ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB146

PRELIMINARY STUDY OF FEMTOSECOND ELECTRON SOURCE BASED ON THz ACCELERATION AND FIELD EMISSION*

Zhenxing Tang, Bingfeng Wei, Guangyao Feng†, NSRL/USTC, Hefei, China

Abstract

In this paper, we propose a novel electron gun based on THz acceleration and field emission to generate femtosecond electron bunches. The field emission cathode is placed in the center of the cavity, and the standing wave field is established in the cavity to achieve the field emission conditions and extract the electron beam. Because the period of THz band is about picosecond, the femtosecond bunch is formed by controlling the field strength and the pulse width of the extracted beam. We analyzed the feasibility of field emission and the length of the pulse beam. The surface peak field intensity of the structure of the cavity with different emitters are simulated by CST software.

INTRODUCTION

In recent years, ultrafast electron diffraction imaging has been widely used in biology, chemistry and other research fields. In the world, many universities and research institutions are studying the generation of ultra fast electron beam now. The quality of the electron source is very important to the performance of the ultrafast electron diffraction system. Therefore, to a certain extent, the performance of the electron source determines the performance of the whole device.

The development of free electron laser (FEL) benefits from the high quality electron source produced by the photocathode based microwave electron gun. At present, the electron source design of the ultrafast electron diffraction device is basically from the free electron laser, that is, the photocathode microwave electron gun. After the picosecond beam is generated at the photocathode, the beam length is compressed to femtosecond level by the beam compression system. Although the method can produce femtosecond beam, it is complex in structure and expensive in cost, which is not conducive to wide application.

In this paper, we propose a novel electron gun based on THz acceleration and field emission to generate femtosecond electron bunches. The field emission cathode is placed in the center of the cavity, and the standing wave field is established in the cavity to achieve the field emission conditions and extract the electron beam. Because the period of THz band is about picosecond, the femtosecond bunch is formed by controlling the field strength and the pulse width of the extracted beam.

* Work supported by National Natural Science Foundation of China(Grant No. U1832135 and 11805199) and Fundamental Research Funds for the Central Universities (Grant No. WK2310000072)
† tangzhx@ustc.edu.cn

FIELD EMISSION THEORY

When the electrons in the solid get enough energy under the action of external field, the kinetic energy of some electrons may escape from the solid surface to form electron emission. For the hot electron emission in the external field, the potential barrier will decrease and become thinner, and the emission current will increase with the third half power of the applied voltage. If the intensity of the applied electric field continues to increase, the top of the barrier will drop below the Fermi level, and a large number of electrons will escape from the metal. In the free electron model, electrons exist in a potential well with a density of states described by Fermi-Dirac statistics. The field emission current density j satisfies the Farrell Nordheim formula

$$j = \frac{1.54 \times 10^{-6} E_S^2}{\phi t^2 (y)} \exp\left[\frac{-6.8 \times 10^{-7} \nu (y) \phi^{\frac{3}{2}}}{E_s}\right], \quad (1)$$

where j is the emission current density in units of A/cm^2, E_s is the surface electric field in units of V/cm, ϕ is the work function of the material in units of cV, and $t(y)$ and $\nu(y)$ are dimensionless elliptic functions of E and ϕ, $y = 3.79 \times 10^{-4} \frac{\sqrt{E_s}}{\phi}$.

The input power determines the electric field strength inside the cavity. For the RF field changing with time, the peak surface electric field intensity changes with the phase, so the emission current density also changes with the phase. By controlling the RF power, the pulse width of the generated beam can be controlled, that is, the bunch length as shown in Fig. 1. According to the Fig. 1, in a certain range, the bunch length can be reduced by reducing the input power.

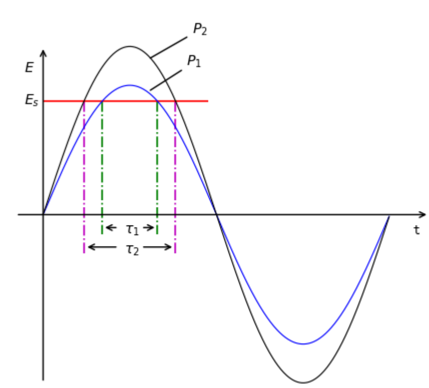

Figure 1: The relationship between the bunch length and the power of the beam.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB146

The current I for a given emission area S can be written as

$$I = \frac{1.54 \times 10^{-6} E_s^2 S \beta^2}{\phi t^2 (y)} \exp\left[\frac{-6.8 \times 10^{-7} v(y) \phi^{\frac{3}{2}}}{E_s}\right], \quad (2)$$

where β is the field enhancement factor over S.

In RF period, assuming the RF field varying as $E_s \sin(\omega t)$, the total current can be written as

$$I_t = \frac{1}{t} \int_0^t I(t)\, \mathrm{d}t. \quad (3)$$

DESIGN OF EMITTER AND CAVITY STRUCTURE

The structure of emitter belongs to micron level, which needs micro nano machining. The hemispherical structure of the emission surface is beneficial to increase the emission area and the charge of the beam. In this paper, we study two kinds of emitter shapes, conical emitter and arc emitter, as shown in the Fig. 2.

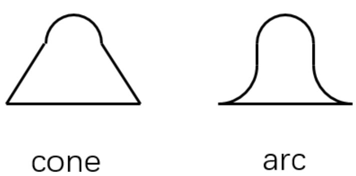

Figure 2: Emitter shape.

The cavity is a single cavity structure, and the emitter is located in the center of the cavity, that is, the place with the maximum field strength, as shown in Fig. 3. The single cavity structure is beneficial to manufacturing.

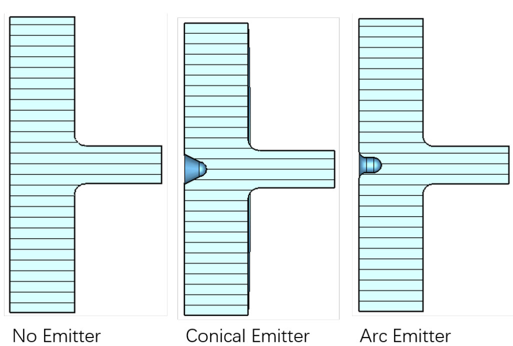

Figure 3: Three kinds of cavity structure.

SIMULATION OF FIELD DISTRIBUTION IN CAVITY

We use CST software [1] to simulate and calculate the field distribution of three kinds of cavities. The profiles of three-dimensional field distribution are shown in Fig. 4.

The peak surface field strength of the three structures are shown in Fig. 5.

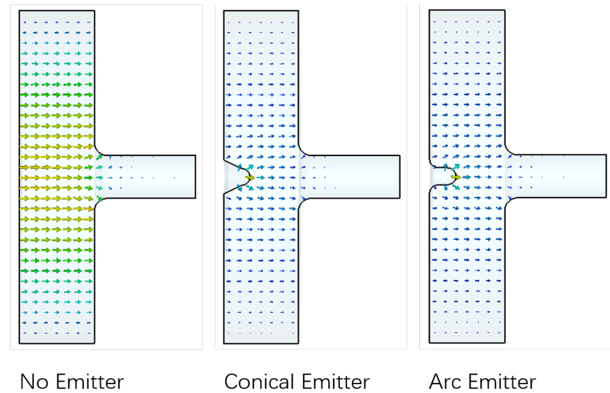

Figure 4: The filed distribution of the π and 0 mode.

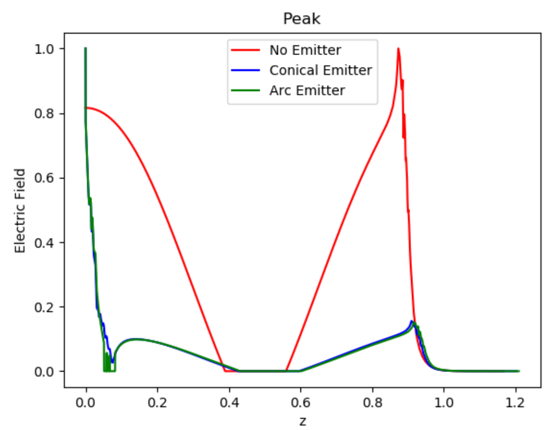

Figure 5: The peak surface field strength.

The simulation results show that when there is no emitter cathode, the peak field intensity of the inner surface of the cavity is at the chamfering of the beam exit. When the conical emitter and the arc emitter are used, the peak field intensity of the surface is at the apex of the emitter, which is about 5 times larger than that of the chamfering of the beam exit. Therefore, the results show that there is no secondary electron emission when the emitter produces field emission.

CONCLUSION

In this paper, the shape of the emitter, the structure of the cavity, the field distribution inside the cavity and the characteristics of the peak field intensity on the surface are studied. It is proved that the scheme is feasible.

ACKNOWLEDGEMENTS

We appreciate the support from National Natural Science Foundation of China (Grant No. 11805199 and U1832135) and Fundamental Research Funds for the Central Universities (Grant No. WK2310000072).

REFERENCES

[1] CST-Computer Simulation Technology, https://www.3ds.com/products-services/simulia/products/cst-studio-suite