Characterization of Coplanar Waveguide on Epitaxial Layers

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***Abstract*- We examine the effect of thin AlInAs/GaInAs epitaxial layers on the propagation of electrical signals in coplanar waveguide transmission lines fabricated on semi-insulating indium phosphide substrates. We show that argon isolation implants effectively reduce conduction losses in these layers to negligible levels at radio, microwave, and millimeter-wave frequencies.**

INTRODUCTION

We use the calibration comparison method [1] as implemented in [2] to determine the propagation characteristics of coplanar waveguide (CPW) fabricated on AlInAs/GaInAs epitaxial layers grown on semi-insulating indium phosphide (InP) substrates. We show that argon isolation implants are effective at reducing conduction loss in the transmission lines at radio, microwave, and millimeter wave frequencies.

The calibration comparison method [1] compares scattering parameter calibrations to determine differences in their reference impedance, differences in their reference plane positions, differences of measured scattering parameters, and bounds on those measurement differences. When the reference impedance of one of the calibrations is already known, the method determines the reference impedance of the other calibration.

Reference [2] showed how to use this comparison method to determine transmission line inductance L, capacitance C, resistance R, and conductance G per unit length. A multiline thru-reflect-line (TRL) calibration [3] in the transmission line measures the line's propagation constant γ directly. A comparison of this calibration, whose reference impedance is equal to the characteristic impedance Z_0 of the transmission line [4], to a multiline TRL reference calibration with reference impedance correction [5] determines Z_0. Then L, C, R, and G are found from $R+j\omega L \equiv \gamma Z_0$ and $G+j\omega C \equiv \gamma/Z_0$.

Reference [2] applied this procedure to determine the characteristic impedance of CPW fabricated on a number of substrates, including lossy silicon substrates. Here we apply the method to the characterization of CPW lines fabricated on AlInAs/GaInAs epitaxial layers grown on InP substrates.

EPITAXIAL LAYER CHARACTERIZATION

We electroplated approximately 1.8 µm thick gold CPWs on a semi-insulating gallium arsenide (GaAs) substrate and several InP substrates. In each case the CPW had 26 µm wide signal lines separated by 22 µm wide gaps from two 26 µm wide ground planes. The lines had lengths of 650 µm, 912 µm, 2.685 mm, 3.75 mm, 7.115 mm, and 20.245 mm.

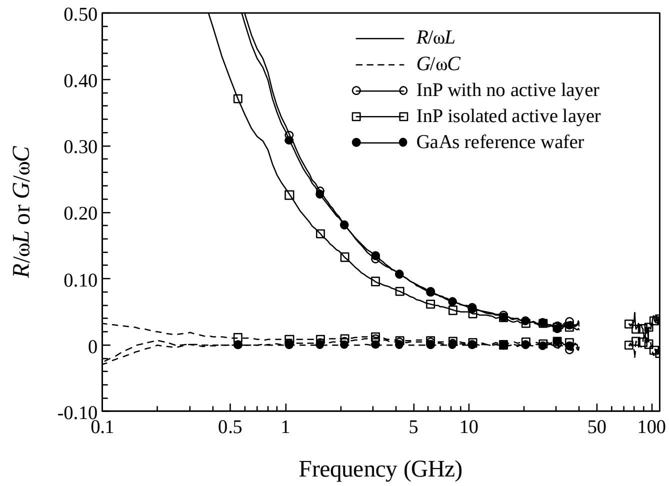

Fig. 1. The ratios $R/\omega L$ and $G/\omega C$ determined by the calibration comparison method.

We first characterized our GaAs CPW, which we treated as our reference lines, by comparison to similar CPW lines fabricated at the National Institute of Standards and Technology (NIST). The NIST CPW had 73 µm wide signal lines separated by 49 µm wide gaps from two 250 µm wide ground planes that were deposited by electron-beam evaporation on semi-insulating GaAs substrates. Figure 1 labels $R/\omega L$ and $G/\omega C$ for our GaAs reference lines determined from this comparison with solid circles. This comparison verified that the capacitance per unit length of our GaAs reference lines was frequency independent (not shown in the figure) and that their conductance per unit length was small compared to ωC, important assumptions of the calibration comparison method we employed [1].

We also tested CPW lines fabricated on epitaxial layers grown on semiinsulating InP. The epitaxial layers, which were intended for MODFET and MMIC applications, were grown by molecular-beam epitaxy. They consisted of a 3000 Å buffer layer of undoped $Al_{0.48}In_{0.52}As$ followed by a 200 Å channel of undoped $Ga_{0.47}In_{0.53}As$, a 50 Å spacer layer of undoped AlInAs, a 5×10^{12} cm^{-2} Si planar doping layer, a 150 Å Schottky layer of undoped AlInAs, and a 100 Å GaInAs cap layer doped with 5×10^{18} cm^{-3} of Si. These epitaxial layers were so highly conductive that they shorted the metal CPW conductors together and we were not able to propagate signals through the CPW fabricated on them.

However we were able to propagate signals through CPW fabricated on epitaxial layers that had received argon isolation implants. We implanted these epitaxial layers with 1×10^{15} cm^{-2} of positive argon ions at 100 keV at room temperature. In order to avoid channeling effects, the samples were implanted with an incident angle of 7° normal to the sample surface. The expected range for this implantation was 1000 Å, which is located in the InAlAs buffer layer. Post-implant annealing was performed in a tubular furnace under N_2 gas for 10 hours at 300° C. The measured dc sheet resistance after implantation was about 3×10^7 Ω/□.

We characterized these CPWs by comparing them to our GaAs reference lines: this resulted in better measurement precision than comparison to the NIST lines, which had a significantly different conductor geometry. Figure 1 compares $R/\omega L$, which is a measure of the resistive losses in the metal CPW conductors, and $G/\omega C$, which is a measure of the conductive losses in the substrates, for two of the CPW we fabricated on InP substrates to the same quantities for our GaAs CPW reference lines. The curves labeled "InP with no active layer" (hollow circles) correspond to CPW lines fabricated on a bare InP semi-insulting substrate while the curves labeled "InP isolated active layer" (hollow squares) correspond to CPW lines fabricated on a AlInAs/GaInAs epitaxial layer grown on the semi-insulating InP substrate and isolated with an argon implant.

The figure shows that the CPW fabricated on the InP substrate had a slightly lower resistive loss than the other CPWs: this is consistent with its measured dc resistance per unit length, which we found to be lower than that of the other CPWs and attributed to somewhat thicker metal conductors. A detailed examination of the data plotted in the figure shows that the measured values of $G/\omega C$ vary randomly around 0: we interpreted this to mean that the actual values of $G/\omega C$ are too small for the method to measure accurately. The figure also shows that the resistive metal losses in the CPW are much greater than the conductive substrate losses at all measurement frequencies, even for the CPW fabricated on the isolated epitaxial layers.

CONCLUSION

We used the calibration comparison method to characterize CPW fabricated on thin epitaxial films. We found that the effects of conductive losses in semi-insulating InP substrates and AlInAs/GaInAs epitaxial layers isolated with argon implants on our CPW were small compared to ohmic loss in the metals and can be ignored.

REFERENCES

[1] D. F. Williams, R. B. Marks, and A. Davidson, "Comparison of On-Wafer Calibrations," *38th ARFTG Conf. Dig.*, pp. 68-81, Dec. 1991.

[2] D. F. Williams and R. B. Marks, "Accurate Transmission Line Characterization," *IEEE Microwave Guided Wave Lett.*, pp. 247-249, Aug. 1993.

[3] R. B. Marks, "A Multiline Method of Network Analyzer Calibration," *IEEE Trans. on Microwave Theory and Tech.*, pp. 1205-1215, July 1991.

[4] R. B. Marks and D. F. Williams, "A general waveguide circuit theory," *J. Res. Natl. Inst. Stand. Technol.*, pp. 533-561, Sept.-Oct. 1992.

[5] R. B. Marks and D. F. Williams, "Characteristic Impedance Determination using Propagation Constant Measurement," *IEEE Microwave Guided Wave Lett.*, pp. 141-143, June 1991.