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A Tunable Radiation Source from Laser-plasma Generated Electrons

Z. Jin,[1] Z. L. Chen,[3] H.B. Zhuo,[3,5] A. Kon,[3] M. Nakatsutsumi,[3] H. B. Wang,[2] B. H. Zhang,[2] Y. Q. Gu,[2] Y. C. Wu,[2] B. Zhu,[2] L. Wang,[2] M. Y. Yu,[6,7] Z. M. Sheng,[8,9] and R. Kodama[1,3,4]

[1]*Photon Pioneers Center, Osaka University, 2-1 Yamada-oka, Suita, Osaka, 565-0871 Japan*
[2]*National Key Laboratory of Laser Fusion, CAEP, Mianyang 621900, China*
[3]*Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka, 565-0871 Japan*
[4]*Institute of Laser Engineering, Osaka University, 2-6 Yamada-oka, Suita, Osaka, 565-0871 Japan*
[5]*School of Science, National University of Defense Technology, Changsha 410073, China*
[6]*Institute for Fusion Theory and Simulation, Zhejiang University, Hangzhou 310027, China*
[7]*Institute for Theoretical Physics I, Ruhr University, Bochum D-44780, Germany*
[8]*Key Laboratory for Laser Plasmas (Ministry of Education) and Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China*
[9]*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, CAS, Beijing 100080, China*

Near-infrared radiation with wavelength around 1000 nm is experimentally observed by coupling a periodical metal grating to the MeV electron beams with high current density generated in the intense ultra short pulse laser and solid target interaction. Simulations prove a prospect of tuning such kinds of radiation into sub-mm waves, which holds a promise for a tunable compact “table-top” powerful Tera-Hertz source.

1. Introduction

Special radiation called Smith-Purcell Radiation (SPR) could be generated when electrons pass by a metal surface with periodical grating structure. Such radiation was firstly observed by S. J. Smith and E. M. Purcell, and proved to be tightly related to the electron velocity, the grating period, and the observation angles in both the experiments and the theories. The radiation wavelength λ is found to have a relationship as [1]

$$\lambda = \frac{l}{|n|}\left(\frac{1}{\beta} - \cos\theta\right) \quad (1),$$

where l is grating period, θ is observation angle, n is harmonic order of the radiation, $\beta = v / c$ is electron velocity, and c is light speed.

In this paper, we present a different configuration to generate such kinds of radiation by use of the energetic electron beams produced from the intense ultra short pulse laser and plasma interaction. Near-infrared radiation (NIR) with wavelength around 1000 nm is clearly observed in our experiments and shows an exact satisfaction to the Eq. (1). PIC simulations prove a prospect of tuning such kinds of radiation into Tera-Hertz (THz) wave, strongly indicating a hope for the fruitful applications by having a tunable “table-top” THz source.

2. Experimental results and discussions

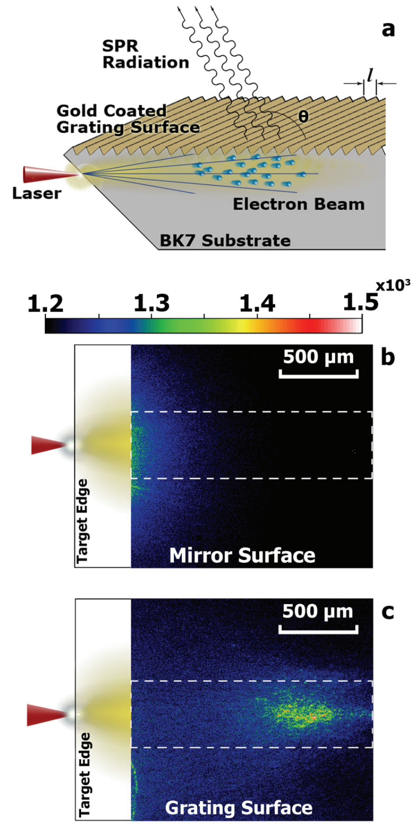

Fig.1. (a) Experimental configuration of the electron beam and the grating structure. Images at the emission, or upside, surface of the solid target for targets with smooth (b) and grated (c) surfaces.

Experiments were performed in both the SILEX-I laser facility in National Key Laboratory of Laser Fusion, CAEP in China, and the P3 laser facility in Graduate School of Engineering, Osaka University in Japan. The experimental configuration is shown in Fig. 1(a). A 1/830 mm grating is chosen to realize output radiation in the NIR range, to which our spectrometer and CCD camera are sensitive. For comparison, another target with the same specifications but having a smooth flat upside surface is also used. Both targets are made of BK7 glass, with the upside surface coated with gold.

The spatial distributions of the NIR radiation from the targets with grated and smooth upside surfaces are shown in Fig. 1(b)-(c). The effect of the grating on the radiation can be clearly seen by comparing the radiation patterns from the grated and smooth surfaces in Fig. 1(b) and (c), respectively. A bright radiating spot, of width 500 μm and nearly flat intensity distribution, on the grated surface is recorded by the CCD camera. In contrast, with the smooth surface the emission intensity reaches a peak close to the spot where the laser hits the target and decreases exponentially away from it. The energetic electron beam originating from the laser spot first propagates inside target plasma, and SPR is emitted when it reaches and propagates along the grated surface.

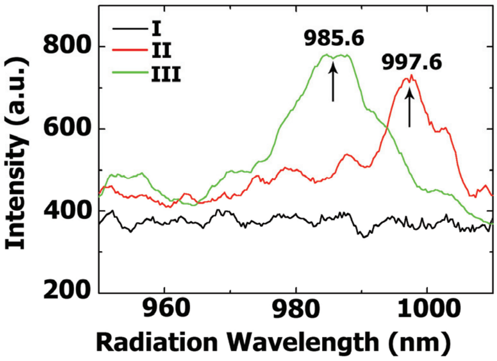

Fig. 2. Dependence of the radiation wavelength on the observation angle θ. The black (I), the red (II), and the green (III) solid lines give the radiation spectra emitted from the side mirror surface and the side grating surface at the observation angle of θ=80.2°, and from θ=79.6°, respectively.

Radiation spectra in Fig. 2 measured by the spectrometer clearly show a characteristic radiation peak around 1000 nm emitted from the grating surface whereas no emission peak appears from the mirror surface. The spectrum peak shifts from 985.6 nm to 997.6 nm as the observation angle changes from 79.6° to 80.2°, which is exactly coincident with the theoretical calculation results based on the Eq. (1) where the shift is from 983 nm to 996 nm at these two observation angles.

2D PIC simulations are carried out using the PDLPICC2D code [2]. Figure 3 illustrates the simulation results for grating with $l = 10\,\mu$m . The crescent-shaped wave fronts of the low frequency radiation shown in Figs. 3(a) correspond to that of the classical Smith-Purcell result. The Fourier spectra of the emission fields are shown in Figs. 3(b). One can clearly see that the results from the first order Smith–Purcell relation agree well with that from the simulations. And the result indicates a coherent radiation with tens GV/m field strength.

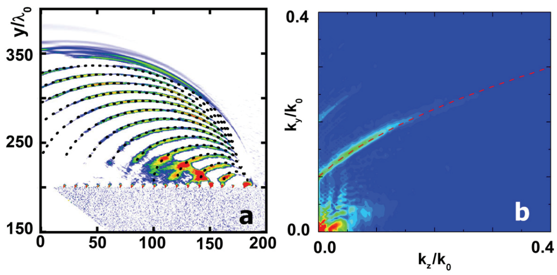

Fig. 3. Snapshots from the 2D PIC simulations. (a) The emission field $eE_z/mc\omega_0$ and (b) the Fourier spectrum $E_z(k)$ for l=10 μm at 200 laser periods. The black dots and the red dashes represent the calculated first order SPR results.

3. Acknowledgments

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