CHARACTERIZATION OF CONDUCTOR-BACKED COPLANAR WAVEGUIDE USING ACCURATE ON-WAFER MEASUREMENT TECHNIQUES

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ABSTRACT

The conductor-backed coplanar waveguide has been experimentally characterized using accurate on-wafer S-parameter measurement techniques. An uncertainty analysis was conducted to quantify the measurement errors. Measured characteristic impedance, effective dielectric constant, and attenuation constant are in good agreement with the theory.

INTRODUCTION

Conductor-backed coplanar waveguide (CBCPW), shown in Figure 1, is a useful transmission-line medium for monolithic microwave integrated circuit (MMIC) applications. Its transmission-line characteristics have been studied recently using quasi-static and full-wave analyses (1,2,3). The full-wave analysis showed that the frequency dispersion of CBCPW is less severe compared to microstrip and coplanar waveguide. However, so far there is no experimental data reported to confirm the analyses.

In this paper, we present some experimental results on the transmission-line characteristics of the CBCPW, including propagation constant and characteristic impedance. The test structures were fabricated on semi-insulating GaAs substrate and characterized using accurate on-wafer measurement techniques. The measured results agree very well with the theory. An uncertainty analysis was conducted to quantify the measurement errors. The phase uncertainty is dominated by probe position errors, approximately 10 μm. The magnitude uncertainty in the through-line measurement is dominated by the system errors.

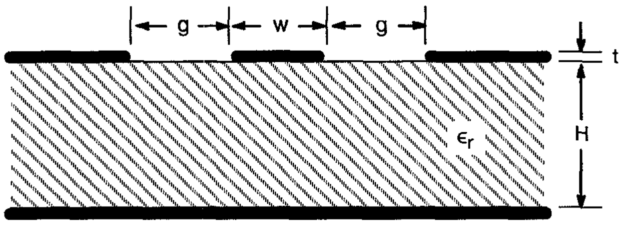

Figure 1 Conductor-backed coplanar waveguide structure

APPROACH

Our approach to the characterization is the direct transmission measurement. Two-port scattering parameters are measured by an HP8510B vector network analyzer integrated with an on-wafer probe station. The magnitude and phase of the S-parameters contains the necessary transmission-line characteristics. With precision calibration standards on wafer, the measured S-parameters are corrected to the probe tips with high accuracy (4,5). The direct on-wafer measurement avoids the tedious de-embedding process required in the conventional test using coaxial test fixtures.

The test patterns of the CBCPW were fabricated on a 100-um thick GaAs substrate (ϵ_r = 12.9). The top-side metal, forming the center conductor and coplanar grounds, was evaporated with gold of 1.5-um thickness. The bottom metal was gold-plated to a thickness greater than 3 μm. Figure 2 shows two typical test patterns, where Figure 2(a) is a through-line

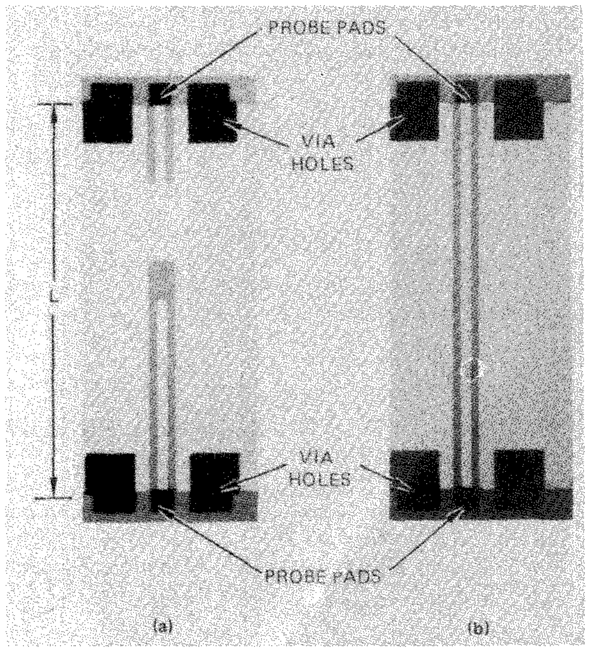

Figure 2 On-wafer test patterns. (a) Thru line, (b) Shorted line.

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structure for transmission-line characterization, and Figure 2(b) is a test structure for uncertainty analysis. The dimensions of the through-lines are summarized in Table 1. To prevent the parallel-plate mode radiation (6,7), we have placed many via holes to connect the coplanar ground to the bottom ground at about 1-mm spacings. Notice that every test pattern contains a pair of gold-plated probe pads with 50 μm in size and spacings.

UNCERTAINTY ANALYSIS

In the transmission-line characterization, the major uncertainty factors are probe contact repeatability and probe positioning. We have designed several experiments to characterize these uncertainty factors. In the first experiment we selected two 50-Ohm through lines and measured their S-parameters. The test was repeated many times by realigning and making probe contacts to the same test patterns without adjusting the spacing between the probes. Based on the through phase measurements, the standard deviation of the probe contact repeatability was found to be about 2.5 μm. Notice that this uncertainty contains the contributions due to HP8510B system noise, two-foot long flexible cables, and other imperfections.

A second experiment was designed to determine the probe positioning uncertainty using the short-circuited CBCPW in Figure 2(b). Because of the total reflection, the phase of S_{11} and S_{22} measurement contains the information on probe position with respect to the probe pads. The same test mentioned above was repeated to form a database. The analysis showed an standard deviation of 10 μm for each individual probe. This uncertainty contains the probe-positioning error, in addition to the probe contact and other system uncertainties. It is now obvious that probe positioning error is the dominant factor. Since during the test we did not adjust the spacing between the probes, the uncertainty of Probe 1 and Probe 2 should be correlated. That is, we should be able to remove the probe positioning error from the parameter of $(360° - \angle S_{11} - \angle S_{22})$. It is verified that the standard deviation of this parameter is reduced to 5 μm, closer to the thru phase measurement. This also confirms that the system uncertainty of HP8510B in $\angle S_{11}$ is higher than that in $\angle S_{21}$ (8).

RESULTS

From the through-line measurements, we can derive the propagation constant and characteristic impedance of the transmission lines defined in Table 1. The theoretical characteristic impedance is also listed in Table 1 for comparison. The theoretical values of the impedance are calculated using a closed-form formula derived by conformal mapping (2). The measured impedances are lower than the theoretical values and the difference increases as the gap width decreases. This is because zero metal-thickness was assumed in the theory. The metal thickness has more effect on the lines with narrower gaps. A correction factor for the thickness effect similar to that proposed in (9) may be applied for the width and gap correction:

$$\Delta = 1.25\, t\, \frac{[1 + \ln (2/t)]}{\pi} \quad (1)$$

With this correction, the theoretical values are lower than the measurements, which indicates that eqn.(1) overestimates the thickness effect.

The measured effective dielectric constant and attenuation constant of the lines are presented in Figures 3, 4, and 5, respectively, for lines A, B, and C as a function of frequency. The theoretical attenuation constant is calculated using incremental inductance rule, applying Equation 1 for thickness correction. The measurements are in good agreement with the theory. The measured effective dielectric constant exhibits very little frequency dispersion, as predicted by the full-wave analysis. The more pronounced disagreement in the narrow line may be due to discontinuities between the line and probe pads which has not been considered in the calculation. The measured attenuation constant seems to raise slightly faster than the $\sqrt{f}$ rule.

It is believed that the elevated GCPW structure shown in Figure 6 will reduce current crowding at the edge and raise the impedance level. We have fabricated and tested a structure

TABLE 1
DIMENSIONS AND CHARACTERISTIC IMPEDANCES OF MEASURED THROUGH LINES
(H = 100 μm, ϵ_r = 12.9)

Pattern I.D.	Width (μm)	Gap (μm)	Zc (t=0)	Zc (t=1..5 μm)	Zc (measured)
A	51	50	50	47.8	49
B	27	20	50	45.3	48
C	14	10	50	41.9	46

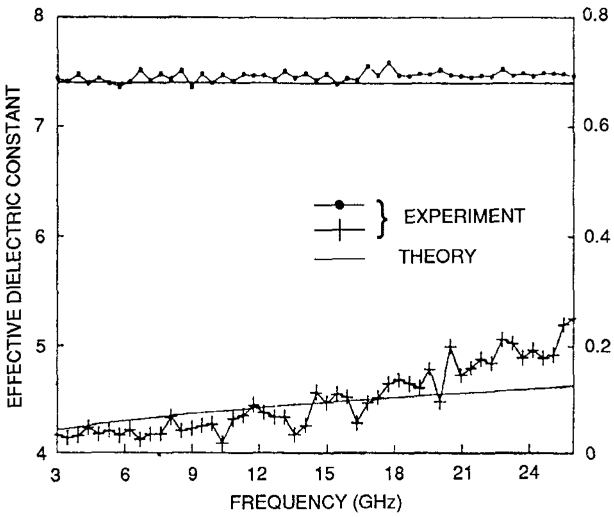

Figure 3 Effective dielectric constant and attenuation constant of line A defined in Table 1 as a function of frequency.

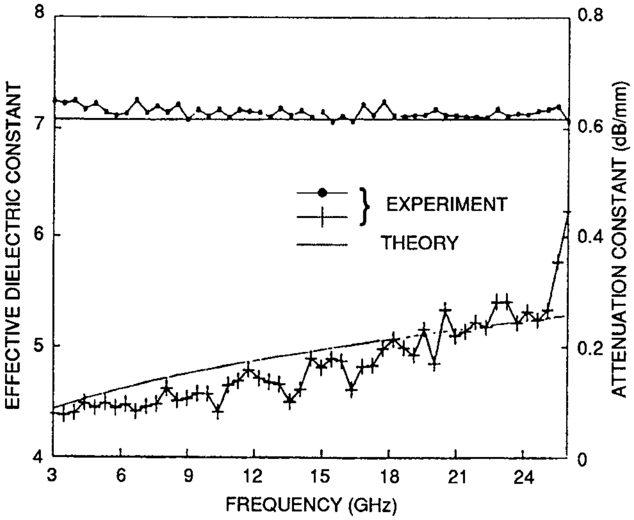

Figure 4 Effective dielectric constant and attenuation constant of line B defined in Table 1 as a function of frequency.

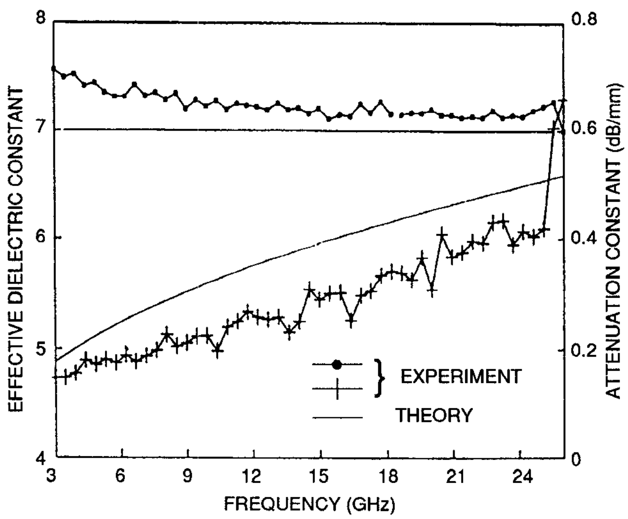

Figure 5 Effective dielectric constant and attenuation constant of line C defined in Table 1 as a function of frequency.

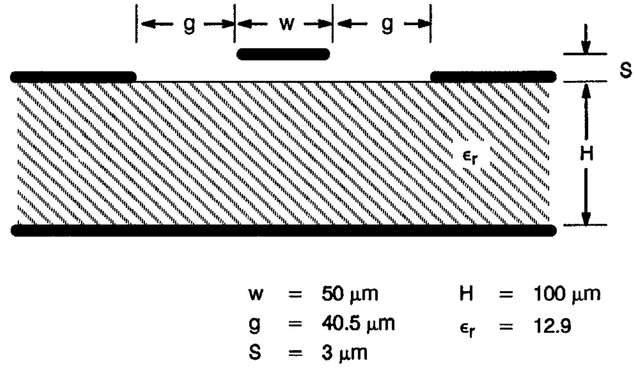

Figure 6 Structures and dimensions of elevated CBCPW.

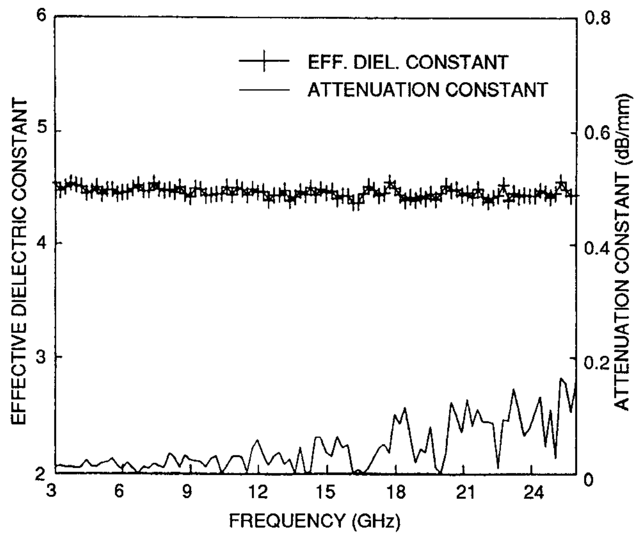

Figure 7 Effective dielectric constant and attenuation constant of the elevated CBCPW as a function of frequency.

with dimensions defined in Figure 6. The measured results are presented in Figure 7, clearly showing the improvement in the insertion loss of the structure. The characteristic impedance of the line is 59 Ohm from the measurement.

Based on the uncertainty analysis, the measured effectric dielectric constant has about 2 percent accuracy. For the attenuation constant measurement, the uncertainty is dominated by the system S_{21} magnitude uncertainty of about 0.04 dB and 0.06 dB at 8 and 18 GHz, respectively (8).

CONCLUSIONS

The transmission-line characteristics of the conductor-backed coplanar waveguide has been experimentally studied. With the aid of precision on-wafer calibration standards, direct on-wafer S-parameter measurement techniques yield accurate results. An uncertainty analysis was conducted to quantify the measurement errors. The dominating phase uncertainty is caused by probe positioning errors, approximately 10 μm. The magnitude uncertainty in the through-line measurement is dominated by the system errors. Measured characteristic impedance, effective dielectric constant, and attenuation constant are in good agreement with the theory.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. C. S. Wu for fabrication of test patterns and Ms. Debbie Hynds for performing on-wave measurements.

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