A Novel Method of Metallization for MMIC's

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Abstract—**A modified electroless method is described which may be a potential alternative to the conventional metallization techniques for monolithic microwave integrated circuit (MMIC's). The measured loss performance of microstriplines fabricated from the new metallization revealed its superiority over the traditional methods. Experimental results are also compared with the theoretically computed results in the frequency range 2-12 GHz.**

I. Introduction

GALLIUM arsenide has become the basic material for monolithic microwave integrated circuits (MMIC's), where both active and passive devices are combined on the same chip. The reason behind it is that, in its semi-insulating form, GaAs can be a low-loss dielectric. GaAs MMIC's have advantages over conventional hybrid circuits in terms of lower weight, smaller size, lower cost, and higher reliability [1]. For direct broadcast satellite systems, monolithic structures on GaAs substrates promise tremendous potential for future applications.

Sputtering and evaporation are the two conventional processes used for GaAs metallization. Metal deposition by these widely used techniques have the following limitations [2].

1) The capital cost of the equipment required for conventional methods (i.e., evaporation and sputtering) is high
2) It takes time to achieve the required vacuum before the deposition of metal.
3) The equipment presents numerous maintenance problems.
4) Materials sputtered or evaporated not only deposit on the substrate but also throughout the dome of the system and fixtures inside it.
5) Both sides of the substrate cannot be coated at the same time.

Electroless plating was found to overcome the above limitations. Only a few chemicals are required, less machine maintenance is needed, and the procedure is simple. Without any metal waste, both sides of the substrate can be coated in one operation. Thus total time required to coat a substrate is considerably less than that in the conventional techniques.

Electroless processes are especially appropriate for plating nonconductive materials such as semi-insulating GaAs. Such a process has been used to plate "via" holes as well as backside of MMIC's. Vertical "vias" are more difficult to plate by the sputtering. Such holes can be plated using the electroless method [3]. Until now, no attention has been given to the fabrication of components on semi-insulating GaAs using an electroless technique, though this technique has been used on alumina for fabricating MIC components.

In order to evaluate the microwave behavior of different metallization techniques for MMIC's, several microstriplines have been fabricated to measure their loss behavior. An important electrical property of an MMIC is the attenuation of the microstripline. The aim of the present work is to make a comparative study of the attenuation properties of microstriplines fabricated by a conventional vacuum technique and the new modified electroless method.

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II. The New Metallization Method

The electroless technique described in [4] can be used for nickel deposition, but this technique is complex and troublesome, requiring surface activation by a compound such as $PdCl_2$. In an attempt to simplify the processing of the semi-insulating GaAs substrates, a new modified electroless method has been employed. The salient feature of the technique was the elimination of $PdCl_2$. In the conventional technique, nickel ions are formed as a result of reduction of nickel solution in the presence of a catalyst (viz., Pd). Here, in the case of GaAs, one of the components (i.e., Ga) displaces nickel from its solution. Once the initial few nuclei of nickel are formed, further deposition will be catalyzed by nickel's self-catalytic action. The plating ceases after a particular thickness of nickel is formed. The maximum thickness achieved was only 400–500 Å for the bath composition given in [4].

Prior to metallization with the new metallization method, semi-insulating GaAs (100) wafers were cleaned sequentially using trichloroethylene, acetone, and methanol. The principal objective behind this cleaning process was to remove the extraneous contaminations present on the wafers. Then, native oxide layers on GaAs were removed by wet etching using $NH_4OH/H_2O_2/H_2O$ etchant. The residual native oxide was etched by dipping the wafer in a solution of dilute HCl. Finally, the wafers were rinsed with deionized water.

A nickel film (300 Å) was deposited on the cleaned and etched surfaces. Subsequently, a gold layer (1000 Å) was deposited by using $KAu(CN)_2$ and hydrazine hydrate bath at a temperature of 95–98°C. The metallized substrates were then annealed at 200–225°C for 30 min. The coating adhesion was tested on small representative samples destructively by using adhesive tape as well as by scratching the metallization with a probe tip.

Because of the application of heat in this novel method, the rate of the metal deposition was increased. Elimination of

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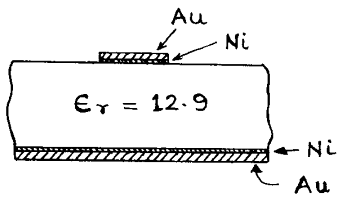
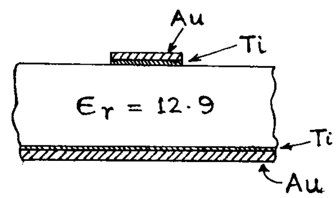
TABLE I
ELECTROLESS AND SPUTTERED MICROSTRIP DATA

ELECTROLESS MICROSTRIP DATA	SPUTTERED MICROSTRIP DATA
	
Thickness of electroless nickel = 300 Å	Thickness of sputtered titanium = 300 Å
Thickness of electroless gold = 1000 Å	Thickness of sputtered sputtered gold = 1000 Å
Thickness of gold after plating = 3 micron	Thickness of gold after plating = 3 micron

surface activation by $PdCl_2$ also simplifies the complexity of the deposition process. Adhesion of the metal to substrate is very good.

III. Fabrication of Microstriplines

In order to ascertain the usefulness of the above electroless method, a comparative study of the attenuation properties of microstriplines fabricated using different metallization methods was done. Twenty semi-insulating GaAs wafers (thickness = 500 μm) were coated by the new electroless method. Metallization of another 20 pieces were done by the sputtering technique.

The metallization for the microstriplines must be sufficiently thick to carry the required current without significant ohmic losses. It should be at least two skin depths thick. Further, the conductor loss may be moderately increased if the conductor is too thick [6]. There exists an optimum thickness of approximately three skin depths (~ 3 μm for gold at 10 GHz) [3]. Thus after electroless plating and sputtering of gold, electroplating was done to increase the thickness of the gold layer to 3 μm. Table I gives the sputtered and electroless microstrip data.

IV. Measurement of Attenuation

Attenuation measurements on several microstriplines fabricated from conventional metallization and the new electroless metallization were carried out in the frequency range 2–12 GHz using a Wiltron network analyzer. The fixture losses were eliminated from the experimentally measured attenuation values for two different lengths of microstriplines by subtraction from the measured results. The attenuation for a known length of the line, and hence, the attenuation per unit length of the microstriplines were obtained. Fig. 1 represents the attenuation characteristics of the microstriplines fabricated from sputtered and electroless substrates. Each experimental point presents a mean of the attenuation values measured on seven substrates. In Fig. 1 experimental values were also compared with theoretically predicted values computed using the formula provided by Pucel *et al.* [7].

V. Discussions

It has been observed through experiments performed on the above system that the attenuation characteristics are better than those deposited by conventional methods (e.g., sputtering) for MMIC's. Experimentally determined attenuation values agree well with the theoretical values. Apart from this, five couplers and four power dividers were also fabricated by using the technique and their performance was also found to be good.

VI. Conclusions

The principal attraction of the MMIC is its potential for cost reduction in volume production. From our experimental studies, it can be concluded that the modified electroless method is a suitable alternative to the conventional vacuum techniques for fabricating passive MMIC components. Moreover, all aspects of this metallization are compatible with the MMIC processing techniques.

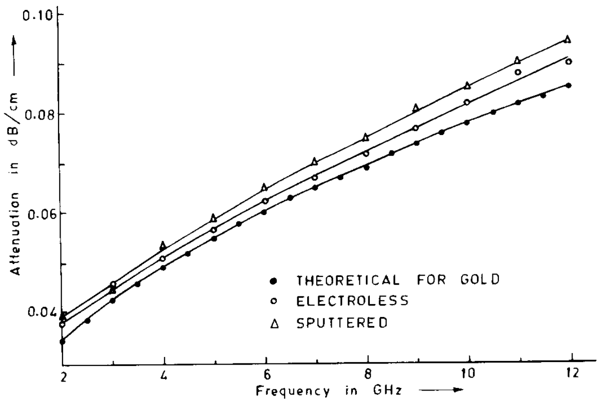


Fig. 1. Measured attenuation versus frequency for sputtered and electroless microstriplines with computed values for gold.

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