Orbital Angular Momentum Generator Based on Super Smith-Purcell Radiation

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***Abstract-* An orbital angular momentum (OAM) generator based on free-electron-driven super Smith-Purcell radiation (super-SPR) is proposed in this paper. The super-SPR carrying the OAM mode can be generated at a specific angle through interaction between the periodically bunched electron beam and a helical grating. The working frequency and topological charge of the OAM mode is related to the dispersion relation and the operating voltage of the free electron beam. The OAM mode of the topological charge of 1 can be achieved at 320GHz at the second harmonic. And the field intensity is significantly enhanced compared with the incoherent Smith-Purcell radiation, which finds potential applications in the OAM communications.**

I. Introduction

Terahertz (THz) communication integrates the advantages of microwave and optical communication, and has many characteristics such as high transmission rate, strong directivity, high security, etc. [1-3]. Orbital angular momentum (OAM), as a new degree of freedom for electromagnetic waves, is used in communication systems to increase the communication capacity[4, 5]. Currently, OAM waves can be generated using geometric mode conversion methods, spiral phase plates, spatial light modulators, metasurface, and array antennas, etc. [6-9]. However, these approaches still cannot conveniently adjust the topological charge. Hence, the OAM terahertz (THz) source with an adjustable topological charge has been an active area of intense research. Super Smith-Purcell radiation (super-SPR) is a promising solution to achieve this goal. In 1998, J. Urata et al. [10] of Dartmouth University discovered a new radiation phenomenon based on the coherent Smith-Purcell (SP) radiation: super-SPR. When the wave vector of the free electron matches with the wavenumber of spoof surface plasmon polariton (SSP), the SSP mode can be effectively excited. The velocity of the direct current electron beam is modulated during the interaction between the beam-SSP interaction and the bunched electron can be obtained. The bunched electron beam carries the energy of harmonics, and super-SPR is formed when the harmonic frequency is located in the radiative region. And the field intensity of super-SPR is much greater than that of incoherent SP radiation (ISPR).

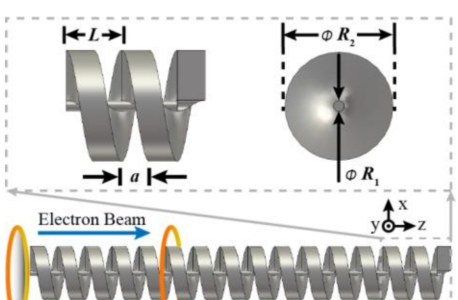

Fig. 1 Structure of helical grating. The ring-shaped electron beam is emitted from left to right, as shown by the blue arrow.

In this paper, the OAM radiation is generated by the interaction of the SSP of helical grating and the electron beam. When electron energy is 20 keV, the second harmonic super-SPR with topological charge of 1 can be carried at 320GHz. The field strength is significantly enhanced compared to the ISPR.

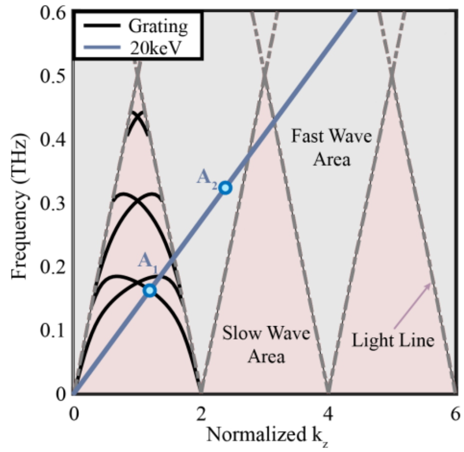

Fig. 2 Dispersion relations of helical grating and electron beam. The black line is the dispersion of the helical grating. The pink and gray region are slow and fast wave areas.

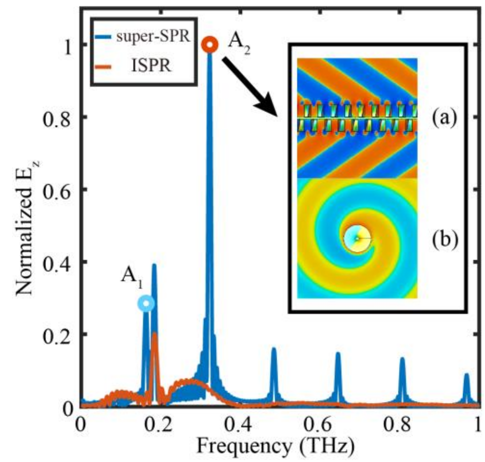

Fig. 3. Normalized Magnitude of E_z at 0.75mm from the grating surface when the electron beam energy is 20keV. The insect (a) and (b) are the radiation pattern and field distribution of E_z at A_2.

II. Analysis and Results

A. Dispersion of helical grating and electron beam

The structure of the helical grating is shown in Fig. 1, which is capable of supporting surface plasmon polaritons carrying OAM [11]. The period L of grating is 0.3 mm, the width a of the groove is 0.15 mm, the inner metal rod radius R_1 is 0.3 mm and the outer radius R_2 is 0.03 mm. Utilizing the finite-difference time-domain method, the dispersion relation of the helical grating is numerically calculated, and is represented by the black line in Fig. 2. The dispersion relation of the electron beam [12] is

$$\omega = v_e k_z \quad (1)$$

which is shown as the blue line in Fig. 2.

B. U = 20keV

When the energy of free electron is 10keV, the intersection frequency, i.e., the frequency of the intersection point between the dispersion line of free electron and the dispersion line of the fundamental mode of the helical grating, is 160GHz (the point A_1 in the Fig.1). Consequently the DC electron beam is modulated and bunched at a frequency $f_{A1} = 160$GHz. Since the second harmonic frequency $f_{A2} = 320$GHz is located in the fast wave region, a second harmonic super-SPR will be generated as shown in Fig. 2, which is validated by the PIC solver in the CST studio. The simulation results are presented in Fig. 3. Compared with the ISPR, the field intensity is enhanced by 5 times while keeping the other parameters unchanged. As shown in the inset of Fig.3 (a), the angle between the radiation direction and the velocity of the electron beam is 55°. The electric field profiles E_z at the radiation frequency $f_{A2} = 320$GHz is shown in the inset of Fig. 3 (b), which indicates that the topological charge of the OAM mode is 1.

III. Conclusion

In this paper, a convenient method for generating a OAM mode in the THz band based on the super-SPR is proposed. The dispersion relation of the spiral grating is calculated by numerical method. When the electron energy is 20keV, the OAM with topological charge of 1 is generated at 320GHz. Compared to incoherent Smith-Purcell radiation, their radiation intensity has been significantly enhanced. The frequency can be tailored by the energy of the free electron, which can be utilized to generate a millimeter wavelength OAM mode in the THz frequency range. The future plan is to develop compact and tunable THz OAM communication sources with higher frequency and higher efficiency based on the proposed method.

Acknowledgment

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