THE IMPLEMENTATION OF CALIBRATION ON COPLANAR WAVEGUIDE FOR ON-WAFER MEASUREMENTS AT W-BAND

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ABSTRACT

The use of 50 ohm co-planar waveguide standards fabricated on semi-insulating gallium arsenide is successfully applied to the problem of probe calibration at W-band (75 to 110 GHz). Experimental verification demonstrates the near-constant characteristic impedance and uniform propagation characteristics of the on-wafer components.

INTRODUCTION

The layout of circuits as MMICs requires the connection of active devices such as transistors to access lines and measurement pads. Consequently in order to obtain the S-parameters of a transistor at the gate and drain locations de-embedding procedures are often required. The usual calibration methods set the measurement planes at the probes tips but it is not normally possible to locate the probe tips at the gate and drain of the transistor. Coupling would occur between the underside of the probes and the area behind and under the probes and the calibration would be invalid. Consequently it is preferable to design calibration pieces which incorporate the same pattern of feedlines and measurement pads as the ones which are present on the layout of the transistor. Furthermore, since it is difficult to fabricate high quality matched loads at W-band, the use of an LRL calibration procedure is likely to be more accurate than the more commonly employed LRM one. The LRL calibration method requires a shorted line section and two different lengths of thru transmission lines with electrical length which differ by approximately a quarter wave-length. Moreover the reference impedance for the measurements is the characteristic impedance of the lines used during the LRL calibration procedure. This reference impedance must be known if the characterized active device is to be successfully used in a circuit design. Consequently measurements of the wavelength and of the characteristic impedance of lines to be used for calibration in W-band have to be made before designing and fabricating calibration pieces suitable for measuring active devices. We describe here the experimental approach which has been chosen to obtain these data. All the lines used are in coplanar waveguide technology where it is known that TEM mode wave propagation takes place provided that the ground to ground spacing of the line is less than a tenth of the wavelength along the line [3]. Under those conditions, the characteristic impedance is independent of frequency and the ambiguity in defining a characteristic impedance in the case of lines in mi-

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crostrip does not arise [1].

EXPERIMENTAL PROCEDURE AND RESULTS

To ensure a TEM wave in W-band , the ground to ground spacing of the lines employed in this work is 50μm. The value of the characteristic impedance of the lines set by the dimension of the center conductor can be calculated using a commercial electromagnetic simulator package (Hewlett-Packard's High Frequency Structure simulator) which requires a long computation time or by alternative full-wave analysis techniques [2,3]. The present work demonstrates an experimental verification of the characteristic impedance of lines which have been designed to be 50Ω and 30Ω. Details of all the dimensions are given in Fig 1. The characteristic impedance according to the customary definition is:

$$\frac{\gamma}{Z_0} = j\omega C + G \tag{1}$$

where G is the conductance per meter of the line, C is the capacitance per meter and γ the propagation constant. As the GaAs substrate is semi insulating we can neglect G in comparison with the term ωC. C is frequency-independent and is measured using a RLC meter at 10MHz.

The first step is the measurement of the S-parameters of 20μm center conductor lines (50Ω lines) in W-band using the HP-8510C network analyzer. The measured lines had lengths ranging between 300μm and 800μm in 100μm steps. The network analyzer was first calibrated using a TRL calibration performed on a calibration substrate provided by the National Institute of Standards and Technology. This substrate has previously been tested only to 40 GHz [4] and its validity was checked in W band by measuring a nominal 50Ω load from the Cascade W-band ISS calibration wafer. The agreement has shown to be within -20dB return loss. The phase constant is deduced from the ratio of measured transmission parameters of two different lengths of lines. We can note from Fig 2 that these transmission lines exhibit very low dispersion and appear to support a TEM mode between 75GHz and 110GHz. This allows the derivation of the characteristic impedance from equation (1). The 10 MHz capacitance has been measured for the different line lengths. The fringing capacitance and the parasitic effects due to the pads and the probe needles have been removed by subtraction of pairs of measurements for the different line lengths. The resulting relationships for capacitance as a function of line length is shown on Fig. 3. The slope is equal to 1.53pF/cm and we find a constant 53Ω characteristic impedance all the way across the W-band (Fig. 4). The imaginary part of this impedance is negligible. After checking the characteristic impedance of the 20μm center conductor lines and deducing the wavelength along the lines (around 1300μm at 94 GHz) from the phase constant, a 400μm line and a 700μm line of the same pattern as those previously measured were fabricated in order to perform an LRL calibration. The short circuit of the calibration set is a separate coplanar waveguide two port short with metallisation of 160μm between the shorts. The same procedure for measuring the characteristic impedance has been followed for 36μm center conductor lines presenting the same measurement pads as the new calibration pieces. The length of these lines ranges between 1000μm to 2200μm in 200μm steps. Fig. 5 shows plots of the phase constant against frequency for ratios of different pairs of lines and clearly shows that a TEM mode propagates along the lines. From the dispersion of the extracted phase constant β, we can estimate the variation in β to be less than 2%. The measured capacitance of these lines is shown in Fig 6. The slope here is 2.9pF$\pm$4fF/cm and we can verify the 30 Ω characteristic impedance (Fig.7) as expected from the computations[3].

CONCLUSIONS

The method described here to verify the characteristic impedance has been previously reported [4] and its validity has been demonstrated only at frequencies up to 40 GHz in the case of coplanar waveguide lines. In this paper we have shown that the method can be successfully extended up to W-band provided that the dimensions are chosen such that a TEM mode is preserved. The very close agreement between the calculated and measured characteristic impedance of the 30Ω lines shows that the loss component G can still be neglected in comparison with ωC even in the W-band. The discrepancy in the case of the 20μm lines is probably due to the differences in GaAs processing and demonstrates the necessity of fabricating calibration pieces incorporating the same feedline structures and on the same type of substrate as the active devices to be measured. This simple method of determining characteristic impedance provides a check on test structures and is a useful aid in the fabrication of on-wafer calibration.

ACKNOWLEDGEMENTS

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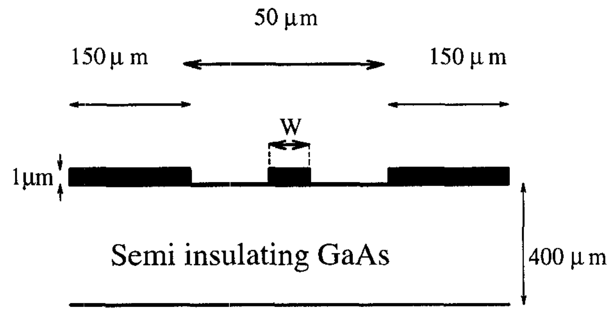

Figure 1: Dimensions of Coplanar Waveguide Transmission Line.
w=20μm, w=36μm.

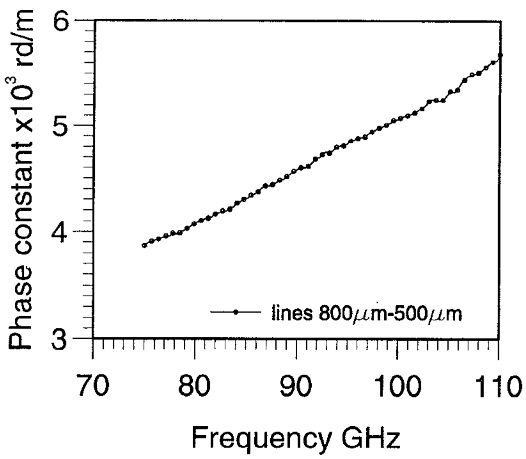

Figure 2: Phase constant vs frequency w=20μm calibration has used NIST test structures

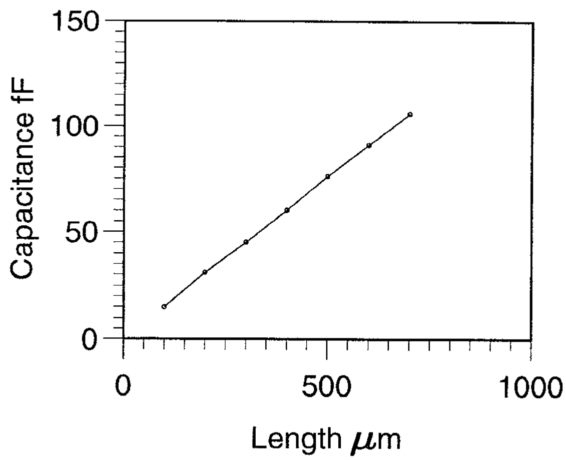

Figure 3: Capacitance of lines vs. length, w=20μm

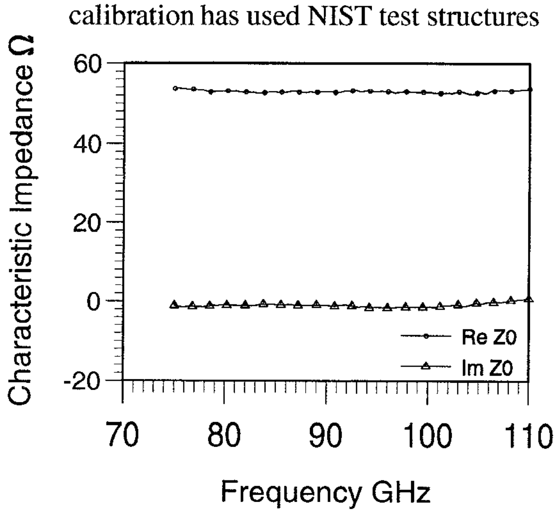

Figure 4: Characteristic Impedance, w=20μm

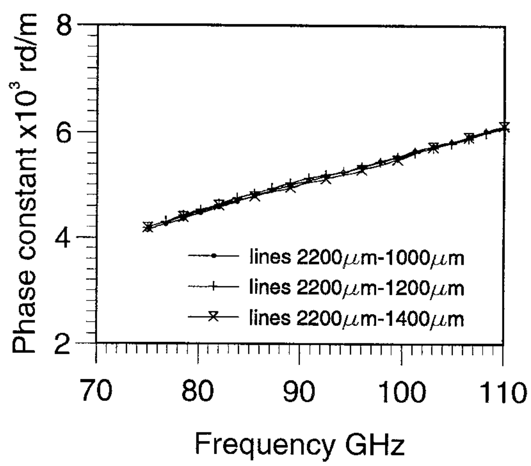

Figure 5: Phase constant vs. frequency, w=36μm

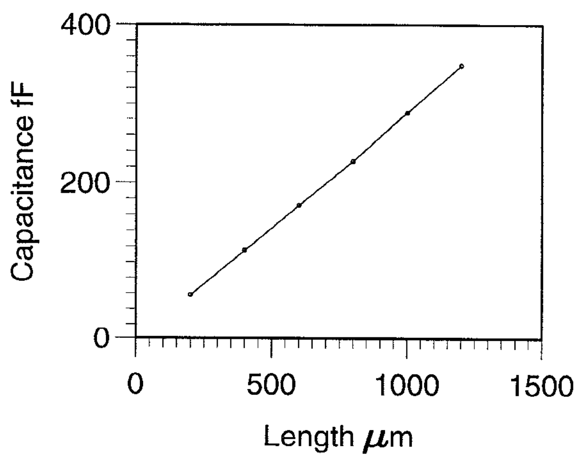

Figure 6: Capacitance of lines vs length, w=36μm

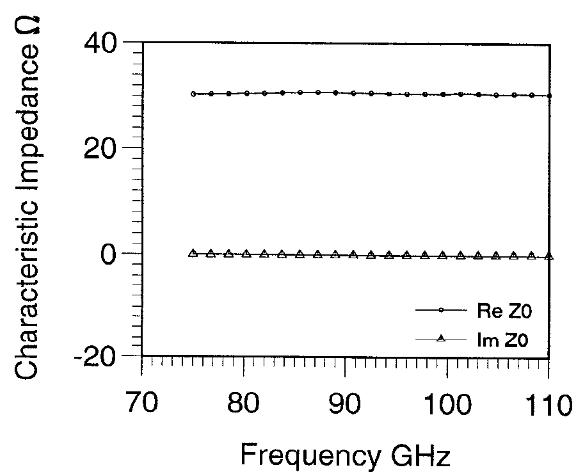

Figure 7: Characteristic Impedance, w=36μm