MICRO-COPLANAR STRIPLINES - NEW TRANSMISSION MEDIA
FOR MICROWAVE APPLICATIONS

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Abstract

In this paper a new transmission line for microwave applications, referred to here as the Micro-Coplanar Stripline (MCPS), is introduced. The propagation characteristics, such as, characteristic impedance (Z_o) and effective dielectric constant (ϵ_{eff}) for a range of MCPS geometries have been modeled using the Finite Difference Time Domain (FDTD) Technique and presented here. Also, preliminary experimental results on the performance of an MCPS-Microstrip transition and an MCPS-fed patch antenna are presented. The results indicate several potential applications of the MCPS line in microwave integrated circuit technology.

I   Introduction

In recent years, wireless communications for audio, video and data transmission have witnessed tremendous growth. The essential requirements for these wireless systems are low cost for affordability and small size for portability. One approach in addressing low-cost requirements is to combine the available digital silicon processing technology with the high frequency silicon germanium device technology. The size and complexity issues that arise with this integration can be addressed by investigating novel integration techniques which rely on multilayer three dimensional transmission lines constructed using very thin glass or silicon dioxide layers. With appropriate interconnect technology available, customized innovative integrated packages can be realized by micromachining the silicon wafer [1]. These techniques, when realized, have the potential to meet the ever increasing demand to lower the cost and size of circuit components.

This paper presents a new transmission line, the Micro-Coplanar Stripline (MCPS). Fig. 1 shows the geometry of MCPS. The MCPS is fabricated on a high resistivity silicon (HR Si) wafer and has a very thin spin-on-glass (SOG) as a spacer layer separating two strip conductors. MCPS has several advantages some of which are discussed here: 1) The dimensions of the strip conductors as well as the spacer layer are of the order of a few microns for a 50 Ω transmission line. Thus the transmission line is very compact, resulting in small amount of parasitics when combined with active devices. 2) The strip conductors are on two levels, thus making vertical as well as horizontal integration possible. This can be useful in applications such as mixers using broad-side couplers with tight coupling and wide bandwidth. 3) The spacer layer is very thin, hence making it possible to realize large capacitances in a small area. This feature is very desirable in the design of compact low-pass and bandpass filters. 4) The two strip conductors form a balanced line, making the MCPS an ideal line for feeding integrated antennas, such as, patches, bow-ties and dipoles.

A number of variants of this basic structure, a few of which are shown in Fig. 2, can be used to achieve several advantages. Fig. 2a shows an insulating layer of Silicon dioxide (SiO_2) which can be used to effectively isolate the RF MCPS from the conductive properties of the low resistivity silicon (LR Si) wafer (few Ohms-cm) below. The advantage gained is that CMOS based circuits for signal processing on LR Si can coexist with the RF circuits thereby simplifying integration. Fig. 2b shows a possible configuration us-

ing HR Si wafer ($>$ 3000 ohm-cm). The advantage here is that the HR Si wafer will lower the attenuation and also improve isolation between adjacent circuits. The additional dielectric layer can be used to improve field confinement or for building RF circuits. Fig. 2c shows a geometry where the upper dielectric layer is replaced by an LR Si wafer with an etched groove which can serve as a metal cover or a ground plane for circuits located above. The last configuration, shown in Fig. 2d, is an MCPS which is shielded and suspended inside an enclosure formed by two LR Si wafers with etched grooves. This line is expected to have very low attenuation since the ϵ_{eff} is approximately equal to that of air. Such a transmission line is ideal for constructing feed systems for high gain, high efficiency planar array antennas.

In the following sections, first, a brief description of the fabrication process for the MCPS is presented. Next, the propagation parameters of the MCPS, such as, Z_o and ϵ_{eff} for a range of MCPS geometries is presented. These have been modeled by using the well known FDTD technique [2], [3], [4]. Finally, to demonstrate the applications of this line, preliminary experimental results on an MCPS-Microstrip broadband transition and a feed network for a patch antenna have been presented. The experimental work was performed using a Duroid based MCPS line for the purpose of validating the applicability of the novel transmission line. Fabrication and measurement of SOG-on-Silicon based MCPS lines is currently in progress.

II   Fabrication of MCPS:

To begin the fabrication process, the lower strip conductor is fabricated on the substrate (ϵ_{r2}) by a lift-off process [5]. Next, the dielectric spacer layer (ϵ_{r1}) is built-up to the required thickness by multiple spin-coats. Lastly, the upper strip conductor is fabricated using the lift-off process once again. An HR Si ($>$ 3000 ohms-cm) silicon wafer is used as the base substrate and the gold metalization of about 1.0 μm thickness is used as the conductor. Accuglass 512 SOG is used as the dielectric spacer layer. The dielectric constant and thickness of the Accuglass used here are 3.1 and 2.5 μm respectively. If a higher dielectric constant or thicker layer is required, it is preferable to use other spin coating materials, such as, polyamides.

III   Characteristics of MCPS.

A number of MCPS geometries have been characterized using the FDTD technique in order to obtain the characteristic impedance and effective dielectric constant. For these lines, a 400 μm thick Silicon substrate ($\epsilon_{r2} = 11.7$) is chosen. The thickness of glass ($\epsilon_{r1} = 3.1$) is 2.5 μm. Tables 1 and 2 below summarize the Z_o and ϵ_{eff} for SOG-on-Silicon MCPS with line widths (W) 135 μm and 94.5 μm respectively for overlap (S) ranging from positive ($+27\mu$m) to negative (-27μm). Here, '+' indicates an overlap between the lines and '-' indicates a separation. From the tables, it can be seen that as the overlap distance between the MCP strips increases, the characteristic impedance decreases. This is because with increasing overlap, the coupling (capacitance) between the lines increases, thereby reducing Z_o. Also it is seen that lowering the stripwidth increases Z_o. From these, it is obvious that by varying the parameters involved, a wide range of desired characteristic impedances can be obtained.

While the above line dimensions are useful for feeding patch antennas and transitions, for integrating CMOS with RF circuits, lines with much smaller dimensions are required. It has been found that a line with W = 10 μm and S = 4 μm yields characteristic impedance close to 50 Ω. Fabrication of this line on HR Si with a 2.5 μm SOG spacer layer is in progress. Although Fig. 1 does not show the probe pads, this line will be characterized using standard on-wafer RF probing equipment.

Table 1: Z_o **and** ϵ_{eff} **of SOG-on-Silicon MCPS:** D_1 **= 2.5**μ**m,** D_2 **= 400**μ**m, W = 135**μ**m**

Overlap S (μm)	Z_o (Ω)	ϵ_{eff}
+27.0	10.7	3.49
+13.5	14.0	3.67
0.0	22.4	4.02
-13.5	51.2	5.61
-27.0	59.0	5.89

IV   Applications of MCPS:

In order to demonstrate the efficacy of this line, a broadband MCPS-Microstrip transition and an MCPS fed Patch antenna have been experimentally charac-

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Table 2: Z_o and ϵ_{eff} **of SOG-on-Silicon MCPS:** D_1 = 2.5μm, D_2 = 400μm, W = 94.5μm

Overlap S (μm)	Z_o (Ω)	ϵ_{eff}
+27.0	11.1	3.40
+13.5	14.6	3.59
0.0	23.9	3.94
-13.5	58.4	5.50
-27.0	66.6	5.79

terized. In doing so, MCPS circuits fabricated on 254 μm and 127 μm thick Duroid have been used.

a) **MCPS-Microstrip broadband transition:** The schematic of an MCPS-to-Microstrip back-to-back transition is shown in Fig. 3. In the figure, section A - B corresponds to the microstrip line while section C - D corresponds to the MCPS. The transition consists of a short length of a 50 Ω microstrip line of width 254 μm whose ground plane is abruptly truncated. At this plane, the tapered MCPS strip conductors form a junction with the microstrip line. At the junction, the tapered section of the MCPS conductors form a symmetric parallel plate line. The conductors of the parallel plate are flared out in opposite directions, forming the regular MCPS with W = 889 μm while facilitating impedance and mode matching. The relevant parameters of this geometry are as follows:
D_1 = 254 μm; ϵ_{r1} = 10.5; ϵ_{r2} = 1; W = 889 μm; W_1 = 254 μm. Fig. 4 shows the measured S_{11} and S_{21} of this transition. From the figure it can be seen that the insertion loss of the transition is close to 0.7 dB at the center frequency of 7 GHz and has a maximum value of 1.0 dB at 14 GHz. This includes the losses due to the two coaxial launchers of the Wilton test fixture which are of the order of 0.25 dB each. Thus it can be seen that deembedding will further reduce the insertion loss to 0.2 dB at 7 GHz, with the maximum loss being 0.5 dB at 14 GHz. These results indicate that the transition has excellent characteristics over a broad range of operation.

b) **MCPS Feed for a Patch Antenna:** The schematic of an MCPS fed patch antenna which is designed to operate at 19 GHz is shown in Fig. 5. In this circuit, power is coupled to the patch radiator through an MCPS-to-Microstrip transition. An interesting feature of this feeding network is that it can provide an optimum substrate for a given frequency band of operation by proper choice of the spacer layer thickness D_1 and dielectric constant ϵ_{r1}. The parameters of this circuit are given below:
D_1 = 127 μm ; ϵ_{r1} = 10.8; D_2 = 762 μm; ϵ_{r2} = 10.2; a = 3429 μm; b = 2286 μm. The measured return loss S_{11} of the antenna using an RF wafer probe (10 mil pitch) is shown in Fig. 6. As seen from the figure, the patch antenna resonates at 18.1 GHz while it is designed to resonate at 19.0 GHz. This shift is due to the parasitics added by the MCPS section which have not been deembedded. It can be seen from the figure that the antenna is well matched to the feed. This demonstrates the feasibility of using MCPS as feed lines in the design of antenna arrays for wireless applications.

V   Conclusion

A new transmission line, the MCPS, which has the potential to provide extremely compact and low cost circuits with wide design flexibility has been introduced. The propagation characteristics for a wide range of circuit parameters have been presented. Also, the applications of this line has been demonstrated by characterizing an MCPS-Microstrip transition and an MCP-fed Patch antenna.

VI   Acknowledgments

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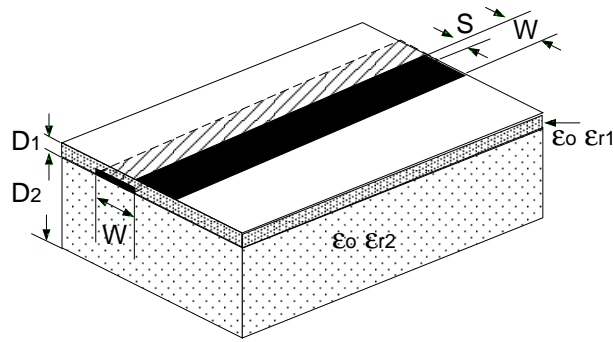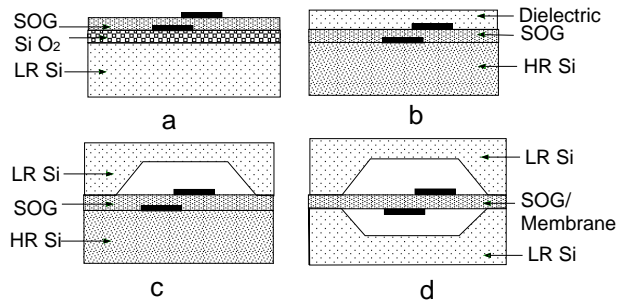
Figure 1: Geometry of MCPS line
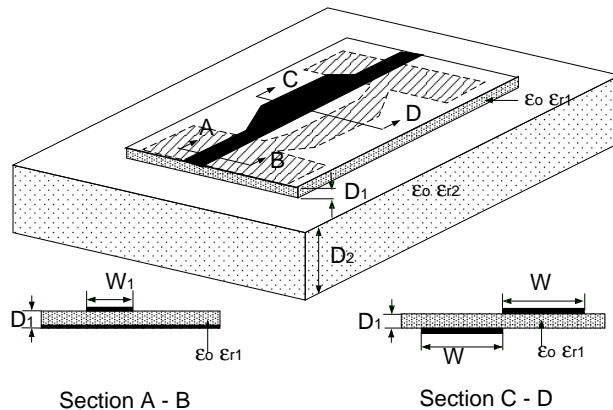

Figure 2: MCPS Variants.
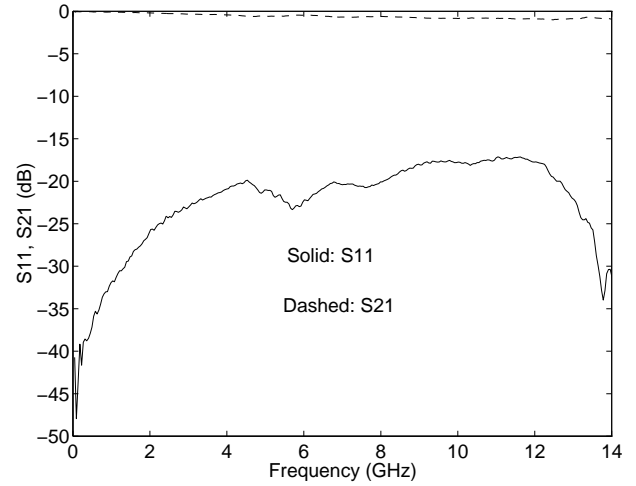

Figure 3: MCPS-Microstrip Transition.

Figure 4: S_{11} **and** S_{21} **of MCPS-Microstrip Transition.**
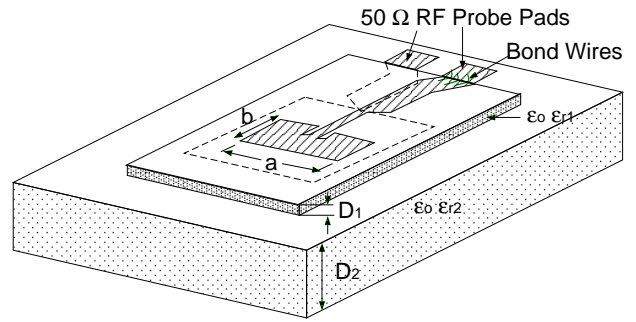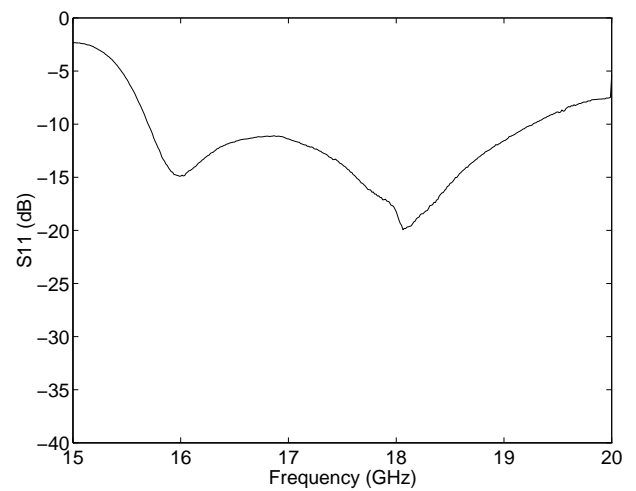

Figure 5: Patch Antenna with MCPS Feed.

Figure 6: Return loss on MCPS-fed Patch Antenna.

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