Copper Airbridged Low Noise GaAs PHEMT with WN_x as the Diffusion Barrier

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Keywords: copper metallization, LNA, PHEMT

Abstract

The silicon nitride passivated copper-metallized airbridges had been successfully integrated on the low noise PHEMT (Pseudomorphic High Electron Mobility Transistor) using WN_x as the diffusion barrier between copper and the conventional gold based electrodes. 400 Å PECVD (Plasma Enhanced Chemical Vapor Deposition) silicon nitride was used for copper airbridge passivation to avoid the copper oxidation. The 0.25×160μm^{2}copper-airbridged PHEMT device shows a transconductance of 480mS/mm and a noise figure of 0.76 dB with an associated gain of 10.4 dB at 12 GHz. The device performance is comparable to devices with gold-metallized airbridges. The performance did not degrade after annealing at 250°C for 20 hours. This study shows promising results for copper metallization of GaAs devices in the future.

INTRODUCTION

Copper metallization process has been widely used in silicon integrated circuit industry in recent years[1]-[3]. However, only a few studies of copper metallization process on GaAs device were reported in the past [4]-[6]. In this paper WNx was used as the diffusion barrier for silicon nitride passivated copper airbridged AlGaAs/InGaAs low noise pseudomorphic high electron mobility transistors (LN-PHEMTs).

Traditionally, plated gold was used for airbridges on GaAs devices, including metal-semiconductor field-effect transistors (MESFETs) and high-electron-mobility transistors (HEMTs). Plated gold has high electrical conductivity, is resistant to oxidation and is ductile. However, gold is expensive which causes the high cost for the GaAs device fabrication. In this work, copper replaces gold as the material used for the airbridges in the GaAs PHEMT's and WNx was used as the diffusion barrier between gold based electrodes and copper airbridges. Plasma enhanced chemical vapor deposition (PECVD) silicon nitride layer was used to passivate the copper airbridges to prevent the copper oxidation after long term use. A PHEMT device with gold airbridges was also processed for performance comparison. The goal is to develop a copper metallized GaAs device with longterm reliability for industry applications.

EXPERIMENTAL

The low noise PHEMT's were grown by molecular beam epitaxy (MBE) on a 3-inch (100) oriented semi-insulating GaAs substrate. The epi-layers of the device, from the bottom to the top, are composed of a 600nm buffer, a 15nm InGaAs channel, a 2nm undoped AlGaAs spacer, a 42nm Si-doped AlGaAs donor layer and a 45nm Si-doped GaAs capping layer.

After mesa isolation, the source and drain ohmic metals (Au/Ge/Ni/Au) were deposited and formed by rapid thermal annealing at 410°C for 20sec. T-shaped Ti/Pt/Au gates were fabricated by electron beam direct writer and lift-off process. The gate length was 0.25μm. The first passivation of silicon nitride was deposited on the device by plasma enhanced chemical vapor deposition (PECVD) process at a substrate temperature of 250°C. The nitride via was plasma-etched by CF_4/O_2 gases.

The photo resist thickness of the first airbridge layer determines the spacing between the bridge and the materials beneath. Hence, the thickness of the selected resist in this layer should be thick enough to reduce parasitic coupling effect during high frequency operation. In this study, the thickness of the first airbridge photoresist was up to 2.6μm. After hard baking of the resist, the thin film layers, including the diffusion barrier and the Cu seed layer, were subsequently sputtered on the wafer. A 40nm-thick sputtered WNx was used as the diffusion barrier between the copper and the underlying gold based contacts and a 100nm-thick sputtered copper was used as the seed layer to conduct electrical currents for electroplating. The second photo process of the airbridge process masked the areas beyond the plating area and 2.2μm-thick copper was electroplated on the sputtered Cu layer. After the un-plated areas of the Cu/WNx layers and the resists were removed, the second passivation film of 40nm-thick silicon nitride was deposited on the copper airbridges by 4minutes PECVD at 300°C in order to test the thermal stability and to avoid the copper oxidation. The fabricated copper airbridges on low noise PHEMT are shown in Figure 1. The device characteristics were compared with those plated with conventional gold airbridges in order to evaluate the applicability of the copper airbridges on the low noise PHEMTs. As judged from the data of X-ray diffraction spectroscopy (XRDS), the WNx film between gold-contact and copper was thermally stable even after 400°C 30min annealing, there is no intermetallic diffusion between this material system, as shown in Figure 2.

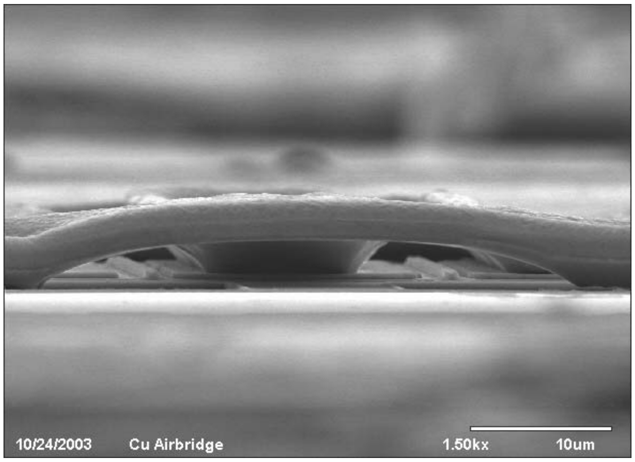

Figure 1. Copper air-bridges on the low noise PHEMT

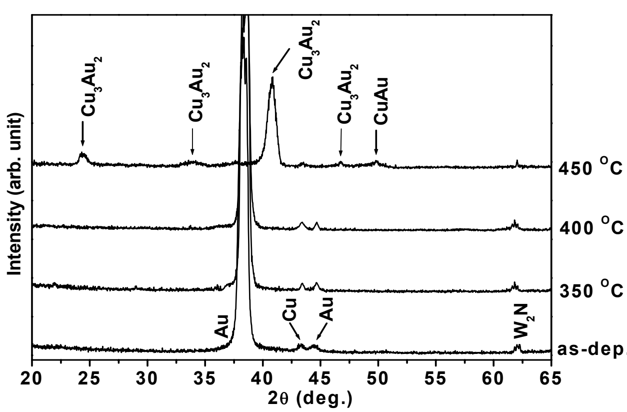

Figure 2. XRDS of Au/WNx/Cu structure with different annealing temperatures

Results

The fabricated low noise PHEMT has a saturation drain current of 200 mA/mm and a transconductance of 480mS/mm at V_{DS}=1.5V. The DC performance shows very little difference between devices fabricated with copper airbridges and gold airbridgse (less than 5% difference in saturation current and transconductance) as shown in Figure 3.

The RF performances of the devices with silicon nitride passivated copper airbridges and gold airbridges were also evaluated and the results are shown in Figure 4 and Figure 5. The noise figure for the 160μm gate-width device was 0.76 dB and the associated gain was 10.4 dB at 12 GHz. The cut-off frequency of the copper airbridged devices was about 70GHz. The device with copper-metallized airbridges showed no degradation even after thermal process, this demonstrated that both the silicon nitride passivation and the WNx diffusion barrier were very stable.

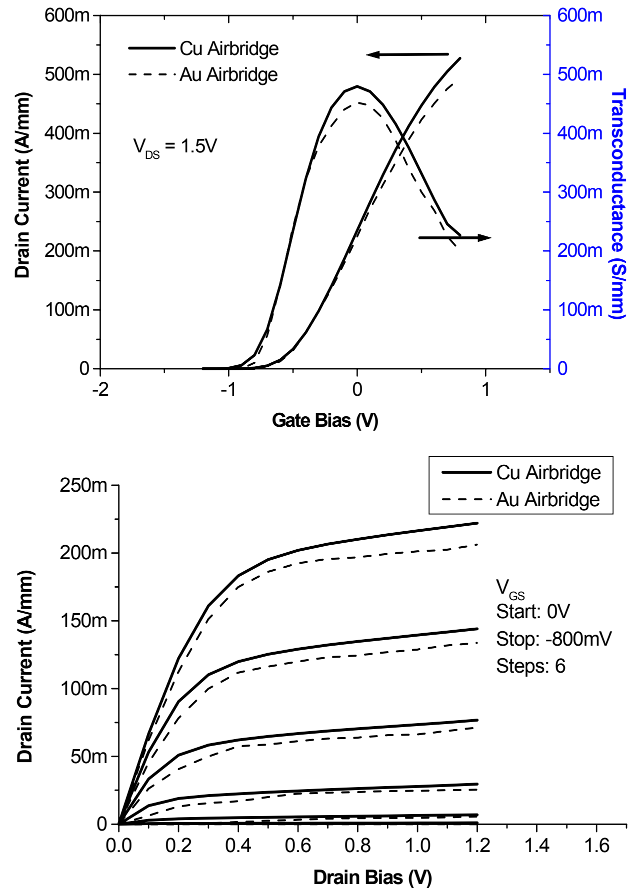

Figure 3. DC characteristics of the devices with copper aitbridges and gold airbridges.

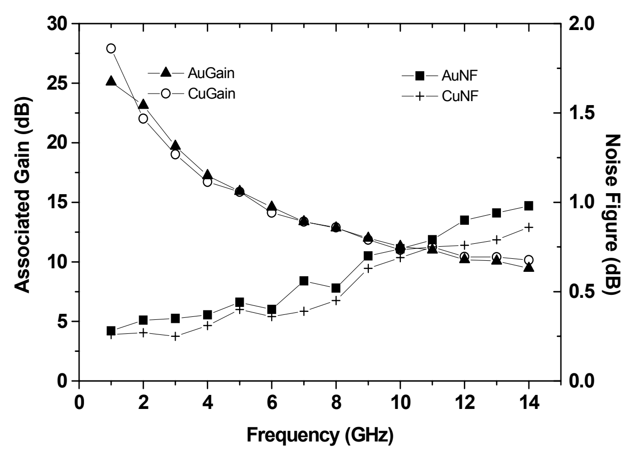

Figure 4. Noise performance of the devices with copper airbridges and gold airbridges

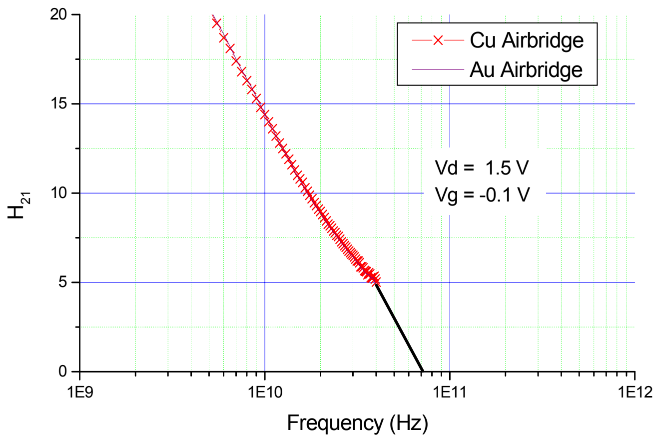

Figure 5. Cut-off frequency of devices with copper and gold airbridge.

CONCLUSIONS

The copper metallized airbridges were successfully applied as the interconnections to the fabrication of the copper airbridged AlGaAs/InGaAs low noise PHEMTs. The fabricated copper airbridged low noise PHEMT with WNx diffusion barrier has a saturation drain current of 200mA/mm and a transconductance of 480mS/mm at V_{DS}=1.5V. Noise figure for the 160µm gate-width device is about 0.76dB and the associated gain is up to 10.4 dB at 12 GHz. The cut-off frequency of the fabricated devices is about 70GHz. The performance of the copper-metallized device was comparable to that of gold-metallized. These results show that tungsten nitride is a thermally stable barrier for copper metallization of GaAs devices and that the copper-metallized airbridges with WNx as the diffusion barrier can be used as the interconnections for the low noise GaAs based PHEMTs.

ACKNOWLEDGEMENTS

The work was sponsored jointly by the Ministry of Education, R.O.C., under the Contract: 89-E-FA06-2-4 and 92-EC-17-A-05-S1-020.

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