A 94 GHz Aperture-Coupled Micromachined Microstrip Antenna

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Abstract

In this paper, we present an aperture-coupled micromachined microstrip antenna operating at 94 GHz. The design consists of two stacked silicon substrates: 1) the top substrate, which carries the microstrip antenna, is micromachined to improve the radiation performance of the antenna, and 2) the bottom substrate, which carries the microstrip feed line and the coupling slot. The measured return loss is -17 dB at 91 GHz for a 10-dB bandwidth of 11 %. The radiation patterns show a measured front-to-back ratio of -10 dB at 91 GHz. The micromachined microstrip antenna is an efficient solution to the vertical integration of antenna arrays at millimeter-wave frequencies.

I. INTRODUCTION

The microstrip antenna is extensively used and studied since it provides a wide variety of designs, can be planar or conformal, and can be fed in many different methods [1,2]. It is also compact and suitable for antenna array designs. Microstrip antennas can be used in any application which requires high-performance, compact, low-cost planar antennas such as imaging arrays, collision avoidance radars. The aperture-coupled microstrip antenna [3,4] is of great interest since it allows for the electromagnetic separation of the radiating element (the microstrip patch) and the feed network by a ground plane. At millimeter-wave frequencies, many limitations have to be overcome in order to design high-performance microstrip antennas on silicon or GaAs substrates.

The high dielectric constant of the substrates used (11.7 for silicon) implies that surface waves are more easily triggered in the substrate. The power lost to surface waves can be reduced by using thin substrates, typically $\lambda_d/10$, where λ_d is the dielectric wavelength. At 94 GHz for silicon ($\epsilon_r = 11.7$), it corresponds to around 100 μm thick substrates. However, while it is possible to design good RF circuits on thin high dielectric constant substrates, the radiation efficiency of microstrip antennas will be greatly reduced.

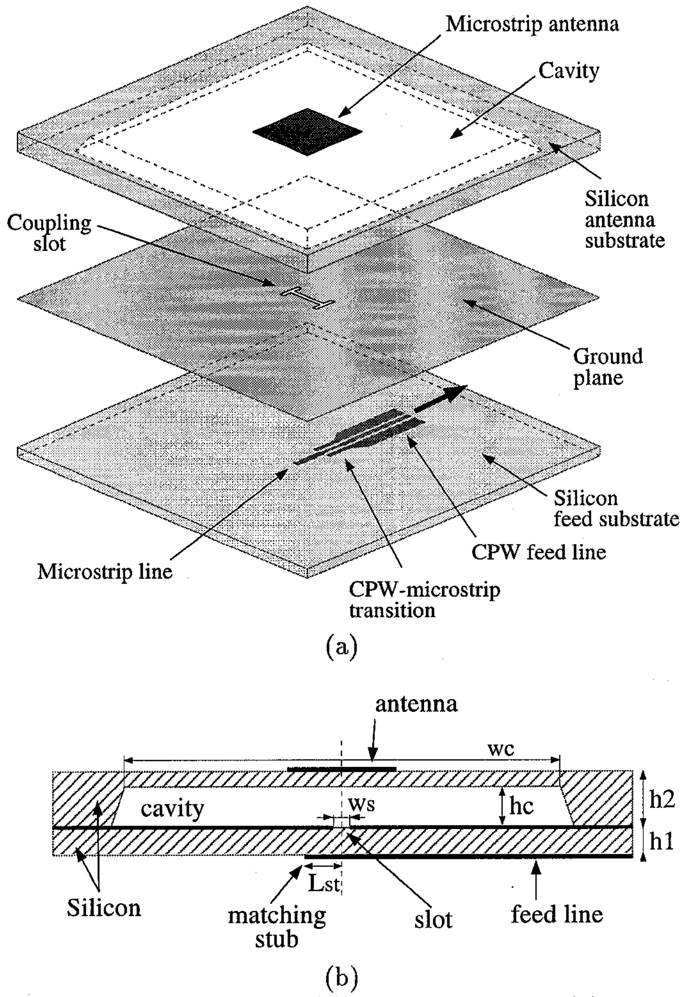

Fig. 1. Perspective view (a) and cross-section (b) of the aperture-coupled micromachined microstrip antenna.

A recent solution is the use of micromachining techniques to artificially remove the substrate around the antenna and therefore locally synthesize a low dielectric constant region around the antenna. This technique has been successfully applied by drilling closely spaced holes [5] or a cavity around and beneath the microstrip antenna [6].

Also, a low-loss transition from microstrip to Coplanar Waveguide (CPW) technology must be designed so as to integrate the microstrip antenna in a configuration where the feed network is CPW-based.

II. ANTENNA DESIGN

Figure 1 shows the perspective view and the cross-section of the aperture-coupled micromachined microstrip antenna. The design of the antenna is summarized below, referring to Fig. 2:

1/ ANTENNA

A cavity is etched in the substrate below the microstrip antenna. The synthesized effective dielectric constant (ϵ_{eff}) is characterized to determine the antenna dimensions (W, L) for a resonance at 94 GHz. The antenna is analyzed using the cavity model including the silicon-air interface of the micromachined cavity. There are no models describing the effect of the cavity width and this will be the object of a further study. We believe that the cavity around the antenna can be designed to resonate close to the microstrip antenna resonance, and therefore resulting in an increase in bandwidth [5].

2/ COUPLING SLOT

The influence of the shape of the slot has been studied previously by [7,8]. We choose to use an H-shaped slot (Fig. 2), which improves the coupling compared to a rectangular slot. The H-slot design results in a short slot and pushes the resonant frequency of the slot above that of the microstrip antenna, thereby improving the front-to-back ratio. The real part of the aperture-coupled microstrip antenna input impedance is fixed by the length of the slot, L_s, and is designed to be 50 Ω.

3/ MICROSTIP LINE AND MATCHING STUB

The microstrip line has a 50 Ω characteristic impedance. The imaginary part of the aperture-fed microstrip antenna input impedance is then compensated by the microstrip line extension, L_{st}, which acts like a matching stub (Fig. 2).

4/ CPW TO MICROSTRIP LINE TRANSITION

In order to integrate the microstrip antenna in an array where the feed network is based on CPW lines, a simple, low-loss and compact CPW to microstrip transition is designed, extending the work of Houdard *et al.* [9] at W-band frequencies. It can be analyzed as a three-line microstrip coupler. Fig. 2 shows the layout and Fig. 3 the measured performance of the transition used at W-Band frequencies. The transition results in 0.2 dB insertion loss with a bandwidth of 20 %. The return loss is better than -17 dB from 85 GHz to 100 GHz.

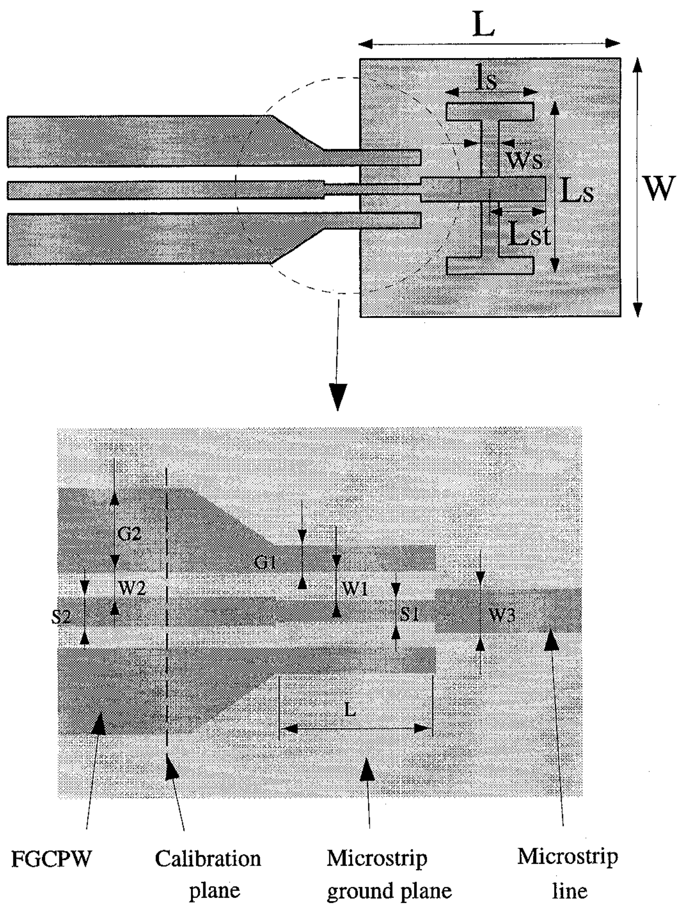

Fig. 2. Top view of the microstrip antenna design and of the CPW-to-microstrip transition.

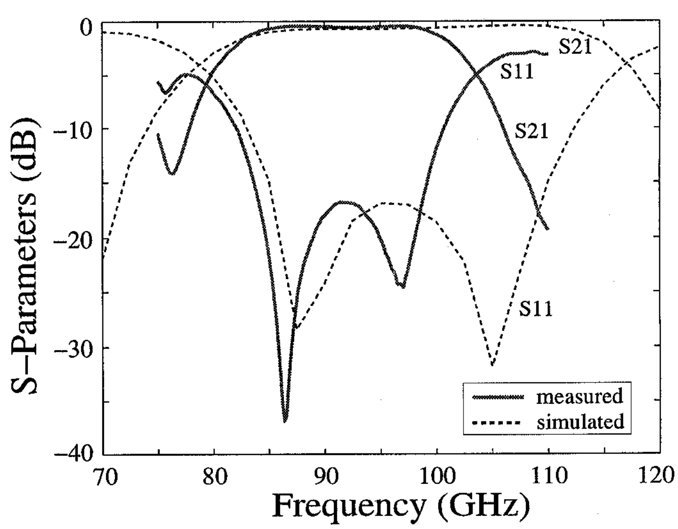

Fig. 3. Measured performance of the CPW-to-microstrip transition (-) vs. Method-of-Moment simulations (- -).

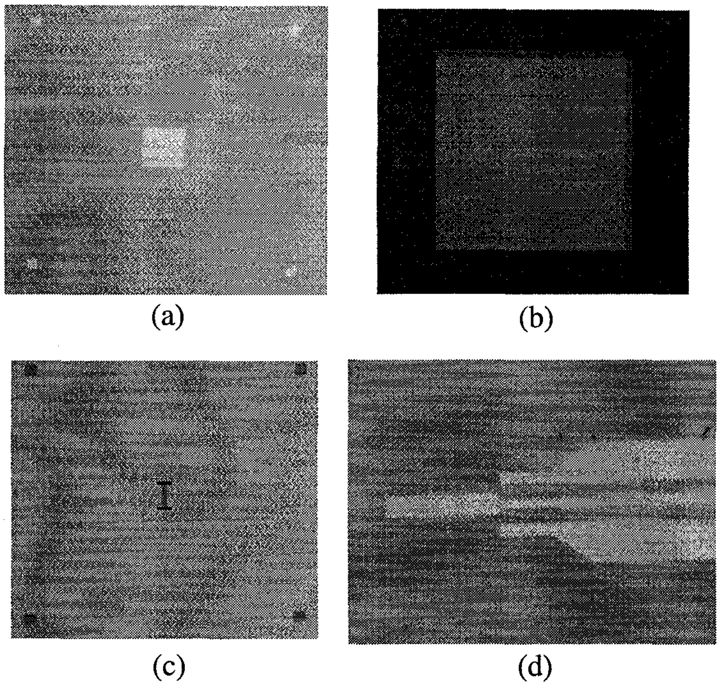

Fig. 4. Pictures of the microstrip antenna (a), micromachined cavity (b), coupling-slot (c) and feed line (d). The four pictures are not at the same scale.

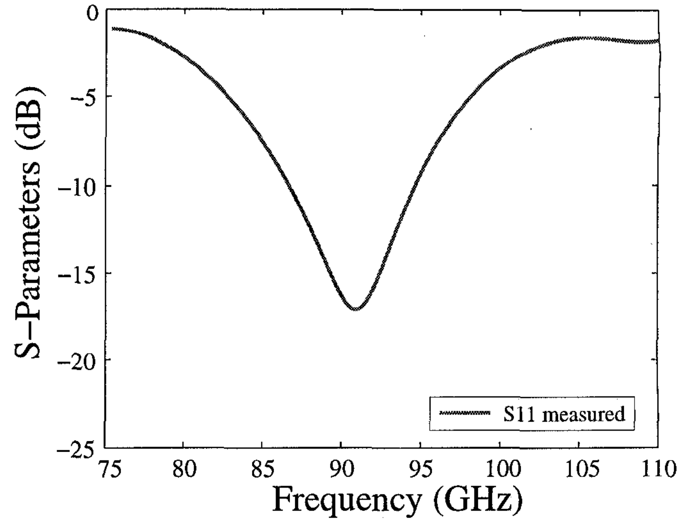

Fig. 5. Measured input impedance of the microstrip antenna from 85 GHz to 110 GHz.

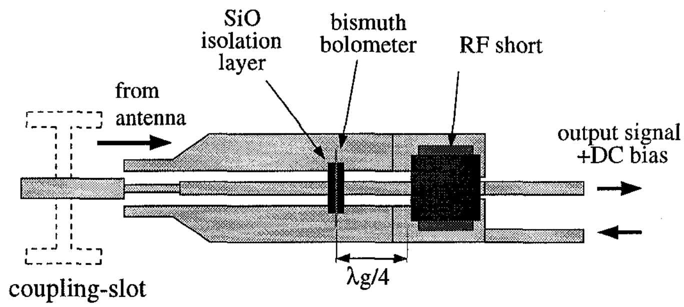

Fig. 6. Layout of the circuit used to measure radiation patterns, with the integrated bismuth bolometer.

II. INPUT IMPEDANCE

An aperture-coupled micromachined microstrip antenna is designed for 94 GHz operation. The top silicon substrate is 200 μm thick (antenna substrate). A 150 μm deep cavity is etched using TMAH wet etching techniques. Referring to Fig. 1 and 2, the antenna dimensions are W $\times$ L=850 μm $\times$ 850 μm. The slot is $L_s \times l_s \times w_s$ =500 μm $\times$ 250 μm $\times$ 50 μm. The bottom silicon substrate is 100 μm thick (feed-line substrate). The microstrip line is W_3=70 μm wide resulting in a 50 Ω characteristic impedance, and the matching stub is L_{st}=160 μm long. The input FGCPW line is also 50 Ω, with S_2=50 μm, W_2=45 μm and G_2=145 μm. The CPW-to-microstrip transition is 280 μm long with S_1=30 μm, W_1=55 μm and G_1=45 μm. All metal layers are 9000 $\AA$ of evaporated gold, corresponding to more than 3 skin depths at 94 GHz. Fig. 4 shows the pictures of the antenna, cavity, slot and feed line.

The input impedance of the antenna is measured using W-band picoprobes on a HP8510 network analyzer. The measured input impedance of the microstrip antenna is shown in Fig. 5 and is -17 dB at 91 GHz with a -10 dB bandwidth of 11 %.

III. RADIATION PATTERNS

To measure the radiation patterns of the micromachined microstrip antenna, a bismuth bolometer is integrated into the circuit (Fig. 6). The RF short in the FGCPW line is provided by a thin-film capacitor (300 μm $\times$ 200 μm $\times$ 4000 $\AA$ of evaporated SiO). Two 100 Ω bismuth bolometers (4 μm $\times$ 4 μm and 1000 $\AA$ thick) are placed in parallel $\lambda_g/4$ away from the RF short (where λ_g is the guided wavelength in the FGCPW line) and result in a 50 Ω bolometer resistance.

The measured radiation patterns are shown in Fig. 7. It is seen that the front-to-back ratio is -10 dB for the E-plane and -8 dB for the H-plane. The ripples in the E-plane are due to the finite ground of the microstrip antenna ($3\times3\lambda_0$). This microstrip-type antenna has an excellent bandwidth (11 %), good patterns and high-efficiency performance, and is compatible with silicon or GaAs MMIC technology.

ACKNOWLEDGEMENTS

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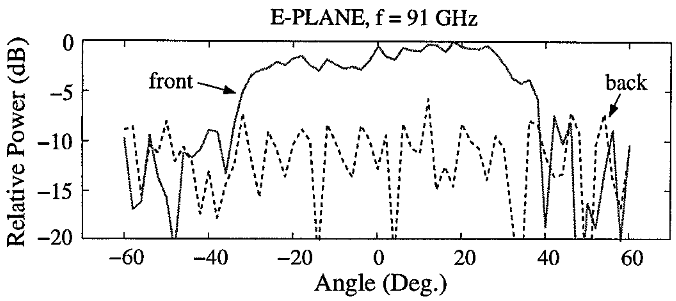
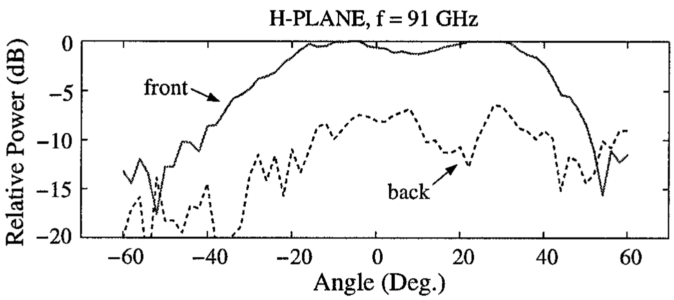


(a)



(b)

Fig. 7. Measured radiation patterns of the microstrip antenna at 91 GHz: E-plane (a) and H-plane (b).

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