§8. Bloch Wave Cavity in Millimeter and Sub-Millimeter Wave Regions

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This project is aimed at studying Bloch wave cavity formed on rectangularly corrugated cylindrical waveguides. The corrugation has amplitude h, width d and period z_0. The corrugation wave number is given by $k_0 = 2\pi/z_0$. The corrugated wall can produce surface waves with wavenumber k_z^+ and k_z^-, as shown in Fig. 1. These surface waves are called surface plasmon polariton-like (SPP-like) waves in optics[1] and are called Bloch waves in this study. Note that the corrugations are structured on the outer wall of cylinder (the convex cylindrical surface) as shown in Fig.1(a) or the inner wall of waveguide (the concave cylindrical surface) as shown in Fig. 1(b). For both cases, Bloch waves on the corrugation surface with a phase velocity slower than the velocity of light are excited by electron beams.[2]

Bloch waves may propagate along the corrugation and be reflected at both ends as shown in Fig. 2. Beam mode and forward and backward Bloch waves are represented by their wavenumbers k_b, k_z^+ and k_z^-, respectively. The reflection coefficients are R_1 and R_2. Due to the axial boundary conditions, Bloch wave cavity is formed on the corrugation. The beam instability for the finite-length cavity becomes a "global instability", which is not the well-known absolute instability for a case of an infinite length. Threshold current and energy exist for intense radiations from Bloch wave cavity, which are called starting current and starting energy, respectively.

By measuring radiations, we examine Bloch wave cavities formation on corrugations listed in Table 1. The Bloch waves have upper cut-off frequencies around 100 GHz (A-type), 170 GHz (B-type), and 240 GHz (C-type) and are excited by coaxially injected annular electron beams in a weakly relativistic region less than 100 kV. Figs. 1(a) and (b) correspond to B-type corrugations. An oscillation starting energy for intense radiations is experimentally demonstrated. Above the starting energy, very intense terahertz radiations on the order of 10 kW are obtained. The operation frequencies are around 100 GHz (A-type), 150 GHz (B-type) and 200 GHz (C-type).[3-5] It is shown that the starting energy is more critical than the starting current for the intense operation of Bloch wave cavity in our 100 GHz frequency ranges.

Weakly relativistic BWOs have been studied using the corrugations in the X-, *K*-, *Q*-bands. These BWOs are based on the global instability driven by an annular electron beam with energy less than 100 keV. The intense radiations have been obtained and their figure of merit Pf^2 is about 0.35 [kW･THz^2]. This project realizes almost the same Pf^2 in the frequency range above 100 GHz, as shown in Fig. 3.

Bloch wave cavity may play an important role for intense radiations of millimeter and sub-millimeter wave regions. It may also of considerable interest for practical use and development of terahertz wave sources and technologies.

Table 1 Parameters of rectangular corrugations

	h [mm]	z_0 [mm]	d [mm]
A-type	0.30		
B-type	0.15	0.5	0.3
C-type	0.075		

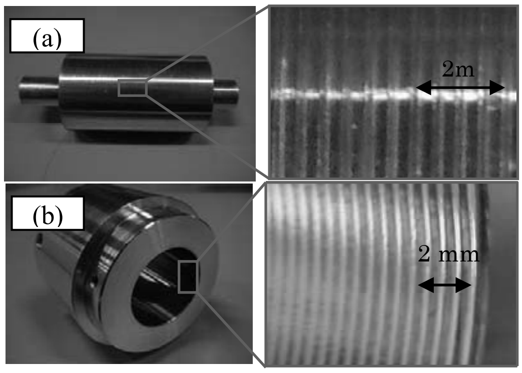

Fig. 1. Photographs of G-band corrugation on (a) the inner wall of waveguide and (b) the outer wall of cylinder.

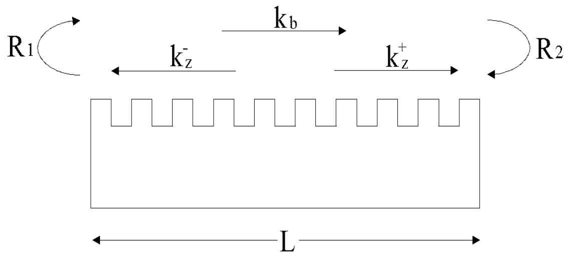

Fig. 2. Formation of Bloch wave cavity.

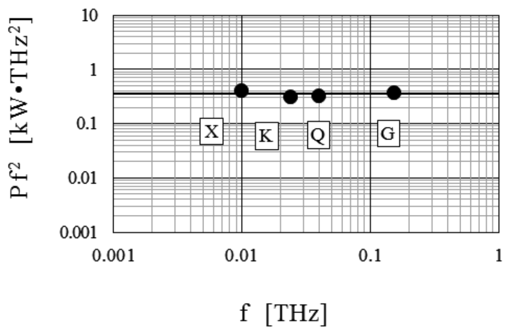

Fig. 3. Performance of weakly relativistic BWO from X- to G-bands.

1) J.B. Pendry et. al. : Science 305(2004)847.
2) K. Ogura et. al. :IEEE Trans. Plasma Sci. 44(2015)201.
3) S. Gong et. al. : J. Appl. Phys. 118(2015)123101.
4) S. Gong et. al. : IEEE Trans. Plasma Sci. 43(2015)3530.
5) M.T. San et. al. : Plasma Fusion Res. 11(2016)2406085.