MILLIMETERWAVE COPLANAR TRANSMISSION LINES ON GALLIUM ARSENIDE, INDIUM PHOSPHIDE AND QUARTZ WITH FINITE METALIZATION THICKNESS

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ABSTRACT

Coplanar lines for the millimeterwave frequency range are required to be of small dimensions, typically 25-50 μm (ground to ground spacing) for the W- and V-band, respectively. The thickness of the metalization, typically 0.5 to several μm, cannot be neglected. The effect of the metalization on the impedance, propagation constant and attenuation is presented theoretically and experimentally for millimeterwave coplanar lines on gallium arsenide (GaAs), indium phosphide (InP) and quartz.

INTRODUCTION

Coplanar lines are becoming an increasingly important transmission media well into the millimeterwave frequency range [1,2]. They offer several advantages. No via hole grounding technology is needed. It is replaced by the technologically more simple air bridge technology. More effective shielding between lines and smaller dimensions are additional advantages. The application of coplanar lines at millimeterwave frequencies requires small dimensions. Ground to ground spacings of 50 and 25 μm have been used in the 60 and 90 GHz range [1, 2], resulting in a center line to ground spacing or a center line width of only a few μm for low and high impedance lines, respectively. The metal thickness ranges typically between 0.5 and several μm, such that its effect on the impedance and propagation cannot be neglected.

Coplanar lines have been analyzed in the past by various computational methods, mostly neglecting the metal thickness. Although there have been attempts to account for it [3,4], they have proven to be inaccurate. Recently, Kitazawa [5] has demonstrated the effect of the metal thickness, using a variational method and quasistatic approximation.

It is the purpose of this paper to point out the necessity of considering the effect of the metal thickness with small-dimension coplanar lines for millimeterwave applications, and to present theoretical and experimental results indicating the magnitude of the effect on impedance, propagation (relative effective dielectric constant) and attenuation. This, and future data, should prove to be of value in the design of millimeterwave ICs.

THEORETICAL AND EXPERIMENTAL RESULTS

Coplanar transmission lines, as illustrated in figure 1, of 4 and 8 mm lengths, with various w and w/d ratios were realized on two inch insulating gallium arsenide wafers of 0.5 mm thickness. The experimental results are shown in figure 2. For several w/d ratios, lines with 25, 50 and 75 μm center lines and two metal thicknesses were investigated. Titanium (0.05 μm) and gold (0.5 μm) were evaporated. On some wafers, an additional 2.5 μm of gold was electroplated, for a total gold thickness of 3 μm.

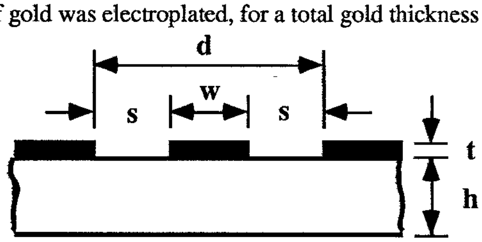

Fig.1: Cross section of coplanar wave transmission line.

The solid experimental points in figure 2 represent the impedance measured for the t=0.5 μm metalization. For this case, no difference in the impedance was observed for lines of equal w/d ratios but different center line dimensions w. For the t=3μm metalization however, distinct deviations were observed for different w.

The line impedances were determined by on-wafer S-parameter

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measurements (HP8510) of the lines, which were layed out for probing with microwave probing heads (Cascade). Measurements were performed over the range 1-26 GHz.

Experimental data for the attenuation of 50 ohm lines are shown in figure 3. The solid and dashed curves are for t=0.5 μm and t=3 μm gold, respectively.

Theoretical results for the line impedances for the three substrates, GaAs, InP and quartz are shown in figure 4 for the parameters d=25, 50 and 100 μm, and t=0.5, 1, 2 and 4 μm. The numerical results are obtained by using the extended spectral domain approach [6].

For zero metal thickness, t=0, theory [7] predicts an effective relative dielectric constant $\varepsilon_{reff}=(\varepsilon_r+1)/2=6.95$ for GaAs with $\varepsilon_r=12.9$, 6.8 for InP with $\varepsilon_r=12.6$, and 2.4 for quartz with $\varepsilon_r=3.8$, and an impedance as illustrated in figure 4. The results for InP closely match those for GaAs as indicated in figure 4(a). It has been pointed out by Kitazawa [5] that the effect of the metal thickness on the impedance is smaller for substrates of higher dielectric constant. This can clearly bee seen from figures 4(a) and (c) or 4(b) and (d). With increasing width d, the decrease in impedance from the t=0 value becomes less, as shown in figures 4(b) and (d). This is in agreement with the experimental data of figure 2, where we observe smaller deviations for the lower w/d values.

Theoretical data for the relative effective dielectric constant ε_{reff} for GaAs, InP and quartz is presented in figure 5 for the line width d=25 μm. Larger dimensions, d=50 or 100 μm have only a small effect, as indicated in figure 5(a). It should be noted that already for small t/s, ε_{reff} deviates appreciably from its t=0 value, which is the upper limit, and illustrated by the vertical axis at t=0. Several experimental values for ε_{reff} are shown in figure 5(a). The normalized propagation constant $(\varepsilon_{reff})^{0.5}$ was measured on a network analyzer (HP8510) at 5-25 GHz by determining the equivalent electrical lengths of the lines. Identical transmission lines of different lengths, 4 and 8 mm, were evaluated to eliminate contact and end effects. Note from figure 5 that the effect of t on ε_{reff} is larger for substrates of higher dielectric constant [5].

CONCLUSION

New theoretical and experimental data has been presented illustrating the effect of gold metalization on the impedance and the propagation constant of coplanar lines on substrate materials commonly used for millimeterwave ICs. Data has been presented for the attenuation of 50 ohm lines of various dimensions and metalization thicknesses.

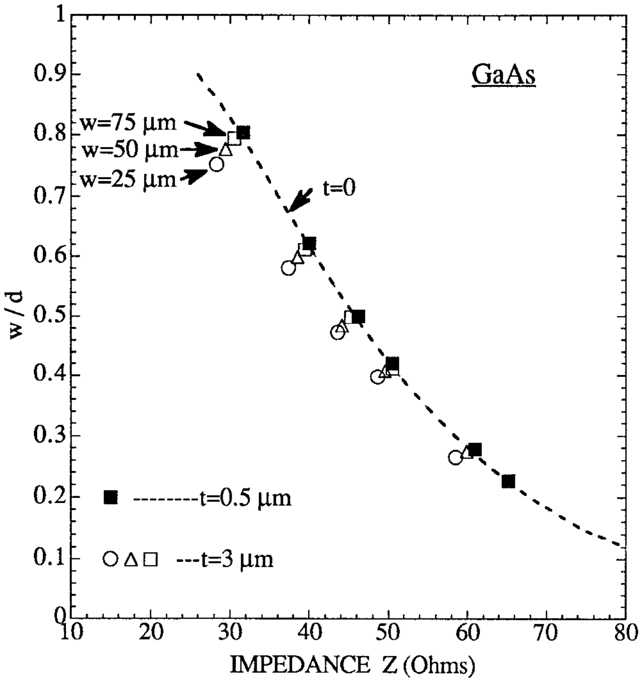

Fig.2: Measured impedances for coplanar lines of different dimensions and two metal thicknesses on gallium arsenide.

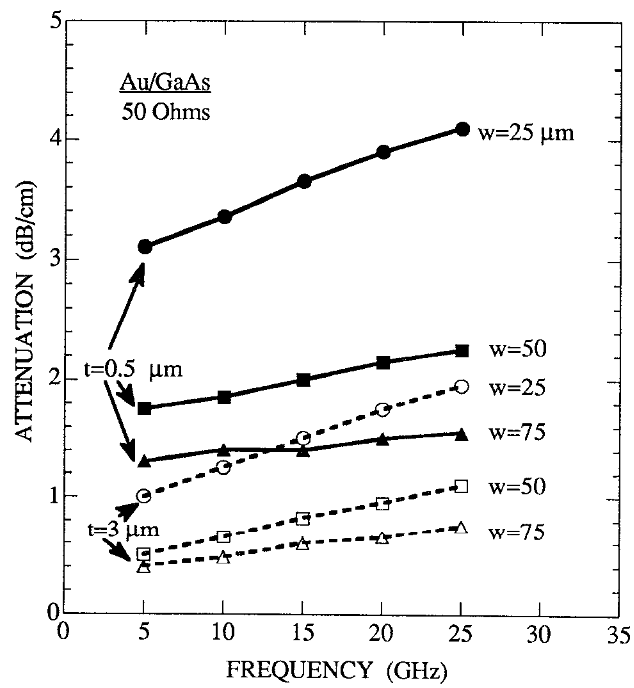

Fig.3: Measured attenuation of coplanar 50 ohm lines on gallium arsenide for two gold metalization thicknesses.

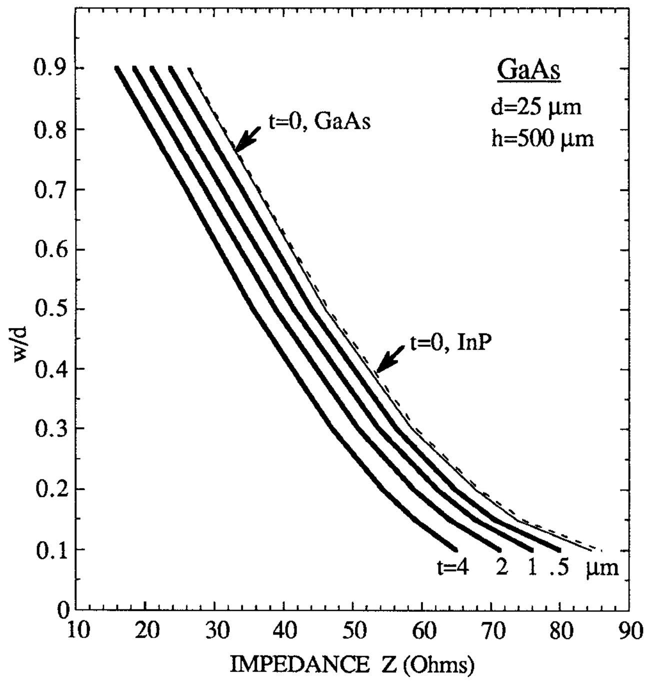

Fig.4(a): Theoretical coplanar line impedance for gallium arsenide, for several metalization thicknesses.

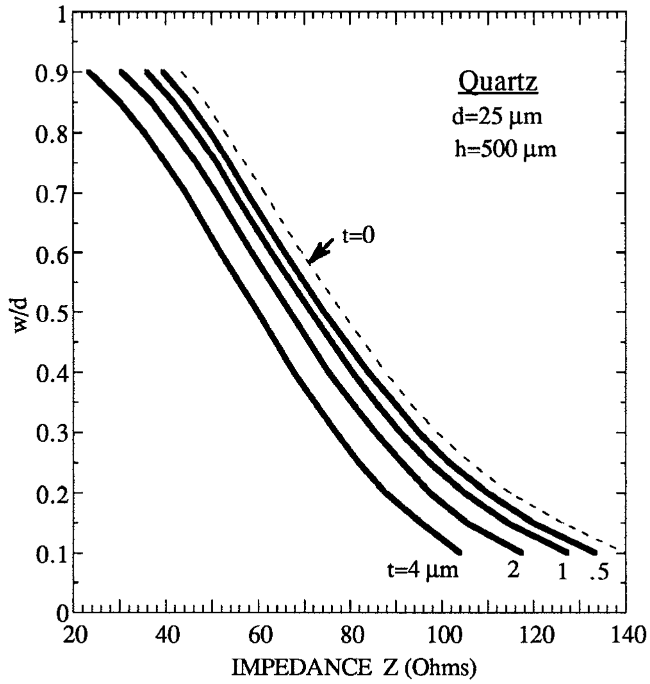

Fig.4(c): Theoretical coplanar line impedance for quartz, for different metalization thicknesses.

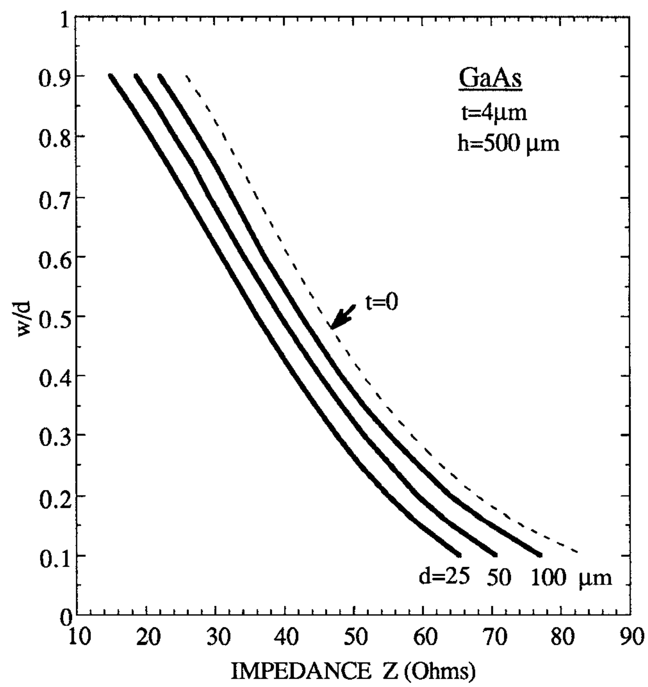

Fig.4(b): Theoretical coplanar line impedance for gallium arsenide, for different line widths.

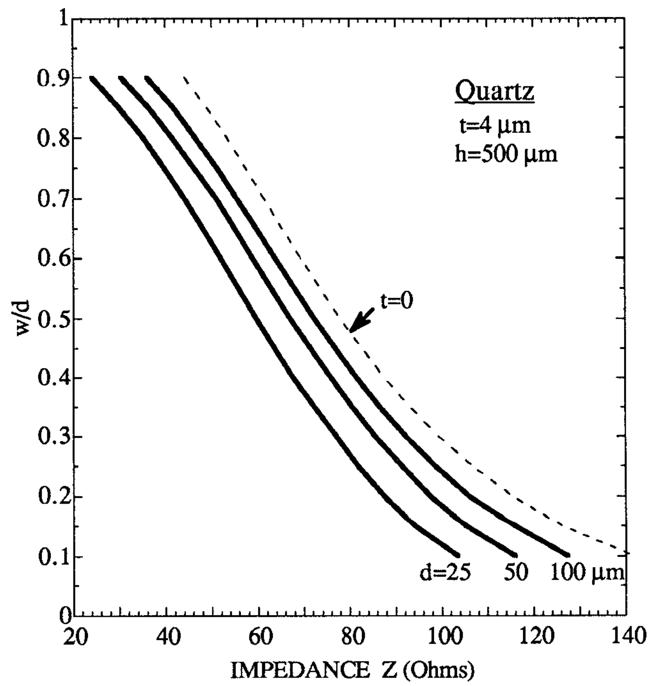

Fig.4(d): Theoretical coplanar line impedance for quartz, for different line widths.

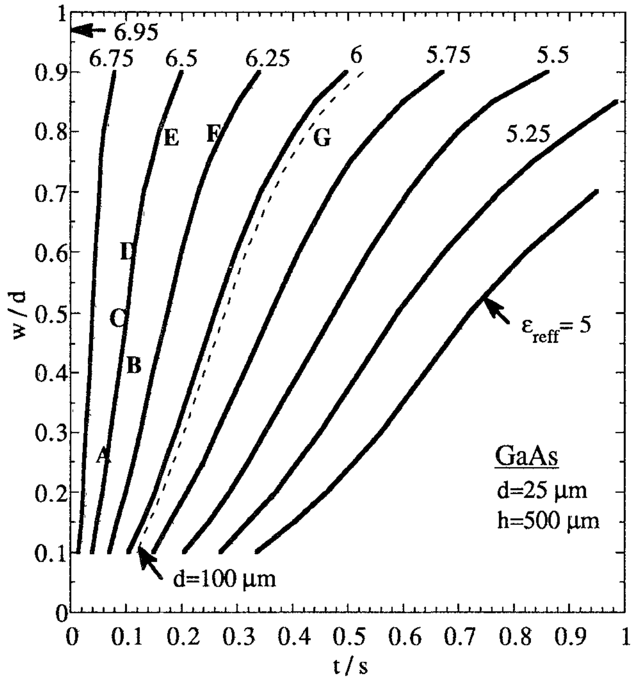

Fig.5(a): Theoretical values for the relative dielectric constant for coplanar lines on gallium arsenide. The experimental values shown for ε_{reff} are : A=6.53, B=6.46, C=6.55, D=6.47, E=6.41, F=6.28, G=6.02

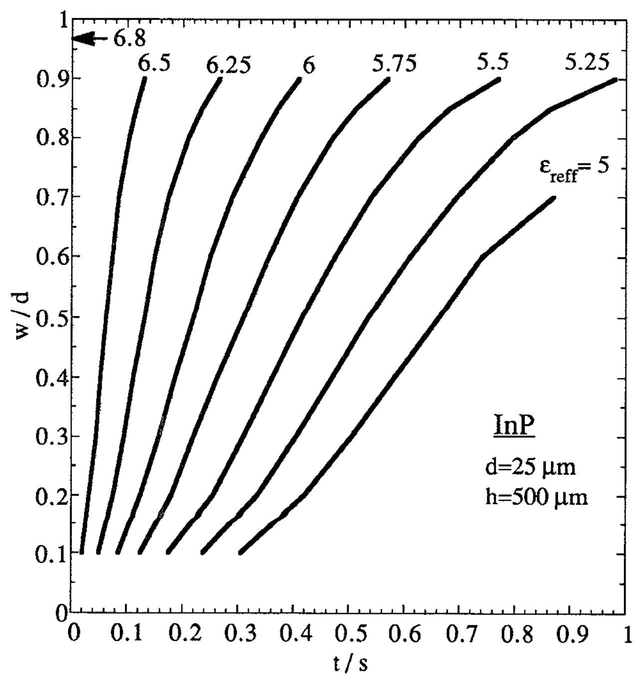

Fig.5(b): Theoretical values for the relative dielectric constant for coplanar lines on indium phosphide.

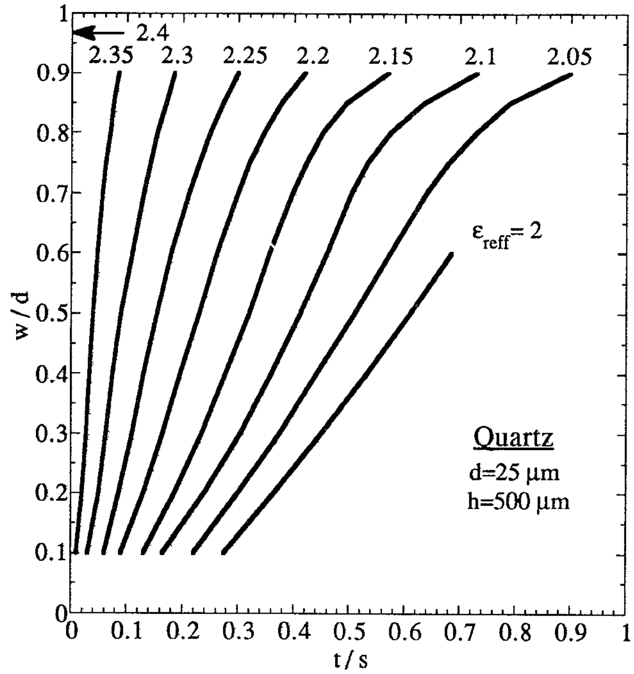

Fig.5(c): Theoretical values for the relative dielectric constant for coplanar lines on quartz.

REFERENCES

[1] R. Majidi-Ahy, M. Riaziat, C. Nishimoto, M. Glenn, S.Silverman, S.Weng, Y.C.Pao, G.Zdasiuk, S.Bandy, Z. Tan, "5-100 GHz InP CPW MMIC-7 section distributed amplifier", 1990 IEEE Microwave and Millimeterwave Monolithic Symp., pp. 31-34.

[2] M. Riaziat, E. Par, G. Zdasiuk, S. Bandy, M. Glenn, "Monolithic millimeter wave CPW circuits", 1989 IEEE MTT-S Digest, pp. 525-528.

[3] "Reference Data for Engineers: Radio, Electronics, Computer and Communications", 7th ed., Howard W. Sams & Co, pp. 29-26, 1989.

[4] Y.C. Shih, M. Maher, "Characterization of conductor backed coplanar waveguide using accurate on-wafer measurement techniques", 1990 IEEE MTT-S Digest, pp. 1129-1132.

[5] T.Kitazawa, Y. Hayashi,"Quasistatic characteristics of a coplanar waveguide with thick metal coating", IEE Proc., vol. 133, pp.18-20, Feb.1986.

[6] T. Kitazawa, T. Itoh, "Asymetrical coplanar waveguide with finite metallization thickness containing anisotropic media", 1990 IEEE MTT-S Digest, pp. 673-676.

[7] R.K. Hoffmann, "Handbook of Microwave Integrated Circuits", Artech House Inc., 1987.