Dyunin E, Lurie Y, et al, Phys. Rev. ST Accel. Beams 8(2005) 03702
[4] J. G. Neumann, R. B. Fiorito, P. G. O'Shea, et al, J. Appl. Phys., 105(2009)053304
[5] Solntsev V. P., et al, J. Crystal Growth, 236(2002)290