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Al-foil-based low-loss coplanar waveguides directly bonded to sapphire substrates

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Abstract

We successfully fabricate coplanar waveguides (CPWs) composed of 17 µm Al foils on sapphire substrates by surface activated bonding (SAB). We demonstrate that transmission and line loss are improved by using Al foils in comparison with CPWs composed of evaporated Al films. The obtained results imply that CPWs with better performances are realized by using SAB.

1. Introduction

Low-loss transmission lines are strongly required in microwave monolithic integrated circuits (MMICs) [1] since their performances are limited by the characteristics of the transmission lines. Given that the loss of transmission lines at several ten GHz is determined by the dielectric properties of substrates (dielectric loss) and the resistance of metal layers (ohmic loss), transmission lines with thicker metal layers are strongly required. The bonding of metal foils using adhesives or resin, which are generally employed in fabricating transmission lines on boards, should be avoided in the on-wafer process. Consequently, such thick metal layers are mainly fabricated by means of the high-speed deposition, sputtering, or electroplating. We have to note, however, that the thickness of metal layers in the above cases determines the period of processing and hence the cost.

In this study, we directly bond Al foils to sapphire substrates by using surface activated bonding (SAB) [2] and fabricate coplanar waveguides (CPWs) [3-4]. It is noteworthy that the period of the SAB process does not depend on the thickness of bonded metal foils. The RF characteristics of fabricated CPWs are compared with those of CPWs made using Al layers evaporated on sapphire substrates.

2. Experimental Procedure

We bonded 17-µm thick Al foils on sapphire substrates without heating. The thickness of the sapphire substrates was approximately 420 µm. The resistivity at room temperature of Al foils was estimated to be $\approx 3.0\times10^{-6}\ \Omega\cdot$cm. We fabricated CPWs, hereafter referred to as CPW-A, by using the conventional photolithography and wet etching of Al. A mixture of H_3PO_4, HNO_3, CH_3COOH, and H_2O was used as etchant. The layout of CPWs is schematically shown in Fig. 1(a). The signal line width (W in Fig. 1(a)) and slot width (S in Fig. 1(a)) of CPW-A were preset to be 100 and 50 µm, respectively so as to obtain a characteristic impedance of 50 Ω. We also prepared another type of CPWs, or CPW-B, by wet etching of 0.1-µm thick Al layers evaporated on sapphire substrates. The resistivity of the evaporated Al layers was $\approx 3.2\times10^{-5}\Omega\cdot$cm. Note that we have a large (~1000 times) difference in sheet resistances between the Al foils and evaporated Al layers. The larger resistivity of the evaporated Al layers was likely to be due to their smaller Al grains. W and S of CPW-B were nominally 110 and 40 µm, respectively, because of the difference in thicknesses of metal layers. Table I summarizes the parameters of CPW-A and CPW-B.
The lengths of fabricated CPWs were between 3 and 11 mm. A view of 11-mm-long meander-shaped CPW-A is shown in Fig. 1(b) as an example. We measured their S-parameters between 0.5 and 40 GHz using a network analyzer.

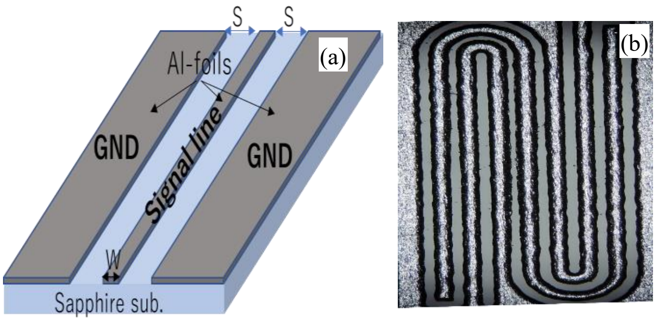

Fig. 1 (a) The layout of CPW composed of Al foils bonded on sapphire substrates. (b) A top view of 11-mm meander-shaped CPWs made of Al foils.

Table I Parameters of CPW-A and CPW-B.

	CPW-A (Al foil)	CPW-B (Al evap.)
Signal line width	100 µm	110 µm
Slot width	50 µm	40 µm
Metal thickness	17 µm	0.1 µm
Resistivity of Al	$3.0\times10^{-6}\ \Omega\cdot$cm	$3.2\times10^{-5}\ \Omega\cdot$cm

3. Results and Discussion

Figures 2(a) and 2(b) compare the transmission characteristics (|S21|) of 3-mm and 11-mm long CPWs, respectively. In case of 3-mm long CPWs, |S21| of CPW-A was ≥ -3dB, while that of CPW-B was ≈ -10 dB at 40 GHz, as is shown in Fig. 2(a). For 11-mm long CPWs, |S21| of CPW-A was still ≥ -3dB over the almost entire frequency range. |S21| of CPW-B was, however, as small as -20 dB at 40 GHz, which means that the transmission loss of longer CPW-B was larger.

The difference in |S21| between the two types of CPWs is clearly attributed to the markedly ($\times\sim 1/1000$) smaller sheet resistance of Al foils.

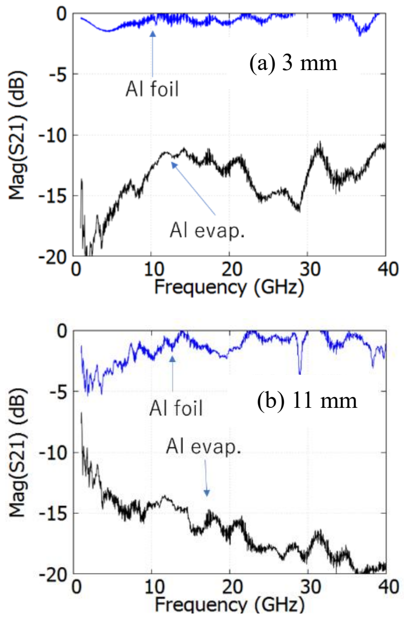

Fig. 2 Transmission characteristics of (a) 3-mm CPWs and (b) 11-mm CPWs.

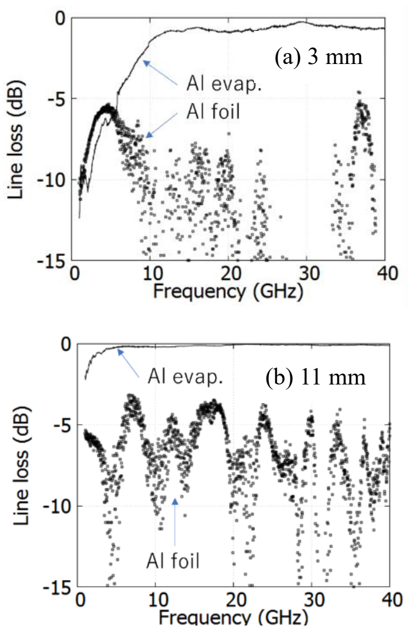

Fig. 3 Line loss characteristics of (a) 3-mm CPWs and (b) 11-mm CPWs.

We obtained the line loss from the S-parameter, which was defined as

$$\text{Line Loss} = 10 \times \log_{10}\left(1 - |S11|^2 - |S21|^2\right)\ (\text{dB}). \quad (1)$$

Figures 3(a) and 3(b) compare the line loss [4] characteristics of CPW-A and CPW-B for the respective waveguide lengths.

In accordance with the behaviors of |S21|, the line loss of CPW-B was approximately 0 dB in each figure, which indicated that the majority of incident powers was dissipated inside of CPWs. The line loss of CPW-A was much smaller than that of CPW-B. However, the loss in CPW-A was not negligible and the larger loss was observed for the longer CPWs. It was possibly because the impedance matching was not achieved due to the side etching in the Al foils.

We also analyzed the dependencies of the phase of S21 on the frequency and estimated the phase velocity (v_p) of transmitted signals. We found that $v_p \approx 1.3\times10^8$ m/s both in CPW-A and CPW-B.

4. Conclusions

We fabricated CPWs composed of 17-µm-thick Al foils on sapphire substrates by SAB, and measured their S-parameters up to 40 GHz. We found that their insertion loss and line loss were much smaller than those of CPWs based on 0.1-µm evaporated Al layers. The lower-loss properties of the Al-foil-based CPWs were attributed to the ~1000 times difference in sheet resistances between the Al foils and evaporated Al layers. The results indicate that CPWs made of metal foils provide practical solution for lower-loss interconnects at high-frequency (~several ten GHz) regions.

Acknowledgement

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References

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