The Influence of the Implant Dose on Characteristics of Schottky Limiting Diode

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Abstract – In this work the influence of the ion implantation dose on sheet resistance active layers and volt-ampere characteristics of Schottky diodes is investigated. The silicon ions with energy 270 keV and doses $3.1 \cdot 10^{12}$, $6.2 \cdot 10^{12}$, $1.2 \cdot 10^{13}$, and $2.5 \cdot 10^{13}$ cm^{-2} were implanted into GaAs for fabrication of power microwave limiters. The dependences of capacity and series resistance of Schottky diodes vs implant dose are presented.

1. Introduction

Monolithic microwave integrated circuit's (MMIC) based on GaAs semiconductors are widely used in the different microwave systems. These circuits are often made by selective ion implantation of Si^+ into semi-insulating GaAs substrate. Due to the fine geometry used in MMIC transistors, these circuits are susceptible to damage from high power spurious EM radiation from microwave transmitters. Especially, the low noise amplifiers (LNA) in the front-end of microwave systems need high power protection, because these amplifiers can sustain only low input power and are out of action when power level exceeds a critical one. To protect these circuits a high power and low loss limiter are required.

A microwave limiter allows low input power signals to pass through it while attenuating the high-power signals above its rated threshold power level. There are several different devices used to realize this component including gaseous or plasma limiters, ferrite limiters and solid-state limiters [1, 2]. For MMICs fabricated with ion implantation technique one of the preferable types of the protect devise is Schottky diode based limiter because both MMICs and limiter can be fabricated on the single GaAs wafer using selective ion implantation. The main basic operations in production of MMICs and limiters may be compatible including the deposition of ohmic contacts and gate metallization.

One of general characteristics of the limiter is high operating speed and the ability to operate under high-power condition. Therefore, Schottky limiting diodes must have high breakdown voltage and small diode's capacity and resistance. These parameters depend on the properties of ion-implanted layer. Thus, it is important to make a right choice of ion implantation dose and energy for fabrication of active layers this Schottky diodes based limiter.

2. Experiment

The proposed Schottky diode structures in this study were fabricated using the selective ion implantation technique. The ions Si^{++} with energy $E = 270$ keV and implantation doses Q $3.1 \cdot 10^{12}$, $6.2 \cdot 10^{12}$, $1.2 \cdot 10^{13}$, and $2.5 \cdot 10^{13}$ cm^{-2} were implanted into semi-insulating GaAs wafers at room temperature. Following the implantation the wafers were annealed for 15 min at temperature 850 °C in H_2–AsH_3 atmosphere for activation the silicon impurities. After these procedures the deep n-type layer on the semi-insulating GaAs surface was formed.

Following ohmic mask was aligned over the active region, and the ohmic contacts were formed by AuGeNi/Au metallization lift-off and alloying. To ensure absolute device isolation the ion bombardment technique was used with Cl^{++} energy up to 270 keV. Next, the Schottky contact was formed inside the 6 μm wide active area of the ohmic contact by using a standard photolithographic technique and deposition Ti/Au as gate electrode metal. The area of individual Schottky diode was 24×2 μm. The silicon oxide was used as a surface passivating layer. Fig. 1 shows Schottky diode's top and cross-sectional views.

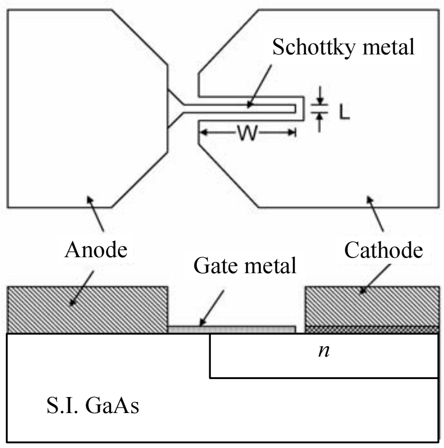

Fig. 1. Schottky diode's top and cross-sectional views

After the individual Schottky diodes were made, lithography process and selective gold electroplating formed the second metal with thick layer of polyimide as interlevel and protect dielectric. The wafers were then lapped to 0.1 mm thick, and via holes were formed with subsequent deposition of ground metal on backside of wafer. Following limiters were separated by automatic sawing. The Schottky diode power limiter comprised a set of antiparallel diodes in shunt configuration; each diode set has sixteen diodes. Two of these sets are used in series to increase the voltage handling capability. Figure 2 shows the fabricated MMIC.

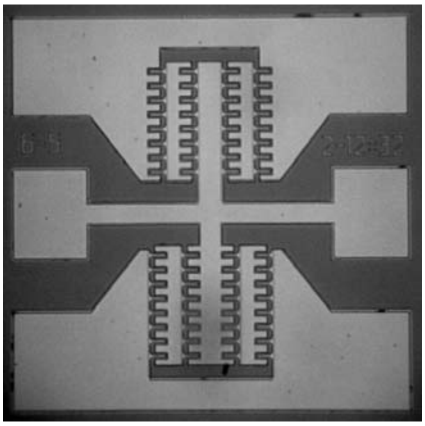

Fig. 2. The photograph of GaAs MMIC Schottky diode power limiter. The die is 0.7×0.8 mm

3. Results and discussion

The active layers of limiter are formed by implantation of Si^{++} ions with energy acceleration $E = 270$ keV. For this energy, the peak of the Gaussian distribution of implanted ions occurred at a depth near 0.25 μm. The electron concentration on the surface is more than one order of magnitude smaller than the peak value. This buried n^+-layer produced by high energy ion implantation is very suitable for achievement of minimal value parasitic capacity of diode as well as the better breakdown voltage and leakage current characteristics of devices.

One of the main characteristics the implanted active layers is the sheet resistance R_s. As a rule, this parameter depends on dose and energy of implanted ions. The implantation dose was varied at the constant energy $E = 270$ keV, as noted previously. The Fig. 3 shows the dependence of the sheet resistance R_s after implantation within dose interval Q from $3.1 \cdot 10^{12}$ to $2.5 \cdot 10^{13}$ cm^{-2}.

The data has been measured by special tests. These tests included two ohmic contacts with active layer's area 100×100 μm between the pads. As can been seen the values of sheet resistance decreases from 440 to 90 Ohm/sq when the implantation dose rises. The curve $R_s(Q)$ has linear range for wide dose interval. However, the dependence $R_s(Q)$ is saturated when the implantation dose exceeds $1 \cdot 10^{13}$ cm^{-2}. This saturation of sheet resistance is related to the decrease of the impurity activation after implantation with great doses. The electron mobility falls down at the high electron concentration as well. Taking into account that this parameter affected on the operating speed of Schottky diode the linear curve piece $R_s(Q)$ dependency is necessary to select as optimal range of the implantation dose. In this case limiting diodes must have the satisfactory microwave parameters.

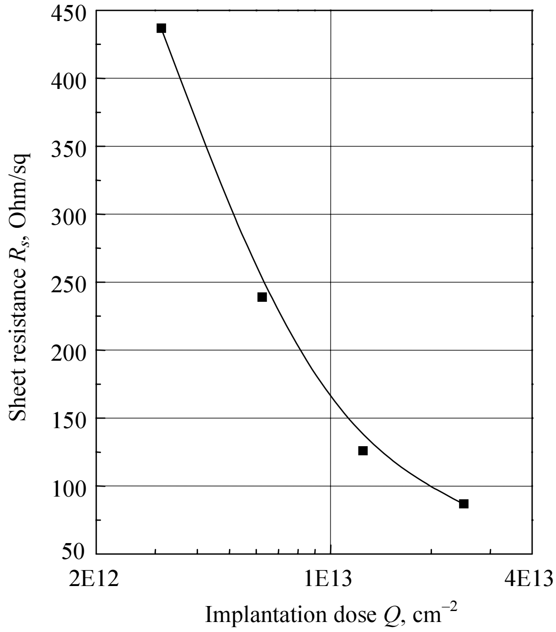

Fig. 3. The dependence of sheet resistance vs implantation dose Q for layers implanted by ions Si^+ with energy $E = 270$ keV

With the increase of impurity concentration, a capacity of Schottky diodes must increase too. The Fig. 4 shows zero-bias capacity of diode vs ion implantation dose. As can been seen from this figure the dependence $C_d(Q)$ is approximately linear for all dose range. The capacity varies from 0.9 to 2 fF/μm^2. The diodes with these values of capacity may be used for microwave application.

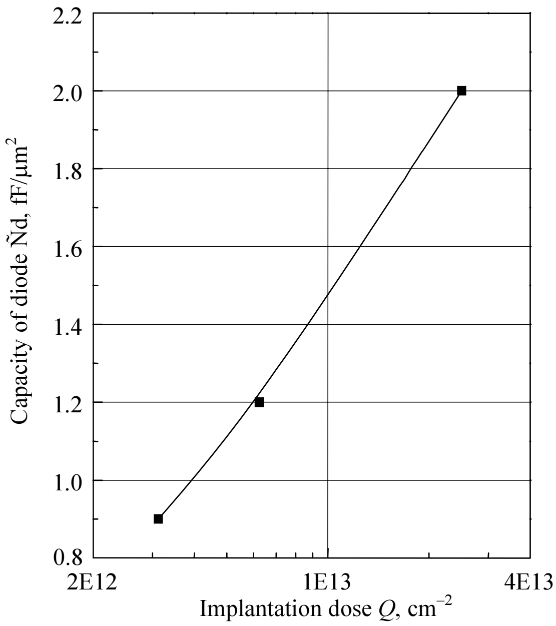

Fig. 4. The dependence of diode's zero-bias capacity vs implantation dose Q

Figure 5 shows the dependence of Schottky diode's series resistance vs ion implantation dose.

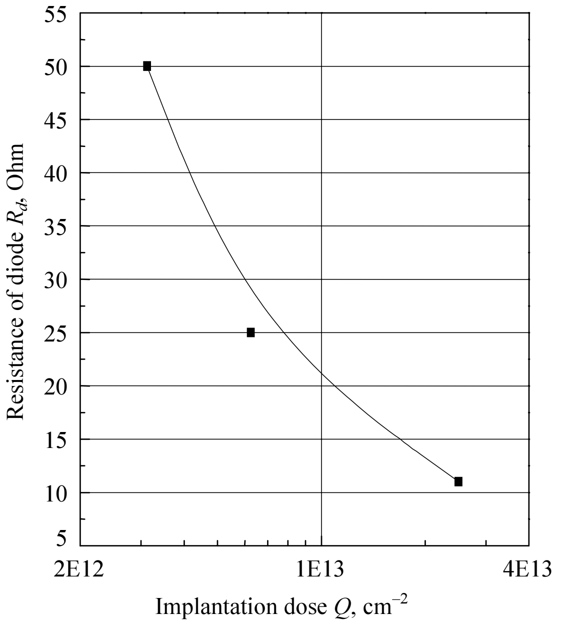

Fig. 5. The dependence of diode's series resistance vs implantation dose Q. The area of each diode is 24×2 μm

The behaviour of this plot and the behaviour of sheet resistance's plot at Fig. 3 are similar as expected. The minimal value of series resistance is obtained for maximal implantation dose and was equal to 11 Ohm for individual Schottky diode. The maximal of diode's resistance was equal to 50 Ohm. Thus, the dependences from Figs. 4 and 5 may be able to select optimal implantation dose for achievement of optimal values of diode's capacity and resistance.

For power microwave application the limiting diode must be able to draw a peak current I_d without failing as much as possible. Figure 6 shows the dependences of I_d and breakdown voltage vs implantation dose.

The values of I_d and breakdown voltage were obtained from the measurement of diode volt-ampere characteristics. Both the peak current and the breakdown voltage vary in wide intervals when the dose changes. The rise of dose results in the increase of peak current owing to growth of electron concentration, but value of Schottky diode leakage current is increased.

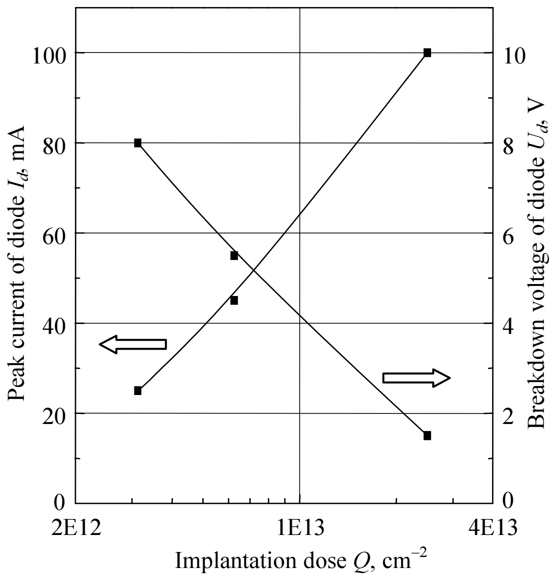

Fig. 6. The dependences of diode's peak current passing and breakdown voltage vs implantation dose Q. The area of each diode is 24×2 μm

The breakdown voltage is decreased as a result. For required high power protection the diode's breakdown voltage must be equal to roughly four volts and peak current passing through the diode must be not less or equal to 40 mA. May been seen from Fig. 6 these values of peak current and breakdown voltage are achieved with interval of implantation dose from $5 \cdot 10^{12}$ to 10^{13} cm^{-2}.

4. Conclusion

In the work, the influence of ion implantation dose on sheet resistance of *n*-type active layers was investigated. The Schottky diode limiters were fabricated and diode's parameters were measured. The dependences of diode's parameters versus implantation dose were presented and discussed. The optimal implantation dose for manufacturing of the limiter was found.

References

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