Study of the Formation of Isolation by Ion Implantation Process

V.S. Arykov, V.Ya. Boyko, and Yu.V. Lilenko

Scientific Research Institute of the Semiconductor Devices, 99a, Krasnoarmeyskaya str., Tomsk, 634034, Russia
E-mail: apblkob@yandex.ru

Abstract – The results of the investigation of the highly resistive layers formed by ion irradiation into *n*-layers on GaAs substrate and the thermal stability of these layers have been presented. The ions He^+, N^+ with energy $E = 100$ keV and ions Cl^{++} with energy 260 keV were used in this work. The dependences of the sheet resistance vs irradiation dose were plotted for each kind of ions. It is concluded that the excellent thermal stability of the isolation may be achieved with the irradiation by heavy ions Cl^{++}.

1. Introduction

Integrated circuits on A_3B_5 semiconductors typically include a plurality of devices formed in a single semiconductor wafer. These devices have to be electrically isolated one from another by a variety of techniques: p-n junction isolation, etched-groove isolation, or oxide channel isolation for example. But the ion irradiation is a widely used process of the formation of highly resistive layers for the inter element electrical isolation in different A_3B_5 devices and A_3B_5 integral circuits [1–3]. When A_3B_5 semiconductors are irradiated with ions, such as protons or much harder particles, the semiconductor is damaged.

Depending upon a number of parameters, such as ion dose and energy, type of ions, conductivity type the damaged semiconductor layers may become highly resistive (up to 10^7–10^9 Ohm/sq). This method is based on creation of radiation defects with deep levels into band gap of the semiconductor due to high-energy ions bombardment. These levels are electron traps. It causes the decrease of electron concentration in conduction band of semiconductor and the sharp increase of sheet resistance of conductive layer on the substrate surface as a result. In general, the resistivity of proton and other ions bombarded material is highly stable. However, a subsequent heat treatment may reduce the resistivity to that of the unirradiated material or nearly so, especially in the cause of protons. Thus, it is important to make a right choice of ions to produce inter element isolation with sufficient thermal stability.

2. Experiment

The proposed structures in this study were made by ion implantation. The technique of ion implantation into semi-insulating GaAs for formation *n*-layers on the surface was used. The ions Si^+ with energy $E = 100$ keV were implanted into semi-insulating GaAs wafers with dose $Q = 2.8 \cdot 10^{13}$ cm^{-2} at room temperature. Following the implantation, the wafers were annealed for 15 min at temperature 850 °C in H_2–AsH_3 atmosphere. These conditions were chosen on the basis of experience with similar implants in GaAs, where the silicon impurities are found to be activated with protection against surface degradation. After these procedures the *n*-type layer on the semi-insulating GaAs surface was formed. The thickness of this layer is near 0.2 μm and value of the sheet resistance R_s is 100 Ohm/sq.

Following samples for experimental research were prepared. The first step is deposition and annealing of ohmic contacts AuGeNi/Au on the surface of *n*-layer. In the second step, the samples were separated by sawing from the wafer. The size of each sample was 2×6 mm. The size of open GaAs surface was 2×2 mm and ohmic contacts had the areas 2×2 mm as well.

The schematic cross-section (not to scale) of the sample during irradiation is shown in Fig. 1. The protective mask with sufficient thickness to prevent the bombardment of ohmic contact areas was used.

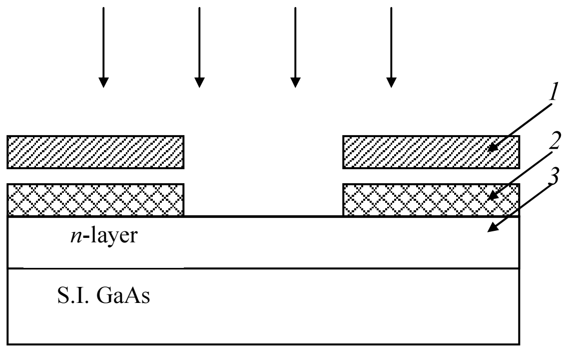

Fig. 1. Schematic cross section of sample used in the experiment: *1* – protective mask; *2* – ohmic contact; *3* – *n*-layer with thickness *d*

The samples were bombarded with ions He^+, N^+ and Cl^{++}. The acceleration energy *E* was 100 keV for ions He^+ and N^+, and $E = 260$ keV for ions Cl^{++}. These ions typically penetrate into GaAs to a depth greater than thickness *d* of *n*-layer ($d \sim 0.2$ mm) because it has an approximately Gaussian distribution in the semiconductor with the peak of the distribution occurring at a depth greater than d. Maximum dose of irradiation came to values up to $1.5 \cdot 10^{14}$, $7 \cdot 10^{13}$, and $4 \cdot 10^{12}$ cm^{-2} for ions He^+, N^+ and Cl^{++}, respectively. The beam current was kept to be not more than 0.1 μA/cm^2 for large doses to minimize heating of the samples.

Following irradiated samples were annealed to investigate the thermal stability of the isolating layers fabricated by the ion bombardment. The thermal annealing was carried out at temperatures between 200 and 550 °C for 15 min. The SiO_2 cap was formed on the surface of GaAs to prevent the degradation of the surface during annealing. The gas used in annealing was N_2 to prevent oxidation of the surface of the samples.

3. Results and discussion

3.1. Dose dependence of sheet resistance

The Fig. 2 shows the irradiation dose of sheet resistance R_s for samples bombarded by ions He^+, N^+, and Cl^{++}. As may be seen from this picture the values of the sheet resistance R_s shows the sharp increase when the dose of irradiation Q for all kinds of bombarding ions (He^+, N^+, and Cl^{++}) rises.

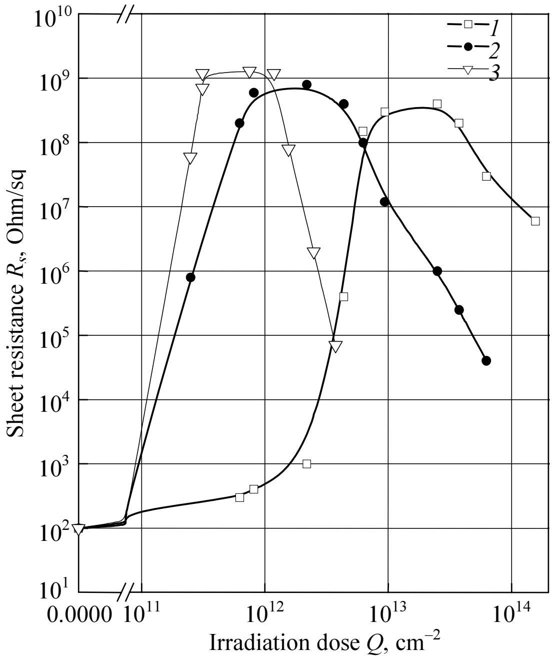

Fig. 2. The dependence of sheet resistance vs irradiation dose Q: *1* – He^+ 100 keV; *2* – N^+ 100 keV; *3* – Cl^{++} 260keV

Thus, as a result of ion bombardment the sheet resistance of *n*-layers on the surface of semi-insulating GaAs increases from 10^2 Ohm/sq to $5 \cdot 10^8$–$1 \cdot 10^9$ Ohm/sq. It is important however, that R_s achieves maximum values at different doses of irradiation for ions He^+, N^+, and Cl^{++}. So, maximum R_s are obtained at doses 10^{13}, 10^{12}, and $3 \cdot 10^{11}$ cm^{-2} for ions He^+, N^+, and Cl^{++}, respectively. The discrepancy between masses of bombarding ions results in different shape of R_s vs dose Q dependencies for ions used to produce radiation damages in this study. In accordance with these results, the rate of the creation of radiation defects has the greater values for heavy ions in comparison with more light ions. For example the rate of the removal of the electrons in conduction band after irradiation (and the increase of R_s as a result) for heavy ions Cl^{++} is more than one order of magnitude greater relative to light ions He^+ and has the greatly larger value than for ions N^+. As can be seen from Fig. 2 there are areas on R_s vs dose Q dependencies where R_s has the approximately equal values (up to 10^9 Ohm/sq) after ion bombardment within sufficiently wide dose interval. These plateaus may be observed on R_s vs dose Q curves in dose intervals $(1–4) \cdot 10^{13}$, $(1 - 5) \cdot 10^{12}$, and $(0.3–1.0) \cdot 10^{12}$ cm^{-2} for ions He^+, N^+, and Cl^{++}, respectively. Thus, the highly resistive layers may be obtained with irradiation by used ions with doses within corresponding intervals. The ion bombardment with doses beyond optimal ranges for each sort of used ions leads to considerable decrease of R_s. It is typically for GaAs crystals that the radiation damages stimulate this decrease of the semiconductor resistance when the high resistive GaAs semiconductor is bombarded by energetic particles with the great doses of the irradiation.

It should be noted from Fig. 2 that this degradation of the highly resistive layers after excessive doses of the irradiation has the most noticeable development for the heavy ions Cl^{++}. In this case, R_s falls from 10^9 Ohm/sq to approximately 10^5 Ohm/sq when the dose Q exceeds 10^{12} cm^{-2}. The effect of the degradation of R_s due to high dose irradiation is less pronounced for light ions.

For example, in the case of ions He^+ the drop in R_s is less than two orders of magnitude from maximum value when the dose Q exceeds $4 \cdot 10^{13}$ cm^{-2}. In accordance with the presented results, it may be concluded that the increase of the mass of bombarding ions results in the formation of more destructive radiation damages than in the case of light ions.

3.2. Annealing of radiation defects

To investigate the thermal stability of the isolating highly resistive layers formed by ion irradiation the isochronous annealing was carried out and the curves R_s vs T were obtained after annealing at various temperatures. Fig. 3 shows the annealing temperature dependencies of sheet resistance R_s for the samples irradiated by ions He^+ with doses Q $1.9 \cdot 10^{13}$, $5.0 \cdot 10^{13}$, and $1.3 \cdot 10^{14}$ cm^{-2}. As may be seen from this figure for the dose $1.9 \cdot 10^{13}$ cm^{-2} (after irradiation R_s shows maximum value, see Fig. 2) the sheet resistance decreases abruptly at $T \geq 300$ °C and falls down to initial value before irradiation (about 10^2 Ohm/sq) after annealing at $T = 500$ °C.

The subsequent rise of the irradiation dose increases the thermal stability of the radiation damages. So for $Q = 5 \cdot 10^{13}$ cm^{-2} the sheet resistance falls down only at $T \geq 400$ °C and for $Q = 1.3 \cdot 10^{14}$ cm^{-2} R_s may increase over a broad range of temperatures from 400 to 470 °C with subsequent lowering at $T \geq 500$ °C. Similar shape of R_s vs T dependence can be explained by the incomplete annealing of the radiation defects at $T \leq 470$ °C.

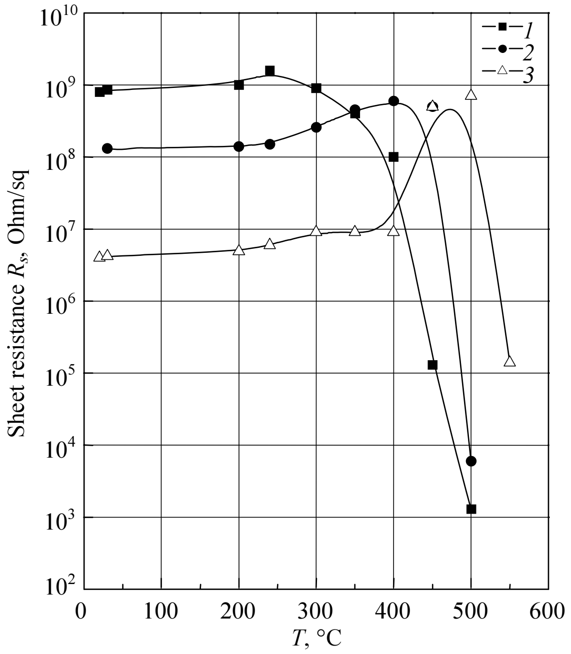

Fig. 3. The dependence of sheet resistance vs annealing temperature T for layers irradiated by ions He^+ with energy $E = 100$ keV and different irradiation doses Q, cm^{-2}: *1* – $1.9 \cdot 10^{13}$; *2* – $5 \cdot 10^{13}$; *3* – $1.3 \cdot 10^{14}$

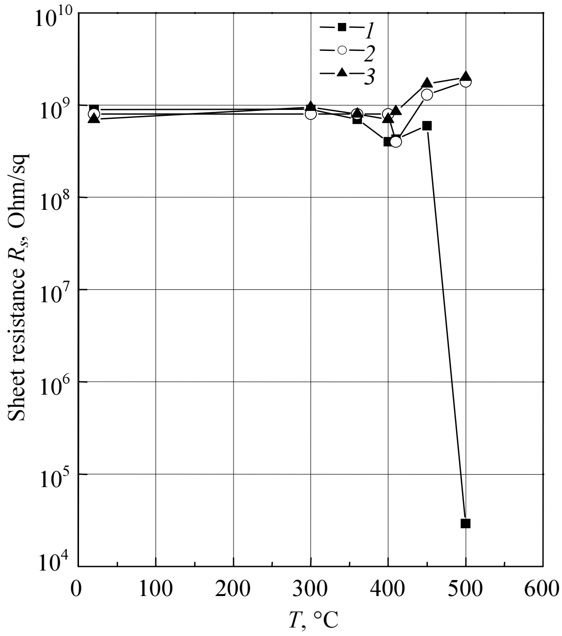

Fig. 4. The dependence of sheet resistance vs annealing temperature T for layers irradiated by ions N^+ with energy $E = 100$ keV and different irradiation doses Q, cm^{-2}: *1* – $9.3 \cdot 10^{11}$; *2* – $2.5 \cdot 10^{12}$; *3* – $3.8 \cdot 10^{12}$

Much better thermal stability of the highly resistive layers formed by irradiation has been obtained with ions N^+ and Cl^{++}. Figure 4 shows the annealing temperature dependencies of R_s for the samples irradiated by ions N^+ with different doses of irradiation.

As may be seen the sheet resistance remains relatively constant over a wide range of temperatures up to 500 °C. Only after irradiation with small dose $9.3 \cdot 10^{11}$ cm^{-2} the value of R_s begins to decrease at $T \geq 450$ °C.

As regards the thermal stability of the highly resistive layers formed by Cl^{++} ions bombardment we can say that in this case any essential changes of sheet resistance of the samples irradiated within dose interval $(0.5–1.0) \cdot 10^{12}$ cm^{-2} has not been found during annealing at temperatures up to 550 °C.

4. Conclusion

The evolution of sheet resistance R_s of *n*-layers on semi-insulating GaAs during irradiation by He^+, N^+, and Cl^{++} ions and after isochronal annealing of the irradiated layers was investigated. The threshold doses Q to convert a conductive layer to a highly resistive one are determined for each kind of ions. A sheet resistance as high as $1 \cdot 10^9$ Ohm/sq was obtained after ion bombardment. The thermal stability of the isolation, i.e., the temperature range for which the R_s is maintained at $(0.5–1.0) \cdot 10^9$ Ohm/sq was found to be dependent on type of bombarding ion. Heavy ions such as Cl^{++} have been desirable for the formation of the highly resistive layers with excellent thermal stability, because the heavy ions effectively transferred their energy to the crystal atoms.

References

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