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A FOLDED SLOT ANTENNA WITH PRE-ETCHED CAVITY AND BCB SUPPORT MEMBRANE ON SILICON WAFER

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Abstract—This letter demonstrates a technique for a folded slot antenna fabricated on low resistive silicon wafer, using pre-etched cavity and Benzocyclobutene (BCB) support membrane. The most distinctive feature of this method is that a cavity is pre-etched before the antenna fabrication process using low-cost potassium hydroxide (KOH) wet etching. BCB membrane is employed to support the antenna above the cavity for its low permittivity as well as excellent thermal and mechanical stability. The fabrication process discussed in detail and the fabricated antenna was characterized. Experimental results show that the antenna resonates at 15.4 GHz with a very wide impedance bandwidth, up to 14.6%.

1. INTRODUCTION

In microwave system integrated with 3 dimensions System in Package (3D-SiP) architecture, good performance, high reliability and small size are the main attractive properties. Regarding microwave system packaging, wafer-level microwave multi-chip module (MMCM) technology is more and more used for its low insertion loss and parasitics. Antenna is an essential component in Transmit/Receive (T/R) modules, whose wafer level integration still confronts many challenges, of which narrow bandwidth and high loss are the main problems due to thin dielectric layer and low resistive silicon. To

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overcome these problems, the traditional method is to insert low permittivity material [1, 2] or etch a cavity below the radiation unit [3, 4]. There are many requirements on the material for insertion, such as low permittivity and matched coefficient of thermal expansion (CTE). The cavity backed antenna has better performance [5–8] because it makes the effective permittivity of substrate closer to that of vacuum. However, considering the low cost and high reliability, the fabrication process is difficult to handle. In Ref. [3], 2 μm Silicon dioxide (SiO_2) was used as support layer above cavity and may cause some reliability issues since the SiO_2 layer is too thin and fragile.

Folded slot antenna has many advantages to the wafer level package. The most important one is its wide bandwidth [9]. Moreover, for its coplanar waveguide structure, it is easily connected with other chips. In this letter, a technique for the fabrication of folded slot antenna is presented using pre-etched cavity and BCB support membrane. The cavity is pre-etched using KOH wet etching and BCB membrane is used as a support layer. These measures reduce the insertion loss and improve performance of the fabricated antenna.

2. DESIGN AND FABRICATION

The schematic diagram of the folded slot antenna is shown in Fig. 1. The antenna consists of three layers: top layer, BCB layer and the SiO_2/Si_3N_4 dielectric layer. The radiation unit and ground are deposited in the top layer. BCB that serves as dielectric layer is coated in the middle layer. SiO_2/Si_3N_4 dielectric layer is used as the etching-stopped layer in the last step. An air cavity is etched below the antenna, which is used to improve its performance.

To simplify the design process, the size was determined based on the assumption that only air surrounds the antenna. Then it is

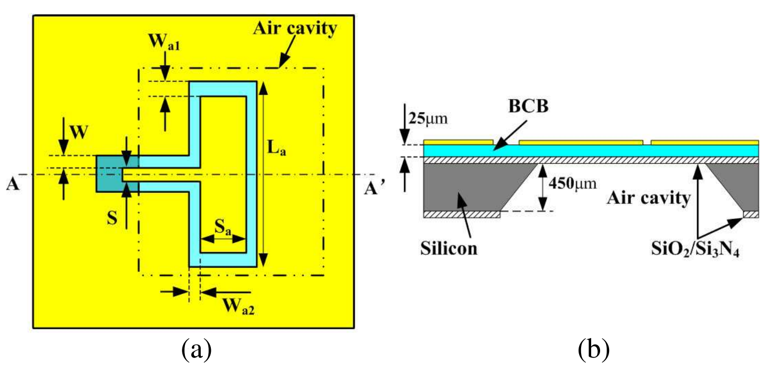

Figure 1. The schematic diagram of the folded slot antenna. (a) Top view and (b) cross-sectional view (along AA′).

optimized using the software HFSS. The details on how to determine the size is not given in this letter since it is matured and can be widely referenced [10]. The determined parameters are given in Table 1.

Table 1. Parameters profile.

Parameters	Value (μm)
W_{a1}	180
W_{a2}	70
S_a	2000
L_a	8000
W	100
S	100

The fabrication process is summarized in Fig. 2 and detailed as follows: a) Following a 2 μm thick thermal oxide film growing on the 450 μm thick low resistive silicon wafer, a 1000 Å thick silicon nitride (Si_3N_4) is deposited on the substrate using low-pressure chemical vapor deposition (LPCVD). A window is etched on the back side using reactive ion etching (RIE) process. b) Cavity in the back side is formed using KOH anisotropic wet etching. After that, a bulk silicon membrane is created. The thickness of the silicon membrane is designed to be 50 μm so that it will be robust enough for the following front-side antenna fabrication process. c) A BCB layer as thick as 25 μm is coated on the top side of the substrate and hard cured at

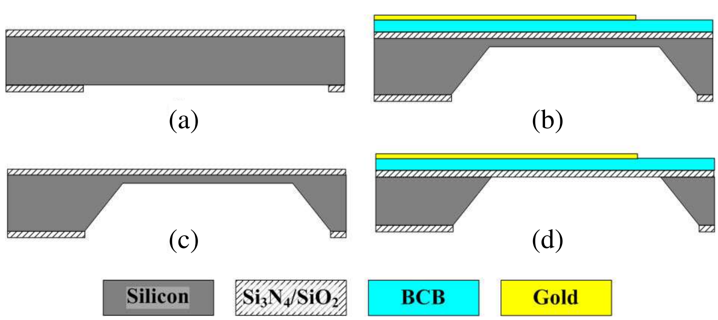

Figure 2. Cross-sectional process flow showing the main fabrication steps for the proposed antenna device. (a) Thermal oxidation, LPCVD deposition of Si_3N_4 and SiO_2/Si_3N_4 patterning by RIE process. (b) KOH wet etching a cavity. (c) Antenna fabrication on the top side. (d) DRIE is used to completely remove the bulk silicon in the cavity.

250°C for 60 min. After a seed layer (Cr/Au) is sputtered on the BCB layer, the lithography and electroplating are implemented to form the antenna structure, including the ground and radiation unit. d) Deep reactive ion etching (DRIE) is used to completely remove the remaining bulk silicon membrane. The SiO_2/Si_3N_4 layer on the top side also serves as a barrier layer to protect BCB layer from being destroyed in this step. This is the reason why both silicon oxide and silicon nitride used as mask.

3. RESULTS AND DISCUSSION

Figure 3 shows the optical micrographs of the fabricated antenna. The antenna structure, BCB layer and the cavity can be clearly seen. In our work, full-wave electromagnetic field analysis method is applied to simulate and analyze electric field distribution for the folded slot antenna using Ansoft HFSS. A probe station with 150 µm pitch ground-signal-ground (GSG) microprobes is used to measure the return loss of the antenna, as shown in Fig. 4. The wafer was lifted off from the probe station plate to provide enough distance from the electrical ground in order to imitate the operation environment of the antenna.

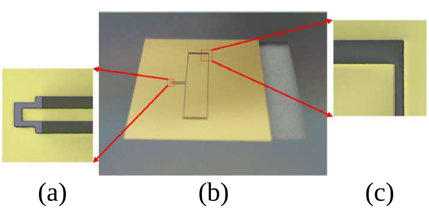

Figure 3. A photo of the fabricated antenna.

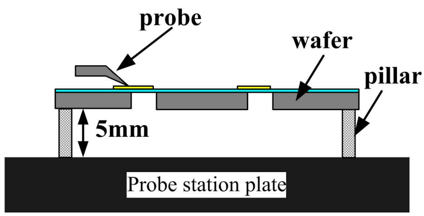

Figure 4. The test setup. The wafer is lifted 5 mm up instead of attached to the plate.

Figure 5 shows the simulated corresponding radiation pattern. Figs. 6 and 7 show the comparisons of measured and simulated return loss (S_{11}) and VSWR for the fabricated antenna, respectively. The folded slot antenna resonates at 15.4 GHz with 14.6% impedance bandwidth (VSWR $<$ 2). The bandwidth of this folded slot antenna is much wider than that of cavity-backed patch antenna on silicon wafer [2]. The measured centre frequency is 0.2 GHz larger than the simulated result, which may be attributed to the fabrication tolerance. The deviation can be ignored due to its wide bandwidth. Overall, the tested results agree well to the simulated ones.

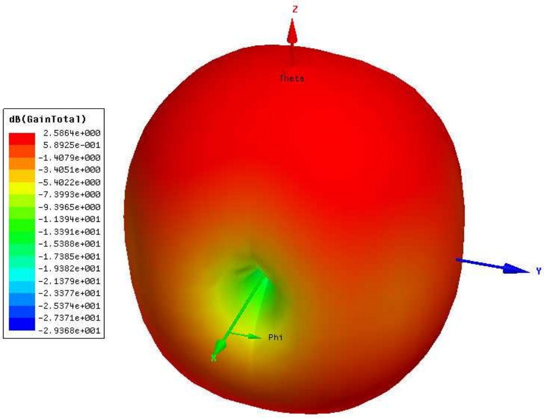

Figure 5. Simulated 3D radiation patterns at 15.2 GHz.

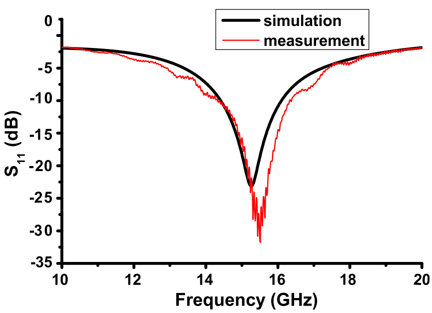

Figure 6. Comparison of measured and simulated return loss (S_{11}) for the fabricated antenna.

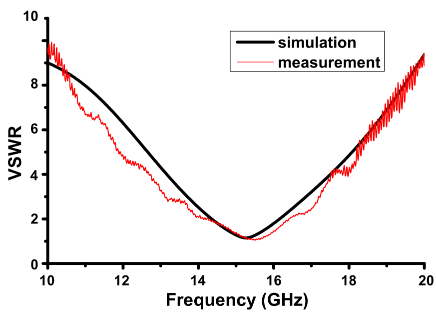

Figure 7. Comparison of measured and simulated VSWR for the fabricated antenna.

4. CONCLUSION

A high performance folded slot antenna with backside air cavity was fabricated with normal low resistive silicon wafer. The air cavity was partially pre-etched before antenna fabrication process using low-cost KOH wet etching, and completely etched using DRIE at the last step. BCB membrane was used to support the antenna above the air cavity. The antenna resonates at 15.4 GHz with 14.6% impedance bandwidth, agreeing well to the simulated one. It proves that this approach is feasible, and with the potential applicability for future RF-SiP.

ACKNOWLEDGMENT

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