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Letter

A common metallization scheme for ohmic contacts to n-type and p-type GaAs: the Al–Ni–Sn system

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Abstract

Results are presented on the use of Al–Ni–Sn metallization system as a common metallization scheme to realize ohmic contacts to both p-type and n-type GaAs. The ohmic contacts yield a specific contact resistance in the range from 10^{-5} to 10^{-4} Ω cm^2 for both p-type and n-type GaAs. The presence of a cap during the annealing step brings about a significant reduction in the specific contact resistance. The surface morphology of the contacts is smooth and uniform unlike the usually rough and uneven surface morphology of the (Au–Ge)/Ni ohmic contacts to n-GaAs.

Keywords: Gallium arsenide; Contact metallurgy; Contact resistance; Electrical measurements

1. Introduction

Ohmic contacts are essential features of any GaAs device technology. For example, in the fabrication of GaAs metal semiconductor field effect transistors (MESFETs), the source and drain regions of the MESFET are defined by the formation of low resistance ohmic contacts. Similarly, in the fabrication of heterojunction bipolar transistors (HBTs), the base, emitter, and the collector regions are formed by using low resistance ohmic contacts. The performance of any GaAs device depends on the performance of the ohmic contacts so formed.

It is widely known that the best ohmic contacts to GaAs are obtained by using gold-based alloys and different alloys are needed for n-type and p-type GaAs [1,2]. This would complicate the fabrication process of HBTs on GaAs since the collector and emitter regions require an n-type ohmic contact and the base region requires a p-type ohmic contact. This means an additional masking step in the fabrication process. In order to eliminate this additional masking step, some studies into using a common metallization scheme for both n-type and p-type GaAs have been carried out [1,3]. In this work, preliminary results on the use of the Al–Ni–Sn system as a common ohmic metallization scheme for both n-type and p-type GaAs are presented.

2. Experimental procedures

The starting material used in this study was either n-type or p-type epitaxial GaAs layers grown by molecular beam epitaxy on semi-insulating GaAs substrates. The doping density was varied from 10^{17} to 10^{18} cm^{-3}. After standard cleaning procedures, either rectangular [4] or circular [5] transmission line structures were patterned using photolithography. Subsequently, about 50 nm of Sn, followed by 50 nm of Ni and finally 100 nm of Al was evaporated onto the patterned surfaces of the semiconductor in an electron beam evaporator. The contact structures were subsequently defined by the removal of unwanted photoresist and the metal using lift-off techniques. The wafers were divided into two groups. A 250 nm thick layer of SiO_2 was r.f. sputtered onto the front surface of wafers from one group to act as a cap during the annealing step.

Annealing of the ohmic contacts was carried out using either rapid thermal annealing (RTA) or pulsed

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laser beam annealing. For laser annealing, a pulsed ruby laser was used. The pulse duration was 40 ns and different laser energies were used for alloying for a constant time of 30 s for uncapped wafers and 60 s for SiO_2 capped wafers. On the other hand, RTA was carried out at 750 °C for different times in a forming gas ambient. After the annealing step, the SiO_2 cap from the capped wafers was removed by etching in buffered HF (5:1 by volume of NH_4F:HF) solution. Subsequently, the wafers were passivated with a 400nm thick plasma chemical-vapour-deposited silicon nitride layer.Via-holes were opened in the nitride film and a 500 nm thick Al film was evaporated for probing purposes.

Room temperature current–voltage I–V measurements were carried out to determine the specific contact resistance ρ_c of both types of contacts using appropriate models [4,5]. High temperature aging was carried out at 200 °C for various times in order to assess the thermal stability of the ohmic contacts.

3. Results and discussion

Fig. 1 shows the effect of RTA on the specific contact resistance ρ_c for both n-type and p-type GaAs contacts. Each data point shown in the figure represents the best (lowest) ρ_c value obtained for the appropriate doping density of the active GaAs epitaxial layer. As expected, the ρ_c value decreases with increase in the doping density of the semiconductor. In the case of uncapped wafers, the best value of ρ_c was 9×10^{-5} Ω cm^2 for n-type GaAs for an annealing time 15 s. Similarly the lowest value of ρ_c for p-type GaAs was 1.2×10^{-4} Ω cm^2 for an annealing time of 20 s. In both the cases, the doping density of the semiconductor was 10^{18} cm^{-3}. On the other hand, the values of ρ_c decreased significantly in the presence of an SiO_2 cap during the annealing. In the case of capped n-GaAs wafers, the lowest ρ_c value was found to be 8×10^{-6} Ω cm^2 for a doping density of 10^{18} cm^{-3}, the annealing time being 40 s. Similarly, for p-GaAs wafers, the lowest ρ_c was 2×10^{-5} Ω cm^2 for a doping density of 10^{18} cm^{-3}, the annealing time being 50 s.

In Fig. 2, we plot the results of laser beam annealing on the ρ_c of the semiconductor. Various laser energy densities ranging from 0.2 to 1 J cm^{-2} were tried in order to optimize the specific contact resistance. The results are comparable to those obtained for rapidly thermally annealed contacts. Again, it is observed that the specific contact resistance decreases significantly in the presence of a cap during the annealing step. The lowest ρ_c value was almost the same for both n-type and p-type GaAs (capped samples), about 10^{-5} Ω cm^2, when the doping density ws 10^{18} cm^{-3}. In the case of uncapped samples, the ρ_c value was again found to be almost identical at about 1.1×10^{-4} Ω cm^2.

The ρ_c values reported here are significantly lower than the results reported by Roedl et al. [1]. The decrease in ρ_c in the presence of a cap can be attributed to increased incorporation of the dopant into GaAs. Earlier work on the effects of a cap during the annealing of ohmic contacts [6,7] has clearly shown a considerably enhanced incorporation of the dopant into GaAs. Although it might be possible to reduce further the contact resistance by varying the annealing parameters, such a study was deliberately avoided. It should be noted, however, that the Al–Ni–Sn metallization system offers a promising potential as the ohmic metallization system for both n-type and p-type GaAs. Further studies are required to find out various ways of reducing the specific contact resistance to levels comparable to the standard (Au–Ge)/Ni ohmic contacts to n-GaAs.

The surface morphology of the contacts was observed under high magnifications in both optical microscope and scanned electron microscope. The

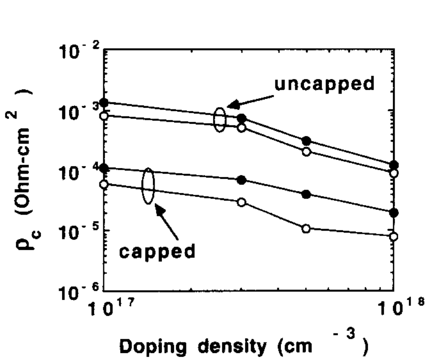

Fig. 1. The effect of RTA on the specific contact resistance ρ_c of Al–Ni–Sn ohmic contacts to n-type (○) and p-type (●) GaAs. Each data point shown in the figure represents the lowest ρ_c value obtained for the appropriate doping density of the active GaAs epitaxial layer.

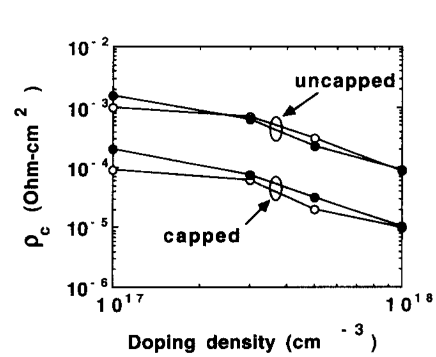

Fig. 2. The effect of pulsed ruby laser annealing on the specific contact resistance ρ_c of Al–Ni–Sn ohmic contacts to n-type (○) and p-type (●) GaAs. The annealing time was 30 s for uncapped contacts and 60 s for capped contacts.

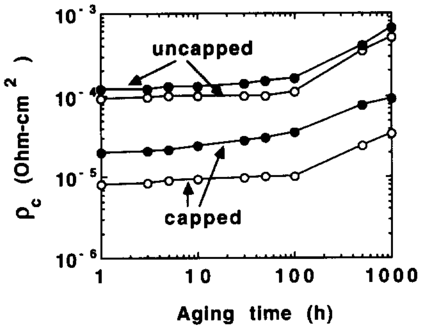

Fig. 3. The effect of 200 °C aging on the specific contact resistance ρ_c of rapidly thermally annealed Al–Ni–Sn ohmic contacts to n-type (○) and p-type (●) GaAs. The doping density of the active GaAs epitaxial layer was 10^{18} cm^{-3}.

surfaces, regardless of the annealing technique, revealed fairly smooth morphology unlike the usually rough surface morphology that is routinely seen on (Au–Ge)/Ni ohmic contacts.

When the contacts were aged at 200 °C for various times, there was very little increase in the ρ_c value during the first 100 h of annealing. Beyond this, the specific contact resistance monotonically increased with aging time. However, the extent of increase is fairly small. This is shown in Fig. 3, where ρ_c, for the active GaAs epitaxial layer doping density of 10^{18} cm^{-3}, is plotted as a function of aging time. Although the results are shown only for contacts annealed using RTA, the behaviour was also similar in the case of contacts annealed by pulsed ruby laser. Even after 1000 h of aging, the change in ρ_c is less than by factor of 5 for both n-type and p-type GaAs. This increase in ρ_c is considerably smaller than that of (Au–Ge)/Ni ohmic contacts to n-GaAs [8], where the increase in ρ_c is shown to be due to the effect of Au diffusion into GaAs. We believe that the contacts exhibit excellent thermal stability and could find suitable high temperature applications in the electronics industry. Also, the use of the Al–Ni–Sn metallization scheme would be ideal in the fabrication of HBTs since it would simultaneously form a low resistance ohmic contact to emitter (n-type), base (p-type), and collector (n-type) regions, thus eliminating the need for a separate masking step for the p-type base region.

4. Conclusions

We have successfully fabricated ohmic contacts to both n-type and p-type GaAs using a common metallization scheme using the Al–Ni–Sn system. The specific contact resistance for both types of GaAs is acceptable for routine GaAs device fabrication. The thermal stability of ohmic contacts is found to be excellent with less than a fivefold increase in the specific contact resistance after 1000 h of aging at 200 °C.

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