Progress In Electromagnetics Research Letters, Vol. 30, 145–152, 2012

EFFECT OF AMORPHOUS, NONMAGNETIC BARRIER LAYER ON THE PERFORMANCE OF A MULTISECTION WILKINSON BROADBAND POWER DIVIDER

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Abstract—A four-layer metallization Cr-Cu-NiP-Au with amorphous and nonmagnetic NiP as a barrier layer is one of the promising candidates for use in microwave integrated circuits. Multi-section Wilkinson broadband 1 : 2 power divider circuits are delineated photolithographically on alumina substrates metallized by Cr, TiW, Ni, NiP, copper and gold using different metallization processes. The adhesion and dc resistivity are compared for different metallization scheme. Testing and evaluation have been carried out for multi-section Wilkinson broadband 1 : 2 power divider in the 10 MHz–6 GHz frequency range for Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au to see the effect of NiP. Insertion loss, return loss and isolation are measured and compared. The microwave properties do not show any appreciable differences due to the various metallizations.

1. INTRODUCTION

Electroless nickel plating is used in integrated circuit (IC) interconnections [1], micro-electro-mechanical systems (MEMS) devices [2] and printed circuit boards (PCBs) [3]. In general, sputtered and electrochemically deposited Ni have been used as a barrier layer between Au and Cu in electronic connectors, solder interconnections, and multichip electronic packaging [4] to retard diffusion of copper to the gold surface [5]. Diffusion barrier properties of electrochemically deposited Ni, and the Au/Ni/Cu system were studied [6] and some authors claimed that only electroless-deposited NiP, CoP, and NiCoP alloys have barrier properties for Cu diffusion. In addition, electroless-deposited barriers were compared with Ni and Co barriers produced by electrodeposition or evaporation and were proved to have superior barrier function because for example in case of NiP introduction of P atoms can stuff the

Received 11 February 2012, Accepted 8 March 2012, Scheduled 15 March 2012
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void in the grain boundaries of Ni film, whereby improving its barrier function.

Not only Electroless nickel acts a barrier layer but also it provides very good protection against corrosion [7], a high abrasion resistance, a good adhesion with most metals which makes it an excellent surface finishing [8], a very conformal film structure without the influence of electric field or overhang problems and therefore is suitable for fabricating an ultra-thin barrier for Cu interconnects. NiP layer is also thermally very stable [9] and it also provides more uniform thickness distribution in comparison to electroplating [6].

Even if electroless nickel plating is used in electronics, but no attention has been given about the MICs based on Cr-Cu-NiP-Au metallized alumina substrates for space applications. In this work, performance of the broadband power divider realized on metallization Cr-Cu-NiP-Au is compared to that of realized on Cr-Cu-Au and TiW-Ni-Au metallized alumina substrate to evaluate the effect of NiP on the performance of broadband power divider.

2. EXPERIMENTAL METHOD

In the reaction the deposited nickel is not provided by an anode but by some nickel salt. The salt is dissolved in the aqueous solution resulting ionic nickel. The nickel ions are then reduced by the electrons not provided by an external current source but by a reducing agent also dissolved into the solution. Complete electroless nickel deposition process is described somewhere else [10]. On sputtered on Cr-Cu metallized alumina substrate NiP is deposited followed by 2 μ gold layer. For TiW-Ni-Au and Cr-Cu-Au metallization, sputtering technique was used and electroplating was further used to increase the thickness of gold.

Several techniques of characterization tools were employed for analysis and measurement. Adhesion test for adhesion, dc four-probe method for sheet resistance. X-ray diffraction and gravimetric analysis were used for microstructural characterization for composition analysis respectively. A network analyzer was used to collect full, two-port S-parameters.

3. RESULTS AND DISCUSSION

3.1. Adhesion Test and DC Resistivity

Sheet resistivity of all samples was measured by DC four-probe method. Adhesion was tested destructively after engraving the

Table 1. Comparison of adhesion strength and DC resistivity.

	Metallization		
	TiW-Ni-Au	Cr-Cu-Au	Cr-Cu-NiP-Au
adhesion strength	$> 590\,\mathrm{kg/cm^2}$	$> 480\,\mathrm{kg/cm^2}$	$> 694\,\mathrm{kg/cm^2}$
DC resistivity	$0.0055\,\Omega/\square$	$0.0045\,\Omega/\square$	$0.0045\,\Omega/\square$

adhesion pattern by stud pull test method. Adhesion strength and sheet resistivity are shown in Table 1.

3.2. XRD and Gravimetric Analysis

Figure 1 shows the XRD patterns of Cr-Cu-NiP metallized alumina substrate. The sharp intense peaks of Cu and alumina have been observed so diffraction peaks can be indexed to alumina and copper. A broad and weak peak is observed at 45° which mean that NiP is amorphous. Gravimetric analysis is used for compositional analysis and phosphorus content was found to be 8–10%. NiP with 8–10% phosphorus is nonmagnetic [11, 12].

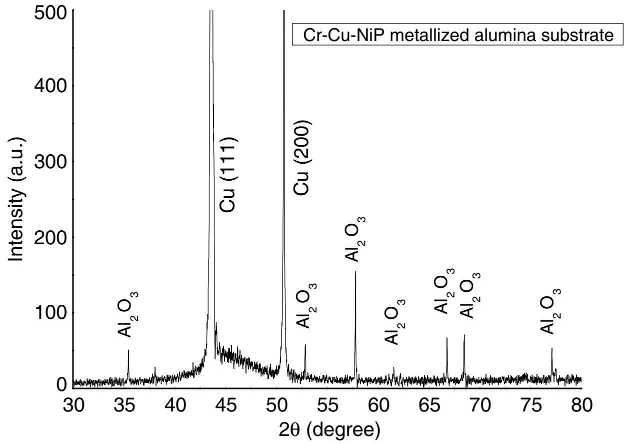

Figure 1. XRD pattern of the Cr-Cu-NiP metallized alumina substrate.

3.3. Microwave Characterization

A multi-section broadband Wilkinson power divider was fabricated on the TiW-Ni-Au, Cr-Cu-Au and Cr-Cu-NiP-Au metallized alumina substrate. Layout of fabricated multi-section broadband Wilkinson

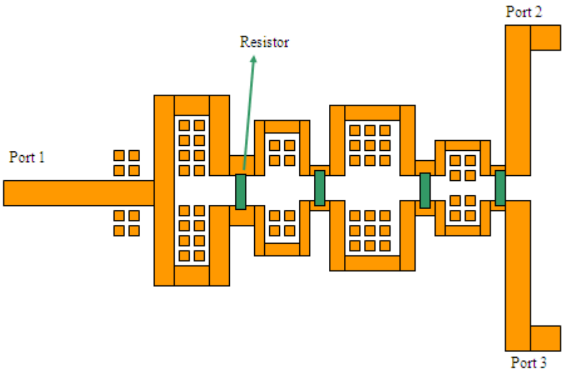

Figure 2. Layouts of the multi-section broadband Wilkinson power divider.

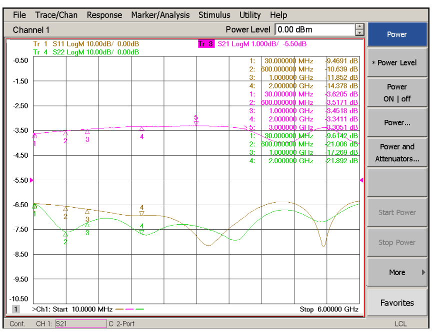

Figure 3. S_{11}, S_{22} and S_{21} vs. frequency.

Figure 4. S_{11}, S_{22} and S_{21} vs. frequency.

power divider on metallized alumina substrate is shown in Figure 2. The dimension of the broadband Wilkinson power divider is 25 mm $*$ 14 mm, so the whole micro stripe circuit is confined within a 1 inch $*$ 1 inch substrate. Resistors of 2.5 mm $*$ 1.2 mm size are used. The design methodology of the fabricated power divider is given in Reference [13]. Isolation, insertion and return loss were measured across a range of frequencies (10 MHz to 6 GHz) in decibels using a two-port network analyzer along with an attenuator of 60-dB (with a characteristic impedance 50 Ohms for third port). S_{11}, S_{22} and S_{21} are presented as dB vs. GHz for Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au metallization in Figures 3, 4 and 5 respectively. S_{11}, S_{33} and S_{31} are also measured and presented as dB vs. GHz for Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au metallization in Figures 6, 7 and 8 respectively (in Figure number 6, 7 & 8, S_{22} is S_{33} and S_{21} is S_{31}).

Figure 5. S_{11}, S_{22} and S_{21} vs. frequency.

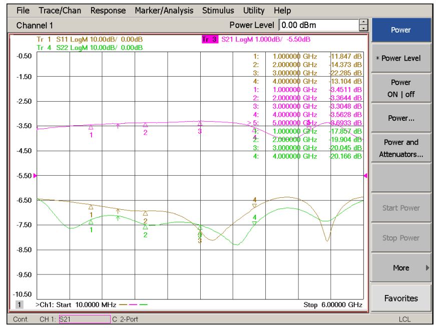

Figure 6. S_{11}, S_{33} and S_{31} vs. frequency.

Figure 7. S_{11}, S_{33} and S_{31} vs. frequency.

Figure 8. S_{11}, S_{33} and S_{31} vs. frequency.

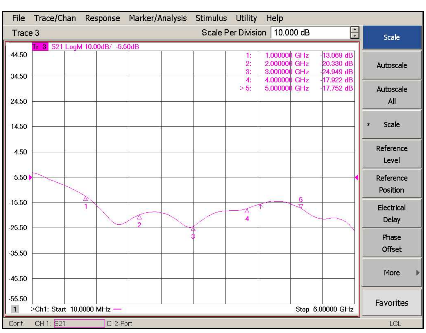

Figure 9. S_{23} vs. frequency.

Figure 10. S_{23} vs. frequency.

Finally, S_{23} is presented as dB vs. GHz for Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au metallization in Figures 9, 10 and 11 respectively. Input & output return loss, insertion loss and isolation ($|S_{23}|$) were

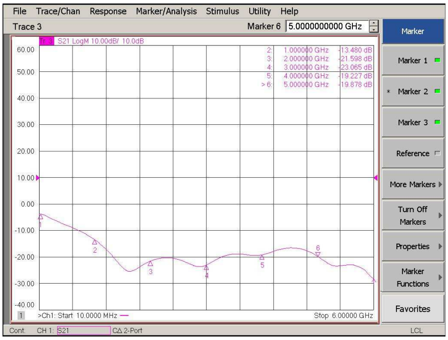

Figure 11. S_{23} vs. frequency.

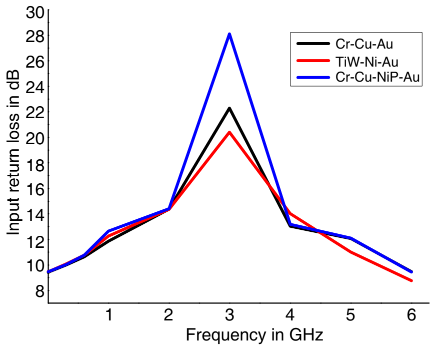

Figure 12. Input return loss vs. frequency.

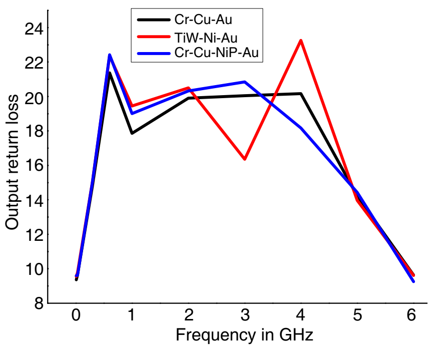

Figure 13. Output return loss vs. frequency.

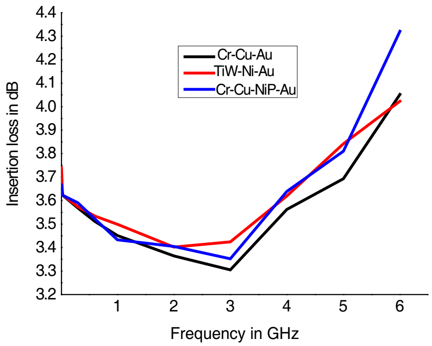

Figure 14. Insertion loss vs. frequency.

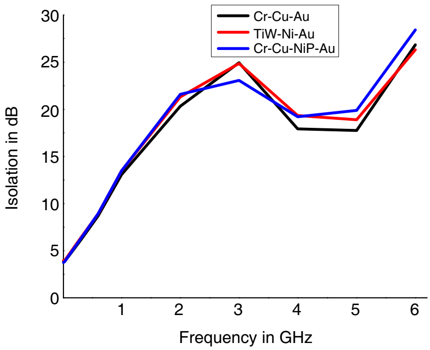

Figure 15. Isolation vs. frequency.

Table 2. Working centre frequency and bandwidth.

Metallization scheme	Centre frequency	Bandwidth
Cr-Cu-Au	2.25 GHz	3.5 GHz
TiW-Ni-Au	2.20 GHz	3.6 GHz
Cr-Cu-NiP-Au	2.20 GHz	3.6 GHz

compared for the same power divider realized on Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au metallized alumina substrate and shown in Figure 12, Figure 13, Figure 14 and Figure 15 respectively. Working centre frequency and bandwidth are given in Table 2. Amplitude imbalance abs (S_{21}–S_{31}) and phase imbalance abs (phase (S_{21})-phase (S_{31})) are approximately same for all three Cr-Cu-Au, TiW-Ni-Au and Cr-Cu-NiP-Au metallization. From this experiment, we conclude that presence of NiP in between Cu and Au is not degrading the performance of broadband power divider.

4. CONCLUSIONS

No degradations were observed in performance of the power divider realized on Cr-Cu-NiP-Au metallized substrate with amorphous barrier layer in comparison to Cr-Cu-Au and TiW-Ni-Au in terms of insertion loss, return loss and isolation in the frequency range 10 MHz–6 GHz. Amorphous NiP barrier layer does not affect the performance of a broadband power divider. Ni also does not degrade the performance of broadband power divider. In Cr-Cu-NiP-Au metallization scheme, NiP can be plated directly on the top of the Cu followed by gold which is not possible in the case of Cr-Cu-Au and TiW-Ni-Au because for Cr-Cu-Au and TiW-Ni-Au metallization, gold plating requires sputtered gold before gold plating. Therefore, from fabrication point of view, Cr-Cu-NiP-Au metallization scheme is reducing the limitation of physical deposition techniques.

ACKNOWLEDGMENT

The authors would like to thank Shri Rajkumar Arora, DD ESSA and Shri Apurba Battacharya, GD MEG for their support, motivation, encouragement & valuable discussions. Authors would also like to thank Shri K. S. Parikh, DD SNAA and Shri Surinder Singh, GD RFSG for a critical reading of the manuscript and informative discussions. Authors are grateful to Smt. Pankaj Jain for providing circuit details and Shri Raghunath P V for microwave characterization.

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