Low Loss Millimeter Wave Antennas Using Modified Silicon Micromachining Process

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***Abstract*—In this paper, modified silicon micromachining process is proposed for designing low loss antennas in millimeter wave band. Low loss property is important for improving radiation efficiency, especially in millimeter wave applications. Modified silicon micromachining process is a novel MEMS micromachining technology. With this technique, millimeter wave antennas can be fabricated with air media instead of dielectric, which effectively reduces the dielectric loss. Moreover, the technology is a MEMS process, so it is very suitable for system-on-chip (SoC) applications. In this paper, the fabrication processes and principles are demonstrated, and three low loss antennas are presented in 60 GHz millimeter wave band.**

Keywords—modified silicon micromachining process; low loss antenna; millimeter wave.

I. Introduction

Millimeter wave is a key technology in 5G communication systems [1]. High frequency in millimeter band contributes a lot to high-speed wireless communication. However, with operating frequency increases, the wavelength in millimeter wave band decreases. The fabrication processes in millimeter wave applications face more challenges. In the past few decades, several technologies are proposed to design millimeter wave antenna with high precise.

Printed circuit board (PCB) is a widely used technique, which has the advantages of low-cost, compact size and easy for fabrication [2]. SU-8 is another attractive technique to design thick and high-resolution structures in millimeter wave band or even terahertz applications [3]. Moreover, low temperature co-fired ceramic (LTCC) is very popular technique to design millimeter wave antenna [4]. LTCC technique is suitable to realize multilayer structures and integrate with chip in system-on-chip (SoC) applications. However, in millimeter wave band, the abovementioned techniques suffers from dielectric loss, which affects radiation efficiency. As a result, a low loss fabrication process is significant in millimeter wave antenna design.

Recently, a modified silicon micromachining process is proposed to design antenna in millimeter wave band [5]-[7]. The fabrication process is based on bulk silicon MEMS micromachining technique. By modifying the micromachining technique, it is very suitable to design antenna with air media, which can effectively reduce dielectric loss in millimeter wave band.

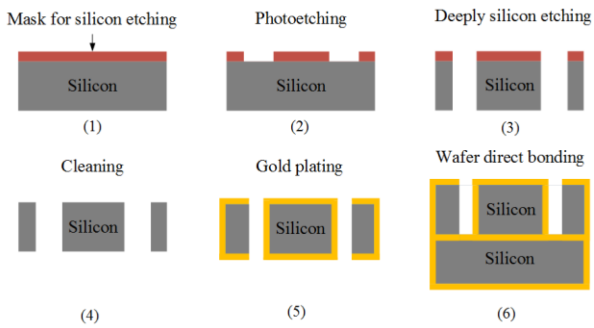


Fig. 1. Production process flow chart.

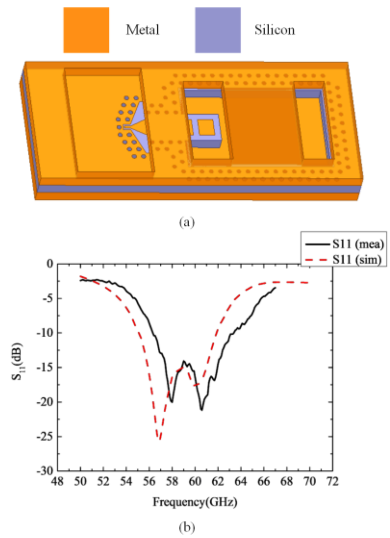
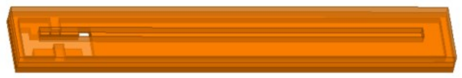


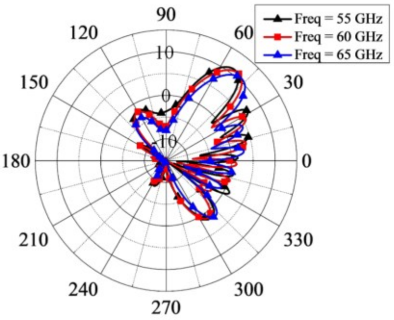
Fig. 2. The configuration of an air-filled slot antenna in millimeter wave band. (a) Antenna geometry. (b) Simulated and Measured S_{11} results.

II. Fabrication Processes

The production process flow chart of the modified silicon micromachining process is shown in Fig. 1. At first, a mask layer is generated on the surface of silicon wafer as shown in Fig. 1(1). Then, photo-etching technique is utilized to etch the mask as shown in Fig. 1(2). Thirdly, the silicon wafer is deeply etched by etching gas. The etching gas would only

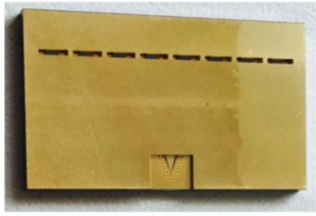


(a)

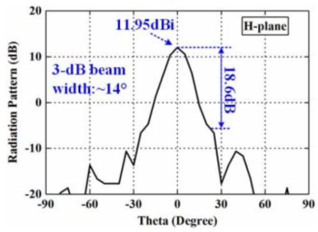


(b)

Fig. 3. An air-filled leaky-wave slot antenna. (a) Configuration of the antenna. (b) Radiation patterns with different operating frequencies.



(a)



(b)

Fig. 4 Configuration of a low-sidelobe air-filled slot array.

etch the area where the mask is etched by photo-etching technique. By deeply etching, the silicon wafer is etched through as shown in Fig. 1(3). After that, the fabrication processes are cleaning and gold plating the silicon wafer as shown in Fig. 1(4) and (5). Finally, several silicon wafers are bonded together as shown in Fig. 1(6). The most outstanding characteristic in the modified process is the deeply silicon etching, which etches through the silicon wafer and makes it suitable for designing antenna with air media.

III. Three Antenna Examples

A millimeter-wave using the modified silicon micromachining process is shown in Fig. 2. The antenna consists of three silicon layers and uses a patch feeding structure to excite two radiation slots [5]. The patch feeding structure solves the mismatch issue between the silicon wafer and air media. Fig. 2(b) illustrates the S_{11} result, which shows the patch feeding structure broadens the impedance bandwidth. The simulated radiation efficiency is about 0.95, which shows the modified silicon micromachining process can effectively mitigate the dielectric loss issue.

Besides the low loss property, the antenna with air media also has other characteristic. By utilizing the modified silicon micromachining process, a leaky-wave slot antenna is proposed as shown in Fig. 3(a). Because the antenna utilizes air media, the phase constant in the leaky-wave slot approximately equals to the wavenumber in free space [6]. As a result, when operating frequency changes, the radiation pattern of the antenna points at the same direction. Fig. 3 (b) shows when the operating frequency varies from 55 GHz to 65 GHz, the radiation patterns changes for only 5°.

By using the modified silicon micromachining process, one can also design antenna array. Fig. 4 shows a low-sidelobe slot array with air media. The antenna array use an eight-way unequal power divider to excited eight air-filled slots, which presents tapered excitation coefficients. As shown in Fig. 4(b), the broadside gain of the antenna array is 11.95 dBi and the sidelobe level is 18.6 dB at 58.5 GHz.

IV. Conclusion

In this paper, the modified silicon micromachining process is proposed to design low loss antennas in millimeter wave applications. By using the technology, one can design antenna with air media, which effectively mitigates the dielectric loss. Moreover, the air media also provides several attractive characteristics, such as fixed beam in leaky-wave antenna and designing low-sidelobe array. In conclusion, the modified silicon micromachining process is with high potential in low loss millimeter wave applications.

Acknowledgement

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