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STUDY INTO CONDUCTOR LOSS ESTIMATIONS, WITH PARTICULAR EMPHASIS ON THE CONSEQUENCES OF TITANIUM'S ADHESIVE LAYER IN THE MICROWAVE, MILLIMETRE, AND TERAHERTZ FREQUENCY RANGES

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ABSTRACT

This study examines conductor loss calculations from 1 GHz to 1000 GHz, taking into account the impact of a titanium adhesive coating. Here, we compare the Thin Film Microstrip line's experimental conductor loss to loss estimates derived from suggested models for TFML topologies. In comparison to the microwave frequency range, it is discovered that the loss estimation for thin film microstrip lines in the millimetre wave and terahertz frequency ranges is significantly higher with an adhesive coating than without one. This paper concludes that the losses due to adhesion layer in terahertz frequency range increase very sharply at 1000 GHz observed analytically and in Microwave range losses due to such adhesion layer films are below 3%, when we take the thickness of the adhesion layer to be greater than that of the skin depth in that frequency range and with high conductivity. This results in reduced losses in TFML structure with the adhesion layer in Microwave range.

INTRODUCTION

We are motivated to work towards more accurate Thin Film Microstrip line loss estimation before manufacturing the MMIC components [1] due to the growing demand for high speed devices operating in the terahertz region.

Conductor width in thin film technology typically ranges from 1 um to 40 um, and thickness is typically 10 um in thin film microstrip line [2]. Small size modules are ideal for these dimensions. However, an adhesive layer is typically required in structure to provide mechanical strength to the conductor strip on the substrate when installing such thin conductor films. The normal adhesion layer range is approximately 8 um. The conductor strip thickness and the adhesion layer thickness are roughly the same as we can observe. To ensure that conductor losses of TFML are not increased, conductor thickness is, nevertheless, best taken as several times the skin depth (d) and adhesion layer is best taken thinner. When the conductor's skin depth reaches a point where its thickness is comparable, signal would then enter the adhesion layer, increasing conductor loss since the adhesion layer has a finite resistance.Additionally, at terahertz frequencies, the wavelength is substantially smaller and skin depth is likewise smaller due to high frequency, which results in short skin depth and thin conductor thickness.

We'll demonstrate how conductor loss in the range of 10 GHz to 1000 GHz would be impacted by this. In Fig. 1, "tal" denotes the thickness of the adhesive layer, "t" denotes the thickness, and "W" denotes the width of the conductor strip. H stands for the height of the substrate.

2. Thin sheet material with an adhesive layer Microstrip

Due to their excellent conductivity, group 1B metals including copper, silver, and gold are typically selected for conductor strips. Due to its excellent conductivity and resistance to environmental changes, gold is preferred. But because of gold's inert behaviour, which prevents it from forming oxides, its adherence to substrate is poor.

Through experiments [3], it was demonstrated that gold-Titanium has good mechanical strength because, unlike other transition metals, a stable coating of titanium can form over the surface of gold without diffusing. Titanium is employed because of its indisputable benefits, including its machinability, corrosion resistance, affordability, and high conductivity. Here, we've carried out an analytical examination of loss computation that incorporates a titanium adhesion layer and a gold conductor strip.

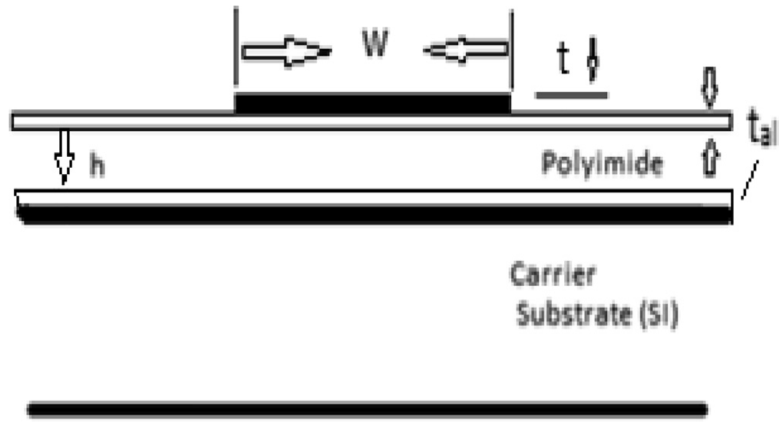

Fig. 1. Schematic of Composite TFMS.

2.1. **Attenuation in thin film Microstrip**

Usually in Microsrip line, there are different types of losses namely, Conductor loss (loss due to Conductor strip), Dielectric loss (loss due to lossy dielectric), surface wave loss and Radiation loss etc. Among these Conductor loss is dominant and contributing for about 90% of the total loss. We hve calcualted conductor loss due to strip conductor of gold with conductivity rc = 4.5E7 (Resistivity, qc = 1/rc) and adhesion layer of Titanium of conductivity ral = 2.38E6 at 273 K [4] (Resistivity, qal = 1/ral). Generally adhesion layer is taken of high conductivity to have less conductor loss contribution. We have used the closed form expression given below for calculating conductor loss with and without adhesion layer [5]. Conductor loss that we have calculated from imroved Holoway and Kuester Model for TFML using perturbation method with stopping distance for rectangular strip [6].

Including these factors i.e. effect of thickness and stopping distance in the calculations of conductor loss gives more accurate results. In literature ([5,7]) these formulations are given for conventional lines. We have used these closed form expressions along with expression suggested for dispersive conductivity for Thin Film Microstrip Lines.

3. Conductivity of Microstrip conductor and conductivity of adhesion layer

We can take the conductivity of thin film less in comparison with Bulk or thick film at the same temperature as given in literature [8]. The reason behind this would be because bulk conductivity is more due to more no. of electron density than that of thin film of any metal hence at any frequency at same temperature conductivity will be less for thin film. Bulk films shows more rapid increase towards cryogenic temperatures than thin film. Usually finite conductivity of thin film also leads to more conductor losses in low frequency range. But when we saw variation of thin film for high frequency it shows increase with more rate than bulk film [8].

More recently such conductivity increase with frequency has been measured for the thin gold film (9–20 nm) on 0.04 mm thick Kapton substrate in the X-band [9].

We know bulk Conductivity of Gold is 4.8 _ 107 at 295 k temperature. Also we have taken into acoount dispersive conductivity bahviour of thin film metals. Thin Gold film static conductivity is less than bulk at the same temperature. As frequency increases conductivity of thin film shows a slight incraese with frequency shown in Eq. (4), this equation for dispersive Conductivity is suggested by Konno [10]. Here we have considered Kirschinning and Jensen model [11] model for dispersive effective relative permitivity.

We suggest the value of Co = 0.0005 (empirical value) for conductor loss calculation for TFML in this range. This gives more accuracy towards experimental results.

Results

We have shown results of this comparison between losses from closed form model including effect of adhesive layer and without adhesive layer in comparison to measured attenuation for the

structure in figures below. We have shown comparison of conductor loss experimental [2] (without adhesive layer) & Model with adhesion layer and without adhesion layer of Titanium film of 200 Angstrom with Gold film of thickness 1.3um on Polyimide substrate. Relative permittivity 3.12 of 7.4 um thickness and strip width is varied from 5, 7.1, 9.5, 12.5, 16.4, and 34.4 um. We have separated the conductor loss from measured loss by taking % contribution of conductor loss in structures on 3D EM simulator [12].

This paper presents results for strip widths i.e. w = 5um in Fig. 1, w = 12.5 um in Fig. 2 and w = 34.4 um in Fig. 3 with strip thickness 1.3 um on DuPont PI-2611(Polyimide) substrate of thickness 7.4 um. Here we have experimental or measured results for frequency from 1 GHz to 100 GHz. We have extrapolated the results using our suggested model up to 1000 GHz.

We can see from Figs. 2, 3 and 4 that for smaller frequencies i.e. in Microwave range (1 GHz to 100 GHz) contribution of adhesion layer losses are relatively lesser as compared to terahertz range i.e. from 100 GHz to 1000 GHz.

We have also calculated the ratio of effective conductor loss due to adhesive layer to conductor loss without adhesive layer for first structure.

In Fig. 5 we can see that the sharp increase in loss is viewed at 1000 GHz i.e. about 27% (Ratio = 1.27) increase of conductor loss than without adhesive layer. Below 100 GHz the increase in loss is below 3% i.e. ratio is about 1.029.

These results can be used to have an estimation of attenuation of signal over a wide range of frequency for device fabrication using thin film Microstrip line with adhesion layer.

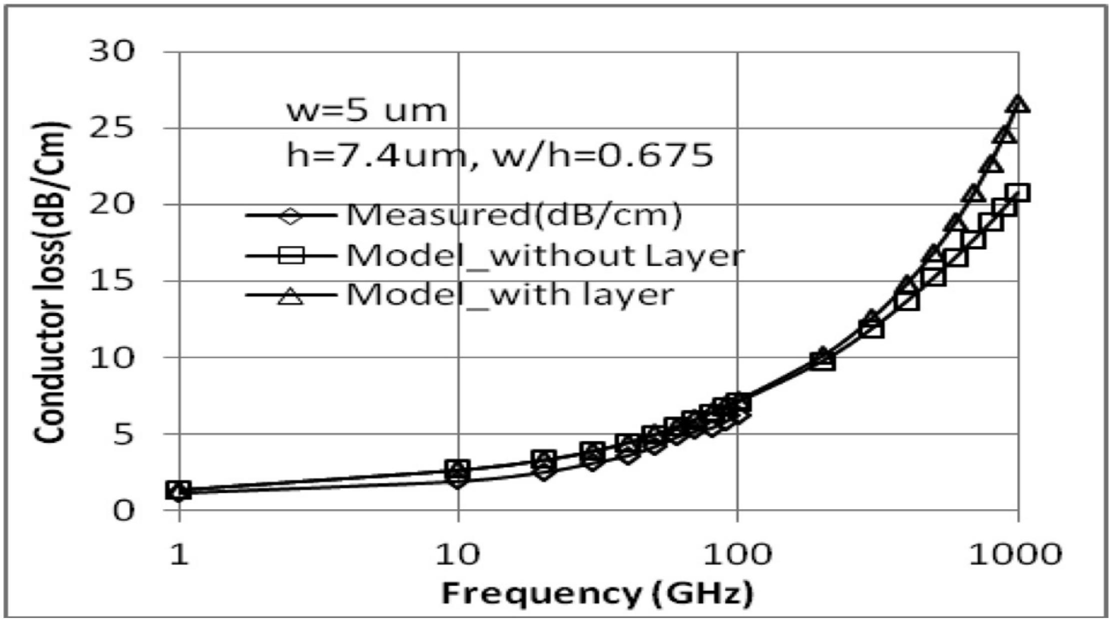

Fig. 2. Conductor loss for w = 5um.

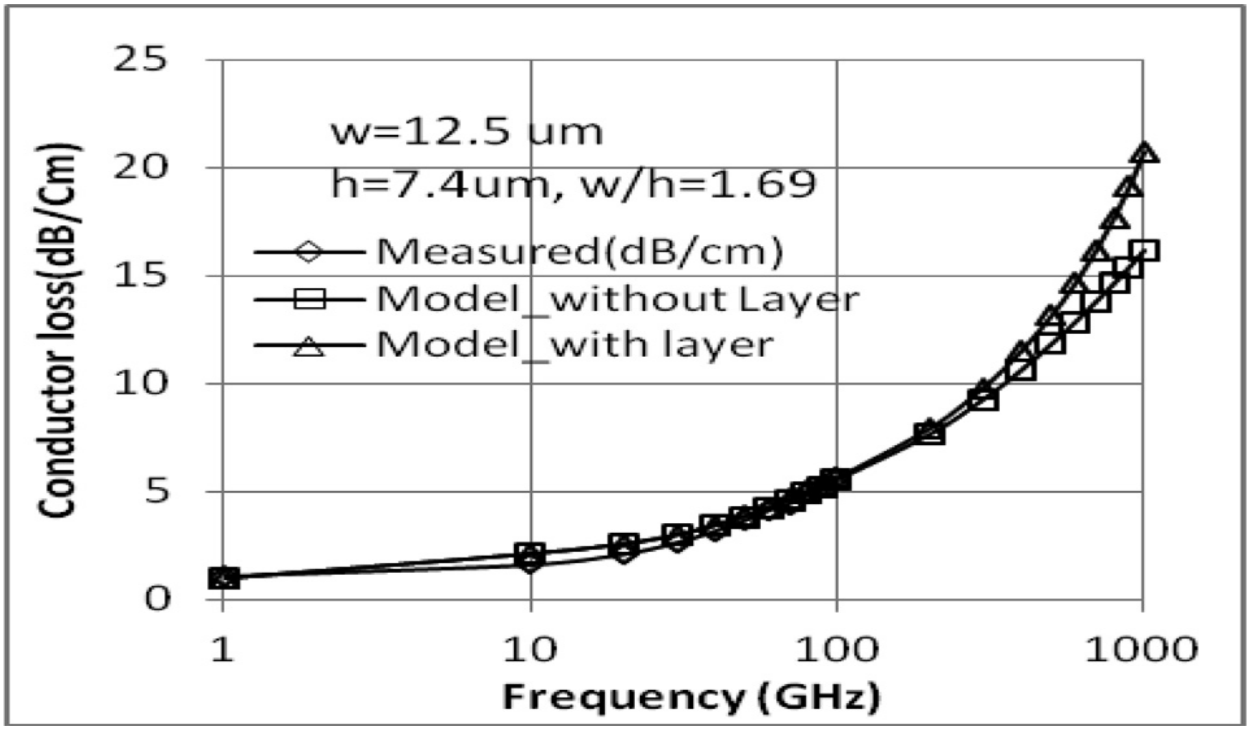

Fig. 3. Conductor loss for w = 12.5um.

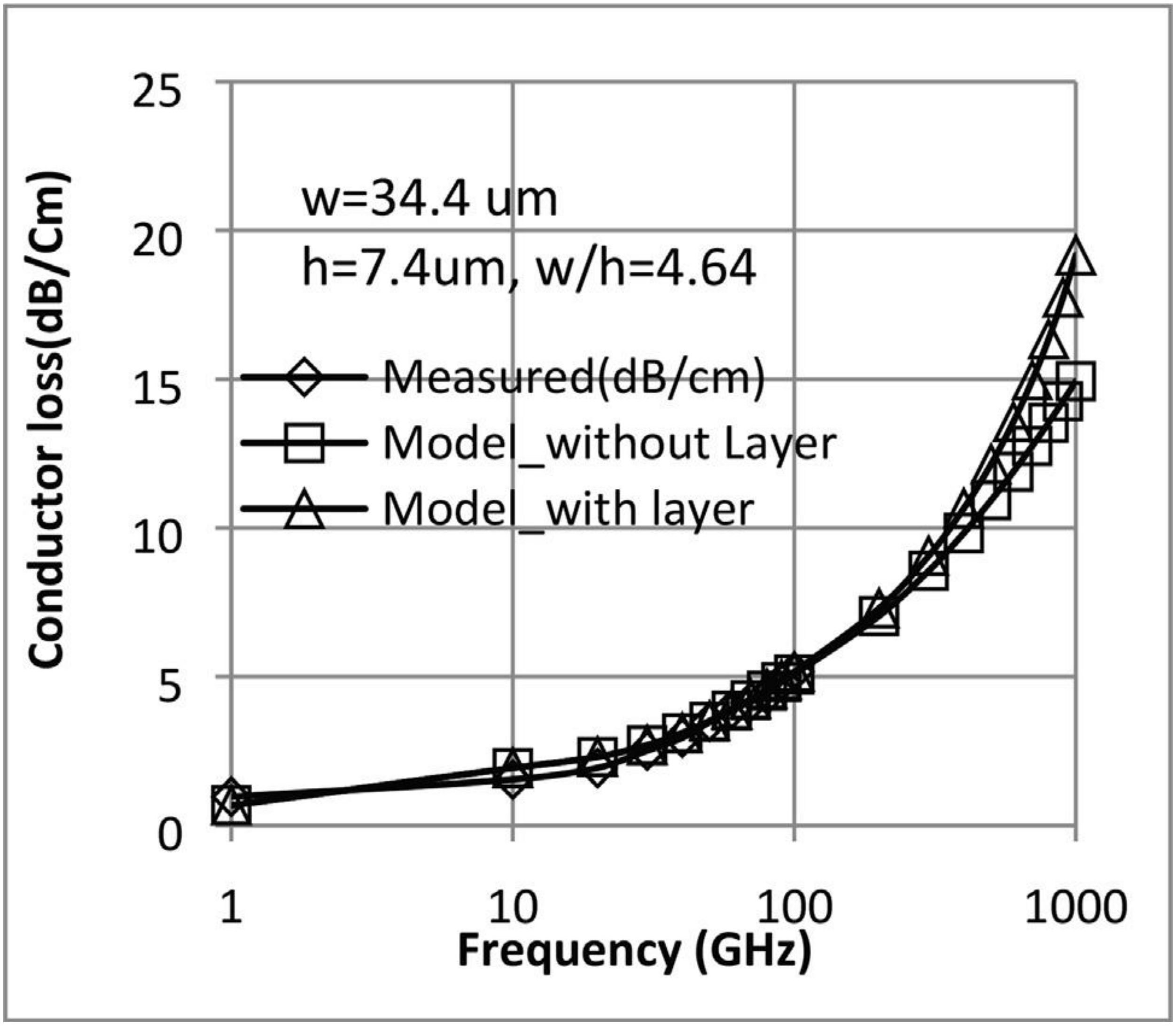

Fig 4. Conductor loss for w = 34.4um.

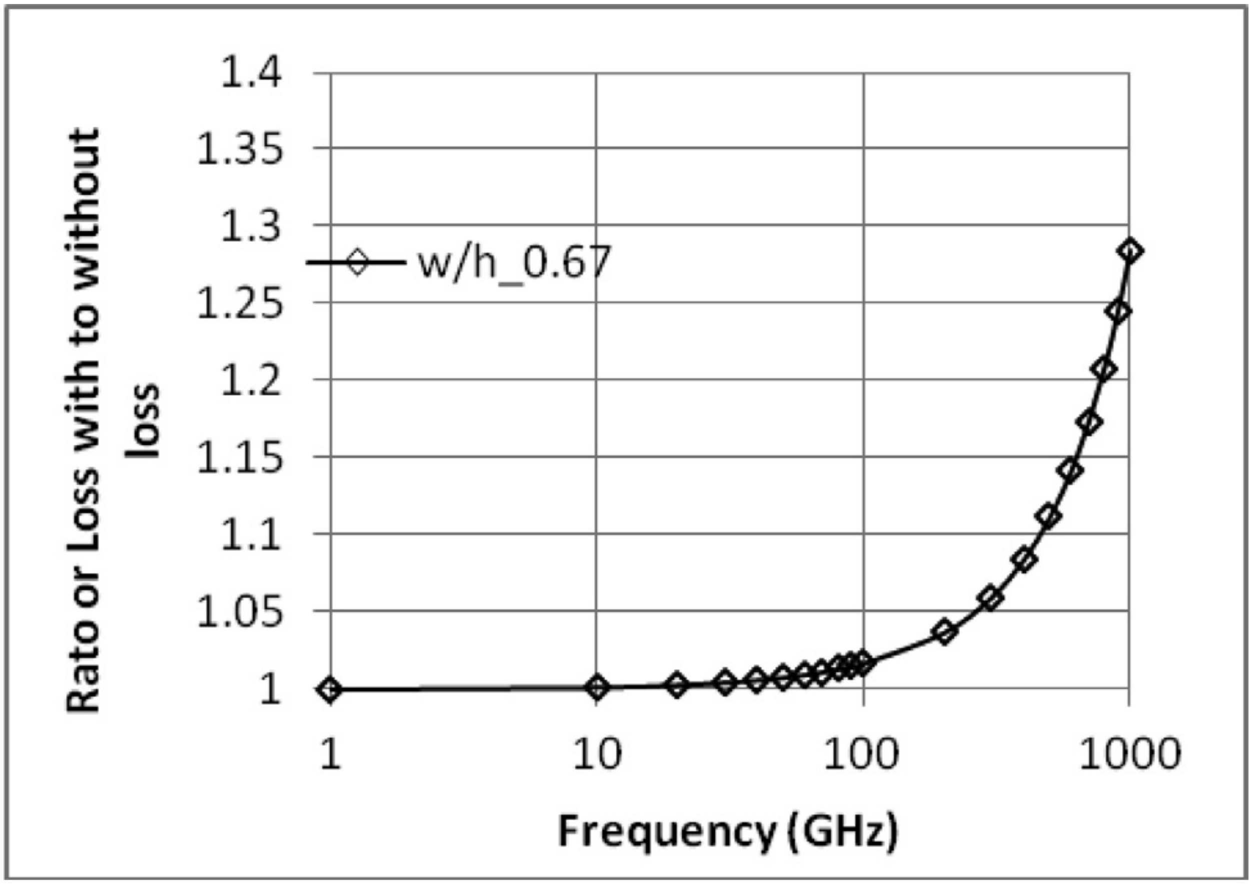

Fig. 5. Ratio of Conductor loss with layer to without adhesion layer for different w/ h ratio.

CONCLUSION

We have shown how the losses caused by adhesion layer presence vary over frequency range from 1 GHz to 1000 GHz for various structures. The conductor strip in this instance is made of a thin gold film with a thickness of 1.3 um and a conductivity of 4.5x107 S/m, and an adhesive layer made of titanium with a thickness of 200 Angstrom and a conductivity of 2.38x106 S/m. This paper comes to the conclusion that, when we assume the adhesion layer's thickness to be greater than the skin depth in that frequency range and with high conductivity, losses due to adhesion layer in the terahertz frequency range increase very sharply at 1000 GHz observed analytically and in the microwave range losses due to such adhesion layer films are below 3%. Because of the adhesion layer in the microwave range, this reduces losses in the TFML structure.

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