ATTENUATION OF MILLIMETERWAVE COPLANAR LINES ON GALLIUM ARSENIDE AND INDIUM PHOSPHIDE OVER THE RANGE 1-60 GHz

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ABSTRACT

Extensive attenuation data of coplanar lines on semi-insulating GaAs and InP is presented over the frequency range 1-60 GHz. On-wafer measurements were used to obtain the S-parameters.
A ground-to-ground spacing of 30, 60 90 and 120 mm, typical for that used in todays microwave and millimeterwave integrated circuit applications, was investigated.
The center line width (impedance) and the evaporated gold metal thickness were varied.
For the frequency range investigated (metal thickness less than 2-3 times the skin depth), the attenuation was found to be inversely proportional to the metal thickness.
The attenuation varies with frequency as f^n, with $n < 0.5$.

INTRODUCTION

Coplanar transmission lines are well established as a transmission media, having a number of advantages when compared to the popular media microstrip line [1]. Their potential, in the development of microwave and millimeterwave frequency integrated circuits, has effectively been demonstrated in the past, at frequencies as high as 100 GHz [2-3]. In contrast to the vast database which exists for microstrip lines, little is known about the propagation characteristics of coplanar lines, especially at millimeterwave frequencies.
In the design of millimeterwave integrated circuits, the propagation parameters velocity (effective dielectric constant ε_{reff}), and attenuation are of importance.
It is the purpose of this paper, to present experimental data on the attenuation of coplanar lines of small dimensions on semiinsulating ($\rho = 10^7$-10^8 Ohm·cm) gallium arsenide (GaAs) and indium phosphide (InP) substrates over the frequency range 1-60 GHz. The dimensions of the coplanar lines are chosen to reflect those actually used in the design of millimeterwave circuits. Ground-to-ground spacings of 30-120 mm were chosen. Metal thicknesses of 0.25-1 µm have been used. The resistance and attenuation of the coplanar lines are thus not effected by the skin effect, since the metal thickness is less than 2-3 times the skin depth.

EXPERIMENTAL

Coplanar lines, as illustrated in fig. 1, of different ground-to-ground spacing d, center-line-width w, and metal thickness t, were realized on semiinsulating GaAs and InP wafers of 500 µm thickness. Lines of two different lengths (total length of center conductor, including a 25 µm long and 50 µm wide probing pad for CASCADE on-wafer probing, and a 45° taper to the center conductor), 2.75 and 5.5 mm, were made, spaced 0.5.mm apart. Electron beam lithography, using a Cambridge EBMF 10.5 system, was used to define the pattern in two-layer PMMA-P(MAA-MMA) resist. Metalization was performed, using a lift-off technique, and consisted of 300 Å titanium followed by 0.25, 0.5 or 1 µm evaporated gold. The dc resistivity of the gold was 3 µOhm.cm for 1 µm Au, which is higher than the bulk value.
Measurements were performed on a HP 8510 network analyzer, consisting of two test sets, covering 0-40 and 40-60 GHz, by determining the S-parameters over this frequency range. Following a parameter extraction method developed for FETs [4], the parameters of a transmission line may be determined as a function of frequency.
Alternative methods have been used by us to model transmission lines, such as parameter fitting, using commercially available optimization programs (EESOF-Libra).
Recently, time domain measurements have also been applied succsessfully in the characterization of coplanar lines [5].

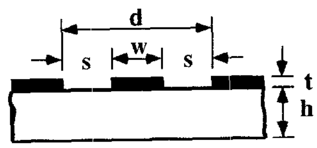

Fig.1: Cross section of coplanar transmission line.

Attenuation results on InP substrates, 0.5 mm thick, are illustrated in figures 2 and 3. The attenuation was found to be similar for GaAs substrates, since their dielectric constants are similar, $\varepsilon = 12.9$ for GaAs and $\varepsilon = 12.6$ for InP. Some of the data has been fitted with an expression for the attenuation of the form $a_0 f^n$. Note that $n \approx 0.2$ for the high impedance lines with small w / d ratio, and ≈ 0.3 for the low impedance lines with high w / d ratio.
Figure 3 illustrates the results for a metal thickness of 0.5 µm. The metal thicknesses correspond to practical thicknesses which can still be evaporated without excessive cost. Whereas additionally plated gold may be used for the lines of the greater dimensions, plating is impractical with the smaller dimension lines, especially for the high and low impedance values.
Figure 4 illustrates more experimental attenuation data on GaAs and InP. Calculations were performed using closed form expressions from ref.[6], which however only apply for $t > 3$ times the skin depth, indicated by HOFF. They approach the measured values at the highest frequencies and thicker metalization, where this condition is better satisfied.
Using a hybrid mode approach, one of the authors (T. Kitazawa) has performed calculations which fit the measured data as shown, indicated by KIT.

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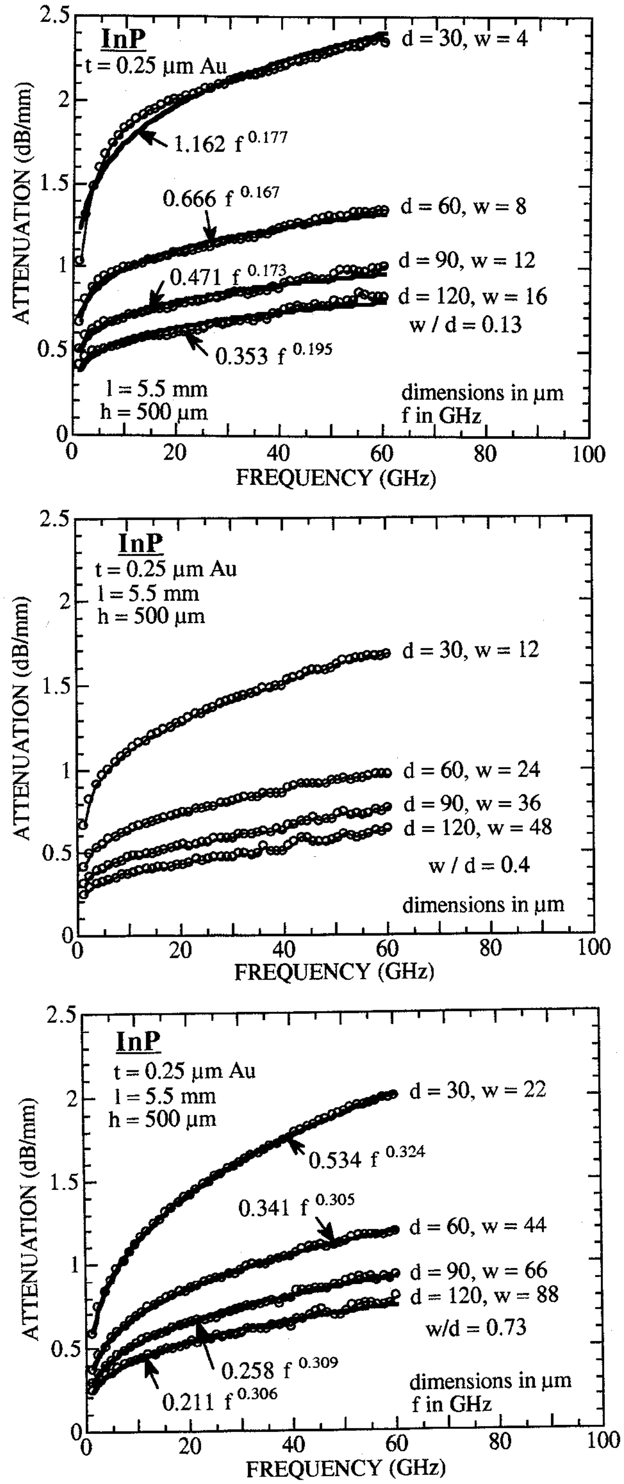

Fig.2: Measured (circles) attenuation of coplanar lines on InP for 0.25 μm gold metalization. Solid lines represent fit of data of the form $a_0 f^n$.

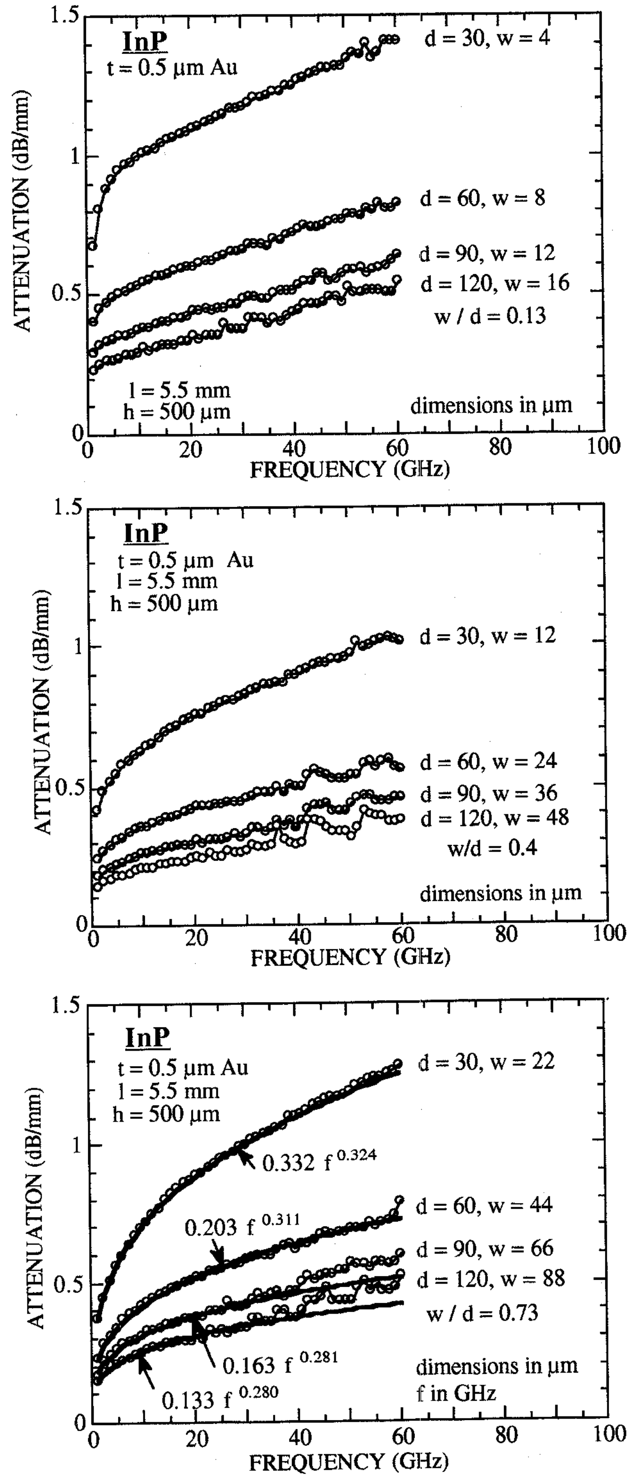

Fig.3: Measured (circles) attenuation of coplanar lines on InP for 0.5 μm gold metalization. Solid lines represent fit of data of the form $a_0 f^n$.

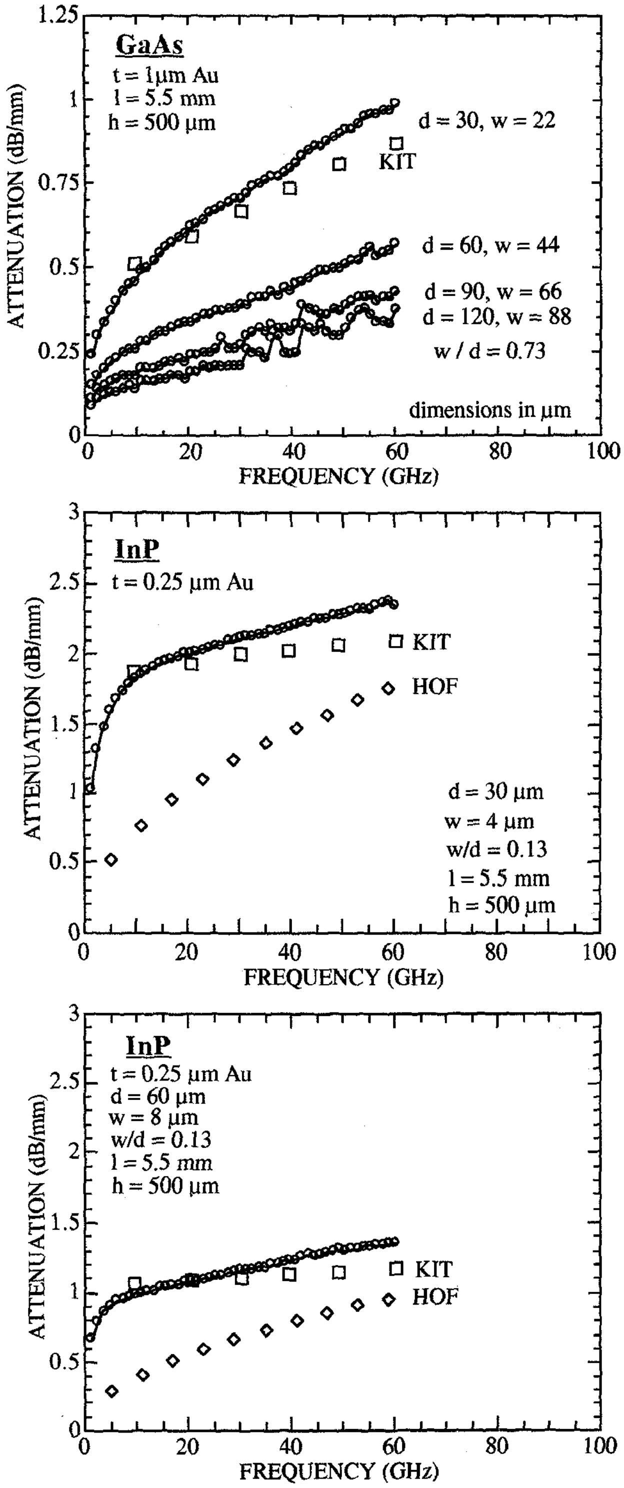

Fig.4: Measured (circles) attenuation of coplanar lines on GaAs for 0.5 µm, and InP for 0.25 µm gold metalization. KIT represents calculated data (Kitazawa, this paper). HOFF represents calculated data, using expressions from [6].

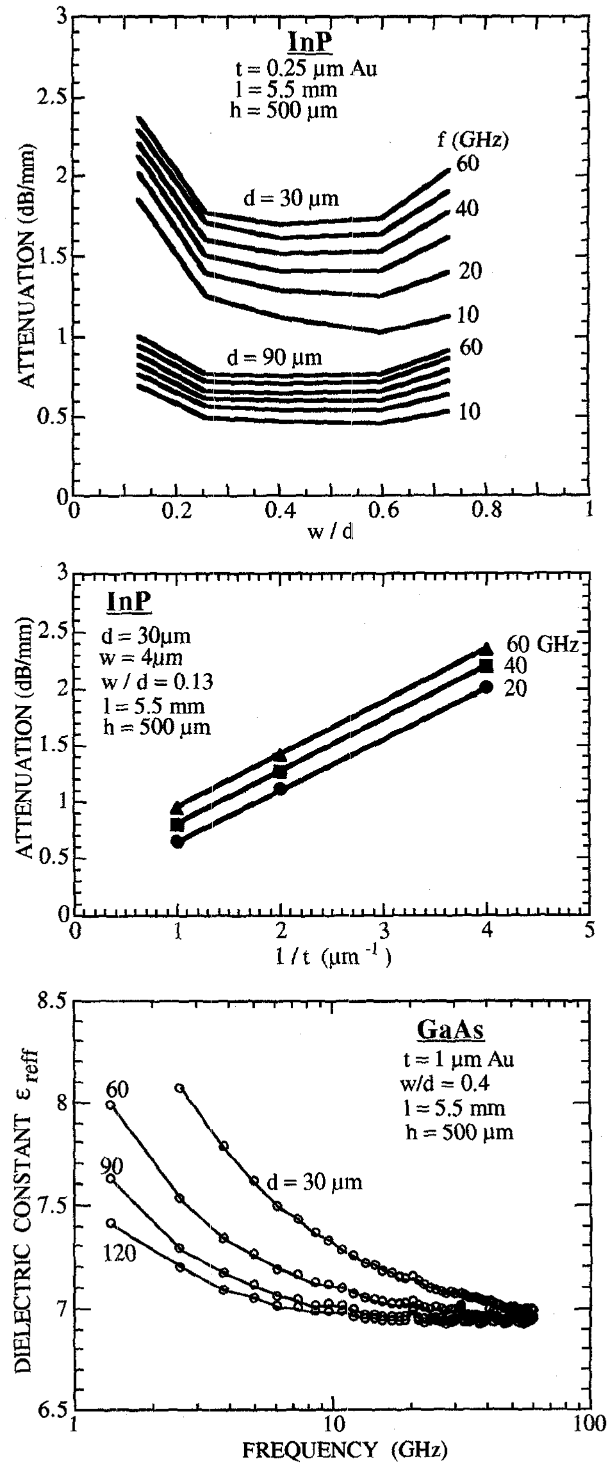

Fig.5: Top: The measured attenuation of 0.25 µm gold on InP as a function of the ratio w / d (impedance).
Center: The measured attenuation as a function of metal thickness. The attenuation varies linearly with thickness, since t < 3 times the skin depth.
Bottom: The extracted relative effective dielectric constant.

The attenuation as a function of frequency and impedance, or w / d ratio, is shown in figure 5 (top). The attenuation is lowest in the 40 - 60 Ohm range, and increases sharply with decreasing line dimension d.

Because the metal thickness t is always less than 3 times the skin depth δ, which is 0.5 μm at 60 GHz, the attenuation varies inversely with metal thickness t, as illustrated in figure 5 (center).

Using a transmission line parameter extraction program [7], the relative effective dielectric constant ε_{reff} was extracted. One example is shown in figure 5 (bottom).

CONCLUSION

We have presented experimental data on the attenuation of coplanar transmission lines on GaAs and InP over the frequency range 1-60 GHz. The data was obtained by on-wafer measurements of the S-parameters and subsequent extraction of the transmision line parameters [7].

The data can best be fitted by functions of the form $a_0 f^n$, where n is dependent on the geometry of the line, and found to be in the range 0.2 - 0.3.

The metalization thickness t always satisfies the condition $t < 3\delta$, with the consequence that the attenuation is inversely proportional to the metal thickness.

Models have been developed to extract the transmission line parameters. They will be described in more detail at a future time.

REFERENCES

[1] W. H. Haydl, T. Kitazawa, J. Braunstein, R. Bosch, M. Schlechtweg, "Millimeterwave coplanar transmission lines on gallium arsenide, indium phosphide and quartz with finite metalization thickness", 1991 IEEE MTT-S International Microwave Symp. Digest, pp. 691-694, June 1991.

[2] 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.

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

[4] M. Berroth, R. Bosch,"Broad-band determination of the FET small-signal equivalent circuit", IEEE Trans. Microwave Theory Tech., vol. 38, pp. 891-895, July 1990.

[5] A. Deutsch, G. Arjavalingam, G. V. Kopcsay, "Characterization of resistive transmission lines by short-pulse propagation", IEEE Microwave and Guided Wave Letters, vol. 2, pp. 25-27, Jan. 1992.

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

[7] P. Tasker, unpublished.