실리콘 이방성 습식 식각과 BCB 폴리머 접합을 이용한 기판 집적형 도파관(SIW) 기반의 차폐된 스트립선로의 제작

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Fabrication of Substrate Integrated Waveguide (SIW)-based Shielded Stripline using Silicon Anisotropic Wet-Etch and BCB-based Polymer Bonding

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Abstract - This paper reports on a fabrication of novel substrate integrated waveguide (SIW)-based shielded stripline applicable to the broadband transverse electromagnetic (TEM) single-mode propagation. We suggested a structure for half-SIW and half-shielded stripline, which combined through the benzocyclobutene (BCB) bonding layer. The electrical interconnection between the sidewall of anisotropic wet-etched silicon and patterned BCB layers is measured subsequent to the metalization on the side wall. The proposed SIW-based shielded stripline has great potential in terms of simple fabrication, integration with planar circuits and monolithic system fabricated on a SIW structure.

1. Introduction

As wireless communication system market grows, various studies for the development of effective transmission lines were demonstrated. A microstrip is one of the predominantly used transmission line in microwave frequencies. However, it has some limitations in the millimeter wave applications due to its structural geometry. Firstly, the radiation loss grows by higher frequencies because the signal line is exposed itself to air. Secondary, the non-coplanar geometry which makes it difficult to connect elements in shunt to ground (GND). A co-planar waveguide (CPW) is an alternative to a microstrip in the limelight. It is easy to integrate other elements with itself due to its co-planar geometry, and is also little sensitive to the permittivity of substrate. However, it still has suffered from the inherently excessive loss at high- and low- impedance extremes [1]. A stripline can be another alternatives, because it can implement a transverse electromagnetic (TEM) propagation. From this reason, it shows good performances such as non-dispersion and high isolation. A conventional stripline consists of a flat strip of metal sandwiched between two parallel GND planes. The isolation can be improved by adding GND planes at the side with respect to the application areas, called "shielded stripline." When a highly-sensitive-to-noise system (e.g., permittivity measurement) or security communications, the GND shielding of sidewall should be considered to screen the systems from outside. Its application to actual devices, however, is still limited in part by difficulties of fabrication and geometric restrictions. At first, some lumped elements and active components should be buried between the GND planes with the flat strip together, or transition to microstrip has to be employed to make the complete device. The other disadvantage, geometric restriction, is related with the width and thickness of the substrate. A substrate width should also be much narrower for 50 Ω impedance and board thickness than for a microstrip [2]. These can be solved applying a substrate integrated waveguide (SIW) technology into the fabrication of stripline. SIW structure consists of the sandwiched substrate (dielectric) which includes the bilateral periodic via-array, between a pair of GND planes similar to the rectangular waveguide (RWG) ones. The periodic rows of via, connecting the top and bottom GND planes, take a role of sidewall GND of RWG [3-5]. It can be used to raise a cut-off frequency without narrowing substrate, then it helps to implement broadband TEM single-mode propagation. Soft boards, printed circuit boards (PCBs) and low temperature co-fired ceramic (LTCC), are generally used technology for SIW due to its merits in fabricating multilayer structure and metal vias. However, the mechanical perforation of vias which they use, has recently encountered limitations in accuracy.

In this paper, we proposed a SIW-based shielded stripline for broadband TEM single-mode propagation, using conventional silicon micromachining techniques. The proposed structure was verified by EM simulation and measuring dc resistance between interconnecting part.

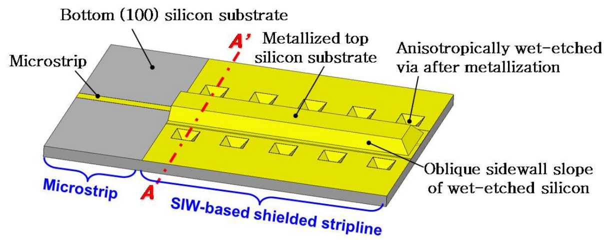
2. Design

The SIW-based shielded stripline was considered to embody the broadband TEM single-mode propagation over 20 GHz, which is free to strip width and outside noise. The waveguide mode (TE_{10} mode), caused by an RWG structure of the shielded stripline, has to be suppressed over the operation frequency range to avoid a signal dispersion. A cut-off frequency of the dominant higher-order mode, TE_{10} mode, is calculated to be

$$f_c = \frac{c}{2w\sqrt{\mu\epsilon}} \qquad (1)$$

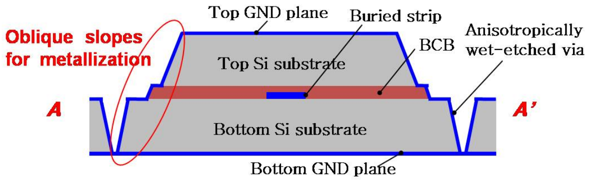
, where c is the light velocity in free space, w is width of the RWG structure, and ε and μ are relative permittivity and permeability of dielectric material, respectively [5]. Thus the width of RWG structure of the shielded stripline gets narrower, as the cut-off frequency gets higher. The SIW can solve this size limitations by replacing the sidewalls into the periodic vias.

For an accurate manufacture of the device, a conventional micromachining technology, which based on anisotropically wet-etched slope of silicon for a interconnection and photo-defined BCB for a bonding layer, was tried. It was expected that the 54.74° (111) the sidewall slope angles relatively to surface by anisotropic wet-etch of (100) silicon might be helpful to interconnect between the top and bottom GND planes using the conventional metal deposition process (e.g., sputtering, evaporation). Figure 1 shows a schematic view of the proposed shielded-stripline based on the SIW structure. The top and bottom (100) silicon substrates, which sandwiches the strip and BCB, were used as dielectric. The sandwiched BCB takes a role of another dielectric as well as bonding layer. The proposed structure is different from the shape of conventional SIW. From the difficulties of interconnection between the GND planes, we used a tricky technique, new hybrid structure: the half-shielded stripline and half-SIW structures over and under the buried strip, respectively. We replaces vias and dielectric over the buried strip, into the patterned dielectric (BCB and top silicon substrate) and top GND plane.



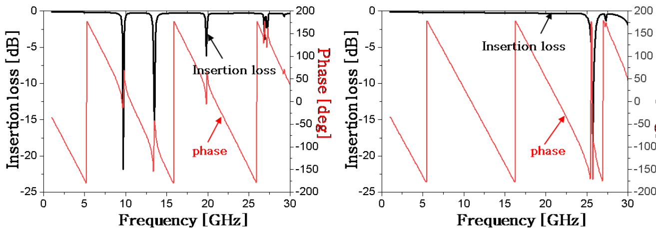
<Figure 1> Schematic view of the proposed silicon SIW

As shown in Figure 2, the vias at the bottom substrate, connected with the bottom GND, accomplish whole interconnections of the shielded stripline between the pair of GND planes using the sidewall slopes of BCB and top silicon substrate. The oblique slopes of those make the metallization more readily to achieve by conventional metal deposition methods from topside, such as sputtering or evaporation.



<Figure 2> Cross-sectional view of the proposed SIW

For the feasibility of the proposed shielded stripline based on SIW structure, radio frequency (RF) characteristics were simulated using a commercial 3D electromagnetic (EM) simulator, High Frequency Structure Simulator (HFSS) (Ansoft, Pittsburgh, PA). The simulation result was compared to the one of the conventional shielded stripline as shown in Figure 3. It is shown that the dominant TE_{10} mode of the proposed SIW-based shielded stripline is generated over 25 GHz, while the TE_{10} mode of the conventional one is generated around at 9.7 GHz.

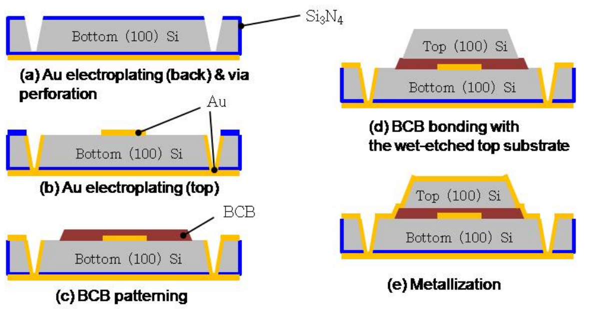


(a) Conventional shielded stripline (b) SIW-based shielded stripline

<Figure 3> Simulation results

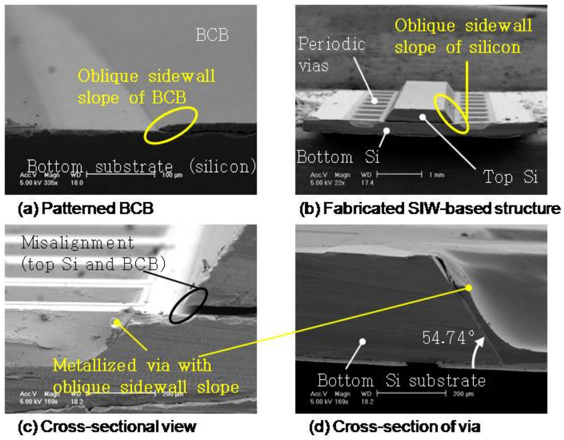
3. Fabrication

Figure 4 shows the process overview of the SIW-based shielded strip line. The process started from Si_3N_4 layer deposition on both substrate as a mask material for silicon wet-etch, using low pressure chemical vapor deposition (LPCVD). At the bottom substrate, vias were chemically perforated just after the electroplating of the bottom GND plane at the backside. The (100) silicon surface was anisotropically etched by a 40 wt. % potassium hydroxide (KOH) solution at 80 °C, then it made the 54.74° of (111) the sidewall angles relative to surface of vias (Figure 4 (a)). The formation of strip on the front side was then followed using an electroplating process. At that time, the metallization of sidewall of vias were also achieved at once (Figure 4 (b)). Next process was the deposition of the BCB bonding layer. A photo-definable BCB, Cyclotene 4026-46, was coated and pattened on the front side, then it offered a 20-μm-thick dielectric layer which has an oblique slope of sidewall (Figure 4 (c)). The top substrate, which had been pattened using KOH anisotropic wet-etch, was bonded with the bottom substrate through a layer of BCB at the temperature of 210 °C. (Figure 4 (d)). Then, the interconnection was finally accomplished using the sidewall slopes of silicons and BCB, through a sputtering process. (Figure 4 (e)).



<Figure 4> Fabrication process

Figure 5 shows the SEM image of the fabricated SIW-based shielded stripline. Figure 5 (a) shows sidewall slope angle of the patterned BCB, before the bonding with top substrate. The shown sidewall slope of BCB, makes it possible to interconnection between top and bottom substrates. The sidewall slope of top substrate caused by anisotropic wet-etch are well shown in Figure 5 (b). The sidewall slope of anisotropically wet-etched vias at the bottom substrate, which helps the interconnection, are well shown in the magnified cross-sectional view of the vias, as Figure 4 (c) and (d). The slope of 54.74° are observed, and the electrical connection through the sidewall slopes of vias are also shown.



(a) Patterned BCB (b) Fabricated SIW-based structure

(c) Cross-sectional view (d) Cross-section of via

<Figure 4> Fabrication result

The dc resistnace of the interconnection between top and bottom GND planes was measured as summarized in Table 1. It has shown that only about 67 % of interconnections shows an uniform electrical connectivities (below 2 Ω). One of the reasons of poor interconnection is the misalignment, as already observed in above Figure 4 (c). The misaligned top substrate on BCB takes a role as the eaves, then the slant of the BCB is screened during the final metallization process. This can be solved by widening the bonding margins enough.

<Table 1> Resistance between top and bottom GND planes

Sample #s	1	2	3	4	5	6	7	8	9
Resistance [Ω]	1.4	1.4	x	10.5	3.4	1.5	1.4	1.3	1.5

4. Conclusion

In this work, a new shielded stripline structure based on the SIW and micromachining technology has been demonstrated, using the sidewall slopes of both anisotropically wet-etched silicon susbstrate and photo-defined BCB for an interconnection. It is expected that the proposed structure is available to the broadband TEM single-mode propagation. The hybrid structure of SIW and shielded stripline helps to avoid higher-order propagation in wider frequency range. It is not restricted by the width of the substrate due to the merits of SIW even it uses a realatively high dielectric. The feasibility was verified through a 3D EM simulator HFSS, the result clearly showed that the device has the possibilities in the application to the broadband TEM single-mode propagation from 1 GHz to over 20 GHz. The measured results of resistance also show the potentialities as an interconnection method using conventional metal deposition techniques.

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