Experimentally Observed Frequency Variation of the Attenuation of Millimeter-Wave Coplanar Transmission Lines with Thin Metallization

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***Abstract*—The attenuation of small coplanar transmission lines on insulating InP and GaAs has been investigated experimentally over the frequency range 0–60 GHz by on-wafer probing. The ground to ground spacing d, the center line width w, and the metal thickness t were varied. For thin (0.25–1 μm) gold metallization, the variation of the attenuation with frequency was found to be dependent on the geometry of the line. A good fit to the experimental data was obtained when the attenuation a was modeled as $a = a_0 f^n$, where a_0 and n are geometry dependent. The exponent n was found to be in the range 0.15–0.35, and to increase with increasing w/d ratio, which is interpreted to be due to a correspondingly varying frequency dependent resistance and current distribution.**

I. Introduction

The attenuation of coplanar lines has been treated both theoretically and experimentally in the past [1]–[7]. A number of experimental results have been reported, generally involving lines of much larger dimensions than those required for microwave and millimeter-wave integrated circuits [8]–[9]. It is the purpose of this letter to present additional experimental data on small (ground to ground spacing less than 120 μm) coplanar lines on insulating semiconductor materials such as InP and GaAs, with thin (less than 1 μm) gold metallization. The metal thicknesses chosen correspond to practical thicknesses which can be evaporated.

We observe a well defined variation of the attenuation with frequency, which is dependent on the geometry of the lines. This variation is interpreted as an equivalent variation of the RF resistance of the coplanar lines, and is proposed to be an indication of the frequency dependent current distribution within the lines.

II. Experimental Results

The parameters of a coplanar transmission line are illustrated in Fig. 1. Evaporated gold coplanar lines of 5.5 mm length on 0.5-mm thick substrates were investigated. The S-parameter data for a number of lines having different metal thicknesses (0.25, 0.5, 1 μm) and a number of different w/d ratios (0.13, 0.26, 0.4, 0.6, 0.73) on GaAs and InP, was evaluated. Representative results are shown in Figs. 2 and 3, for 0.25-μm gold (Au) (preceded by 0.03-μm titanium (Ti)) metallization on 500-μm thick insulating (iron doped, $10^7 - 10^8$ Ohm·cm) InP substrates, over a frequency range 1–60 GHz. The measurements were performed by on-wafer probing, using 60-GHz CASCADE coplanar probes, and a HP8510 network analyzer, consisting of two test sets, covering 0.1–40 and 40–60 GHz, respectively.

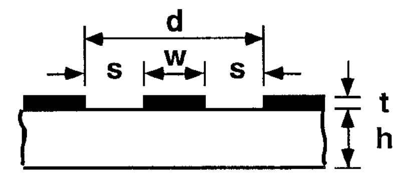

Fig. 1. Cross section of coplanar transmission line.

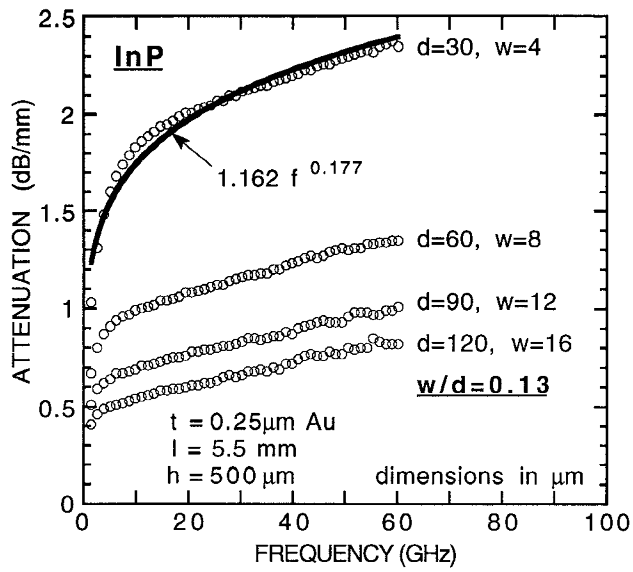

Fig. 2. Measured attenuation of coplanar lines of different size with $w/d = 0.13$.

The experimental attenuation data, as illustrated in Fig. 2 and 3, was found to be best fitted by a relation of the form

$$a = a_0 f^n, \quad (1)$$

for the attenuation a as a function of frequency f, where a is in dB/mm and f in GHz. The fitting parameters n and a_0, for the case of 0.25-μm Au on InP, are illustrated in Fig. 4 and 5, respectively, for several w/d ratios. The variation of n with the line dimensions w and w/d is illustrated in Fig. 4, where a fairly linear variation with both w and w/d is observable.

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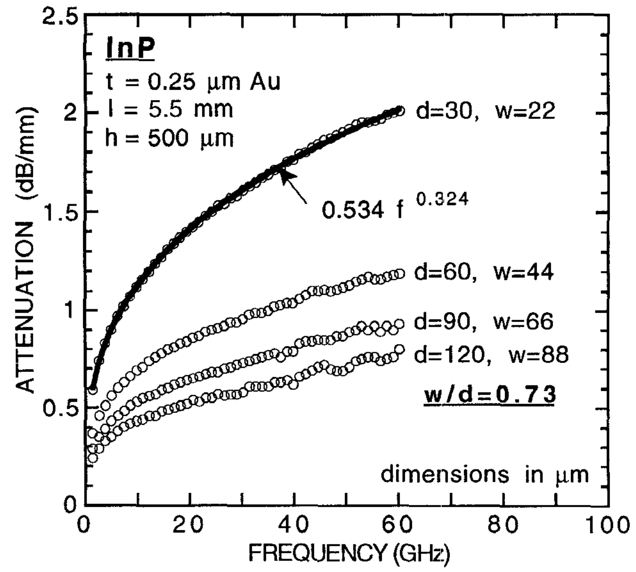

Fig. 3. Measured attenuation of coplanar lines of different size with $w/d = 0.73$.

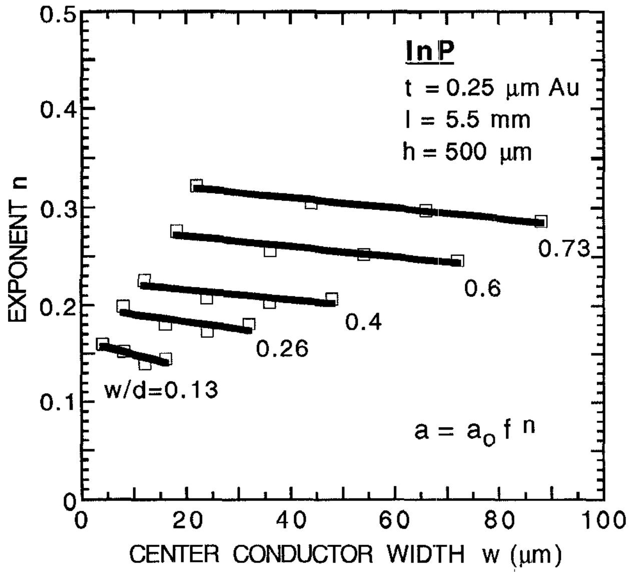

Fig. 4. Exponential factor n of the data of Fig. 2 and 3, fitted to $a = a_0 f^n$.

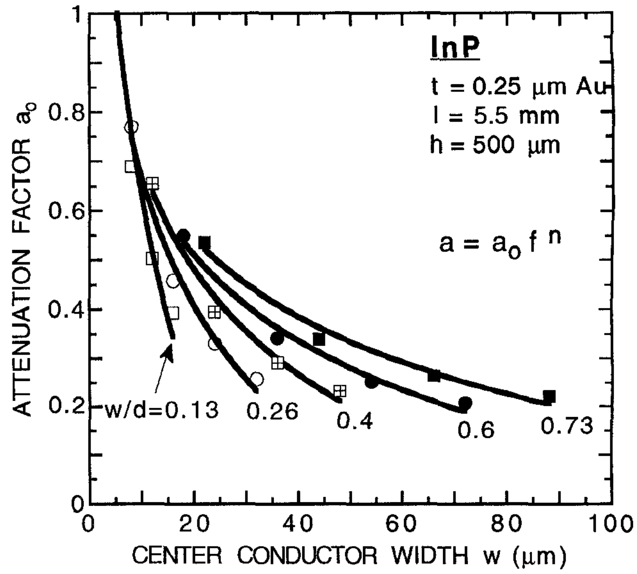

Fig. 5. Attenuation factor a_0 of the data of Fig. 2 and 3, fitted to $a = a_0 f^n$.

Almost identical results for the variation of n were found for the metal thicknesses 0.5 and 1 μm. The magnitude of a_0 was found to decrease with increasing metal thickness t and center line width w, as observable from Fig. 5. As a function of w/d, the magnitude of a_0 was found to exhibit a minimum in the range of w/d = 0.26–0.6.

A small (5–10%) velocity dispersion was observed over the range 10–60 GHz. The variation of the phase constant b with frequency f, could be fitted over the range 1–60 GHz with the linear relation

$$\beta = bf, \tag{2}$$

where f is in GHz, and β in radians/mm. The slope b was found to be 0.0562, and independent of the center line width w. A decrease of b of less than 1% was observed when the metal thickness was increased from 0.25 to 0.5 μm.

The experimentally measured dc resistivity of the 0.25 μm-thick evaporated gold metallization was 3.3 μOhm·cm.

III. Summary and Discussion

The attenuation of small coplanar lines with thin metallization has been investigated experimentally. The data allows safe extrapolation to 90 GHz. For metallization thicknesses greater than three times the skin depth δ, the frequency variation of the attenuation is expected to be of the form, $a = a_0 f^n$, with n = 0.5 [3], [10], [11]. Since the metal thicknesses used by us are less than 3 δ, (δ = 0.35 μm for Au at 60 GHz, 0.3 μm at 90 GHz), a value less than 0.5 can be expected for n. A frequency variation of the form $a = a_0 f^n$ was found, with n increasing from about 0.15 to 0.35, as w/d increases from 0.13 to 0.73 (decreasing impedance), and n decreasing only minimal with increasing w for a given w/d ratio.

For a thin metallization, as defined in this letter, it is proposed that the RF current flow concentrates increasingly at the edges of the lines in the slit region (s, Fig. 1), with increasing frequency. The strong variation of n with w/d suggests that the current distribution in the center conductor does not change appreciably with frequency for small w/d (small value for n), but does so increasingly with higher w/d (large value for n).

It can be shown that the frequency variation of the RF resistance is of the same form as the variation of the attenuation. A complete set of experimental data, including other metallization thicknesses and materials will be published at a later time.

Acknowledgment

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