Full-Wave Analyses of Composite-Metal Multidielectric Lossy Microstrips

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Abstract—**The full-wave mode-matching method is extended to analyze composite-metal multidielectric microstrips commonly used in MMIC's. The theoretical data obtained by the present approach agree favorably with the available experimental data for GaAs-SiN-Ti-Au finite-width, composite-metal and multidielectric microstrips. The effect of the thickness of the finite-width titanium layer is reported and discussed.**

I. Introduction

Design of modern monolithic microwave and millimeter-wave integrated circuits (MMIC's) demands an accurate modeling of various planar and quasi-planar transmission lines as close to their physical and material parameters as possible. In Fig. 1, one practical example of an MMIC microstrip, the Ti layer is sandwiched between gold (Au) and SiN layers for better adhesion of the Au layer in GaAs MMIC technology. Many other possible configurations such as Cr-Au and Ti-Pt-Au were also reported in [1]. Such finite-width, composite-metal and multidielectric microstrip structures have not yet been analyzed and reported rigorously by any full-wave approaches published recently [2]-[5]. The method described in this letter is general enough to tackle any of the aforementioned finite-width, composite-metal and multidielectric microstrip configurations for use in MMIC's; however, only data relevant to Fig. 1 are presented here.

Some early works on the conductor losses of composite-metal microstrip lines were reported by Sobol and Caulton [6] using a simplified TEM perturbational analysis based on an equivalent surface impedance concept. The analysis in [6] assumes an infinitely wide and thick top gold (Au) layer, which corresponds to the case of $w = \infty$ and $t_1 = \infty$ in Fig. 1. The simplified TEM theory defines the surface impedance of the composite-metal strips as the ratio E_z/H_x evaluated at the dielectric-conductor interface $y = d_1 + d_2 + d_3$. The total conductor loss is then approximated to be proportional to the real part of the surface impedance previously defined. It should be pointed out that the analysis in [6] can give only the ratio of the conductor loss in the composite-metal (Ti-Au) system to that in the corresponding single-conductor (Au) system. In contrast, the present full-wave approach can directly result in the complex propagation constant of the microstrip shown in Fig. 1.

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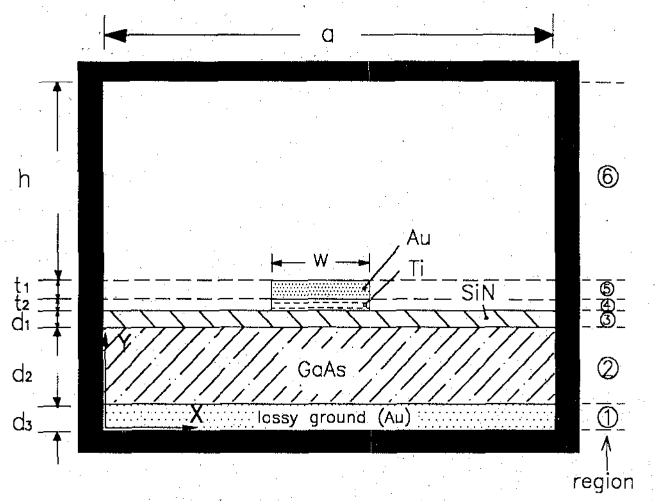

Fig. 1. Microstrip line with composite Ti-Au metals on GaAs-SiN substrate. Structural and material parameters: $d_2 = 100\ \mu m$, $d_3 = 12\ \mu m$, $t_1 = 3\ \mu m$, $h = 2$ mm, $w/d_2 = 0.7$, $a = 10w$. Au: $\sigma = 4.1 \times 10^7$ mho/m, Ti: $\sigma = 2.1 \times 10^6$ mho/m, SiN: $\epsilon_r = 6.5$. GaAs: $\epsilon_r = 12.9$, loss tangent $= 1 \times 10^{-4}$.

II. Method of Analysis

The case of the microstrip line with composite-metal Ti-Au configuration on multidielectric GaAs-SiN layers as shown in Fig. 1, where a ground plane conductor loss is also considered, is analyzed and the results are reported. The conductivities of Au and Ti are 4.1×10^7 mho/m and 2.1×10^6 mho/m, respectively. The GaAs substrate has a relative dielectric constant of 12.9 and loss tangent 1×10^{-4} while the SiN dielectric layer is assumed lossless with a relative dielectric constant of 6.5.

Based on the full-wave mode-matching method described in [5], the waveguide cross-section is divided into six regions as shown in Fig. 1. Next the full-wave hybrid TE-to-x and TM-to-x Hertzian potentials are expanded in each region. Following the terminology reported in [5], regions 2, 3, and 6 consist of air modes only; region 1 has metal modes only; regions 4 and 5 have both air and metal modes. After matching the interface boundary conditions between the adjacent regions, a nonstandard eigenvalue equation is derived. The complex roots of this equation are the solutions for the propagation constants.

III. Dispersion Characteristics of the GaAs-SiN-Ti-Au Microstrip

Given the structural and material parameters shown in Fig. 1 and setting the thickness of the Ti layer and the SiN layer

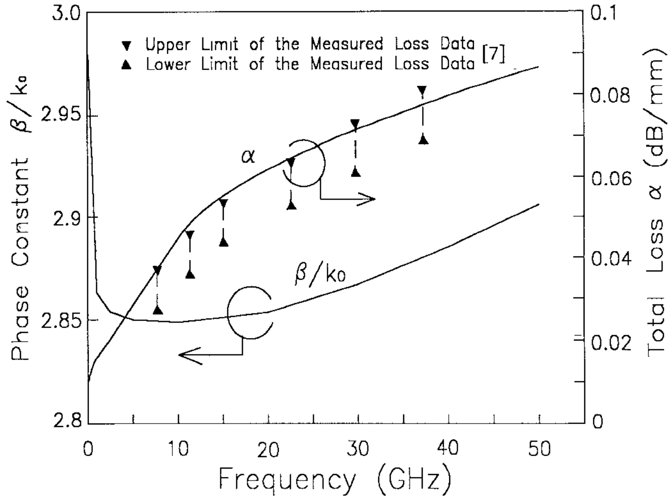

Fig. 2. Dispersion characteristics of the complex propagation constant for the dominant mode of the microstrip line in Fig. 1. $t_2 = 400$ Å, $d_1 = 2000$ Å. Other parameters are given in Fig. 1. Solid lines: Normalized phase constant β / k_0 and total loss α by the present approach. Triangle symbols: Upper and lower limits of the measured total loss α [7].

equal to 400 Å and 2000 Å, respectively, Fig. 2 plots the dispersion characteristics of the normalized phase constant β / k_0 and the total loss α for the dominant mode. Also shown are the upper and lower limits of the measured total loss at six resonant frequency points using the lightly coupled multiple half-wavelength resonators [7]. The accuracy of the converged theoretical solutions, satisfying both relative and absolute convergence criteria [5], is in 0.1% error bound. The theoretical results obtained by the present full-wave approach agree with the measured data in the upper limit below 30 GHz and agree much better beyond 30 GHz. The substantial increase of β / k_0 when frequency is reduced from 5 GHz to nearly DC frequency has also been observed in [3].

IV. Effect of the Ti Layer Thickness

The effect of the thickness of the Ti layer (t_2) on the dominant mode complex propagation constant is plotted in Fig. 3 with a fixed-thickness SiN layer (d_1) of 2000 Å at 1 GHz, 10 GHz, and 50 GHz, respectively. The solid and dashed lines represent the total loss α and the normalized phase constant β / k_0, respectively, which are obtained by the present full-wave approach. The results of the total loss α computed by the simplified analysis in [6] are in circle symbols. Since the analysis in [6] requires the value of α corresponding to zero thickness of Ti layer ($t_2 = 0$) as the starting point, the leftmost circle symbols in Fig. 3, corresponding to $t_2 = 0$, are generated by the present full-wave approach. Fig. 3 shows that the value of β / k_0 slightly decreases by less than 0.1%, when t_2 is increased from zero to 0.5 μm at 1 GHz, 10 GHz, and 50 GHz. For the total loss (α) calculation, the present method and the simplified analysis [6] agree well at low frequencies 1 GHz and 10 GHz, even when a very thick Ti layer of 0.5 μm is employed. As the frequency is increased to 50 GHz or even higher, the simplified analysis [6] overestimates the total loss α because the currents on the edges of Ti and Au metal layers can no longer be neglected and hence it is incorrect to determine the

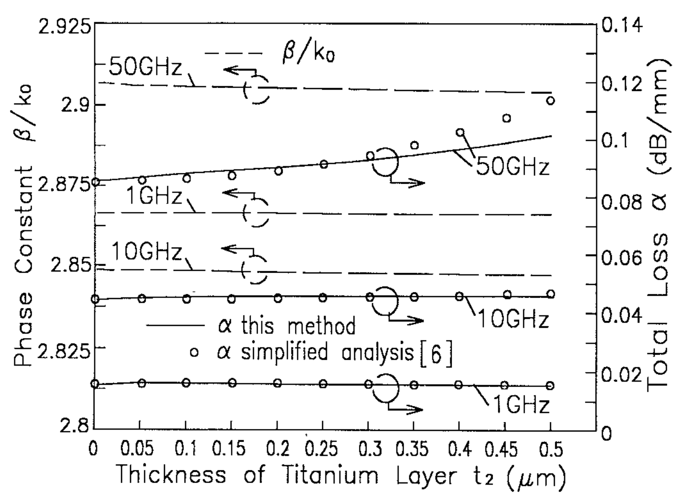

Fig. 3. Effect of the Ti layer thickness on the complex propagation constant at 1 GHz, 10 GHz, and 50 GHz, respectively. $d_1 = 2000$ Å. Other parameters are given in Fig. 1. Solid and dashed lines: Total loss α and normalized phase constant β / k_0 by the present approach. Circle symbols: total loss by the simplified analysis in [6] with the leftmost ones generated by the present full-wave approach.

surface impedance simply at the bottom surface of the Ti-Au composite metals. At 50 GHz the increase of the total loss α from $t_2 = 0$ to $t_2 = 1000$ Å, 2000 Å, and 5000 Å is 3%, 5.3%, and 18.5%, respectively, as analyzed by the present rigorous full-wave approach.

V. Conclusion

The full-wave analyses of a microstrip containing composite finite-width metal strips integrated on SiN-GaAs multidielectric layers are presented for the first time. A test example for an MMIC GaAs-SiN-Ti-Au microstrip is reported and investigated. The results agree favorably with the available experimental data. In the particular case study of the composite-metal microstrip structure, the simplified approach of [6] and the present method agree well for determining the attenuation losses at the lower operating frequencies. The accurate sessment of attenuation losses at higher millimeter-wave frequencies for the composite-metal multidielectric microstrip, however, must be obtained by the rigorous full-wave approach such as the mode-matching method presented in this letter.

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