LOW-LOSS PASSIVE COMPONENTS ON BCB-BASED 3-D MMIC TECHNOLOGY

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Abstract — **This paper proposes low-loss passive components that use a newly developed trench-type transmission line together with BCB-based 3-D MMIC technology. The trench-type transmission lines and via holes for 3-D interconnection are fabricated simultaneously. The trench-type lines effectively reduce the transmission loss of passive components due to their high metal volume, resulting in high performance 3-D MMICs. They are especially suitable for low frequency applications in which loss reduction is critical. Transmission lines and spiral/solenoidal inductors using the proposed trench-type line are demonstrated in this paper. These components offer low-loss and high quality factors. The design flexibility of the trench-type line is very high. This technology promises low cost, high performance, and highly integrated millimeter-wave MMICs including RF and IF circuits.**

I. INTRODUCTION

The recent interest in highly integrated MMICs for millimeter-wave wireless applications such as LMDS, high-bit-rate wireless LAN, and automotive radar system, is being driven by the expansion of the wireless communications market. To realize consumer-oriented millimeter-wave wireless systems, it is essential to reduce the cost of both the MMIC chips and packaging. One of the best approaches is to realize a highly integrated, compact single-chip transceiver MMIC that includes all components, form RF to IF circuits. This single-chip solution eliminates the high cost of the millimeter-wave interconnections between chips. The 3-D MMIC technology [1]-[5] is very effective in achieving the MMICs described above. The 3-D MMIC technology that uses polyimide dielectric film [4] or photosensitive BCB dielectric film [3], [5] offers compact and highly integrated millimeter-wave MMICs. In particular, the BCB-based 3-D MMIC technology offers integration with InP, InGaP, and InGaAs devices, resulting in higher performance millimeter-wave MMICs. This is why the BCB-based 3-D MMIC fabrication process offers shorter

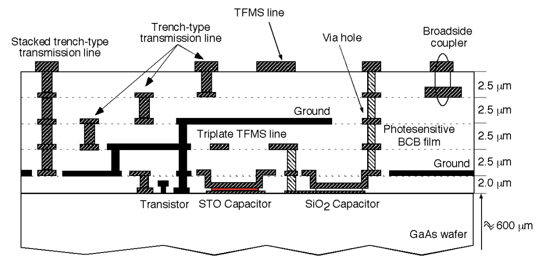

Fig. 1. Structure of BCB-based 3-D MMIC with trench-type transmission line.

turn-around time (1/3 compared to the polyimide-base 3-D MMIC process), and lower fabrication temperature (under 250 °C). The lower moisture absorption (0 – 0.2 %) of the BCB film also offers more flexible metal configuration and simpler packaging such as nonhermetic packaging. Fig. 1 shows the structure of the BCB-based 3-D MMIC with the proposed trench-type transmission line. This structure consists of four 2.5-μm-thick BCB layers, one 2-μm-thick BCB layer as the bottom layer supporting large gate metals of devices, and six stages of conductor metal. The STO and SiO_2 capacitors are formed on the first stage metals. The proposed trench-type transmission lines are also illustrated in this figure. Improving the integrated IF circuits on 3-D MMICs accelerates the realization of highly integrated single-chip millimeter-wave MMICs that include RF and IF circuits, and offers very low cost millimeter-wave equipment. The proposed trench-type transmission line is very effective in realizing IF circuits on highly integrated 3-D MMICs for applications under the C-band. This paper introduces the fabrication process of the proposed trench-type transmission line and demonstrates two applications: transmission lines and inductors.

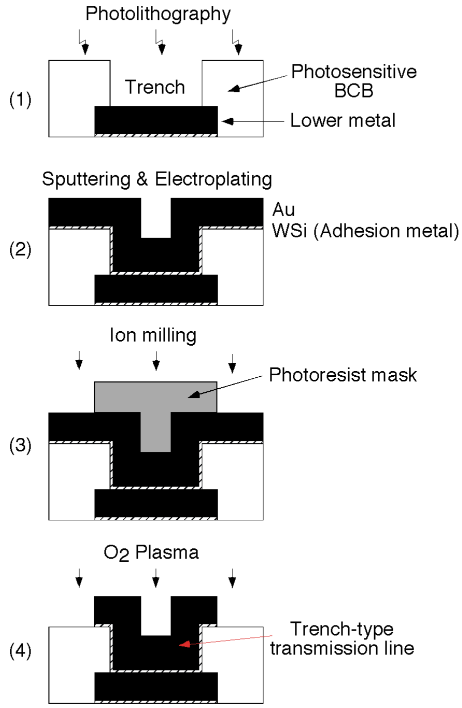

Fig. 2. Process flow of trench-type transmission line.

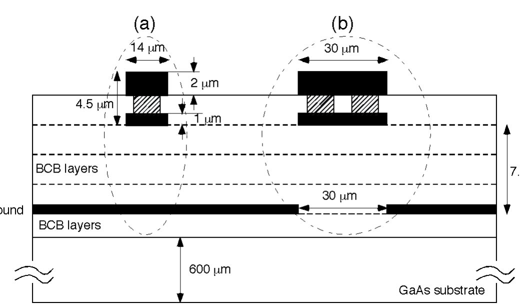

Fig. 3. Structure of trench-type transmission lines. (a) microstrip line, (b) microstrip line with slit ground.

II. Fabrication Process

Fig. 2 shows the fabrication flow of the proposed trench-type transmission line. The trench-type transmission lines and via holes for 3-D interconnection are formed at the same time in the BCB-based 3-D MMIC fabrication process. First, trench patterns are formed in the photosensitive BCB film (Dow Chemical, Cyclotene 4022) by using photolithography. Next, a gold metal is formed by electroplating, after depositing adhesion metal (WSi) and seed metal (Au) continuously by sputtering. Third, the gold metal is patterned by ion milling using a photoresist mask. Finally, the photoresist mask is removed by O_2 plasma, which cannot etch the BCB film. This process realizes the stacked configuration of the trench-type lines. This process is repeated after finishing top level metal fabrication.

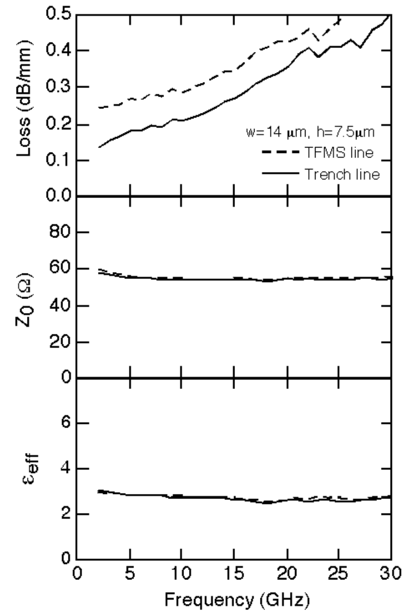

Fig. 4. Measured performance of trench-type transmission line shown in Fig. 3 (a).

III. Transmission Line

Fig. 3 illustrates two trench-type transmission lines. Transmission line (a) shows the microstrip configuration with a line width of 14 µm and a substrate height of 7.5 µm. The trench width is 9-µm mask size and the total metal thickness is 4.5 µm. The cross-sectional area of this trench-type line is 4 times larger than that of a 14-µm-width TFMS line with 7.5 µm-thick BCB substrate. Transmission line (b), illustrated in Fig. 3, utilizes a ground slit. The line width and the slit gap are 30 µm, respectively. Measured performances of the lines are shown in Fig. 4 and Fig. 5. Solid lines plot the trench-type lines while dotted lines plot TFMS lines. The losses of the trench-type lines at 5 GHz are 30 % smaller than those of the TFMS lines, while the characteristic impedance and the effective dielectric constant are only slightly different. The loss reduction of the trench-type line decreases as the frequency increases due to the skin effect. Another benefit of the trench-type line is its high current capability because

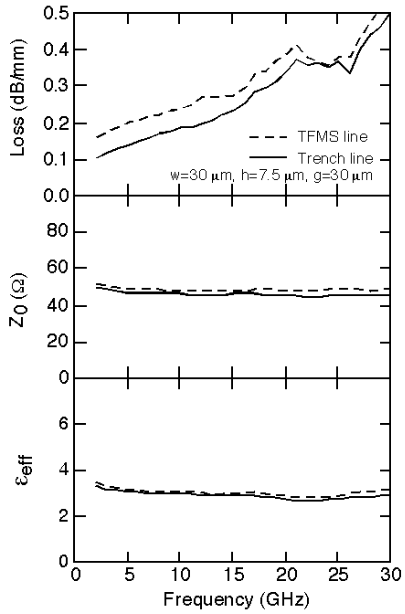

Fig. 5. Measured performance of trench-type transmission line shown in Fig. 3 (b).

of its large cross-sectional area. These results indicate the proposed trench-type line is very effective in reducing the transmission loss at frequencies below 20 GHz. The proposed trench-type line enables us to realize low-loss IF circuits that are integrated with millimeter-wave circuits, resulting in highly integrated single-chip millimeter-wave MMICs.

IV. INDUCTOR

Due to its low-loss, the trench-type transmission line can be used to realize spiral and solenoidal inductors that achieve high Q performance. This application clarifies the excellent design flexibility of the trench-type line.

A. Spiral inductor

Fig. 6 shows a 3-D spiral inductor based on trench-type lines. The spiral pattern and the underpass are formed by trench-type lines. Ground planes are formed on the second level BCB layer and the ground plane below the spiral pattern is removed, resulting in a high-impedance spiral segment. This structure effectively reduces the parasitic capacitance resulting from the 3-D structure. The line width and the spacing of the spiral pattern are 20 µm and 10 µm, respectively. Fig. 7 shows a photograph of a fabricated 3-D 6-turn spiral inductor. The inductor's S-parameter was measured using an on-wafer probe; RF pads were de-embedded. The intrinsic inductor value is 6.2 nH.

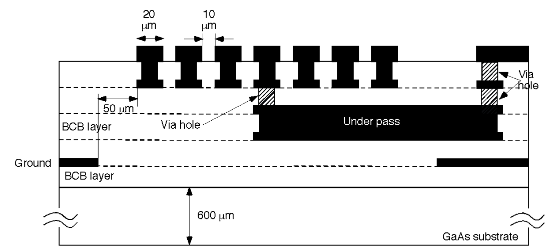

Fig. 6. Structure of 3-D spiral inductor using trench-type line.

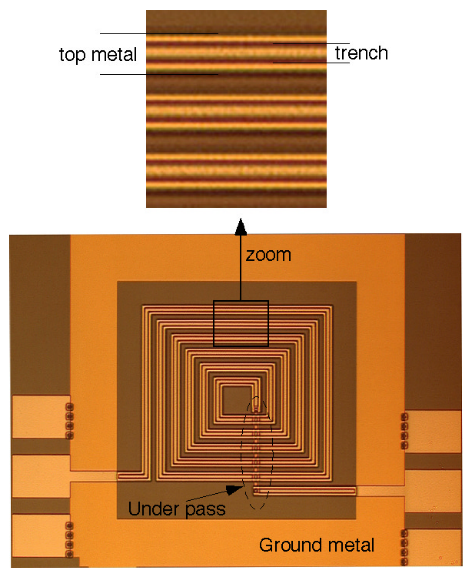

Fig. 7. Photograph of 3-D spiral inductor using trench-type line.

The measured Q-factor of the fabricated inductor is shown in Fig. 8. For a comparison, the dotted line plots the Q-factor of a 6-turn 3-D inductor (L = 6.4 nH) that uses the 20-µm-width TFMS line shown in Fig. 8. The fabricated 3-D inductor achieves a peak Q-factor of 30.5 at 3.6 GHz and its value is more than 30 % higher than that of the 3-D inductor using the TFMS line. The self-resonant frequency is 6.3 GHz. These results indicate that the trench-type line can realize high-Q spiral inductors for low frequency applications, resulting in high performance IF circuits.

B. Solenoidal inductor

The structure of the solenoidal inductor is illustrated in Fig. 8. The solenoidal pattern consists of two trench-type lines; upper line and lower line. They are connected at their edge by via holes. The ground plane with the window formed below the solenoidal pattern is formed on the

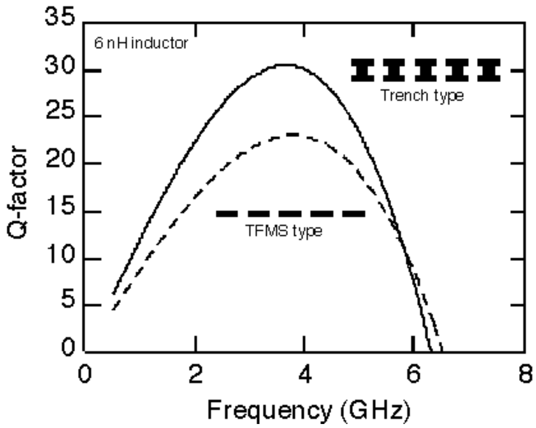

Fig. 8. Q-factor of 3-D inductor using trench-type line.

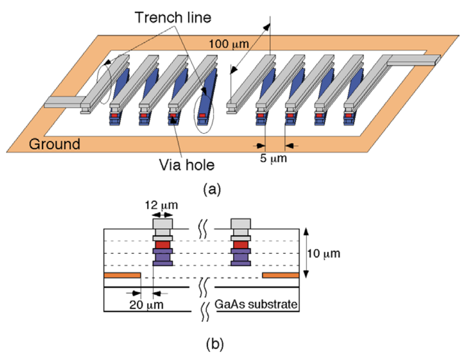

Fig. 9. Structure of solenoidal inductor. (a) Structure, (b) Cross-sectional view.

second level BCB layer. The segment length, width, and spacing of the solenoidal inductor are 100 μm, 12 μm, and 5 μm, respectively. Fig. 10 shows the 15-turn solenoidal inductor fabricated using trench-type lines. The 15-turn solenoidal inductor achieves an inductance of 0.46 nH and a peak Q-factor of 6.6 at 23 GHz. This configuration demonstrates the excellent design flexibility of the trench-type line.

IV. Conclusion

This paper introduced the newly developed trench-type transmission line and several applications. The proposed trench-type transmission line is simultaneously fabricated with via holes for 3-D interconnection in the BCB-based 3-D MMIC process. Transmission lines and

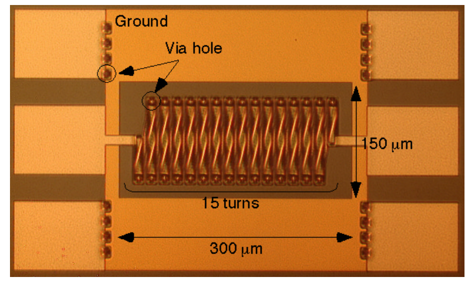

Fig. 10. Photograph of solenoidal inductor.

spiral/solenoidal 3-D inductors using the trench-type line were fabricated and tested. These components offer low-loss and high-Q performance. The trench-type line integrated with the BCB-based 3-D MMIC process promises highly integrated single-chip millimeter-wave MMICs with low-loss IF circuits.

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