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Coplanar Waveguides on AlN for AlGaN/GaN MMIC Applications

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Abstract—**In this paper we present results on the characterization of Coplanar Waveguides (CPW) on AlN substrates. These transmission lines will be used in matching networks for high power AlGaN/GaN amplifiers. The large currents that will flow inside these amplifiers require a large cross-sectional conductor area resulting in CPW lines with large signal-to-ground spacings and/or large center conductor widths. The Line-Reflect-Line (LRL) algorithm was used in combination with a capacitance measurement to determine the transmission line parameters. It will be shown that the CPW lines with large dimensions show non-quasi-TEM behavior presumably related to parallel plate modes which influence decreases with sample thickness. The CPW lines show dispersion in the low-frequency (<10 GHz) region.**

I. Introduction

In the Opto-Electronic Devices group (OED) at the Eindhoven University of Technology we are working towards high power high frequency MMIC amplifiers based on AlGaN/GaN HEMTs. In previous work [1], we reported on the fabrication and characteristics of discrete HEMTs. In order to use these transistors successfully in MMICs, like a two-stage amplifier, one needs passive components for interconnection and matching purposes.

In the case of AlGaN/GaN grown on sapphire one cannot use via-hole technology to make ground connections. Therefore, we have started research on Coplanar Waveguide (CPW) technology. One of the disadvantages of CPW is that this technology has not been implemented in commercial design environments like MDS or LIBRA with sufficient accuracy. Hence, most CPW elements like transmission lines, MIM-capacitors and resistors have to be fabricated, measured and modeled.

In this report we present our results on the fabrication and characterization of CPW transmission lines on an AlN substrate. This substrate was chosen for its superior electrical properties and it can be used as a suitable carrier if flip-chip techniques are pursued.

II. The de-embedding problem

On wafer measurement techniques require probe pads as illustrated in Figure 1. These pads can disturb the measurement especially if the transition between pad and actual device is not smooth.

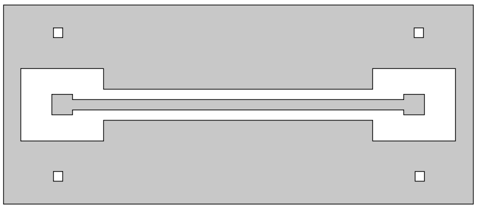

Fig. 1. Transmission line with contact pads on each side.

The problem of extracting the true characteristics of the actual devices requires special attention. A similar problem exists in the calibration of network analyzers (NA). In this case probes, cables and internal circuitry can disturb the measurement. To solve this problem numerous algorithms have been developed which are capable of calibrating the NA up to the probe tips. The same algorithms can be used to eliminate the influence of the probe pads in the case of measuring CPWs.

In our research we have used the Line-Reflect-Line (LRL) algorithm [2] in combination with a capacitance measurement [3] to de-embed the contact pads. The LRL algorithm was modified to account for the symmetrical design of the CPW mask.

III. Short description of the de-embedding procedure

In order to determine the propagation constant and the characteristic impedance of the transmission line, we need a series of measurements; two S-parameter measurements (1-50 GHz in our case) on two lines with different lengths and the capacitance of the two lines measured between the signal and ground lines. The capacitance measurements, done with a HP4275A LZR meter at 2 MHz, yield the capacitance of the transmission line per unit length. The modified LRL

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algorithm can be used to extract the complex propagation constant. The characteristic impedance can be found by combining the results and using,

$$Z_{\text{line}} = \frac{\gamma}{j\omega C + G} \tag{1}$$

where Z_{line} is the characteristic impedance, γ the complex propagation constant, ω the frequency and C and G the capacitance and conductance per unit length respectively. For AlN the conductance can safely be neglected. Equation (1) can be used assuming that the capacitance of the transmission line is frequency independent.

IV. Fabrication

Several CPW lines were processed on AlN samples with a thickness of 0.02". The CPW consisted of a Ti/Au e-beam evaporated bottom metal layer on which 2.5 μm gold was plated to reduce losses. The mask contained a matrix of CPW lines with a center conductor width ranging from 25 to 200 μm and a spacing between the signal and ground lines of 10 to 320 μm. The large center conductor widths were chosen because these lines need to be able to carry high currents (>1 A) if they are used in matching networks for high power amplifiers.

V. Measurement results

A. Quasi-TEM versus non-quasi-TEM

As illustrated below, CPWs with small dimensions showed normal quasi-TEM behavior while CPWs with large dimensions showed abnormal non-quasi-TEM behavior. Non-quasi-TEM behavior implicates that other modes, presumably parallel plate modes, may propagate through the line. The borderline between quasi-TEM and non-quasi-TEM as a function of CPW dimensions is schematically illustrated in table I:

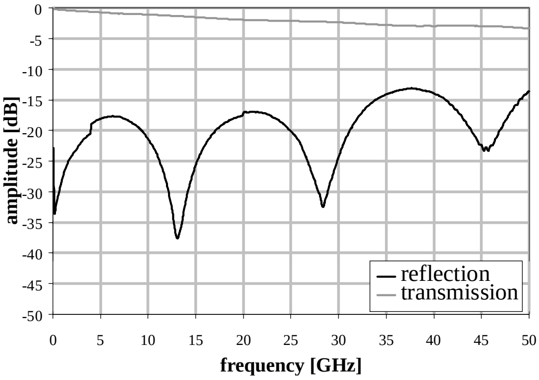

Fig. 2. RF characteristics of a normal quasi-TEM line (width=30 μm, spacing=80 μm, length=3.2 mm).

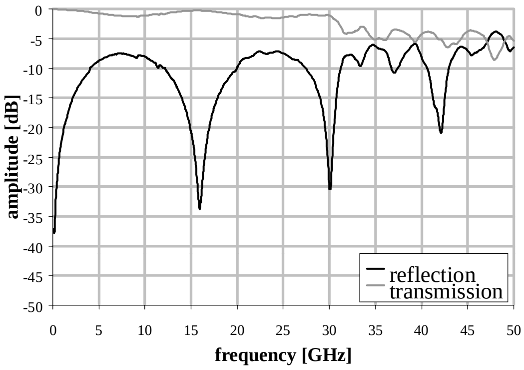

Fig. 3. RF characteristics of a non-quasi-TEM line (width=200 μm, spacing=320 μm, length=3.2 mm).

TABLE I

Separation of the measurements in quasi-TEM (+) and non-quasi-TEM (-).

C [pF/m]		*Width [μm]*					
		25	50	75	100	150	200
Spacing [μm]	10	+	+	+	+	+	-
	20	+	+	+	+	o	-
	40	+	+	+	o	-	-
	80	+	+	+	o	-	-
	160	+	+	+	o	-	-
	320	o	o	o	-	-	-

B. Capacitance measurements

The measured capacitance is illustrated in Figure 4. The observed trends correspond to a parallel plate capacitor if we regard the spacing as the separation between the plates and the center conductor width as the width of the plate.

C. Extracted propagation constants

Ideally, the propagation constant for a lossless CPW should be imaginary and linearly proportional to the frequency. To verify this, the extracted propagation was divided by the frequency, the results of which are presented below (fig. 5).

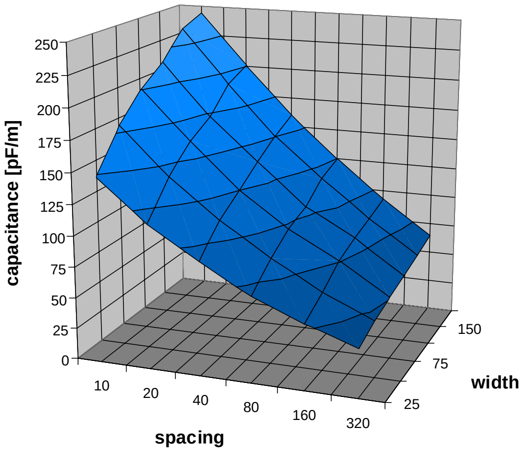

Fig. 4. Measured capacitance.

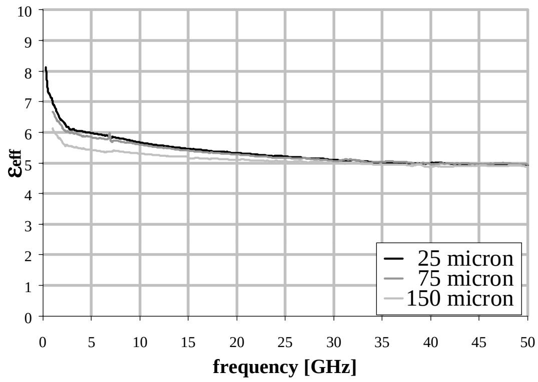

Fig. 5. Imaginary part of the propagation constant divided by frequency, the effective dielectric constant ε_{eff}, plotted versus frequency (spacing=10 μm, varying widths, length=3.2 mm).

The propagation is obviously not frequency independent. Hence, these CPW lines will suffer from dispersion in the low-frequency regime.

D. Extracted characteristic impedance

Using the capacitance data and propagation constants equation (1) can be used to calculate the characteristic impedance. It is therefore also frequency dependent.

If the propagation constants are averaged in the low dispersion regime (>10GHz), the propagation constant can be approximated by a constant and a frequency independent impedance is found. The results of this averaging can be seen in Figure 6.

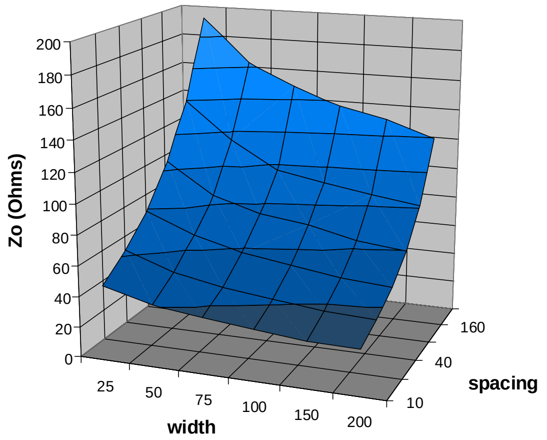

Fig. 6. Characteristic impedance.

E. Substrate thickness

As mentioned before, the non-quasi-TEM behavior becomes visible for CPW with large spacings and/or with large center conductor widths. Parallel plate modes may propagate for these structures. The influence of these modes is related to the thickness of the substrate; a thicker substrate will reduce the influence of these modes. To investigate this, a simple piece of plastic of a few millimeters thick was placed between the chuck and the actual sample effectively increasing the substrate thickness. The effects can be seen in Figure 7.

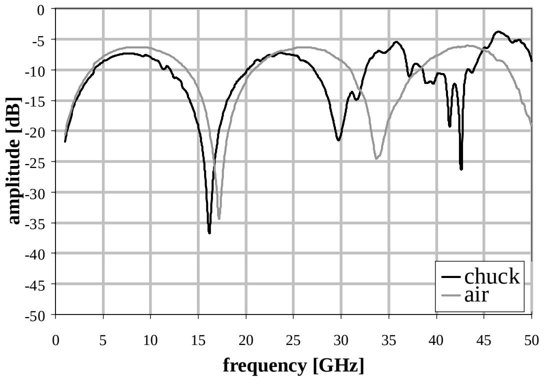

Fig. 7. Restoring the quasi-TEM behavior on the measured reflection (width=200 μm, spacing=320 μm, length=3.2 mm).

The quasi-TEM behavior completely restores backing up the assumption of propagating parallel plate modes.

F. Influence of backside metallization

The CPW lines were all measured lying on a nongrounded conducting chuck. Hence, the CPWs are effectively metallized on the backside. The question remains whether the placement of the sample on the chuck is of crucial importance. To study this effect, a sample was plated at the backside after its properties (without backside metallization) were measured. After plating 2.5 μm gold its properties were compared to the original. No difference could be seen which validates the previously mentioned measurements.

VI. CONCLUSIONS

The properties of CPW lines with varying dimensions were presented. It was shown that CPW lines with either large signal-ground spacings and/or large conductor widths show non-quasi-TEM behavior, which is presumably related to the propagation of parallel plate modes. Using thicker samples can restore quasi-TEM behavior. The extracted propagation constant shows dispersion in the low-frequency regime. Finally, the influence of the conducting chuck is similar to backside metallization.

REFERENCES

[1] B.Jacobs et al., SAFE 1999

[2] C.F. Engen et al, IEEE microwave theory and techniques vol. 27, no. 12, pp. 987-993

[3] D.F. Williams et al, IEEE microwave and guided wave letters, vol. 1, no. 6, pp. 141-143