§20. Bloch Wave on Periodical Corrugation in Millimeter and Sub-Millimeter Wave Region

Ogura, K., Yambe, K. (Niigata Univ.),
Kubo, S., Shimozuma, T., Kobayashi, S., Okada, K.

This project is aimed at studying Bloch waves on rectangularly corrugated cylindrical waveguides as shown in Fig. 1(a). The outer and inner corrugations have amplitude h, width d, period z_0 and average radii R_{out} and R_{in}, respectively. The corrugation wave number is $k_0 = 2\pi/z_0$. The relative phase between the corrugations is denoted by θ. We design K-band and G-band corrugations to examine Bloch waves. The designed parameters are listed in Table 1.

Dispersion curves of G-band corrugation are shown in Fig. 1(b). According to Floquet's theorem, the dispersion curves are periodic in the wave number k_z-space with period k_0. The inner corrugation generates a cylindrical surface wave (CSW) and the outer corrugation generates the TM modes. [1, 2] The slow-waves of CSW and TM_{01} mode near the π point (k_z = 62.8 cm^{-1}) are Bloch waves with frequency f = 170 GHz. The higher order modes are shown up to 600 GHz and are in the fast-wave regions. The higher order modes are TM_{02}, TM_{03}, TM_{04} … and complicated higher order modes composed of the multiple spatial harmonics of TM modes. Bloch waves are largely affected by the corrugation shape. The higher order modes are mainly determined by z_0.

It is elucidated that Bloch waves are examined based on a cavity resonance method.[3] Corrugations are excited by wire-disk antennas, which are composed of a reflector-flange and a wire with a disk on the tip. A network analyzer is used to measure the scattering parameters: the microwave reflection from the structure (S11) and the transmission through the structure (S21). The resonances appear as spikes where S11 decreases while S21 increases. Bloch waves have relatively sharp resonant curves. About 8% differences between the designed and measured frequencies are observed for K-band Bloch waves. This is explained by about 1.5 % (0.015 mm) error in h.

We also fabricate G-band corrugations and measure corrugation parameters in terms of elongated images obtained by a digital microscope as shown in Fig. 2, in which $2h$ = 305 μm, z_0 = 480 μm and d = 307 μm with three digits. Compared to values listed in Table 1, machining errors are on the order of a few %, leading to 10% order changes in frequencies of Bloch wave. Although machining accuracy depends on corrugation shapes, machining errors up to 0.01 mm (10μm) may be expected and have more serious effects when corrugations are considered in G-band or higher bands. However, from a different viewpoint, Bloch wave can be used to estimate the corrugation parameters as demonstrated by the cavity resonance method.

Different method to excite Bloch waves than wire-disk antennas is usage of electron beams. We use disk cold cathodes to generate uniformly distributed annular electron beams,[4, 5] which are injected as schematically shown in Fig. 1(a). For G-band corrugations, a 100 keV beam can couple to Bloch wave at about 170 GHz as can be seen from Fig. 1(b). Excited Bloch waves are surface waves and may be confined along the corrugation surface. Some of them are reflected at the corrugation ends and others are converted to propagating waves.[6] Radiations based on Bloch waves are observed for G-band corrugations as well as K-band corrugations.

Table 1 Parameters of rectangular corrugations

	h [mm]	z_0 [mm]	d [mm]
K-band corrugation	1.10	3.00	1.50
G-band corrugation	0.15	0.50	0.30

(a)
(b)

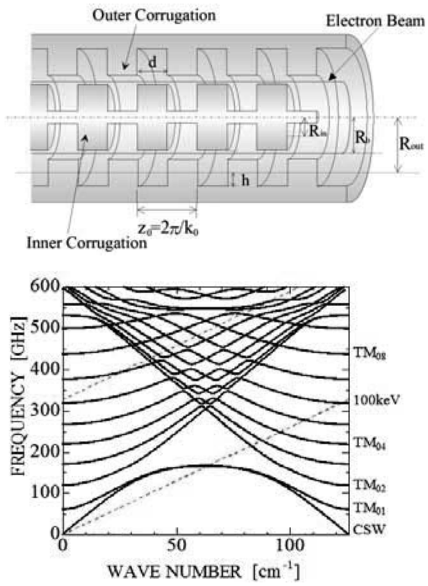

Fig.1 (a) Periodically corrugated cylindrical waveguide and (b) dispersion curves of G-band corrugations with R_{in} =12.6 mm and R_{out} =15.0 mm. In (b), dotted lines are 100 keV beam lines.

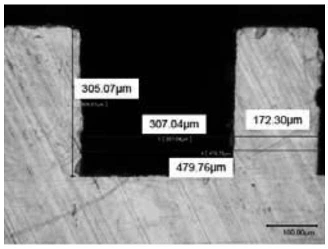

Fig.2 Enlarged cross section of fabricated G-band corrugation.

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2) K. Ogura et. al. :Plasma Fusion Res. 8 (2013) 2401085.
3) K. Ogura et. al. :Plasma Fusion Res. 7 (2012) 2406022.
4) H. Oe et. al. :J. Plasma Fusion Res. SERIES 8 (2009) 1477.
5) K. Yambe et. al. :*4th Euro-Asian Pulsed Power Conference and 19th International Conference on High-Power Beams* (October, 2012, Karlsruhe, Germany) P1D-5.
6) K. Ogura et. al. :Plasma Fusion Res. 6 (2011) 2401039.