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Properties of the Coherent Radiation Emitted from Photonic Crystal in the Millimeter Wave Region. Ⅲ

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Coherent radiation emitted from a Photonic crystal of a cylindrical tube of Teflon with periodic grooves is observed in the millimeter wave region. The observed spectra show a sharp peak at frequency of 4.625 cm^{-1}. The inter-bunch coherence of the radiation is confirmed with an interferometer.

§1. Introduction

When a short-bunched beam of electrons of a linear accelerator passes by near the surface of a photonic crystal (PhC), coherent photonic crystal radiation is emitted in the millimeter wavelength region [1-4].

In this report, to examine possibility of application to beam diagnostics, we have tentatively observed photonic crystal radiation generated from high-energy electrons passing through the center of a tube of Teflon, whose outer surface has periodic grooves.

§2. Experiment

The experimental setup is schematically shown in Fig.1. A short-bunched beam of electrons from the linear accelerator at Laboratory of Nuclear Science (LNS), Tohoku University moved with a constant velocity v along the center line of a cylindrical tube of a PhC. Let suppose that the center line is x axis and horizontal plane is parallel to the xy plane. The photonic radiation from the PhC was guided by a mirror system to a Martin-Puplett type Fourier transform spectrometer and was detected with a low temperature hot-electron bolometer. The emission angle θ was measured from the x direction.

The beam condition was as followings. The energy of the electron was 150 MeV and its spread was less than 2.5%, the macro and micro pulse widths were roughly 1.5 μs and 0.67 ps, respectively. The repetition of the macro pulse was 50/3 Hz and the average beam current was 0.9 μA. The cross section of the beam was nearly circular and about 10 mm in diameter.

The PhC was fabricated from a cylindrical tube of polytetrafluoroethylene (PTFE : Teflon) having the size of 100 × ϕ60 × ϕ30 mm in total length × outer diameter × inner diameter. The outer surface of the tube had periodic grooves with cylindrical symmetry. The cross section of the groove is shown in the

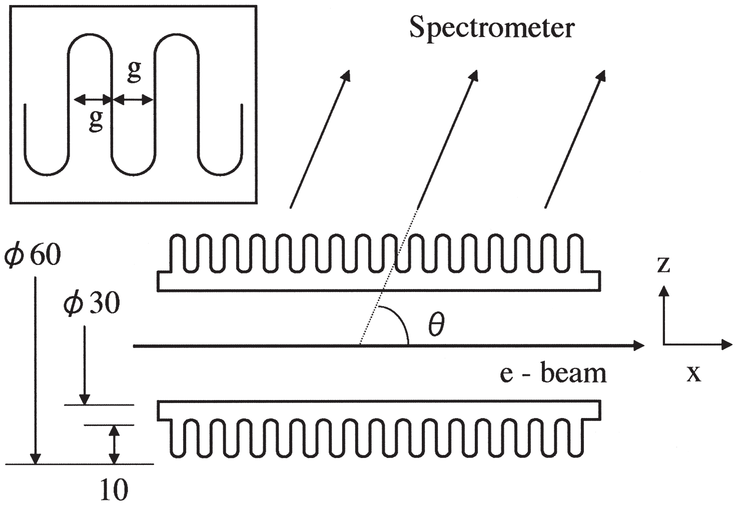

Fig.1. Schematic layout of the experiment. The electron orbit is shown by the thick solid line. The emission angle θ was measured from the x direction. The inset shows the shape of groove.

inset of Fig.1; the top and bottom of the grooves were semi-circle with the size of 3 mm in diameter, and the period of the grooves was 6 mm (g = 3 mm) in the x direction.

§3. Results and Discussion

The spectra of photonic crystal radiation were observed for the emission angles θ of 110°, 100°, 90°, 80° and 70°, and were shown in Fig.2. Each of the observed spectra was composed of several peaks. Every spectrum has the main peak at frequency ν of 4.625 cm^{-1} or wavelength of λ = 2.16 mm and its overtone at 9.25 cm^{-1} though the intensity was weak.

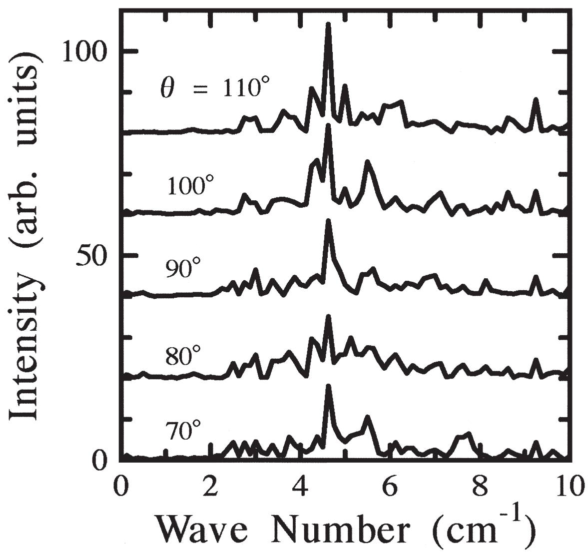

Fig.2. The spectra observed at θ = 110°, 100°, 90°, 80° and 70°. The spectra are vertically shifted to make comparison clear.

When we observed the photonic crystal radiation from the arrayed PTFE spheres or the arrayed PTFE cylinders, the observed peaks satisfied the dispersion relation of Smith-Purcell radiation and/or the new resonant dispersion relation [2-4]. The peak frequency therefore depended on the emission angle θ. On the contrary, the peak frequency in Fig. 2 did not depend on the emission angle. The reason of the difference is not clear at present.

The outer grooves of the Teflon cylinder had the period of 6 mm. Hence, the spectrum observed at θ = 90° was expected to have an intense peak at ν = 1.67 cm^{-1} or at λ = 6 mm. Taking into account the sensitivity of our measuring system, the peak of 1.67 cm^{-1} may be difficult to observe. Even so, the higher harmonics should be observed. However, the peak or one of its overtones was not observed. The reason is not clear.

If we assume that the radiation generated in the Teflon cylinder is confined in the grooves, the radiation having a periodic condition of $g\sqrt{\varepsilon} = \lambda$ will survive, where $g\sqrt{\varepsilon}$ stands for the optical length of one groove. It is interesting that, since $\sqrt{\varepsilon}$ = 1.44 for Teflon, the wavelength with $m = 2$ becomes to λ = 2.16 mm which corresponds to the peak wavelength. It is not clear whether the correspondence was fortuitous or not.

The interferogram of the photonic crystal radiation was observed at θ = 90°, and is shown in Fig.3. The interference pattern around at 0 mm in the optical path difference was repeated at around 105 mm. The result clearly showed the inter-bunch coherence of radiation generated from the S-band linac.

The experimental result showed that the observed radiation will be applicable to beam diagnostics. However, theoretical simulation of the photonic crystal radiation is necessary to forward the application. In the experiment, we fabricated a similar cylindrical photonic crystal of Teflon with rectangular grooves with the same period. But the radiation was scattered over wide emission angle and weak at around θ = 90°. It suggests that the cross section of the groove is important in the application.

Acknowledgement

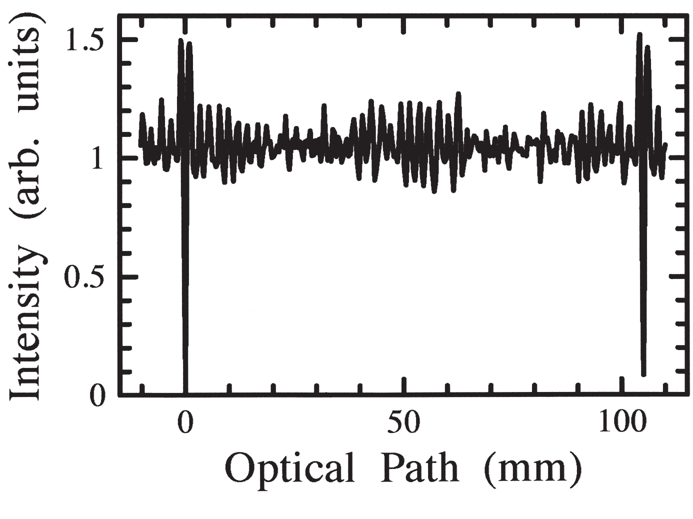

Fig.3. The interferogram observed at θ= 90°.

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