# Low Loss, Finite Width Ground Plane, Thin Film Microstrip Lines on Si Wafers

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## ABSTRACT

Si RFICs on standard, 2 Ω-cm Si wafers require novel transmission lines to reduce the loss caused by the resistive substrate. One such transmission line is commonly called Thin Film Microstrip (TFMS), which is created by depositing a metallic ground plane, thin insulating layers, and the microstrip lines on the Si wafer. Thus, the electric fields are isolated from the Si wafer. In this paper, it is shown through experimental results that the ground plane of TFMS may be finite width and comparable to the strip width in size while still achieving low loss on 2 Ω-cm Si. Measured effective permittivity shows that the field interaction with the Si wafer is small.

## INTRODUCTION

Si Radio Frequency Integrated Circuits (RFICs) are progressing rapidly into the wireless communication and automobile sensor markets, due in large part to significant improvements in SiGe HBTs. However, RF transmission lines on Si substrates suffer from high loss unless novel transmission lines or high resistivity Si wafers are used [1]. On low resistivity, 0.1 to 10 Ω-cm, Si wafers such as commonly used for CMOS and Bi-CMOS circuits, Thin Film Microstrip (TFMS) has been shown to have low loss [2], and it may be manufactured using standard Si processing steps to create Si RFICs [3].

A schematic of TFMS is shown in Figure 1. Typically, a large area of the topside of the Si wafer is metallized and this serves as the ground plane for the TFMS. Thus, the ground plane width, G, is very large and may be considered infinite. This assures that there will be no electric field interaction with the Si wafer and the high loss associated with it. On top of the ground plane, a thin layer of insulating material is deposited to serve as the microstrip substrate. Since polyimide may be deposited in multiple layers of 1 to 20 μm thick and it is used for planarization during Si IC processing, it is often used for the substrate of TFMS lines. Finally, the microstrip circuit is defined on top of the polyimide.

In this paper, we introduce a finite width ground plane TFMS line. Measured attenuation of TFMS show that the ground plane only needs to be 3 to 5 times the strip width, W. Furthermore, measured effective permittivity shows that the finite width ground planes shield the electric fields from the Si wafer. In the full paper, 2D- Finite Element Method (FEM) analysis will be included. It is believed that these narrow, TFMS lines will enable the production of smaller Si RFICs, which will give them a larger cost advantage compared to GaAs and InP circuits.

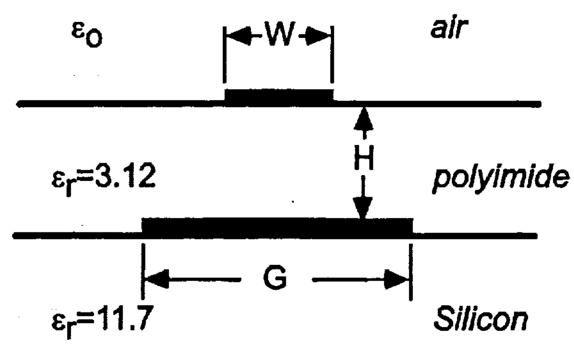



**Figure 1: Schematic of Thin Film Microstrip (TFMS).**

## EXPERIMENT

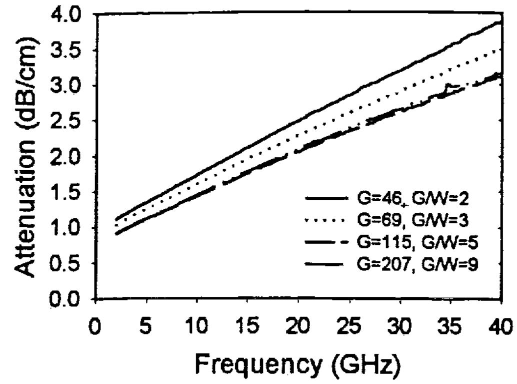
To characterize the propagation characteristics of TFMS on Si substrates, test structures are fabricated on a single wafer. A ground plane consisting of a 200 Å Ti adhesion layer, 1.5 μm of Au, and a 200 Å Cr cap layer is defined on an n-type, 0.5 to 2.5 Ω-cm Si wafer. This is followed by spinning on DuPont adhesion promoter and PI-2611 polyimide and curing it at 350 C for 60 minutes. PI-2611 has a relative dielectric constant, $\varepsilon_r$, of 3.12 [4] measured at 1 MHz and a loss tangent of 0.002 [5] measured at 1 kHz. The finite width ground planes create a nonplanar surface, which is partially planarized by the polyimide, resulting in the polyimide being 11.25 μm thick where there is no ground plane and 11.05 μm thick over the ground planes. Therefore, H=11.05 μm for the TFMS. Ni is used as a hard mask to Reactive Ion Etch (RIE) via holes in the polyimide for topside connection to the ground planes. Finally, a lift off process is to fill the via holes, define the probe pads, and the microstrip lines in a single step; 200 Å Cr and 1.6 μm of Au is used. These dimensions are confirmed through 3D-profiler and SEM measurements, and they also show that surface roughness is small enough to be neglected.

The microwave characterization is performed over the frequency range of 2 to 40 GHz using a HP 8510C vector network analyzer and GGB Industries RF probes. To extract the attenuation and effective permittivity, $\varepsilon_{eff}$, of the TFMS, a Thru-Reflect-Line (TRL) calibration routine implemented through the NIST MULTICAL software routine is used. TRL calibration routines use extra data measured during calibration to determine the propagation characteristics of the delay lines. Each set of calibration standards consists of a 5000 μm thru line, a short circuit reflect, and delay lines of 6800, 7400, 9800, and 15000 μm length. The advantage of the MULTICAL TRL calibration routine is that it uses the weighted average of all four-delay lines at each frequency point to increase accuracy. To improve probe placement accuracy, the probe pads are designed to assure probe placement within 15 μm, which results in a worst case error of 0.6 percent due to probe placement errors.

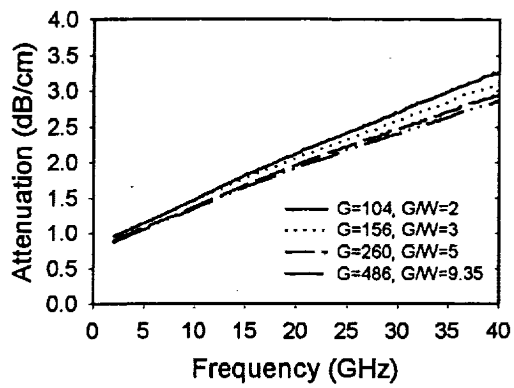
### MEASURED TFMS CHARACTERISTICS

TFMS lines are characterized for line widths of 23 and 52 μm. Employing standard microstrip design equations for infinite width ground planes and the polyimide thickness of 11.05 mm, these TFMS lines have a characteristic impedance of 53 and 31 Ω respectively. Ground plane widths, G, of 2W, 3W, 5W, and 9W are characterized. The measured attenuation of these lines is shown in Figure 2. Although TFMS is considered a lossy transmission line, a minimum attenuation of approximately 3 dB/cm is achieved, which is lower than similarly sized CPW lines on GaAs or Si with a resistivity greater than 2500 Ω-cm [REF PONCHAK]. Across the measured frequency spectrum, the attenuation decreases as the ground plane width increases; however, the difference between very wide ground planes (G=9W) and narrow ground planes (G=2W) is less than 0.8 dB/cm for 53 Ω lines and 0.5 dB/cm for 31 Ω lines at 40 GHz. Figure 3 shows the measured attenuation at 20 GHz as a function of G/W and W/H. It is seen that a ground plane width greater than 3W is required for low attenuation for both the 31 and 53 Ω lines, and wider ground planes do not lower attenuation significantly.

The associated effective permittivity is shown in Figure 4 where it is seen that $\varepsilon_{eff}$ is greater for narrow ground plane lines; however, $\varepsilon_{eff}$ does not change for ground plane widths greater than 3W. While conductor loss in the ground plane is expected to decrease as the ground plane width increases, higher effective permittivity for narrow ground plane lines indicates that some of the increased loss is due to electric fields extending into the Si wafer.




(a)




(b)

**Figure 2: Measured attenuation of TFMS lines as a function of frequency with (a) W=23 μm and (b) W=52 μm.**

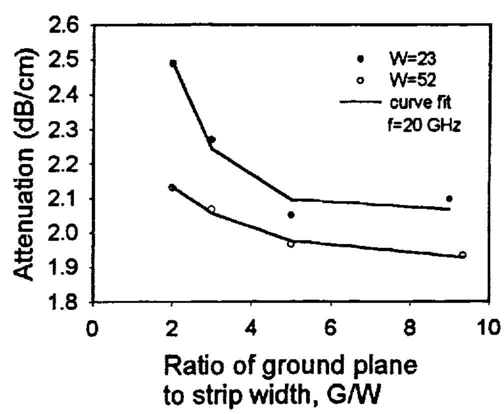
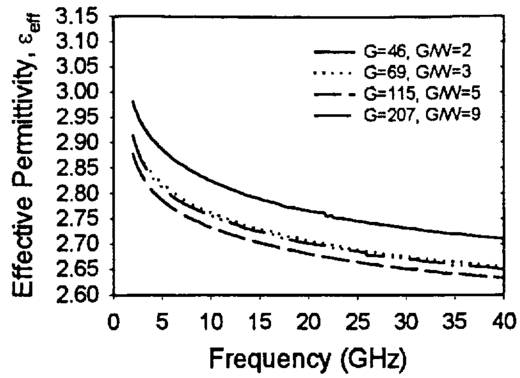
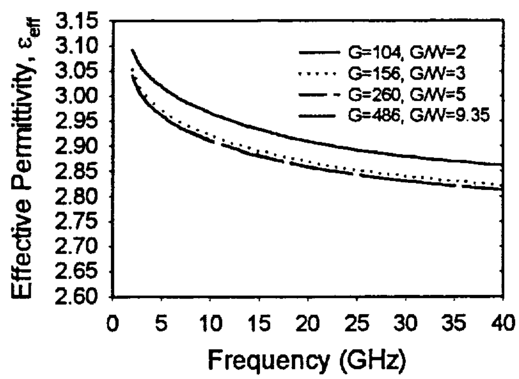



**Figure 3: Measured attenuation at 20 GHz of TFMS as a function of the ground plane width to strip width.**




(a)




(b)

**Figure 4: Measured effective permittivity of TFMS lines as a function of frequency with (a) W=23 μm and (b) W=52 μm.**

## CONCLUSIONS

Through measured propagation characteristics of TFMS lines on 2.5 Ω-cm Si wafers, it is shown that the ground plane may be reduced to 3W without any increase in attenuation. Thus, the area required for the transmission lines is reduced compared to standard TFMS with infinite, or very wide ground planes, and more of the Si wafer is available for active components such as SiGe HBTs and lumped passive elements. Therefore, it should be possible to reduce the size of Si RFICs.

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