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In/AuGeNi/Ag/Au Metallization Ohmic Contacts on n-type GaAs*

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Abstract　A new alloy system, In/AuGeNi/Ag/Au, for GaAs ohmic contact has been proposed and studied in this paper. Our experimental results have shown that this alloy system can not only reduce the ohmic contact resistivity, but also improve the surface morphology of the contact. The typical contact resistivity of In/AuGeNi/Ag/Au metallization to n-type GaAs is $5\times10^{-7}\Omega\cdot cm^2$. Comparing with AuGeNi/Ag/Au metallization, the new system has a thin In layer inserted between AuGeNi and GaAs. It can overcome so called "balling-up" effect, which offen appears in AuGeNi metallization after annealing. In additioin, it was found in our Auger electron spectroscopy profile that Ag can alloy with Au throughout and go into GaAs as well during the annealing at 400℃. It may be helpful to study of the alloy mechanism.

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1　Introduction

The electrical property and surface morphology of metal-semiconductor contacts are critical to the performance of semiconductor devices. As to GaAs devices, such as MESFET and HEMT, lower source resistance (R_s) is needed to obtain higher transconductance and lower noise figure. In general, ohmic contact resistance takes the most part of R_s. To achieve perfect ohmic contacts, not only low ohmic contact resistance but also reliable thermal stability and smooth surface of metallization after annealing are required.

Up to now, various metallization systems for ohmic contacts to GaAs have been studied. AuGeNi system is commonly used to form low resistance ohmic contacts to n-type GaAs[1]. It is mainly because the meatl-semiconductor barrier between AuGeNi and n-type

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GaAs is quite low, less than 0.35eV[2]. AuGeNi also has wide process window by various annealing methods

However, "pits" on the surface of contacts are formed on account of the drastic reaction between Au and GaAs And the phenomenon of balling-up is frequently happened due to the low melting point of AuGe and AuGa formed during annealing[4,8]. Generally, in order to overcome this shortcoming, Ag or Ti, as a diffusion barrier, is inserted between AuGeNi and upper metal Au to improve on the surface roughness of contacts[1].

Several metallization systems without Au have been investigated For example, Murakami, etc have reported the improvement on the surface roughness using NiGe alloyed with n-type GaAs at 600℃[3]. But the ohmic contact resistance is 1.3Ω·mm, much higher than AuGeNi's They have also reported that the ohmic contact resistance was reduced after inserting a third metal layer, such as Au, Ag, Pd, In, between Ge and Ni The lowest contact resistance, 0.28Ω·mm, had been achieved by annealing Ni(60nm)/In(3nm)/Ge(10nm) at 700℃ for 5 s This resistance is nearly the same as AuGeNi's Unfortunately, the high annealing temperature is not suitable to GaAs materials, especially to hetero-epitaxy materials

We fabricated In/AuGeNi/Ag/Au ohmic contacts to seek for lower contact resistance and smooth surface It is effective to insert a thin In layer between AuGeNi and GaAs for this purpose Varying the thicknesses of In and AuGeNi layers and annealing temperature, we investigated the contact resistance and roughness of surface, Our experimental results showed that the typical contact resistivity decreased to $5\times10^{-7}\Omega\cdot cm^2$, and smooth surface of contacts was realized

2 Fabrication and measurement of ohmic contacts

The material used in this investigation was semi-insulate (100) GaAs After Si ion implantation and two steps lamp annealing, 450℃ 2s/800℃ 10s, the $2\times10^{18}cm^{-3}$ n^+ layer about 200nm was formed The sheet resistance of the n^+ layer was about 170Ω/□

We applied Transmission Line Method (TLM) to measure the specific ohmic contact resistance[5,6]. Test patterns were defined as follows At first, mesas were isolated by etching of GaAs wafer using $H_3PO_4:H_2O_2:H_2O=1:1:100$ Secondly, the source and drain windows were opened by photo-lithography followed by removing the remains of photo-resist in windows with oxygen plasma The oxide layer on surface was removed with $NH_4OH:H_2O=1:15$ for 30 s Then, In, AuGeNi, Ag, and Au were evaporated in sequence with background pressure of 5×10^{-4}Pa We used the conventional "lift-off" technique to define metal patterns after the evaporation At last, chips were annealed in a hot plate oven in flowing N_2 for 50 s

To acquire the value of resistance accurately, we applied 4 probes method to eliminate the error due to the voltage drop across the probes Auger electron spectroscopy (AES) was used to acquire element composition The roughness of the surface after annealing was inspected with optical microscope.

3 Results and discussion

Relations of ohmic contact resistivites of In/AuGeNi/Ag/Au versus annealing temperatures are shown in Fig. 1 (a) and (b). The dashed lines are for AuGeNi 60nm/Ag/Au while solid lines for In/AuGeNi/Ag/Au. The thicknesses of Ag and Au layers, 40nm and 160nm respectively, are the same to all samples. And annealing times are all 50 seconds.

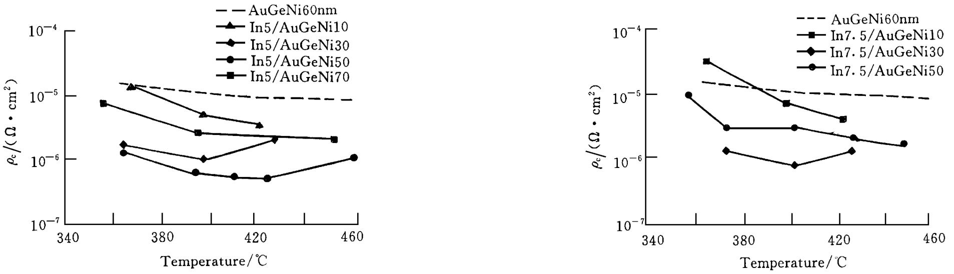
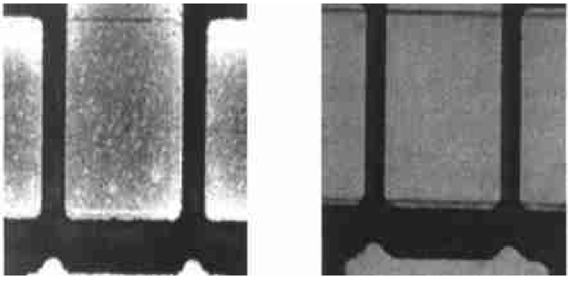


FIG. 1 Contact resistivity versus annealing temperature

(a) The thickness of In layer is 5nm (b) The thickness of In layer is 7.5nm

From Fig. 1, it can be seen that the ohmic contact resistance of In/AuGeNi/Ag/Au metallization is smaller than AuGeNi/Ag/Au's. The ohmic contact resistance of the later is about 0.32Ω·mm, the corresponding contact resistivity (ρ_c) is about $8\times10^{-6}\Omega\cdot cm^2$. This result is in the same level of $5\times10^{-6}\Omega\cdot cm^2$ reported before[7,8]. But for the former, a typical contact resistivity, $5\times10^{-7}\Omega\cdot cm^2$, was obtained with In (5nm)/AuGeNi (50nm)/Ag/Au metallization annealing at 400℃. The ohmic contact resistance is below $0.09\Omega\cdot cm^2$, which is only 28% of AuGeNi's. What's more, the surface of the metallization ohmic contacts with In is much smoother than that without one, as shown in Fig. 2 (a) and (b).



(a) (b)

FIG. 2 Photos of metal surface after annealing

(a) Surface of AuGeNi/Ag/Au (b) Surface of In/AuGeNi/Ag/Au

Inserting an In layer between AuGeNi and GaAs is the key to reduce the contact resistance. There may be two reasons for our results. Firstly, In alloyed with GaAs and formed InGaAs at the interface between metal and GaAs. The barrier of alloyed metal and semiconductor decreased for the existence of InGaAs. So, the contact resistance decreased for tunneling current increased. Secondly, In wetted GaAs well for better adherent ability than AuGeNi. Therefore, In inhibited AuGeNi from balling up and a uniform alloyed interface can be obtained, which should be beneficial to get low contact resistance and smooth surface.

The thickness of AuGeNi layer in In/AuGeNi/Ag/Au metallization is another important factor for the contact resistance. As is shown in Fig. 1 (a), the contact resistivity decreases when the thickness of AuGeNi increases from 10nm to 50nm; But the resistivity turns to increase when the thickness increases from 50nm to 70nm. Similar curves can be seen in Fig. 1 (b). This is because that as the thickness of AuGeNi increases, more Ge atoms diffuse into GaAs as donors resulting in the increment of doping level at the interface. Therefore, the tunneling current can also be enhanced, which makes the contact resistance decrease. However, when AuGeNi is thick enough, much more AuGa is formed for the reaction between Au and GaAs. The barrier between AuGa and GaAs is about 0.7eV[2], much higher than the between AuGeNi and GaAs, 0.35eV. Thus the contact resistance turns to increase. To analyze the ohmic contact further, AES profile is plotted as Fig. 3. Ag formed solid solution with Au after annealing. And Ag diffused into GaAs as well as Au.

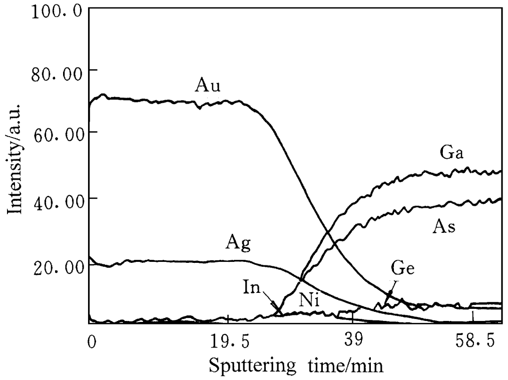


FIG. 3 Profiles of metallization with In after annealing

4 Conclusion

We have fabricated In/AuGeNi/Ag/Au ohmic contacts and compared it with conventional AuGeNi ohmic contact. Lower ohmic contact resistivity, $5\times10^{-7}\Omega\cdot cm^2$, and smoother surface have been achieved after annealing In (5nm)/AuGeNi (50nm)/Ag (40nm)/Au (160nm) at 400℃ for 50 s. Besides, it was found that Ag could alloy with Au throughout and go into GaAs as well after annealing at 400℃. A thin layer of In between AuGeNi and GaAs changed contact resistivity and surface morphology greatly.

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