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

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This project is aimed at studying Bloch waves on rectangularly corrugated cylindrical waveguides. The corrugation has amplitude h, width d and period z_0 and is formed on the inner wall of waveguide or the outer wall of inner cylinder of coaxial waveguide. The corrugation wave number is given by $k_0 = 2\pi/z_0$. Bloch waves are generated on the inner corrugation as a cylindrical surface-wave (CSW) and on the outer corrugation as the TM modes.[1)] We design K-, G- and Y-band corrugations, whose parameters are listed in Table 1.

Applying a cavity resonance method, the K-band corrugation of inner cylinder is excited by a wire-disk antennas composed of a reflector-flange and a disk on the wire tip. A network analyzer is used to measure the scattering parameters: the microwave reflection from the structure (S_{11}) and the transmission through the structure (S_{21}). The inner cylinder is a resonator of Bloch wave and the resonances appear as spikes where S_{11} decreases while S_{21} increases. The Bloch waves have fairly sharp resonance curves as shown in Fig. 1. In region (A), Bloch wave is well confined to the corrugation surface and is named "bounded surface-wave". In region (B), Bloch wave has the field properties of Sommerfeld wave and is named "hybrid surface-wave". Axial mode operation of BWO is based on the bounded surface-wave.

We measured parameters of G- and Y-band corrugations by using elongated images obtained by a digital microscope. Dispersion curves of Bloch wave on the inner corrugation are shown in Fig. 2. The dispersion curves are periodic in the wave number k_z-space with period $k_0 = 125.6$ cm^{-1}. Bloch waves of fabricated G-band (Y-band) corrugation may have upper cut-off frequency f_{uc} about 175 GHz (250 GHz) at the π point ($k_z = 62.8$ cm^{-1}). We excite the G- and Y-band corrugations by a weakly relativistic electron beam less than 100 keV.[3,4)] The corrugations act as a waveguide of excited Bloch waves. At the corrugation ends, some of Bloch waves are reflected and the others are converted to radiation waves. The radiations are measured by detecting system with various cut-off frequencies. For the fabricated G-band corrugation, microwave signals are detected by up to the 174 GHz cut-off detecting systems. However, no signal is detected by the 182 GHz cut-off detecting system. Hence, the radiation frequency is in the range from 174 GHz to 182 GHz. For G- and Y-band corrugations, machining errors are on the order of a few % and result in up to 10% order changes in f_{uc}.[2)] The estimated frequency coincides with the fabricated value rather than the designed value in Fig. 2. With the Y-band corrugation, signals of the 182 GHz cut-off detecting system appear. This is consistent with the Bloch wave excitation near 200 GHz expected from Fig. 2. As for the G- and Y-band corrugations, the cavity method used in the K-band becomes difficult. However, Bloch waves are largely affected by the corrugation shape.[1,2)] We demonstrate that the corrugation parameters can be estimated by using Bloch wave excitation by electron beams.

The cold test technique and Bloch wave excitation by a weakly relativistic electron beam may be of considerable interest for practical use of Bloch wave and development of compact THz wave source. In the THz or sub-millimeter wave region, machining and measuring accuracies up to 1μm may be required. Approach such as periodic arrangement of fine piece as well as machining may be considered to prepare micron size corrugation. Additionally, non-destructive technique needs to be developed to measure practical corrugations.

Table 1 Parameters of rectangular corrugations

Band	h [mm]	z_0 [mm]	d [mm]	f_{uc} [GHz]
K	1.10	3.00	1.50	25
G	0.15	0.50	0.30	170
Y	0.075	0.50	0.30	240

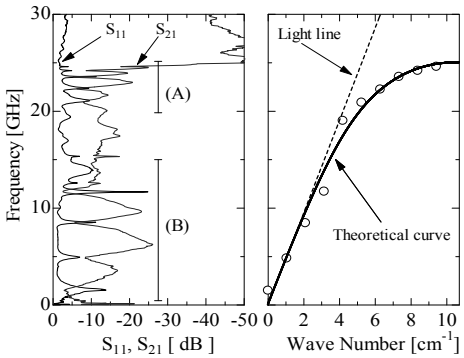

Fig. 1 Resonance curves of S_{11} and S_{21} (left) and axial modes of Bloch wave (right).

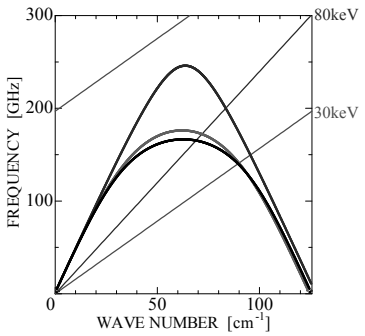

Fig. 2 Dispersion curves of Bloch waves for the designed and fabricated G-band corrugations and the fabricated Y-band corrugation, from the bottom. Thin lines are 80 and 30 keV beam lines.

1) K. Ogura et. al. :IEEE Trans. Plasma Sci. 41 (2013) 2729.
2) K. Ogura et. al. :Plasma Fusion Res. 9 (2014) 3406022.
3) K. Yambe et. al. :IEEE Trans. Plasma Sci. 41 (2013) 2781.
4) S. Magori et. al. :Plasma Fusion Res. 9 (2014) 3406032.