LETTER

Leakage Loss Analysis of Conductor Backed Coplanar Waveguide with Air-Gap-Spacing Dielectric Sheets

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SUMMARY Leakage loss of Conductor Backed Coplanar Waveguide (CBCPW) with air-gap-spacing (AGS) dielectric sheets has been analyzed by using the hybrid 2D-FDTD Method and curve-fitting procedure. From numerical results, the proposed CBCPW with AGS dielectric sheets shows even lower leakage loss characteristics than those of conventional and double-layered one over a wide range of operating frequency. Furthermore, the possibility of the optimum air-gap width for leakage loss has been confirmed.

key words: *conductor backed CPW, leakage loss, FDTD, dielectric sheets, air-gap-spacing (AGS)*

1. Introduction

The coplanar waveguide (CPW) is a fundamental and important element for Microwave Integrated Circuits (MIC's) and Monolithic Microwave Integrated Circuits (MMIC's) due to its compatibility with the flip-chip technology and ease for mounting of the active devices. Although the original structure of CPW has a substrate without any metallization on the backside, in most practical applications, its substrate is 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 waves have harmful influence on the other peripheral elements [3]. To reduce the leakage loss, the CBCPW with the grooving substrate have been proposed [4], [5], but it is much expensive to modify the shape of substrate in the practical manufacturing.

To realize the same effect as the grooving structure with low manufacturing cost, the novel CBCPW structure backing with the air-gap-spacing (AGS) dielectric sheets has been proposed in this paper. It is expected that the backing of the appropriate AGS dielectric sheets on the CPW substrate play the same role as grooving structure.

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2. Analytical Structure of CBCPW

The fundamental structure of the CBCPW investigated in this paper is illustrated in Fig. 1, 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 the permittivity, $\varepsilon_r = 12.9$ and the thickness, $h = 100\,\mu$m. The other structural parameters are $w = 120\,\mu$m and $g = 96\,\mu$m [6], respectively. Perfect conductor with negligible thickness and the dielectric material whose loss tangent is zero have been assumed in the analysis, since it is well-known that the propagation loss in the CBCPW 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, toward the propagation axis by using the hybrid technique with 2D-FDTD full-wave analysis and the curve-fitting procedure [4], [5].

To obtain the space-domain attenuation constant, at first, the time functional electric field component E_x at the observation point placed on the center of the strip is calculated with a given propagation constant β by using 2D-FDTD algorism. In this simulation, 60×173 cells are used for x and y directions. The sizes of each FDTD cell are selected mainly to discretize the structure as accurately as possible, and are chosen as $\Delta x = 20.0\,\mu$m and $\Delta y = 24.0\,\mu$m, respectively, which are much smaller than the wavelength for the operating frequency. The boundary conditions of the FDTD analitical region are treated as same as those in Ref. [5]. Next, to determine accurately the modal frequency, f, and the time-domain attenuation constant, α_t, we apply the curve-fitting scheme by using the below fitting function

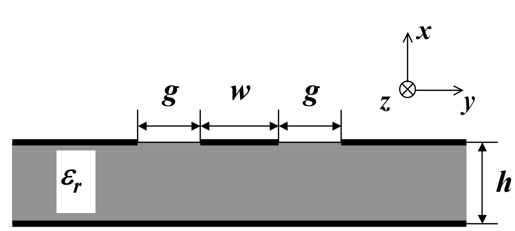

Fig. 1 Geometry of conventional CBCPW.

$$E_x = A\exp(-\alpha_t t)\sin(2\pi f t + B) \tag{1}$$

where the coefficients A and B are additional fitting factors which correspond to the initial amplitude and phase of E_x. Finally, the space-domain attenuation constant α_S can be obtained by using the relationship between the fitting factors α_t, f, and the space-domain attenuation constant

$$\alpha_S = \alpha_t\beta/2\pi f \tag{2}$$

where β is the pre-given propagation constant [5].

3. Leakage Loss Reduction of CBCPW

3.1 Grooving Substrate

The grooving of CBCPW substrate shown in Fig. 2 is one of efficient ways to reduce the leakage loss [4], [5]. The typical leakage loss characteristics of grooving CBCPW are shown in Fig. 3, where the sizes of the groove are chosen as $h_1 = 60\,\mu$m and $L = 120$, 216, and 888 μm, respectively. As a sake of comparison, the result for the conventional CBCPW with no-groove is also drawn with bullets in the same figure. In the Ref. [5], the validity of this analysis is ensured by comparison with the measured data for the no-grooving conventional CBCPW, which is shown in Ref. [6].

From these results, it is shown that the leakage loss drops radically over the wide range of frequency with the introduction of the groove, and, especially, the minimum leakage loss can be observed when the groove width $L = 216\,\mu$m. These results indicate that by modifying the substrate geometry using techniques such as backside etching or micromachining, we can design low loss CBCPW structures to improve the performance of MIC's and MMIC's, but it is much expensive to process the modification of substrate in the practical manufacturing.

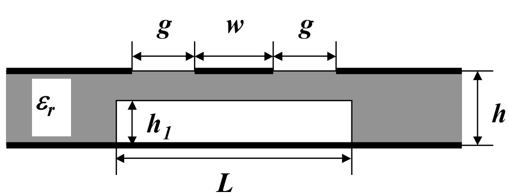

Fig. 2 Geometry of grooving CBCPW.

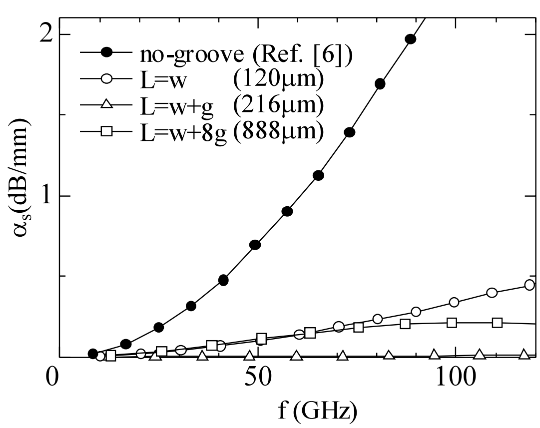

Fig. 3 Leakage loss characteristics of grooving CBCPW with groove width L as a parameter, where the depth of the groove is chosen as $h_1 = 60\,\mu$m.

3.2 AGS Dielectric Sheets Backing CBCPW

To realize the same effect as the grooving substrate with a low manufacturing cost, we have proposed the novel CBCPW structure which has backed with the appropriate air-gap-spacing (AGS) dielectric sheets as shown in Fig. 4. In this analysis, the loss tangent of the backing sheets are not taken into the consideration, that is $\tan\delta = 0$. The air-gap is expected to equivalently play the same role of grooving structure and this structure would be easily realize by holding a pair of dielectric sheets through an air-gap between the CPW substrate and the ground plane.

We estimate the leakage loss of the CBCPW backed with the AGS dielectric sheets, where the thickness of the CBCPW substrate h is kept at 100 μm and the additional thickness of the dielectric sheets are selected as $h_1 = 20$, 40, and 60 μm, respectively. The dielectric sheet material whose permittivity is chosen as lower than that of the CBCPW substrate, $\varepsilon_{r1} = 5.0$ are assumed for backing.

Here, it has been pointed out that the double-layered CBCPW whose bottom-layer dielectric permittivity is lower than that of upper-layer is effective for reducing the leakage loss [2]. To verify the advantage of the proposed novel CBCPW structure, the leakage loss of the double-layered CBCPW with low permittivity layer are also simulated. This structure is regarded as the special case of the proposed structure with no air-gap, that is $L = 0\,\mu$m. The double-layered structure, treated in this paper, is consisted of two materials. The upper-side material and their thickness are assumed to be the same as those of the conventional CBCPW substrate and those of the bottom-layer is to be the same

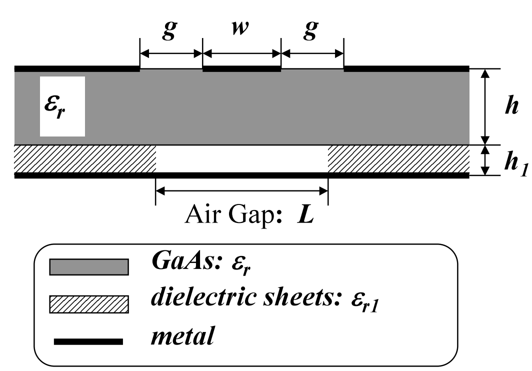

Fig. 4 Geometry of proposed AGS dielectric sheets backing CBCPW.

as the dielectric sheets used in the proposed CBCPW structure. The double-layered CBCPW concept is valid in the case that the permittivity of the bottom-layer is lower than that of upper-layer material.

3.3 Leakage Loss of Proposed Structure

Figure 5 shows the typical leakage loss characteristics of the CBCPW backed with dielectric sheets, whose permittivity is $\varepsilon_{r1} = 5.0$, thickness h_1 is (a) $20\,\mu$m, (b) $40\,\mu$m, and (c) $60\,\mu$m, respectively, where the air-gap width $L = 216$, 312, and $888\,\mu$m. As a sake of comparison, the results for the conventional CBCPW without dielectric sheets [6] with bullets, which appeared in Fig. 3, and those for the double-layered CBCPW with dashed-lines are also drawn in the same figures, respectively. These results are corresponding to the special cases of the proposed structure with $h_1 = 0\,\mu$m, and $L = 0\,\mu$m, respectively.

From these results, it is clarified that the leakage loss of the CBCPW backed with the AGS dielectric sheets much drops over the wide range of frequency. The double-layered CBCPWs with low permittivity material on the bottom-layer also show the lower leakage loss characteristics than those of the conventional one, but the proposed structure with the AGS dielectric sheets shows even lower leakage loss property. To realize more efficient leakage loss reduction with double-layered structure, the optimized design of the layered structure seems to be required.

Figure 5(a) presents that the leakage loss becomes lower as the air-gap width L becomes wider. In the other results shown in Figs. 5(b) and (c), the minimum leakage loss can be observed around the air-gap width $L = 312\,\mu$m. These results have predicted the existence of the optimum air-gap width. To confirm the optimum air-gap width in detail, we have calculated the leakage loss of the proposed CBCPW structure around $L = 312\,\mu$m only for $h_1 = 40\,\mu$m and $60\,\mu$m, respectively.

Figure 6 shows the leakage loss at a given frequency 80 GHz with the air-gap width L as a parameter for each dielectric sheets thickness (a) $h_1 = 40\,\mu$m and (b) $h_1 = 60\,\mu$m, respectively. From these results, it is confirmed that the optimum air-gap width under these structural parameters are obtained nearby $L = 360\,\mu$m for $h_1 = 40\,\mu$m, and $L = 312\,\mu$m for $h_1 = 60\,\mu$m, respectively.

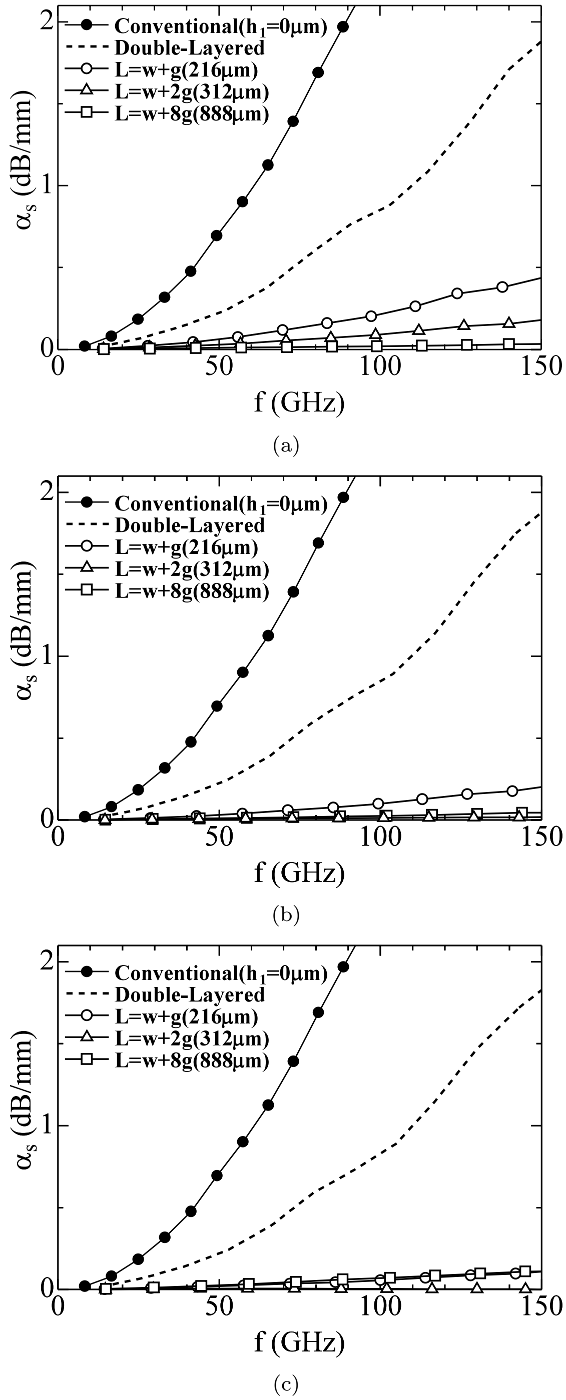

Fig. 5 Leakage loss characteristics of AGS dielectric sheets backing CBCPW with the air-gap width L as a parameter, where $\varepsilon_{r1} = 5.0$. The thickness of dielectric sheets are (a) $h_1 = 20\,\mu$m, (b) $h_1 = 40\,\mu$m, and (c) $h_1 = 60\,\mu$m, respectively.

4. Discussions

The results through Figs. 5 and 6 clarify that the low leakage loss structure can be realized by using the AGS dielectric sheets and the optimum width of the air-gap is existed in each case.

According to the design concept of the double-layered structure [2], the decrease of the effective dielectric constants of parallel-plate mode caused by backing with low dielectric constant layer is larger than that of dominant CPW mode. If the dielectric constant and thickness of the backing sheet is appropriately designed, it is possible to make the effective dielectric constants

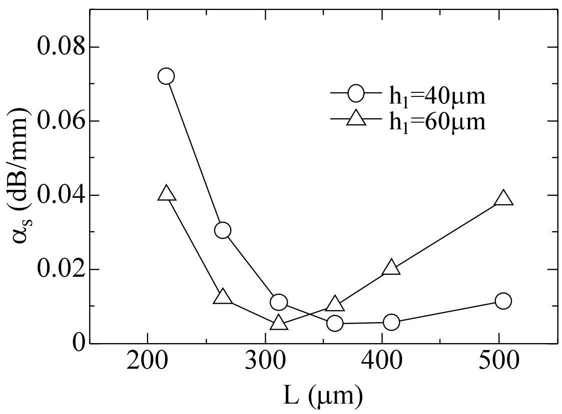

Fig. 6 Leakage loss characteristics of AGS dielectric sheets backing CBCPW at a given frequency, 80 GHz, with the air-gap width L around $312\,\mu$m as a parameter, where $h_1 = 40\,\mu$m and $h_1 = 60\,\mu$m with $\varepsilon_{r1} = 5.0$, respectively.

of parallel-plate mode much lower than that of CPW mode and then the leakage loss becomes small. In the same manner, backing with AGS dielectric sheets, the existence of the air-gap makes the effective dielectric constant of parallel-mode lower. Especially, it would be much effective at the under region of the center strip of the CPW where the electromagnetic field is concentrated. This is one reason why the leakage loss reduction of this proposed structure. In the other viewpoint, the parallel plate mode has the electric field dominantly directed from the center strip to the backside ground plane of CBCPW. The air-gap would suppress this electric field. This means that low dielectric constant layer or air-gap region makes the backside ground plane away from the CPW so the leakage loss becomes low. Additionally, it seems that the existence of the optimum width of the air-gap predicted that not only the above reason but also the edge effects of the dielectric sheets would have some contributions on the leakage loss reduction of this structure [8]. In this point, we must investigated more in detail after now.

5. Conclusions

It is presented that the leakage loss of the appropriate air-gap-spacing (AGS) dielectric sheets backing CBCPW can be reduced sufficiently over the wide range of operating frequency in comparison with those of the conventional CBCPW and also the double-layered one. Furthermore, the possibility of the existence for the optimum air-gap width for the dielectric sheets is also presented. As a future work, we must investigate the distribution of the electromagnetic field in the substrate and the coupling characteristics between the guided-wave and the leaky-wave of this proposed structure more in detail, and also establish the low-loss design procedure which is effective in the practical manufacturing.

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