Terahertz Superradiation from Cylindrical Surface Wave-Annular Electron Beam Interaction within a 3-Mirror Quasi-Optical Cavity

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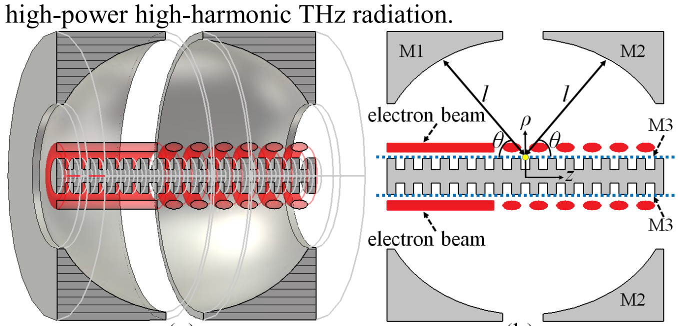
***Abstract*—A cylindrical surface wave-annular electron beam interaction in a special 3-mirror quasi-optical cavity is presented and explored. The study demonstrates THz free electron superradiation from the interaction of cylindrical surface wave and annular electron beam that forms a resonance within the structure, with the 3-mirror quasi-optical cavity enhancing the intensity of superradiation by more than one order of magnitude. Moreover, this system can work with 2nd harmonic superradiation at 0.607 THz with only about 30 A/cm^2 which is a relatively low value.**

I. Introduction

Teratertz (THz) radiation, which lies in the frequency gap between the microwave and infrared waves, has become an attractive and promising region on the electromagnetic spectrum because of its potential applications in security checking, astronomy, imaging, biology, nano-technology and other areas. Recently, studies on THz radiation sources have been extremely active [1]-[4]. As one of the promising approaches, electron-beam (e-beam)-driven sources provide the most power and frequency tuning range at the THz band [1]. However, the performances of these radiation sources are limited by increased operation frequency in the THz region. Using high-harmonic radiation seems a good way to reduce the current density and improve the performances. It is known that the Smith-Purcell radiation (SPR) is generated when an electron passes close over the surface of a period grating [5]. Based on such phenomenon, the super-radiated SPR, which could work at high-harmonic frequency and obtain high power, is proposed [6]. However, for such superradiation, the efficiency and power are yet to improve. Thus, to develop such high-power THz radiation sources, a resonant cavity with high-Q value and available operating at high harmonic is absolutely necessary. Along with the concept of the 3-mirror quasi-optical cavity (3MC) [7], an e-beam-driven THz superradiation generated by annular e-beam-cylindrical surface wave interaction within a 3MC is proposed.

II. Results

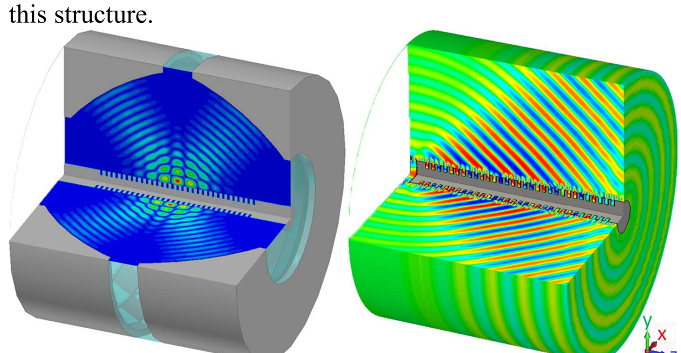
The structure of this e-beam-driven source is described in Fig. 1. Two identical cylindrical Fabry-Perot cavities M1 and M2 have been symmetrically located. A cylindrical grating whose surface acts as the third mirror (M3) is placed in the center. Just as the 3MC shown in [5], the wave will oscillate in this 3-mirror quasi-optical cavity constructed by the M1, M2 and M3. The direct current (DC) hollow cylindrical e-beam is injected and passes over the M3. At the synchronization between the e-beam and the surface wave of M3, interaction takes place, which could generate SP superradiation. Meanwhile, this cylindrical 3-mirror quasi-optical cavity acts as a feedback and oscillation system to enhance the interaction efficiency and superradiation intensity to achieve relatively high-power high-harmonic THz radiation.



(a) (b)

Fig. 1. Sketch of the 3MC structure: (a) a 3-D model of the 3MC; (b) cross-section of the whole system.

First of all, the 3-D electromagnetic simulation software Ansoft HFSS [8] have been applied to study the resonance mode in the 3MC. As the result shown in Fig. 2(a), a distinguished Hermite-Gaussian mode is well established in this structure.



(a) (b)

Fig. 2. (a) Computer simulation of the E_z field intensity in the 3MC by HFSS; (b) Contour map of the superradiation from the modulated e-beam over the cylindrical grating simulated by CST Particle Studio.

Next, the superradiation from the modulated e-beam over the cylindrical grating has been simulated by CST Particle Studio [9]. From the result shown in Fig. 2(b), the superradiation at the prospective angle (54°) along the longitudinal direction is generated when the modulated e-beam passes close over the surface of the cylindrical grating.

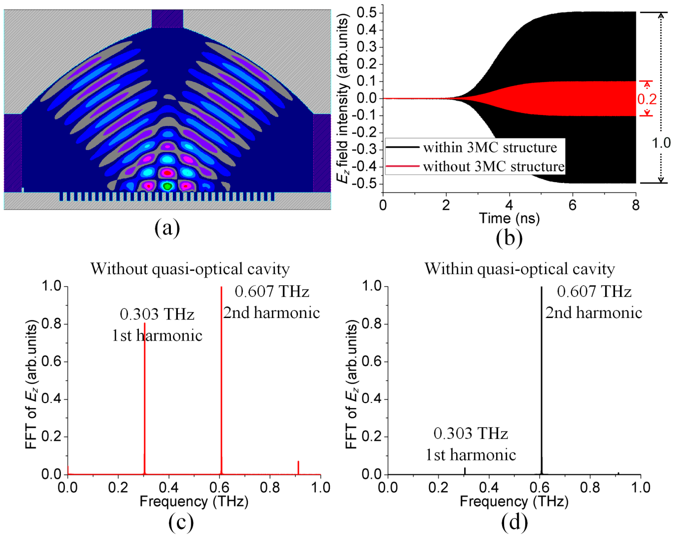


Fig. 3. Computer simulation results: (a) Contour map of the mode excited by the annular e-beam in the 3MC; (b) comparison of the E_z field intensity within and without the 3MC; (c) and (d) the FFT of the E_z without and within the 3MC, respectively.

Finally, a PIC simulation has been carried out. The simulated result of electric field distribution clearly shows that the 2nd harmonic supperadiation could oscillate and establish a well Hermite-Gaussian mode as shown in Fig. 3(a). More importantly, because of the superradiation oscillation and feedback in the 3MC, the interaction and radiation intensity have been enhanced. From the comparison of the superradiation intensity within and without the 3MC structure shown in Fig. 3(b), the radiation field intensity (E_z) within the 3MC has been improved five times than that without the 3MC. As the power is proportional to the square of E_z, the radiated power within the 3MC has been improved more than one order of magnitude. Furthermore, the frequency spectrum comparison shown in Figs. 3(c) and (d) obviously demonstrates that the 3MC enhances the radiation intensity and purifies the spectrum so that the 2nd harmonic superradiation frequency component is much larger than that of the fundamental frequency in the Fig. 3(d). Moreover, simulation results also show that the starting current density of such THz sources is only about 30 A/cm^2 with 2nd harmonic superradiation at 0.607 THz.

III. Summary

In conclusion, a THz superradiation from cylindrical surface wave-annular electron beam interaction within a 3-mirror quasi-optical cavity has been proposed in this paper. The studies show that in this system THz superradiation from the interaction between the annular ebeam and cylindrical surface wave is efficiently excited and a distinguished Hermite-Gaussian mode well established. Due to the superradiation oscillation and feedback in the 3MC, a pure 2nd harmonic superradiation spectrum and more than one order of radiation intensity enhancement have been achieved by this system. Moreover, such THz superradiation sources could work with 2nd harmonic superradiation at 0.607 THz with only about 30 A/cm^2 which is a relatively low value. The concept of this paper presents an efficient way to develop e-beam-driven THz superradiation sources in cylindrical system, which could be an available way to develop THz sources.

IV. References

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