LEAKAGE-LOSS CHARACTERISTICS OF CONDUCTOR-BACKED COPLANAR WAVEGUIDE WITH AIR-GAP-SPACING (AGS) DIELECTRIC SHEETS

Masashi HOTTA, Kouji MORIYAMA, AND Mitsuo HANO
Department of Electrical & Electronic Engineering, Yamaguchi University
12-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, JAPAN
Tel.: +81-836-85-9436, Fax.: +81-836-85-9401
E-mail: hotta@yamaguchi-u.ac.jp

Low leakage-loss Conductor-Backed Coplanar Waveguide with air-gap-spacing (AGS) dielectric sheets has been already proposed based on the calculation with the hybrid 2D-FDTD analysis and the curve-fitting procedure. The leakage-loss characteristics of CBCPW with AGS dielectric sheets have been calculated in detail by using the much fine Yee cells. From the numerical results, the low leakage-loss characteristics and the existence of the optimum width for the air-gap have been certainly confirmed. In this paper, we have focused on the relationship between the leakage-loss and the permittivity of their additional dielectric sheets. From these analytical results, we have tried to find out what structure of CBCPW with AGS dielectric sheets is effective for the leakage-loss reduction.

1. Introduction

Corresponding to the drastic advance of information and communication technology, the high-speed and vast-capacity data transmission system is required. To realize the compact and the high performance Microwave Integrated Circuits (MIC's) and Monolithic Microwave Integrated Circuits (MMIC's), the easy handling and low-loss transmission line is needed. The planar type microwave circuits are much easy to integrate by using multilayered techniques. The coplanar waveguide (CPW), that is the typical planar type microwave and millimetre-wave transmission line, is a fundamental and important element due to its compatibility with the flip-chip technology and ease for mounting of active devices. The original structure of CPW has a substrate without any metallization on the backside, however, in the most case of the practical application whose substrate is assumed to be backed with conducting material [1], [2]. The conductor-backed CPW (CBCPW) loses its modal power into leaky waves and it has been pointed out that the leaky wave has harmful influence on the other peripheral elements [2].

To reduce the leakage-loss, the CBCPW with the grooving substrate have been proposed [3], [4], but it is much expensive to modify the substrate shape in the practical manufacturing. So, by no modification of the substrate shape, we have proposed the low leakage-loss CBCPW structure with air-gap-spacing (AGS) dielectric sheets [5]-[7]. In this paper, we have recalculated the leakage loss of the CBCPW backed with AGS dielectric sheet more in detail and compared with the double-layered structure [8] backed with the different permittivity material from CBCPW substrate which is efficient for the reduction of the leakage loss, and verify the validity of the structure backed with AGS dielectric sheets.

It is clarified that the appropriately located dielectric sheets across an air-gap on the backside of CBCPW substrate play the same role of grooving structure and can be sufficiently reduced the leakage-loss of CBCPW.

2. Leakage Loss Reduction of CBCPW

The fundamental structure of the CBCPW investigated in this paper is illustrated in Fig.1(a), together with the coordinate system. It is assumed that the CBCPW has an infinite extension toward the $\pm y$ directions and the substrate material is the GaAs with $\varepsilon_r = 12.9$ and h = 100.0μm. The other structural parameters are w = 120.0μm and g = 96.0μm [9]. Perfect conductor with negligible thickness has been assumed here, since it is well-known that the significantly propagation loss in the CBCPW at high frequency region is dominated by leakage loss into the parallel-plate mode. In this paper, the leakage loss of CBCPW are estimated from the space-domain wave attenuation constants per unit length, α_S, calculated by the hybrid technique of the 2D-FDTD full-wave analysis with the finely meshed Yee cells and the curve-fitting procedure [4], [5].

Up to now, making the groove on the backside of CBCPW sustrate as shown in Fig.1(b) is one of the efficient ways to reduce the leakage loss because the parallel-plate mode is suppressed with this substrate modification and also with the edge effect of the groove[3], [4]. This structure can be realized by modifying the substrate geometry using techniques such as backside etching or micromachining, however, it is much expensive to process the modification of substrate in the practical manufacturing.

To realize the same effect as the grooving substrate with a low cost and a easily handling, we have proposed the CBCPW structure which has backed with the AGS dielectric sheets on the backside of the substrate as shown in Fig.1(c). The air-gap is expected to play equivalently the same role of grooving structure and this structure would easily be able to realize by inserting the dielectric sheets between the CPW and the ground plane.

We estimate the leakage loss characteristics of CBCPW backed with the AGS dielecrtric sheets,

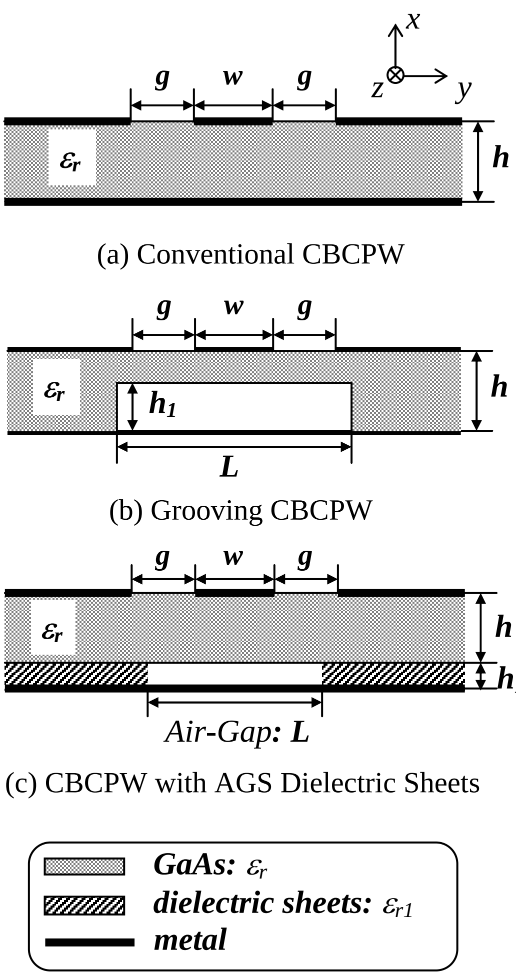

Fig. 1 Geometry of CBCPW

where the thickness of the substrate h is kept at 100.0μm and the all additional thickness of the dielectric sheets are selected as h_1 = 40.0μm where their permittivity are changed as ε_{r1}=5.0, 10.0, and 15.0.

In our former simulations [5]-[7], 60(for x-direction) × 173(for y-direction) Yee type FDTD cells with the size of Δx =20.0μm and Δy =24.0μm for each x- and y-direction. However, the simulation parameters including these cell sizes and cell numbers are not sufficient values for estimating the detailed characteristics of the leakage loss reduction and the optimum air-gap structure. So, in this paper, we have refined the analytical parameters to recalculate the leakage loss characteristics of CBCPW with AGS dielectric sheets, e.g. 100 × 346 Yee type FDTD cells with the size of Δx =10.0μm and Δy =12.0μm and adjusted PML layer are used for the analysis.

3. Effects of AGS Dielectric Sheets Backing

To make clear the effects of the AGS dielectric sheets more in detail, we have estimated the leakage-loss characteristics for the CBCPW with AGS dielectric sheets whose permittivity are ε_{r1}=5.0, ε_{r1}=10.0, and ε_{r1}=15.0 in Fig.2(a), (b), and (c), respectively as a function of air-gap width, L. The thickness of the all inserted dielectric sheet is set as h_1 = 40.0μm. The other CPW structural parameters are ε_r = 12.9, h = 100.0μm, w = 120.0μm, and g = 96.0μm. As the sake of the comparison, the results for no-air-gap, but with the dielectric sheet structure, that is the double-layered CBCPW [8], and the conventional CBCPW [9] backed with no additional dielectric sheets are also shown in the same figure by dashed-lines and solid-lines, respectively. Here, the double-layered CBCPW, in this paper, means the substrate is consisted with two materials. One is 100.0μm thickness GaAs and the other is 40.0μm thickness dielectric layer whose permittivity is the same as each corresponding AGS dielectric sheets.

From the Figs.2, the leakage-loss characteristics of the double-layered CBCPW have changed with the dielectric sheet permittivity. Furthermore, the leakage-loss of the CBCPW backed with the AGS dielectric sheets is smaller than the double-layered one, and in each case the optimum air-gap width seemed to be existed. In the cases of the permittivity of the AGS sheets are ε_{r1}=5.0 and 10.0, the leakage-loss is much low around the air-gap width L=216.0μm, and the case of ε_{r1}=15.0, that is much low around L=312.0μm.

To investigate the more optimum air-gap width in detail, we have estimate the leakage-loss at the operating frequency is 80GHz with the air-gap width are changing by $2\Delta y$ = 24.0μm. Fig.3 shows the leakage loss characteristics for CBCPW with AGS dielectric sheets as a function of air-gap width at 80GHz where the permittivity of the dielectric sheet is a parameter. Each curve in this figure is drawn by using the third-order spline interpolation.

From these results, the each optimum air-gap width for leakage-loss reduction is existed around L=168.0μm for ε_{r1}=5.0, around L=264.0μm for ε_{r1}=10.0, and around L=288.0μm for ε_{r1}=15.0, respectively, and that becomes wider as the permittivity of the AGS sheets is higher.

Finally, to investigate the tolerance of the air-gap location, in the case of ε_{r1}=15.0, we have calculated the leakage loss characteristics at the operating frequency is 60GHz and 80GHz with the air-gap position is shifted, L_1, toward the right-way from the center of the structure with keeping that width at L=408.0μm, as shown in Fig.4, which is 120.0μm wider than the optimum air-gap width of this structure. The results are shown in Fig.5. The solid line and the dashed line in the same figure are the results with the third-order spline interpolation, respectively. As a sake of comparison, the leakage loss with the optimum air-gap width L=288μm at 60 and 80GHz are the both less than 10^{-3}dB/mm. From

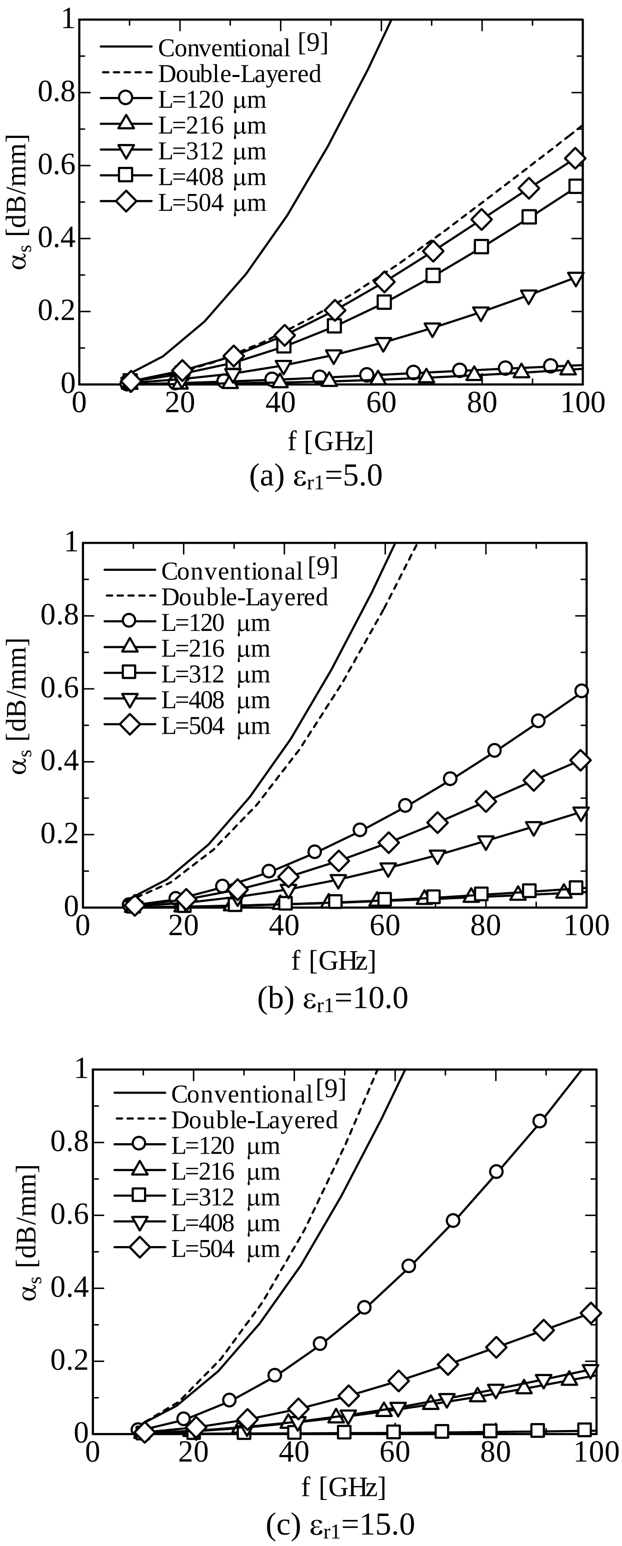

Fig.2 Leakage loss characteristics for AGS dielectric sheets backing CBCPWs as a function of the operating frequency where h_1=40.0μm and the air-gap width is a parameter.

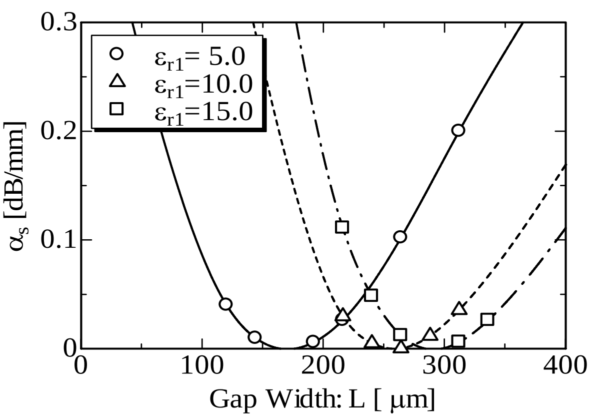

Fig.3 Leakage loss characteristics for CBCPW with AGS dielectric sheets as a function of air-gap width at 80GHz where the permittivity of the dielectric sheet is a parameter.

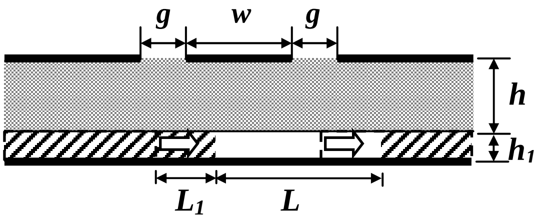

Fig.4 Tolerance of AGS dielectric sheets position. The L=408.0μm width air-gap between the dielectric sheets is shifted L_1 toward the right.

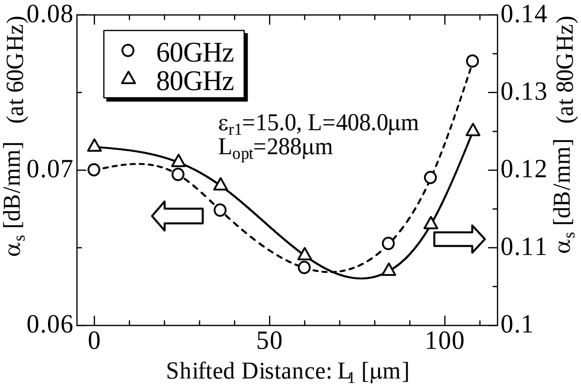

Fig.5 Leakage loss characteristics for the AGS dielectric sheets location at operating frequency is 60GHz and 80GHz.

these results, if the air-gap width is wider than the optimum value the leakage loss becomes large. Furthermore, if the air-gap position is shifted, the point for the minimum leakage loss can be observed. The details of this result would be described in the presentation.

4. Conclusions

It is clarified that the CBCPW backed with AGS dielectric sheets shows sufficiently low leakage loss characteristic and also, by changing the permittivity of the dielectric sheets, the optimum air-gap width is shifted. At this time, to verify the effectiveness of the construction of the air-gap structure on the backside of CBCPW substrate experimentally, we have prepared for the fabrication of low leakage loss CBCPW and measurement of their leakage loss characteristics. As a future work, we must find out the relationship between the permittivity of the dielectric sheets and the optimum air-gap width by investigating the dispersion characteristics of the AGS dielectric sheets backing CBCPW, and to establish the way to design of low loss CBCPW structure.

Acknowledgement

This work was partly supported by the Grant-in-Aid of the MEXT, Japan for Young Scientists (B) 15760243.

References

[1] K.C.Gupta , R.Garg, I.Bahl, and P.Bhartia, *Microstrip lines and slotlines*, *2nd Ed.*, Artech House, Boston, 1996, Chap.7.

[2] H.Shigesawa, M.Tsuji, and A.A.Oliner, “Conductor-Backed Slot Line and Coplanar Waveguide: Dangers and full-wave analyzes,” 1988 IEEE MTT-S Int. Microwave Symp. Dig., pp.199-202.

[3] M.Hotta, Y.Qian, and T.Itoh, “Leakage Loss Analysis of Conductor Backed Coplanar Waveguide with a Hybrid 2D-FDTD/Marquardt Technique,’’ Proc. 1998 Asia-Pacific Microwave Conf., vol.2, pp.409-512.

[4] M.Hotta, Y.Qian, and T.Itoh, “Efficient FDTD Analysis of Conductor Backed CPW’s with Reduced Leakage Loss,’’ IEEE Trans. Microwave Theory & Tech., vol.47, no.8, pp.1585-1587, Aug. 1999.

[5] M.Hotta, K.Kisaka, T.Inoue, and M.Hano, “Leakage Loss Reduction of Conductor Backed Coplanar Waveguide Backed with Dielectric Sheets,” Proc. 2000 Japan-China Joint Meeting on Optical Fiber Science and Electromagnetic Theory (Osaka, Japan), pp.365-368,Dec. 2000.

[6] M.Hotta, T.Inoue, M.Kobayashi, and M.Hano, “Leakage Loss Analysis of Conductor Backed Coplanar Waveguide with Air-Gap-Spacing Dielectric Sheets,” Trans. IEICE on Electron., vol.E85-C, no.7, pp.1519-1522, July 2002.

[7] M.Hotta, A.Karita, S.Nakayama, A.Kohno, and M.Hano, “Effects of Air-Gap on Leakage-Loss of Conductor-Backed Coplanar Waveguide with Air-Gap-Spacing Dielectric Sheets,” Proc. 2002 Asia-Pacific Microwave Conf. (Kyoto, Japan), vol.1, pp.567-560.

[8] Y.Liu, K.Cha, and T.Itoh, “Non-Leaky Coplanar (NLC) Waveguides with Conductor Backing,” IEEE Trans. Microwave Theory & Tech., vol.43, no.5, pp.1067-1072, May 1995.

[9] T.Krems, W.H.Haydl, M.Massler, and J.Rudiger, “Advantages of flip chip technology in millimeter-wave packaging,” 1997 IEEE MTT-S Int. Microwave Symp. Dig., pp.987-990.