

# Ultra-wideband GCPW-MS-GCPW transitions on Si wafers for microwave photonic components

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**Abstract** — We present back-to-back GCPW-MS-GCPW (Grounded Coplanar Waveguide-Microstrip lines) transitions on substrates in thin film on cheap silicon wafers, constituted of a 1-cm microstrip line and pads or stubs compatible with CPW probes. Their bandwidth can cover the frequency range between 180 MHz and 60 GHz. These performances are obtained without making via-hole in the substrate and patterning the bottom ground plane. These transitions using the electromagnetic coupling between the bottom and top ground planes simplifies the manufacturing and facilitates the characterization, by means of coplanar probes, of microwave photonic devices realized from materials in thin film and whose driving electrode is a microstrip line, such as electro-optic modulators based on polymer poled by Corona effect.

**Keywords** — electro-optic modulators, GCPW-MS-GCPW transitions, ultra-wide bandwidth, microwave photonic devices, polymers, thin film.

## I. INTRODUCTION

THE characterization of microwave circuits and microwave photonic components on wafer requires the use of probe stations for reason of convenience [1]-[3]. Most of these test systems are equipped with probes compatible with coplanar transmission lines of type GSG (Ground-Signal-Ground) insuring a good reliability of the electrical contact. A transition between coplanar and microstrip lines (CPW-MS) is thus indispensable to characterize components driven by microstrip lines with CPW probe station.

Generally, in electro-optic modulators based on polymer, the chromophores responsible for the electro-optic effect are oriented perpendicularly to the substrate by corona effect. The driving signal must be applied using a microstrip line. One solution for their characterization with CPW probes is to physically connect the coplanar ground planes to the bottom ground plane of microstrip line with a via-hole, which is complicated and difficult to achieve especially when the polymer is crosslinked. It is in this context that we conducted a comprehensive study of transitions between coplanar and microstrip lines on substrate in thin film, to find a simple and efficient method for the characterization of components driven by

microstrip line with CPW probes. As one of the key advantages of electro-optical modulators is their very board bandwidth, the transition used for their characterization and realization must therefore have the bandwidth as wide as possible to cover that of the modulators.

To characterize their modulators based on electro-optic polymer driven by microstrip line with CPW probes, R. Michalah *et al.* [4] studied transitions between microstrip and coplanar transmission lines with a radial stub to avoid physical connection between ground planes by via-holes. Their GCPW-MS (Grounded Coplanar Waveguide-Microstrip lines) transition with a 5-mm microstrip line presents certainly a bandwidth up to 45 GHz, but its lower limit is about 2 GHz even with a radial stub diameter of 3 mm, which is very disadvantageous because they do not provide access to modulators' performance on the frequency range below 2 GHz.

In this paper, we present a theoretical study and an experimental validation of back-to-back GCPW-MS-GCPW transitions with an ultra-wide bandwidth without making via-holes in the substrate and patterning the bottom ground plane, so the transitions can be realized on cost-effective Silicon wafers independently of their resistivity and an additional alignment of mask for the bottom ground plane is avoided. These transitions are made on dielectric substrates of thickness  $h = 8 \mu\text{m}$  with a bandwidth exceeding 60 GHz, their 180-MHz low frequency limit makes them suitable for applications in radio over fiber [5]. To our best knowledge, such bandwidth has never been achieved so far by via-free GCPW-MS-GCPW transitions. These transitions will greatly facilitate the characterization of microwave photonic components on thin film materials and their packaging.

## II. SIMULATIONS AND MEASUREMENTS

The two structures of GCPW-MS-GCPW transitions studied in this paper are shown in Fig. 1. These transitions are built on a substrate deposited on a Silicon wafer. The experimental validation has been carried out with a 8- $\mu\text{m}$  resin SU8. The thickness of the resin has been determined in the study of the optical single-mode waveguide of a modulator based on the electro-optic polymer PIII (PGMA/DR1) [6] to obtain a maximum confinement factor and minimum driving voltage, using SU8 as optical cladding. Due to its thermal crosslinking ability, the polymer PIII has an improved stability of its electro-optic effect. From this thickness and the dielectric constant of the resin SU8 ( $\epsilon_r = 3.55$ ), we used the software Linecalc

Authors would like to thank the Region of Pays de la Loire and the ANR (French National Research Agency) for their support through respectively the project Mattador/MILES and the project ModPol. Mohammed El Gibari is with the laboratory Institut de Recherche en Electrotechnique et Electronique de Nantes Atlantique (IREENA, EA 1770 and FR CNRS 2819), Université de Nantes, Faculté des Sciences et Techniques, 2 rue de la Houssinière, 44322 Nantes cedex 3, France (phone: 33-251 125 578; e-mail: mohammed.el-gibari@univ-nantes.fr).

Agilent Advanced Design System (ADS 2006 version) to determine the dimensions of the transitions in order to have a characteristic impedance of  $50 \Omega$  for both the microstrip section and the CPW section: the width of the central strip  $W = 17 \mu\text{m}$ , the coplanar gap  $G = 13 \mu\text{m}$ . The length of the microstrip line  $L$  is 1 cm.

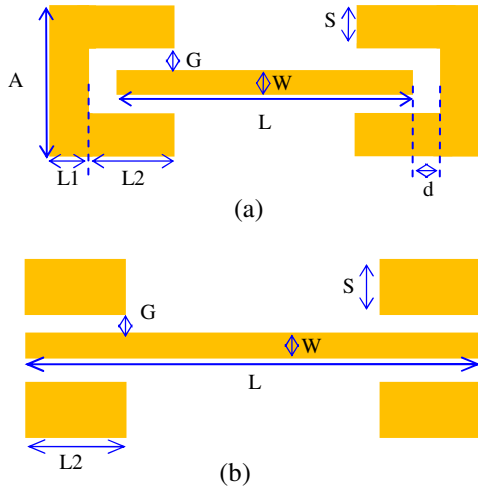


Fig. 1. The two structures of back-to-back GCPW-MS-GCPW transitions. (a) The first structure with rectangular stubs; (b) The second structure with CPW pads.

#### A. Transitions with rectangular stubs

The lower frequency limit of the bandwidth depends upon the surface of the stub, to reduce it as low as possible without affecting significantly the higher frequency limit, we take the length of the stub  $L_1 = 1 \text{ mm}$  and the width of the stub  $A = 2.043 \text{ mm}$  ( $A = W + 2 \times G + 2 \text{ mm}$ ). For the distance  $d$  between the end of the microstrip line and the inner part of the stub, we take  $100 \mu\text{m}$  to avoid harmful influence of parasitic capacity between signal and ground strips (in Fig. 1-a). The condition  $d > (W + 2 \times G)$  should be satisfied to get rid of this parasitic capacity according to [7]. The length of the coplanar ground plane  $L_2$  has been fixed to  $1 \text{ mm}$  so CPW mode can be stabilized and converted to MS mode.

Figure 2 shows the simulation results with HFSS of a back-to-back GCPW-MW-GCPW transition on SU8 resin directly deposited on a low resistivity silicon (LRS, resistivity =  $0.001 \Omega \cdot \text{cm}$ ) wafer, the aluminium thickness is  $4 \mu\text{m}$ . The loss tangent of the SU8 resin is estimated between 0.043 and 0.078 according to [8] and [9]. We have chosen the value of 0.043 for all our simulations because this value gives the best correlation between measurements and simulations. As one can see, a very wide bandwidth is obtained when the dielectric losses are negligible. Not only the bandwidth exceeds  $40 \text{ GHz}$ , but also, what is even more remarkable, the lower limit frequency goes down to  $180 \text{ MHz}$ , against  $2 \text{ GHz}$  for the transition with radial stub proposed by R. Michalah *et al.* under conditions similar to ours in terms of thickness and permittivity of the substrate [4]. When the dielectric losses of SU8 are taken into account, the bandwidth is limited to  $20 \text{ GHz}$  without affecting its lower frequency limit.

For experimental realizations, we have, on a  $380 \mu\text{m}$  thick LRS wafer used as ground plane, deposited by spin coating two layers of  $4 \mu\text{m}$  polymer SU8; the first layer having been crosslinked before depositing the second layer. To measure S-parameters of our realized structures, we used a network analyzer Agilent E8364B with probes Cascade I40AGSG250 (bandwidth of  $40 \text{ GHz}$ , inter-probe distance of  $250 \mu\text{m}$  and probe width of  $12 \mu\text{m}$ ). The calibration method used is the LRM (Line-Reflect-Match) method with a calibration substrate Cascade AE-101-190. The whole system is controlled by the software Wincal Cascade.

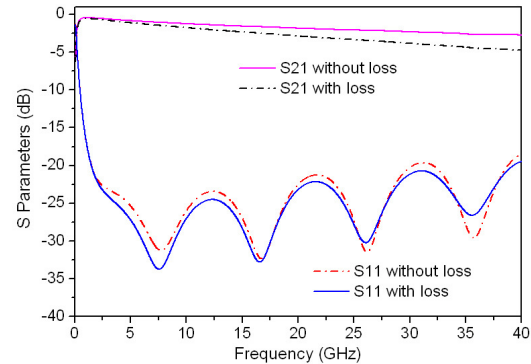


Fig. 2. Simulation results of a transition on SU8 with and without taking into account the dielectric losses, the aluminium thickness is assumed to be equal to  $4 \mu\text{m}$ .

Due to bad adhesion of the aluminium to the SU8 resin, we had to limit the thickness of the aluminium layer to  $370 \text{ nm}$ . This small thickness is responsible for the insertion loss of  $-4.3 \text{ dB}$ . Nevertheless measurements and simulations (cf. Fig. 3) are in perfect agreement in terms of the S21 parameter and in less good agreement for the S11 parameter due to impedance mismatch caused probably by a poor uniformity of the strip width. The measured bandwidth of the GCPW-MS-GCPW transition covers the frequency range between  $420 \text{ MHz}$  and  $8.95 \text{ GHz}$ .

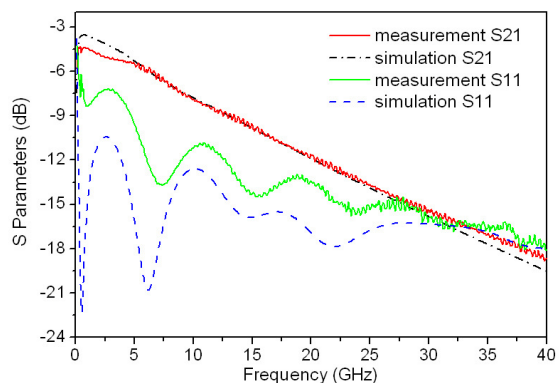


Fig. 3. Simulation and measurement results of a GCPW-MS-GCPW transition with rectangular stubs on SU8 resin with  $370\text{-nm}$  aluminum metallization.

Thanks to their board bandwidth and their exceptional lower frequency limit, the GCPW-MS-GCPW transitions with rectangular stubs are very useful for characterization of components driven by MS electrode with CPW probe station. But they are not suitable to connecting the driving MS electrode to electrical connectors due to their “closing” stubs. That’s why we also studied transitions with simple



