Coupling Between Microstrip Lines With Finite Width Ground Plane Embedded in Polyimide Layers for 3D-MMICs on Si

George E. Ponchak[1], Edan Dalton[2], Emmanouil M. Tentzeris[2], and John Papapolymerou[2]

1. NASA Glenn Research Center, Cleveland, OH 44135
2. School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

***Abstract* — Three-dimensional circuits built upon multiple layers of polyimide are required for constructing Si/SiGe monolithic microwave/millimeter-wave integrated circuits on CMOS (low resistivity) Si wafers. Thin film microstrip lines (TFMS) with finite width ground planes embedded in the polyimide are often used. However, the closely spaced TFMS lines are susceptible to high levels of coupling, which degrades circuit performance. In this paper, Finite Difference Time Domain (FDTD) analysis and experimental measurements are used to show that the ground planes must be connected by via holes to reduce coupling in both the forward and backward directions.**

I. Introduction

There is a rapidly expanding market for Si Microwave/Millimeter-Wave Integrated Circuits (MMICs) fabricated in standard CMOS foundries to replace GaAs MMICs in wireless communication systems, phased array radar, and other applications where the circuit cost is a major factor in determining the system cost. However, microwave passive elements and transmission lines placed directly on standard CMOS and BiCMOS grade Si, which have resistivities of 1 and 20 Ω-cm respectively, have low quality factors (high attenuation), which necessitates novel transmission line structures [1] that are typically embedded in polyimide that is deposited over the Si substrate. Moreover, highly integrated systems that include the RF circuits, digital data processing circuits, and bias control circuits on a single chip or within a single package also rely on multiple layers of polyimide to construct three-dimensional circuits that are smaller than what would normally be possible.

Thin film microstrip (TFMS) embedded in polyimide solves the problem of high attenuation and smaller sized circuits, but closely spaced TFMS lines also increases the potential for high levels of coupling between lines. If the interline crosstalk is too high, the circuit characteristics are severely degraded. Prior papers on reducing coupling between microstrip lines built on Low Temperature Cofired Ceramic (LTCC) have shown that a roll of via holes placed between the two lines reduces coupling by 8 dB if the via holes are connected on the top and bottom by a strip and the ground plane respectively [2]. This shield has also been shown to reduce coupling between TFMS lines embedded in polyimide on Si substrates [3]. However, completely covering the Si wafer for the TFMS ground plane does not leave substrate area for the Si circuit components. Therefore, TFMS with finite width ground planes is a more realistic transmission line, and if the ground plane is greater than 3 to 5 times the strip width, acceptable attenuation is achieved [4].

In this paper, a systematic evaluation of the coupling between TFMS lines with finite width ground planes embedded in polyimide built upon CMOS grade Si is presented for the first time. This in depth characterization includes a comparison of the coupling between transmission lines built on different layers of polyimide, and the use of metal filled via posts to connect ground planes on different layers. To characterize the coupling, Finite Difference Time Domain (FDTD) and measurements are used.

II. Circuit Description

Figure 1 shows a cross sectional cut through microstrip lines embedded in polyimide upon a Si substrate. TFMS lines are characterized with ground plane widths of 3 and 5 times the strip width. W1, W2, and W3 are 23 μm, 52 μm, and 25 μm respectively to yield 50 Ω transmission lines for the polyimide thickness, h, of 10 μm. In several coupled microstrip lines, the two ground planes on different layers are connected by a single roll of 20 by 20 μm via holes spaced 100 μm apart. The parameter C is the distance between the center lines of the two microstrip lines.

A four-port circuit is used for characterizing the coupling between the microstrip lines with probe pads orientated so that each port may be probed simultaneously and the port numbering as shown in Figure 2. The coupling region, or the section of parallel transmission lines labeled L in Figure 2, is 5000 μm long for the experimental characterization, but the coupling length was varied for the FDTD analysis.

ports are terminated in 50 Ω loads built into especially designed RF probes.

V. Microstrip Coupling Results

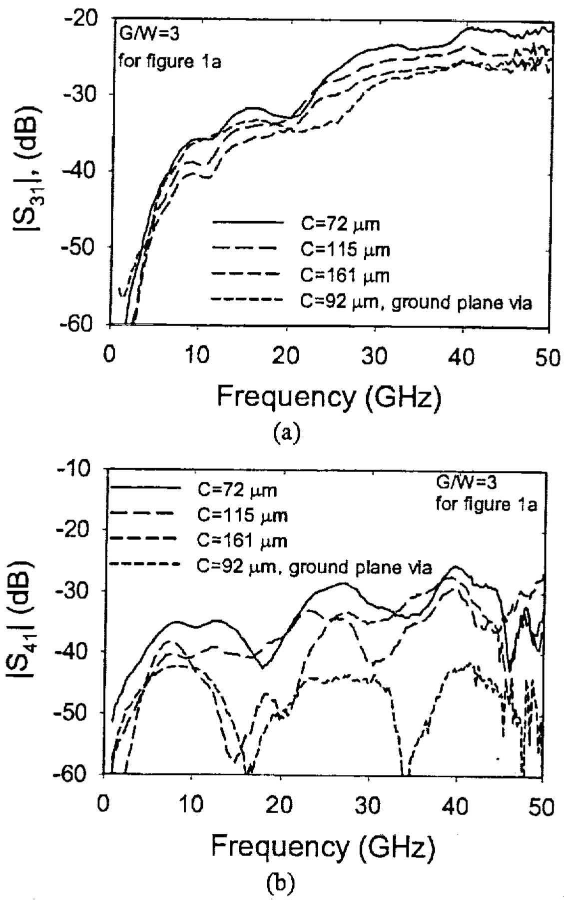

Figure 3: Measured S-parameters for coupled microstrip lines with the same substrate thickness (Figure 1a) as a function of frequency (a) forward coupling and (b) backward coupling.

First, the measured and FDTD analysis results for the embedded microstrip lines were compared across the frequency band of 1 to 50 GHz; the agreement was found to be very good with a difference less than 3 dB, thus allowing the derivation of conclusions from either method. A set of measured S-parameters for the coupled microstrip lines of Figure 1a is shown in Figure 3. Typical of all of the results presented in this paper, $|S_{31}|$ increases monotonically with frequency as shown in Figure 3a, and the slight variations in $|S_{31}|$ with frequency are shown by the FDTD analysis to be artifacts of the measurement setup. Without the ground plane via posts, $|S_{41}|$, increases with frequency, but there is also a periodic component that the FDTD analysis proves to be dependent on the coupling length, L. This is an indication that there are two components of coupling, direct coupling and indirect coupling through a phantom circuit or a parasitic mode [10]. When the ground planes are connected by via posts, $|S_{41}|$ is periodic with frequency and all of the peaks are at the same level, which is typical for coupled line structures. Throughout the rest of the paper, presented results are backward coupling defined as $-20*\log|S_{41}|$ and forward coupling defined as $-20*\log|S_{31}|$.

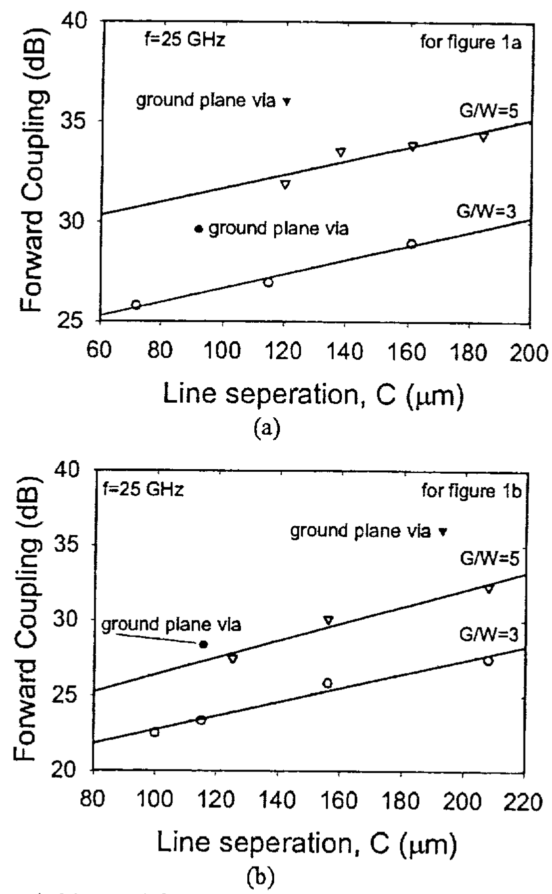

Figure 4: Measured forward coupling at 25 GHz of microstrip lines with (a) the same substrate thickness and (b) different substrate thickness as a function of center to center spacing, C.

The measured forward coupling for all of the lines is summarized in Figure 4. It is seen that coupling decreases as C increases, but the dependence is weak, especially compared to the coupling of TFMS with infinite ground planes presented in [3]. Furthermore, the forward coupling of the finite width ground plane TFMS is approximately 5 dB higher for small C and 10 dB higher for large C when compared to the infinite ground plane TFMS [3]. It is seen in Figure 4 that coupling decreases as the ground plane