# Monolithic Implementation of Coaxial Line on Silicon Substrate

In-Ho Jeong and Young-Se Kwon

***Abstract*—A coaxial line has been monolithically fabricated on silicon substrate using Benzocylobutene (BCB) for dielectric spacers. Because of its closed structure, it is an effective interconnection method to reduce parasitic radiation and coupling effect. The fabricated coaxial line with 2 mm length has high isolation ($<-60$ dB), low attenuation ($<0.08$ dB/mm) and low return loss ($<-32$ dB) in the range of 1 GHz–20 GHz. It can be easily fabricated using standard silicon IC technologies, and requires no wafer thinning and backside processing. In view of cost performance and integration density, the coaxial line on low-resistivity silicon is shown to be suitable for RF interconnect and multichip module (MCM) package applications.**

***Index Terms*—BCB applications, Coaxial line, silicon substrate, transmission line.**

## I. INTRODUCTION

FOR microwave and millimeter-wave circuit designs, the planar transmission lines such as microstrips, striplines and coplanar waveguides are widely used to achieve design flexibility and low cost [1]. In spite of these advantages, the planar transmission lines are inadequate to apply to electronic communication systems, mainly due to the significant microwave transmission loss and serious crosstalk. Several studies have been published in the past [2]–[7] to minimize crosstalk and parasitic radiation. Weller *et al.* [3] proposed a microshield line using micromachining techniques, which provided high performance in transmission loss and broadband operation. Ishikawa [4] used buried microstrip line (BMSL), which offered the possibility to obtain low loss and high isolation. While these are effective approaches to achieve high performance in loss and frequency characteristics, the parasitic effects such as radiation and coupling still exist due to their open structure. To overcome this barrier, a perfectly shielded transmission line is needed.

In this letter, we propose a monolithic coaxial line, that is completely shielded to minimize the crosstalk between two parallel lines on silicon substrate and has higher isolation than the air-filled rectangular coaxial line [10] having partially open structure. Using Photo-BCB (Cyclotene 4024–40, DOW chem.) for the dielectric spacer, the coaxial line was monolithically fabricated on silicon substrate by simple processes.

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## II. EXPERIMENT

The coaxial line was implemented as a straight line of 2 mm length. BCB was used as the dielectric spacers. Its dielectric constant and dissipation factor are 2.7 and 0.008, respectively [8]. The dimensions of the coaxial line were decided by the value of the characteristic impedance. In this experiment, the coaxial line was designed to achieve 50 $\Omega$ characteristic impedance. It is simulated by 2 D-FDTD (signal line width $(w) = 30$ $\mu$m, signal line height $(h) = 5$ $\mu$m, out conductor width $(s) = 150$ $\mu$m, out conductor height $(y) = 60$ $\mu$m). Fig. 1 shows its process steps and dimensional parameters. There are three main steps in realizing the coaxial line.

The first step is the formation of the lower cavity region and the planarization of its surface. The second step is for the core electrode, and the last step is to make the upper cavity region, as shown in Fig. 1. To form the lower cavity region [Fig. 1(a)], the $p$-type silicon with low-resistivity ($\rho = 5$–$10$ $\Omega$-cm) was etched by KOH at 70 °C. The etching depth and width are 30 $\mu$m and 150 $\mu$m (200 $\mu$m), respectively. And then lower ground metal (Cr/Au; 500 Å/2000 Å) was evaporated. Three layers of BCB were coated to fill the lower cavity region. The BCB spin coating thickness was determined by the cavity depth. The first spin coating thickness in the cavity region was about 15 $\mu$m. After the first spin coating, the coated layer was exposed UV light, because the used BCB was the negative photo polymer (UV exposed region was not developed). For multiple layer process, soft curing was required to promote the adhesion between layers. The second spin coating thickness was about 9 $\mu$m. After the second coating, the exposure and soft curing processes were performed. The third spin coating thickness was about 7 $\mu$m. And then the exposure process was performed. The process conditions of second and third BCB layers were the same as those of first BCB layer formation. After the three-layer-formation, the BCB was cured with a vacuum oven of 240 °C for 4 h. The RIE etching process ($CF_4/O_2$; 6/24 sccm) was performed after curing process for cavity height adjustment. Due to the lithography process, the edge of BCB for the lower cavity region was built up above the Si substrate, but the build up is removed during the formation of the upper cavity region. The second step is signal line formation. The signal line was fabricated by conventional Au electroplating on BCB [Fig. 1(b)]. The thickness and width of signal line are 5 $\mu$m and 30 $\mu$m (35 $\mu$m), respectively. Finally, the same method of forming the lower cavity region was used to make the upper cavity region. But the spin speed and the coating thickness (10 $\mu$m) were changed. The lithography process was performed three times to adjust the upper cavity height. The upper ground layer was plated Au of 3

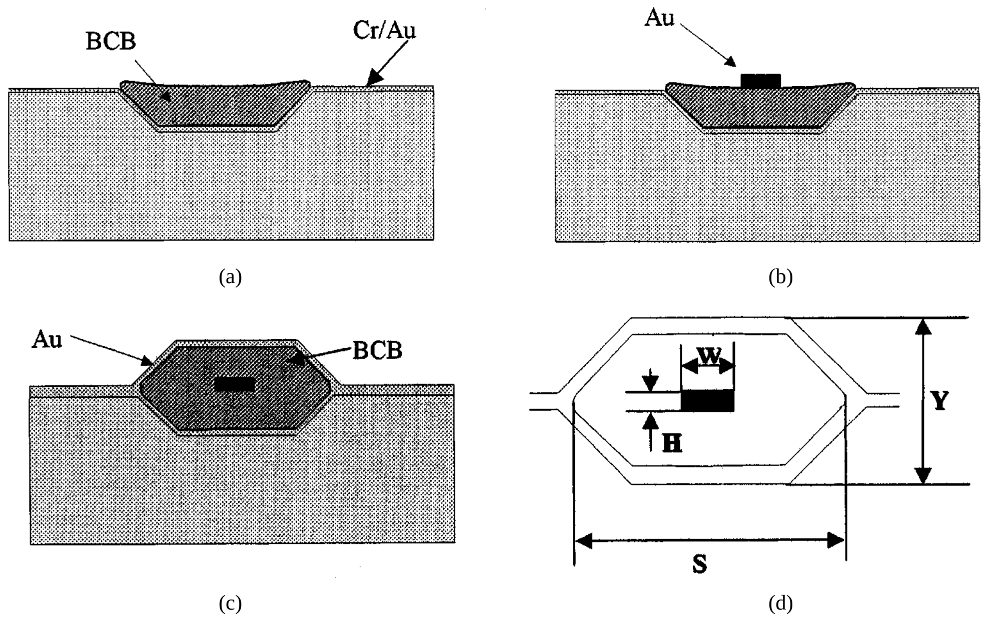


Fig. 1. Procedure and dimensional parameters of the coaxial line: (a) Defining the lower cavity region and BCB planarization. (b) Using Au plating for signal line formation. (c) Formation of the upper cavity region and ground metal. (d) Dimensional parameters of the coaxial line.

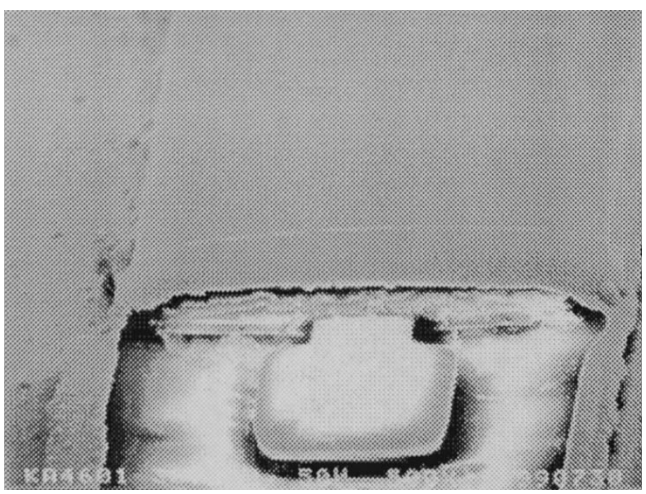

Fig. 2. SEM picture of the coaxial line ($w = 30$ $\mu$m, $h = 5$ $\mu$m, $s = 150$ $\mu$m, $y = 60$ $\mu$m).

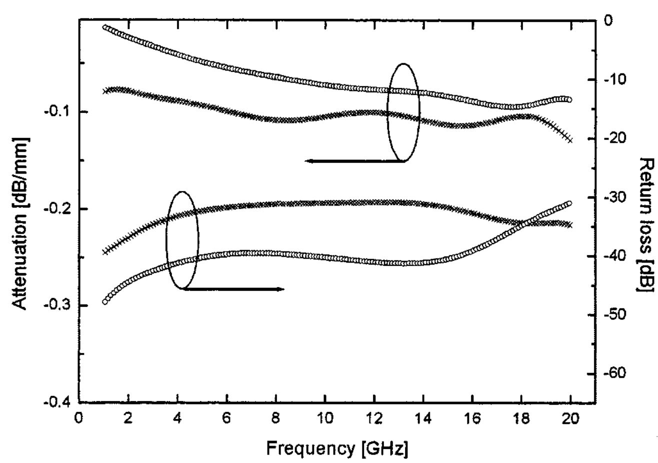


Fig. 3. Attenuation and return loss of the coaxial line on silicon substrate.
----X----: ($w = 35$ $\mu$m, $h = 5$ $\mu$ $\mu$m, $s = 200$ $\mu$m, $y = 60$ $\mu$m).
---- o ----: ($w = 30$ $\mu$m, $h = 5$ $\mu$m, $s = 150$ $\mu$m, $y = 60$ $\mu$m).

$\mu$m thickness [Fig. 1(c)]. Fig. 2 shows the SEM picture of the fabricated coaxial line.

## III. Results

To measure the coaxial line up to 20 GHz, conventional on-wafer characterization was utilized in conjunction with the short-open-load-through (SOLT) calibration technique. The measurement set up consists of HP 8720C network analyzer, a Cascade Microtech probe station, and GGB Industries ground-signal-ground (GSG) probes that have a probe pitch of 150 $\mu$m. The calibration was achieved using the GGB CS-5 calibration kit.

The pads to measure the coaxial line by GSG probes are modeled by combinations of capacitor and resistor. To obtain the original line characteristics, the pads effect was de-embedded [9].

Fig. 3 illustrates the measured attenuation and return loss. The attenuation of these two types of coaxial lines were less than 0.12 dB/mm and 0.08 dB/mm over the frequency range of 1 GHz–20 GHz. The attenuation less than 0.12 dB/mm is an improved value compare to that of the previously reported value (above 0.3 dB/mm at 10 GHz [1]) for conventional coplanar waveguide. The return loss of the 2-mm-long coaxial line was less than $-32$ dB for $w = 30$ $\mu$m and $-30$ dB for $w = 35$ $\mu$m. This showed that good impedance matching was achieved and the characteristic impedance was about 50 $\Omega$, which was the designed value. To investigate the crosstalk characteristic, which is important to high-density integration, we have measured the coupling between two 50 $\Omega$ coaxial lines. The coupling length was 2 mm and the line spacing the distance between the two closed signal lines was 200 $\mu$m. Fig. 4 showed the coupling of coaxial lines versus frequency. The input signal was fed into port1 and the output signal was measured from port2. Port3 and

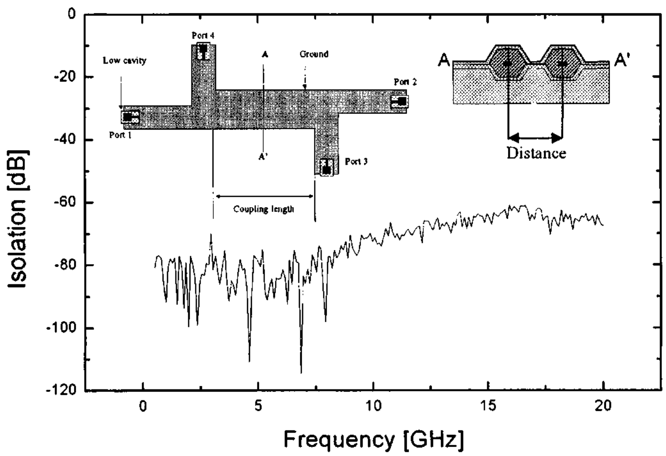


Fig. 4. The coupling of two coaxial lines (distance: 200 $\mu$m; coupling length: 2 mm). Each coaxial line has $w = 30$ $\mu$m, $h = 5$ $\mu$m, $s = 150$ $\mu$m, and $y = 60$ $\mu$m.

port4 were terminated by standard 50 $\Omega$ load. The coupling is less $-60$ dB throughout the measured frequency range.

## IV. Conclusion

In this letter, a coaxial line monolithically fabricated on silicon substrate using BCB as dielectric material is presented. Due to its shielded structure, this coaxial line provides lower attenuation and higher isolation even with the low-resistivity silicon substrate. The attenuation of 2 mm-long coaxial line is lower than 0.08 dB/mm and the return loss is less than $-32$ dB at all measured frequency. The coupling level is below $-60$ dB with 2-mm coupling length and 200 $\mu$m spacing. This coaxial line can be applied to the VLSI technology for direct interconnections. Using flip-chip or wire bonding technology, it can be applied also to MCM-Si packaging technology. Thus, in view of cost and high-density integration, the proposed coaxial line shows a good potential for high-performance microwave packaging and interconnection of Si-MMIC.

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