Membrane-Supported Coplanar Waveguides for MMIC and Sensor Application

A. Dehé, H. Klingbeil, C. Weil, and H. L. Hartnagel

***Abstract*—Membrane-supported coplanar waveguides (CPW's) are needed for low-dispersive and low-loss millimeter- and submillimeter waves as well as for power sensor applications. This letter demonstrates CPW's on polyimid membranes micromachined on gallium arsenide (GaAs) that meet the requirements of a typical microwave monolithic integrated circuit (MMIC) process. The influence of the design parameters is simulated by finite difference in frequency domain (FDFD), in excellent agreement with the experiment. For a membrane CPW with ground to ground spacing of only 50 μm and characteristic impedance of 115 Ω, relative effective dielectric constants near 1.02 and attenuation of 0.14 dB/mm at 25 GHz have been achieved.**

***Index Terms*— Coplanar waveguide, field simulation, gallium arsenide, membrane, micromachining, MMIC.**

I. Introduction

THE importance of the coplanar waveguide (CPW) is based on its excellent high-frequency characteristics. This is true for the lower frequency range but problems arise for the monolithic microwave integrated circuit (MMIC) application in the millimeter- and submillimeter-wave range, where dispersion and radiation losses due to the substrate begin to dominate. Hence, several approaches have been studied to remove the substrate [1]–[3]. Some drawbacks of these approaches result in difficulties for the application in MMIC. The dimensions of the cited membrane-supported CPW realizations—with ground-to-ground spacing between 110 and 570 μm—do not match the typical micron and submicron dimensions of active microwave transistors and diodes. Furthermore, in the case of silicon micromachined CPW's, a monolithic integration with III–V compound semiconductor active devices is not possible at all.

Another application of membrane supported CPW's are the recently reported GaAs integrated microwave power sensors that need the membrane concept to increase sensitivity and speed [4]–[6]. For these sensors a proper understanding of the influence of the membrane part of the CPW is needed to achieve a good calibration.

This letter describes the design parameters for membrane supported GaAs CPW's. FDFD simulations have been carried out with great care in order to demonstrate a tool for first-pass success. The simulations are compared to scattering parameter measurements of membrane CPW's and the influencing design parameters of the membrane part and the bulk membrane transition have been extracted.

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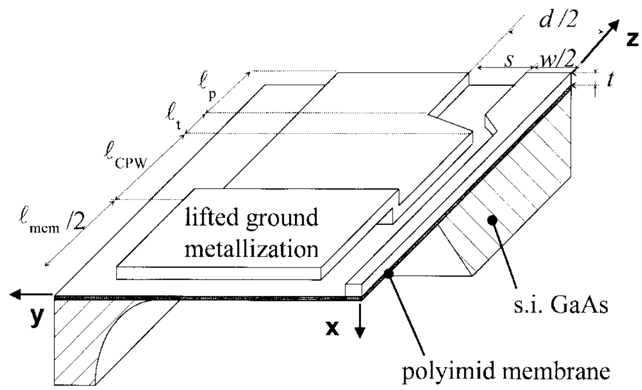

Fig. 1. Cross-sectional drawing of the membrane-supported CPW with feed lines. The metallization thickness is $t = 3$ μm. For the application in power sensors the ground metallization is lifted 4 μm over the membrane part.

TABLE I
Description of the Studied CPW

description	l_i [μm]	$s/w/d$ [μm]	$\lvert Z_W \rvert$ [Ω]
probe pads	100	36/48/120	50
taper	50		50
standart CPW	200	16/18/50	50
membrane CPW	400	16/18/50	115

II. Membrane CPW Design

The CPW that is the object of this work is sketched in Fig. 1. Only a quarter of the whole structure is shown since it exhibits x/y- and x/z-plane symmetry. It relates closely to the through connection power sensor in CPW technology formerly published in [5] and [6]. The cross-sectional dimensions are typical for the MMIC layout (Table I). As indicated in Fig. 1 the ground metallization is lifted 4 μm above the membrane. Regarding the power sensor, this is necessary to allow the sensor to get close to the center conductor. Alternatively, the ground metallization can lie on the membrane as for usual MMIC application. These structures are compared to a standard CPW on bulk GaAs.

The above-described membrane can be fabricated with a micromachining process. After front-side processing, the membrane is released by wet chemical etching the substrate from the back side. The membrane consists of spin-coated 1-μm-thin polyimide with a permittivity of $\epsilon_r = 2.9$.

III. Experimental and Theoretical Approach

Regarding the designed structure the following effects are expected to influence the wave transmission:

- increased reflection coefficient and insertion loss due to the change of characteristic impedance Z_W from bulk to membrane supported CPW;
- additional reflection due to the scattering behavior of the transition between bulk and membrane;
- different reflection for lifted and nonlifted ground metallization;
- strongly reduced effective dielectric constant $\epsilon_{\rm r,\,eff}$.

The CPW structures have been simulated with a finite difference method in frequency domain (FDFD), including metallic and dielectric losses [7]. The metallization of the CPW has a thickness of typically 3 μm and consists of electroplated gold with a measured conductivity of $3.15 \cdot 10^7$ S/m. Since the loss tangent of the polyimide was not known, we neglected it in the simulations. Its influence should be low because of the small membrane thickness. This is justified by the good agreement between experiment and simulation.

Different approaches have been used to separate the effects. In a first-order approximation the scattering parameters of the whole CPW can be described by two-dimensional (2-D) simulations of each different CPW cross section and cascade connection of the individual scattering matrices.

The second approach uses a three-dimensional (3-D) simulation of the whole CPW structure in consideration of the discontinuity at the transition from the bulk material to the membrane.

In this letter the simulations are compared to the measured CPW. Using standard calibration procedure the whole CPW was measured with an HP8510B network analyzer in the frequency range from 45 MHz to 26.5 GHz. This of course does not give direct access to the intrinsic membrane scattering parameters. Hence, a direct way has been applied to characterize only the membrane part of the CPW. This is possible with special calibration standards that allow to fix the reference plane to the transition from the bulk to the membrane CPW. Fig. 2 shows the layout of the used load, open, short, and through standards.

IV. Results and Discussions

Fig. 3 shows the overall reflexion coefficient of the CPW structure as shown in Fig. 1, but without lifted ground metallization. The cascade connected simulations are shown as well but do not lend to satisfying agreement.

On the other hand the 3-D full simulation results in excellent agreement. The difference between both approaches is that only the second one takes account of the scattering behavior of the discontinuity between bulk and membrane. The micromachined cavity effects an effective extension of the membrane.

A 3-D FDFD simulation of this discontinuity up to 100 GHz shows a constant reflexion coefficient equivalent to that

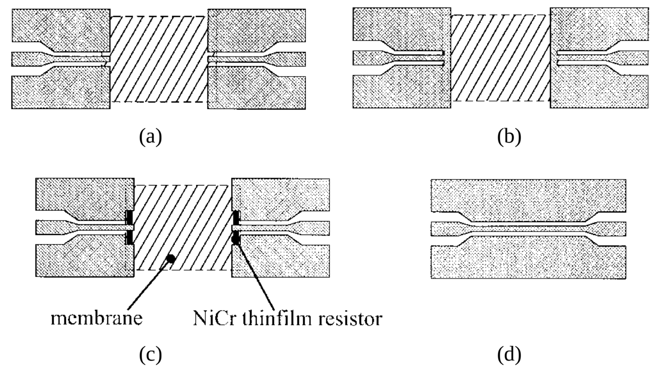

Fig. 2. 50-Ω calibration standards for pure measurement of the scattering parameters of the membrane CPW. (a) Open. (b) Short. (c) Load 50 Ω. (d) Through.

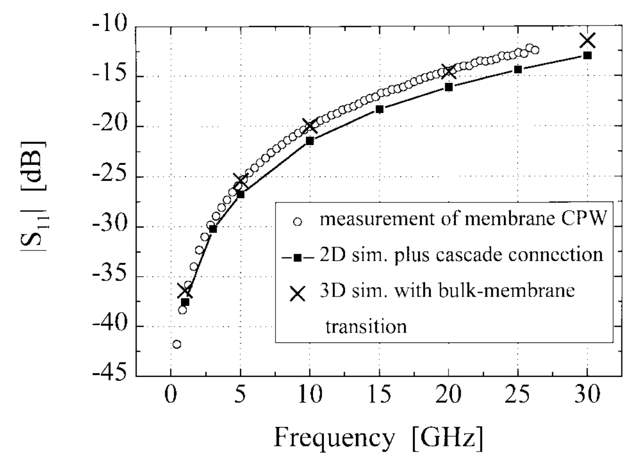

Fig. 3. Comparison of the measured reflexion coefficient ($Z_0 = 50\ \Omega$) of a membrane CPW (without lifted ground metallization) with simulated data. The small difference for the two simulations is explained by the membrane-bulk discontinuity.

resulting from the impedance mismatch. Hence, no scattering effects are observed within the inspected frequency range for substrate thicknesses of 100–200 μm. In the case of the nonmatched membrane CPW the contribution of the transition is negligible.

The above-described calibration method has been applied to show the influence of bulk, membrane, and lifted ground metallization (Fig. 4). The effects could be separated clearly in perfect agreement with the simulation. The main contribution in the reflexion coefficient is the impedance mismatch. If the membrane CPW is considered, there is no difference in the scattering parameters whether the ground metallization is lifted or not since the electric field distribution of the CPW is concentrated between the slots and the effective dielectric constant does not change significantly. For the same measurement the phase of the transition coefficient shows perfect linearity implementing a constant delay of 29, 46, and 47 ps/m for membrane, bulk with lifted ground, and bulk CPW, respectively.

From the measured scattering parameters the attenuation α and the effective dielectric constant $\epsilon_{\rm r,\,eff}$ of the membrane CPW have been derived (Fig. 5). The effective dielectric constant approaches values of 1.02 up to 25 GHz. The at-

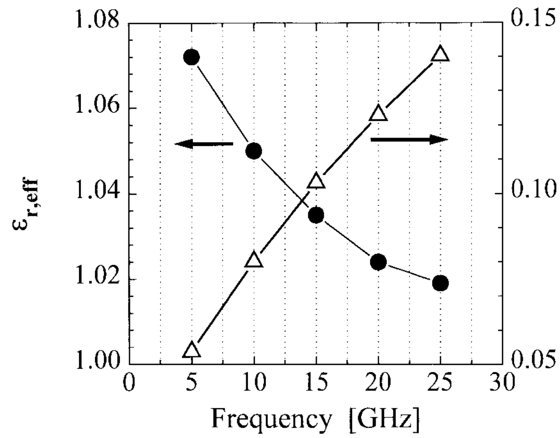

Fig. 4. Scattering parameter measurement ($Z_0 = 50\ \Omega$) of the membrane CPW part after calibration with the standards of Fig. 2. Perfect agreement with the FDFD simulation (large symbols) is obtained.

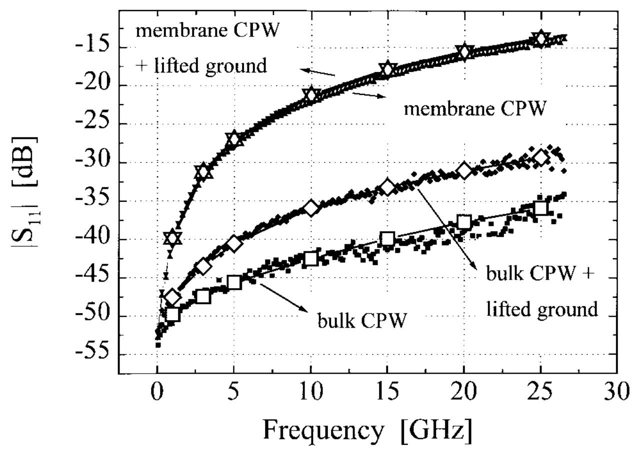

Fig. 5. The effective dielectric constant $\epsilon_{\rm r,eff}$ and attenuation α of the membrane CPW have been extracted from measurements (Fig. 4).

tenuation of this 115-Ω transmission line shows a square root dependence as expected for the dominating metallic losses. It has about half the attenuation of conventional 50-Ω CPW's. To achieve a 50-Ω membrane CPW design for MMIC application a $s/w/d$ dimension of 3/44/50 μm would be needed. This is confirmed by 2-D FDFD simulations.

V. Conclusions

This letter has shown that GaAs-based membrane supported CPW's can be fabricated with MMIC typical geometries so that integration with active devices is possible. The excellent agreement between measurement and FDFD simulation allows future design with first-pass success. This study was also important to verify the experimental results of through connection power sensors. In this case the necessary lifted ground metallization does not show significant influence. Since future power sensors to be implemented into network analyzers should be designed with characteristic impedance of 50 Ω, the proposed narrow slot design is of advantage to increase the sensitivity of the sensor.

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