Research on New Grating Structure Based on 340GHz Super Smith-purcell Radiation

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Abstract: In this paper, a new grating structure based on Smith-Purcell superradiation is studied. Smith-Purcell super-radiation is coherent Smith-Purcell radiation generated by free electrons swept over the surface of the grating. Its frequency is a multiple of the surface wave. In this paper, the structure and size of the grating were optimized through simulation. The terahertz wave at 340GHz was obtained under the electron beam of 15keV. Compared with the ordinary grating structure, it shortened the oscillation time and reduced the required current density. The waveform is also more stable. The research in this paper is of great significance for the realization of compact, adjustable, high-frequency terahertz radiation sources.

Keywords: Terahertz waves;Super Smith-Purcell radiation ; Grating structure

Introduction

In 1953, Smith and Purcell first discovered that when free electrons passed over the surface of a periodic metal grating, the surface of the grating would radiate electromagnetic waves outward. The radiation relationship is as follows[1]:

$$\lambda = \frac{L}{|n|}\left(\frac{1}{\beta} - \cos\theta\right) \qquad (1)$$

where λ is the wavelength of the Smith-Purcell radiation wave, L is the size of a single period of the grating, n is the order of the Smith-Purcell radiation wave, β（β=v/c） is the ratio of the electron velocity to the speed of light in a vacuum, and θ is the angle at which the observer observes the radiation wave . In 1998, J. Urata and others at Dartmouth University in the United States discovered the SSPR phenomenon (Super Smith Purcell Radiation) in experiments [2]. The mechanism is that continuous electron beams interact with slow waves on the surface when they pass through the surface of a periodic metal grating to formelectron clusters. These periodically clustered electron beams can greatly enhance Smith-Purcell radiation, thereby generating surface wave multiplication Super radiation.

This paper mainly researches and analyzes the continuous electron beam modulated rectangular grating through computer simulation, and achieves 100mw output in the frequency band higher than 340GHz.

Design of Grating Structure

The design model is shown in Figure 1. The grating structure is placed at the center of the bottom of the simulation area. We add side walls equal to the grating on the left and right sides of the grating, and add baffles that are higher than the grating on the front and back sides of the grating. In general, a periodic grating groove is dug out from the center of a rectangular conductor.

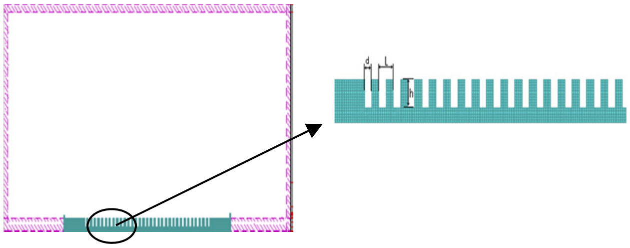

Figure 1. Schematic diagram of new grating structure

A rectangular emitting surface of $0.108 \times 3.6\,\boldsymbol{mm^2}$ is set at the far left of the structure, and the electron beam density is 25A $/\boldsymbol{cm^2}$. The rightmost side of the structure is a rectangular collector. The entire simulation space background is a vacuum environment. A static magnetic field of 1T is set along the positive direction of the grating x to ensure that the electron beam passes smoothly through the grating. The main parameters of the grating simulation calculation are shown in Table 1.

Table1 The main parameters of the grating

Grating period length L	0.26mm
Grating groove depth h	0.36mm
Grating groove width d	0.135mm
Grating periods	35
Grating width w	3.6mm
Electron beam energy	15keV

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Theoretical calculations and simulation results

Before the simulation, we analyzed the dispersion of an open flat grating. It is assumed that the TEM mode electromagnetic wave propagates in the grating groove. As described in Reference 7, the dispersion of a two-dimensional grating can be used to describe the dispersion of a three-dimensional grating. The two-dimensional plate grating cold cavity dispersion equation can be simplified as [3]:

$$\frac{cot(\omega\cdot h/c)}{\omega\cdot h/c}-\sum_{n=-\infty}^{\infty}(\frac{sin\theta_n}{\theta_n})^2\frac{d}{\gamma_{n\cdot h}}=0 \qquad (2)$$

where$\theta_n=\rho_n\cdot\frac{d}{2L}$,$p_n=k\cdot L+2n\cdot\pi$,$\gamma_n=\sqrt{{p_n}^2-(\omega\cdot L/c)^2}$, c is the speed of light in a vacuum. We bring the parameters of Table 1 into equation (2) to get the dispersion curve of the two-dimensional grating. As shown in Figure 2, the intersection of the electron beam line and the grating dispersion line f1 = 171.2GHz, that is, the surface slow wave frequency. The electron beam line f2 = 342.4GHz (the double frequency point of the surface wave) falls in the radiation zone, and the electromagnetic wave of this frequency is the superradiation wave.

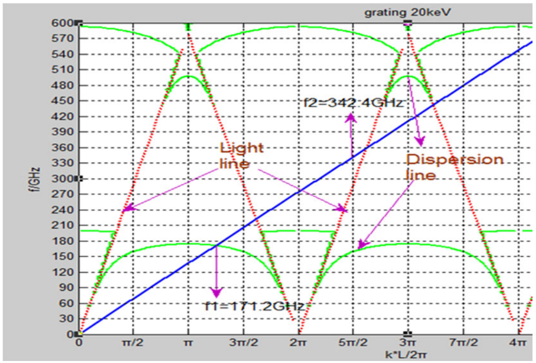


Figure 2. Two-dimensional grating dispersion curve chart, 0 ～ 2π, 2π ～ 4π, corresponding to the 0th and -1th order dispersion intervals

The simulation of the structure in Figure 1 was performed using Magic simulation software. As shown in Figure 3, it can be seen that the incident electron beam has completely started to vibrate.

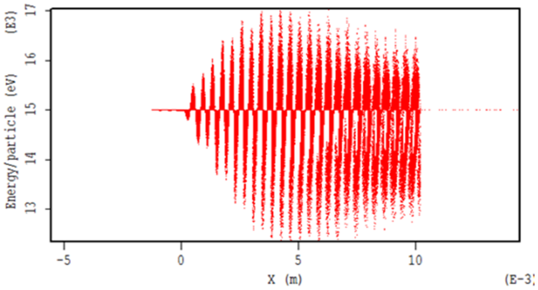


Figure 3. Electron momentum diagram

We will observe the contour map of the magnetic field in the z direction above the entire grating. Because the magnetic field on the surface of the grating is too strong, we will mainly take a 0.468mm distance from the grating to the upper boundary to observe. As shown in Figure 4, the -1 order superradiation beam can be clearly observed on the right side of the figure, and the radiation angle of 34.4 ° is the same as the calculation result of equation (1).

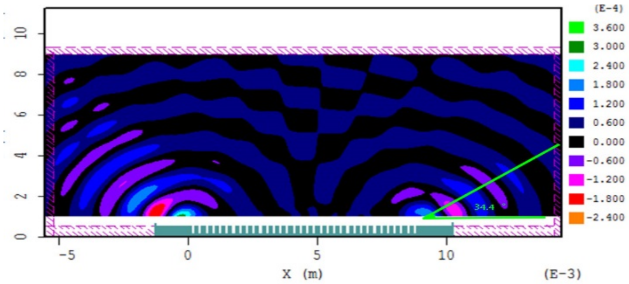
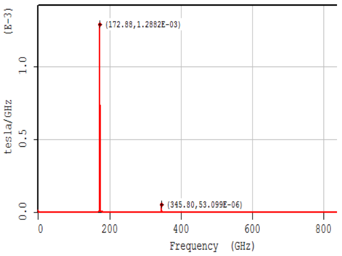


Figure 4. Isopotential diagram of magnetic field above the grating

Set the observation point and rectangular viewing side at 1.44mm away from the grating surface in the radiation direction (1.35mm in the x direction and 3.6mm in the z direction). As shown in Figures 5 and 6, there are surface wave frequency signals and surface waves. The super-radiated frequency signal of 2 times, and according to the proportion of the second harmonic component, the average radiated power of the observation surface is 103mw.



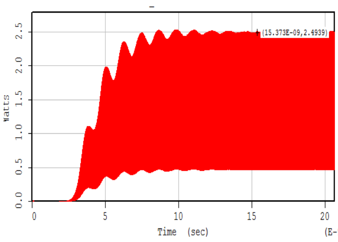


Figure 5. Frequency domain diagram

Figure 6. Power diagram of of detection point magnetic field observation surface

Conclusion

In this paper, theoretical analysis and simulation calculation of 340GHz Smith-Purcell super-radiation grating structure are performed. This grating structure is relatively simple and can obtain 103mW, 345GHz terahertz waves under the electron beam of 15keV, 25A $/cm^2$. , Is expected to develop into a compact, adjustable, high frequency, high power terahertz radiation source

Acknowledgements

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