GROOVED WAFFLE WAVEGUIDE ANALYSIS AND ITS APPLICATION TO THZ CIRCUITS MADE OF NONCONTACT MICROMACHINED HALVES

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1. Introduction

Applications of terahertz technology expand to biomedical fields in addition to submillimeter-wave astronomy and remote sensing [1]. Terahertz antenna and circuit components are much smaller and more precise than microwave components, and micromachined structures have been studied [2]. A micromachined rectangular waveguide of WR-4 was reported, which consisted of metalized halves of etched silicon wafer [3]. The two halves meet at the center of the broader walls of the rectangular waveguide where no crossing current flows. An insertion loss comparable to that of a metal waveguide was measured in 200~255 GHz (24 % fractional bandwidth). A Grooved Waffle waveGuide (GWG) consisting of noncontact halves was proposed and analyzed by the image parameter method [4], [5]. The GWG confined a guided electromagnetic wave in a groove surrounded by upper and lower conductive plates and periodic structures of bosses on them (waffle-iron structure). Suitable dimensions for micromaching were given for the GWG in 200 GHz band and the analyzed results showed a single-mode transmission bandwidth of 47 %. The noncontact geometry was expected to give a solution to difficulties of surface smoothness and flatness of the meeting planes, and their alignment.

In this paper, the waffle-iron structures of finite periods are analyzed for the GWG to build terahertz circuitry. The waffle-iron structure is represented approximately by an equivalent circuit of a corrugated structure. Transmission-parameter analysis gives necessary number of periods to confine the guided wave. An equivalent electric sidewall is determined from the input admittance of the periodic structure. A feasible configuration is considered for a GWG coupler made of micromachined halves using the equivalent sidewall concept.

2. Configuration of GWG

The configuration of the GWG is shown in Fig. 1. The GWG consists of upper and lower conductive plates with bosses arranged periodically except for a wave-guiding groove. The waffle-iron structure has feature of a wide stop-band and insensitivity to incident angle of electromagnetic waves, and was applied to low-pass waffle-iron filter of 3:1 stop bandwidth [6]. The two plates are supported by outside walls, keeping the spacing b" between tops of bosses. The noncontact configuration is expected to tolerate looser surface smoothness and flatness. It is convenient for self-alignment mechanism, too.

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An example of the dimension is given in Table I for the 200 GHz-band GWG. The height b_0 of the groove is set equal to the spacing b between bottoms of slots to simplify the structure, and the width a_0 of the groove equal to double of the period (l+l'). The small-size and precise structure of the upper and lower plates is suitable for batch process from silicon wafers using micromachining techniques.

3. Analysis of Finite Periodic Structure

The waffle-iron structure can be replaced by an equivalent corrugated structure for a plane wave propagating in x-direction. Cross-section of the corrugated structure and its equivalent circuit are shown in Fig. 2. The low-impedance section takes larger value of b' than b" to compensate increase of capacitance by absence of slot S$_l$ [6]. The symbol l_1' is assigned to the length of the first and last low-impedance sections. The length l_1' is equal to l'/2 for a usual periodic structure, and is modified to adjust an equivalent electric sidewall.

The low- and high-impedance sections are represented by transmission line of normalized characteristic admittances $\bar{Y}_{02}$ and $\bar{Y}_{01}\left(=\bar{Y}_0=1\right)$ and the fringing capacitances at and between the steps by normalized susceptances $\bar{B}_{c0}, \bar{B}_{c2}$, and $\bar{B}_{c1}$, respectively [6], [8]. All admittances and susceptances are normalized by the characteristic admittance of the high-impedance section.

The attenuation L and the normalized input admittance $\bar{Y}_W$ of the periodic structure are given by

$$L = 10\log\left[1+\left|\frac{B-C}{2}\right|^2\right] \qquad \text{[dB]} \qquad (1)$$

$$\bar{Y}_w = \frac{A+C}{A+B} \qquad (2)$$

where A, B, C and D are transmission parameters of the corrugated structure.

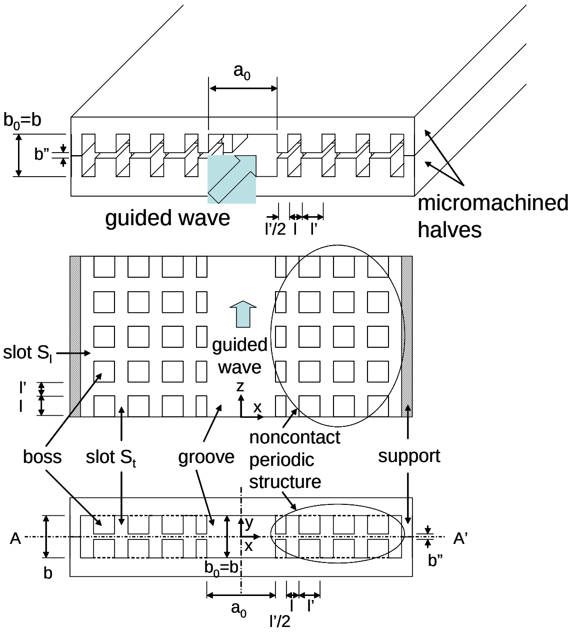
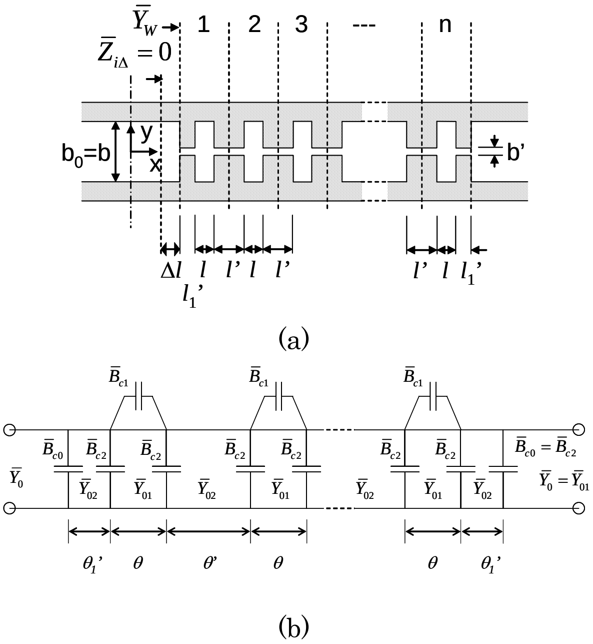


Fig. 1. Configuration and cross sectional views of grooved waffle waveguide (GWG).

Table I
Dimensions for 200 GHz-band GWG

a_0=1.3 mm, b_0=0.8 mm
b=0.8 mm, l=0.25 mm
b"=0.1 mm, l'=0.4 mm
(f_c=130GHz, 160-230GHz)



(a)

(b)

Fig. 2. Equivalent corrugated structure for the waffle-iron structure. (a) Transverse cross-section. (b) Equivalent circuit.

The calculated attenuation is shown in Fig. 3 for the corrugated structures with periods n=1, 2, and 3, and for a single low-impedance section. Two-period corrugated structure gives attenuation of higher than 20 dB in 115~335 GHz band, which is sufficient to confine the guided wave in the groove. The capacitance between the steps contributes to broadening the stop bandwidth.

The cutoff frequencies of the GWG are determined from the input admittance $\bar{Y}_W$ by use of the transverse resonant method [5], [7]. Figure 4 shows the cutoff frequency for the GWG with dimensions in Table I. The single mode transmission band of the GWG extends from 130~230 GHz (55% fractional bandwidth) for the groove width a_0 = 1.3 mm. Avoiding a high dispersive frequency band, the GWG can be applied to build circuitry in 160 ~ 230 GHz, where the difference of phase constants between the GWG and rectangular waveguide is less than 8%.

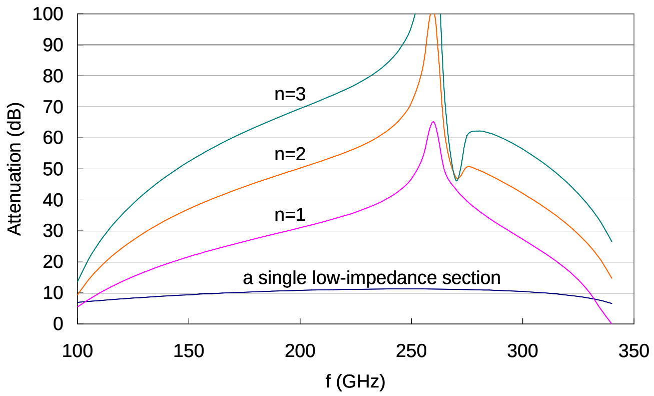


Fig. 3. Calculated attenuation by the corrugated structures with periods n=1, 2, and 3, and a single low-impedance section. The dimensions are given in Table I and *b*’=0.124 mm

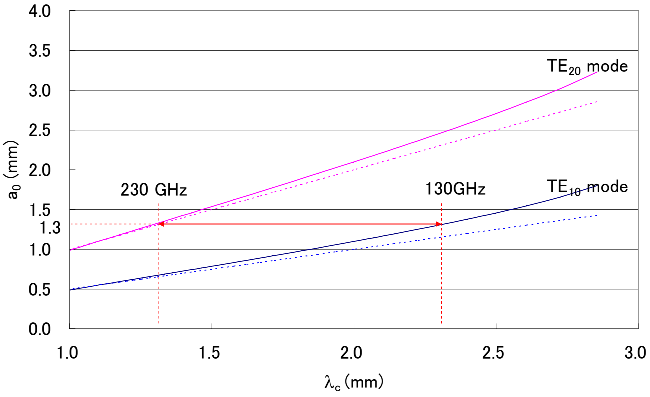


Fig. 4. Cutoff wavelength for the GWG with dimensions in Table I and a rectangular waveguide with the same cross the groove. The solid lines indicate the wavelength for the GWG and the broken lines for the rectangular waveguide.

3. Consideration of Waveguide Circuitry Made of Noncontact Micromachined Haves

In order to build terahertz waveguide circuitry consisting of noncontact micromachined haves, fundamental components are necessary such as susceptances, bends, branches, coupling sections, etc. Concept of an equivalent electric sidewall formed by the periodic structure is useful to get an idea of such components. It is desirable to adjust the sidewall location by partial modification of the periodic structure. The length l_1’ of the first low-impedance section is varied for the adjustment.

The location of the wall is represented by a distance Δl from the first impedance step of the periodic structure, which is given by

$$\Delta l = \frac{\lambda}{2\pi}\tan^{-1}\left[\frac{b}{b_0}\frac{1}{\bar{B}_w(\lambda)}\right] \qquad (3)$$

where $\bar{B}_w(\lambda)$ is the susceptive component of $\bar{Y}_w(\lambda)$ and λ is the free-space wavelength.

Figure 5 shows the location of the equivalent electric sidewall adjusted by modification of the first low-impedance section. The periodic structure is fixed with the dimensions in Table I, and the length l_1’ of the first low-impedance section is varied from 1/8 to full length l’ of the periodic low-impedance section. The wall location can be adjusted almost proportional to l_1’ of the first low-impedance section.

Figure 6 shows a conceptive configuration of a GWG directional coupler. Two parallel grooves are bent by modifying the first bosses at both sides of the groove, and are closely located to couple each other. This is an example of the short-slot hybrid junction with a ridge [9].

3. Conclusion

A grooved waffle waveguide is analyzed and its application to terahertz circuitry is consider. Three or four periods of the waffle-iron structure are sufficient to confine the guided wave in the groove over a 55 % fractional bandwidth. The equivalent electric sidewall can be adjusted to build circuitry by partial modification of the periodic structure.

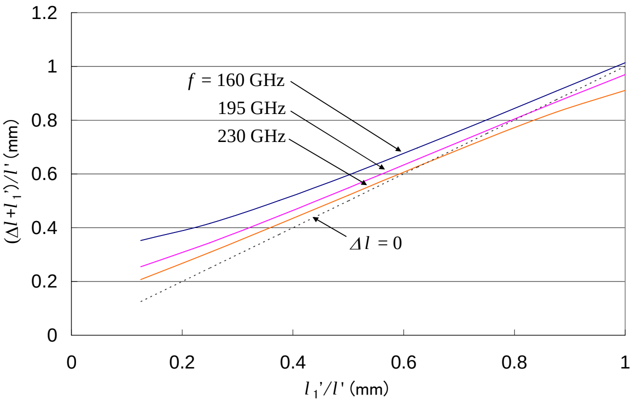


Fig. 5. Location of the equivalent electric sidewall adjusted by modification of the first low-impedance section. The periodic structure is fixed with the dimensions in Table I, and the length l_1’ of the first low-impedance section is varied.

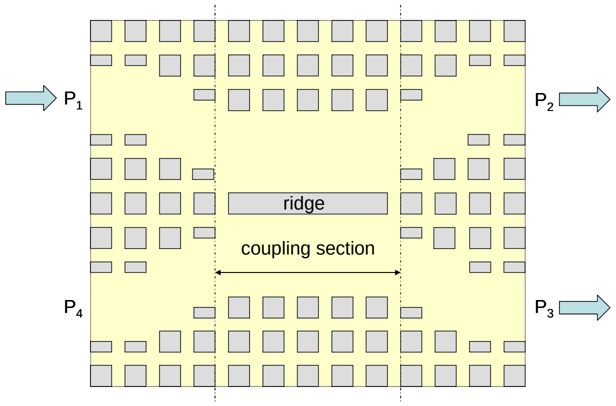


Fig. 6. Conceptive configuration of a GWG directional coupler. (top view of the lower half)

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