Fig. 5. Experimental and simulated I-V characteristic of sample D02.

Experimental I-V characteristic of diode D02 is shown at the Fig. 5, from here we derived diffusion current density as In using. Forrasch diode current density can be written as

\[ J = \frac{q}{2\pi} \exp \left( \frac{qV}{KTV} \right) \exp \left( \frac{qV}{KT} \right) \]

where \( q \) is the electronic charge, \( \mu \) is the electron mobility, \( N \) the doping density, \( V \) the applied voltage, \( K \) is the Boltzmann constant, and \( T \) is the absolute temperature.

Fig. 6. Extraction of recombination and generation lifetime from I-V and C-V experimental data of the sample D02.

As measured
As simulated

1. INTRODUCTION

The influence of irradiation on semiconductor materials and devices is presented in many issues [1-5]. At the same time are resolved the questions of electronic devices radiation hardness, the understanding of a radiation defect creation and its kinetics and an application high energy ion irradiation for a deep implantation.

The scope of this paper is to present the effect of 305 MeV Kr and 710 MeV Bi ions irradiation with a fluency of 10^10 cm^{-2} and 10^17 cm^{-2} on the MOS structures and the behavior of ionizing radiation induced defect on the same structures under an isochronal annealing.

2. EXPERIMENTAL

\(<100>\) oriented e-type antimony doped silicon homogenous wafers with a resistivity of 2.5 ohm cm and a 300 \( \mu \)m thickness were used as a substrate of the investigated MOS structures. The gate SiO2 layers were grown by a thermal oxidation in an atmosphere of a dry oxygen at 1050°C for 90 minutes. The thickness of the SiO2 layer was about 100 nm. All gates were prepared by a vapour deposition of Al (a thickness 1.3 \( \mu \)m) and patterned photo lithographically. After the MOS structures manufacturing the sample was annealed in \( N_2 + H_2 \) at 460°C for 20 minutes. The ohmic contact from the backside of the wafer was prepared by an Al vapour deposition. These structures were marked D0.

For a low fluence of 10^9 cm^{-2} the MOS structures were exposed to a 305 MeV Kr ion irradiation with a fluency of 10^12 cm^{-2} (samples D1) and fluency 10^13 cm^{-2} (D2) and to a 710 MeV Bi ion irradiation with fluency 10^12 cm^{-2} (D8) and with a fluency of 10^13 cm^{-2} (D6) at the Joint Institute for Nuclear Research in Dubna, Russia [6] Kr and Bi ions in the MOS structures after ion exposure calculated by implanted process simulations in the Monte Carlo code Transport of Ions in Matter (TRIM-2000) [7] are shown in Fig. 1. These simulations affirmed the assumptions: the concentration \( N_{\text{max}} \) maximum is deep in substrate below the structure active region and its position is greater about 14% after the irradiation by high-energy Bi than Kr ions at the same fluence.

\[ \phi_{\text{Kr}} = \phi_{\text{Bi}} \]

Fig. 7. Epi layer lifetime versus \( t_s \) as a function of layer thickness for as measured effective lifetime \( \tau_{\text{eff}} \).

REFERENCES


CHARACTERIZATION OF HIGH ENERGY IRRADIATED MOS STRUCTURES USING THE CAPACITANCE METHODS

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Summary

The formation and annealing of radiation-induced defects in MOS structures exposed to 710 MeV Bi ions and 305 MeV Kr ions radiation with a fluency of 10^10 and 10^17 cm^{-2} have been studied by capacitance methods. Electrical activity of the defects has been increased by interface trap density \( D_\text{it} \) and a sharp decrease to the generation parameters \( \tau_p \) and \( \tau_n \). The parameters of nine deep levels were detected in the investigated MOS structures. Eight of these levels were radiation defects.

This dependence was obtained from integration of the low frequency C-V curve and is given as

\[ \phi_i = \int \frac{C(V)}{C_i} dV \]

where \( C(V) \) is the gate capacitance and \( C_i \) is the intrinsic capacitance.
The capacitance of the interface trap is given as

$$C_{IT} = C_{IT\text{, red}} - C_{IT\text{, mod}}.$$  

(4)

where $C_{IT\text{, red}}$ is the measured capacitance and $C_{IT\text{, mod}}$ is the ideal capacitance. The density of interface traps is given by [11]

$$D_{IT} = \frac{1}{Q} C_{IT}.$$  

(5)

The flat-band voltage $U_F$ and the free carriers concentration profile $n(x)$ have been determined by high frequency capacitance-voltage (C-V) method [12].

The relaxation time $\tau$, generation lifetime of minority charge carriers $\tau_g$ and surface generation velocity $S_g$ characterizing the electrical behaviour of defects in the MOS structure have been diagnosed by non-equilibrium C-t method [13].

A depth profile of a generation lifetime $\tau(x)$ has been established by a time-domain constant capacitance (C-t) technique [14]. Multistep C-t technique is an excellent alternative to the Zerbst technique. Capacitance of an initially deep-depleted MOS-C is maintained at a constant value by increasing the gate charge by a computer-controlled voltage source. The value of generation lifetime is then calculated from the slope of voltage transient, moreover depth profile of the generation lifetime can be obtained.

C-V, C-t and C-t measurements were performed using the 4280 I MHz C Meter/C-V Plotter Hewlett-Packard.

Electrically active radiation-induced defects have been studied by standard Deep Level Transient Spectroscopy (DLTS) measurements [15]. DLTS is a high-frequency transient capacitance thermal scanning method, where an electrical excitation pulse causes the capacitance transient effect in a potential barrier of a semiconductor. DLTS measurements have been performed using a Polaron BioRad DLTS spectrometer with a boxcar detection system for acquiring the DLTS output signal. The values of the activation enthalpies $\Delta E_A$ of electron deep levels were determined from an Arrhenius diagram using known equations

$$\ln \frac{C}{T^2} = \ln(\sigma K_b T^2) - \frac{\Delta E_A}{k_B T},$$  

(6)

where $\sigma$ is the emission rate, $K_b$ - a material constant, $T$ - the absolute temperature, $k_B$ - the Boltzmann constant. C-V, C-t and standard DLTS methods were applied on all irradiated MOS structures before and after the isochronal annealing.

Further from characteristic high frequency C-V (Fig. 3) and C-t (Fig. 5) curves measured on the non-irradiated MOS structures $D_0$ and the irradiated MOS structures $D_1$, before and after annealing we can see that the antimony doped MOS structures had the same or only a slightly lower concentration of impurities $N_0$. The rise in the density of radiation defects is expressed quantitatively through a considerable decrease of generation lifetime $\tau_g$ values and an increase of a generation surface velocity $S_g$. After the annealing we observed the lengthening of the relaxation time $\tau$. Annealing temperature increase reveals a reduction of defects and decrease in their activity. Also the changes in $\tau_g$ and $S_g$ reveal significant reduction of electrically active defects in the depleted region and on a Si-SiO$_2$ interface (Tab. 1).

Fig. 6 shows a depth profile of a generation lifetime $\tau(x)$ on MOS structure $D_1$ after annealing at 300°C obtained by C-t method. Measured values are in good agreement with result obtained by C-t method. According to

$$1/T = N_T,$$

where $N_T$ is the trap concentration, we shall assume homogeneous depth distribution of traps in space charge region.

The values of $D_{IT}$ in Tab.1 were determined at 0.22 eV over the mid-gap (Fig. 4). The non-irradiated sample $D_0$ has the lower value of $D_{IT}$. The $D_{IT}$ increasing was observed on the $K^+$ ions irradiated sample $D_1$ (Tab.1). The higher value of $D_{IT}$ in comparison with the sample $D_1$ detected on sample $D_2$ was due to the same radiation with higher fluency. The highest value of $D_{IT}$ was observed on the sample $D_8$ irradiated by Bi ions.

Fig. 4. Energy distribution of interface trap density of structures $D_0, D_1, D_2$ and $D_8$.

By comparison with the values of the generation surface velocity $S_g$ (Tab.1) obtained from C-t measurements (Fig. 5) we registered a good agreement with the results gained from quasistatic method ($D_0$). Moreover we determined the magnitude of the capture cross-section $\sigma_c$ which defines the electrical activity of traps [16].

$$S_g = \sigma_c v_e,$$  

(7)

where $v_e = 10^{16}$ ms$^{-1}$ is electron thermal velocity for silicon.

Fig. 5. Typical high frequency C-V curves measured on structures $D_0, D_1, D_2$ and $D_8$ before and after isochronal annealing.

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Fig. 5. Typical high frequency C-V curves measured on structures $D_0, D_1, D_2$ and $D_8$ before and after isochronal annealing.
3. EXPERIMENTAL RESULTS AND DISCUSSION

The radiation changes interface trap density \( D_{t} \) have been observed at the slope of low frequency C-V curves (Fig.2) in depletion and weak inversion region and in an increased flat band voltage \( U_{fb} \). We assumed that the increased flat band voltage \( U_{fb} \) (Fig.2 and Fig.3) is resulted of a rise in the positive defect charge in the oxide and at the interface with the silicon substrate after the high energy heavy Kr or Bi ions irradiation on the MOS structure.

Further from characteristic high frequency C-V (Fig.3) and C-t (Fig.5) curves measured on the non-irradiated MOS structures D0 and the irradiated MOS structures D1, before and after annealing we can see that the antimony doped MOS structures had the same or only a slightly lower concentration of impurities \( N_{t} \). The rise in the density of radiation defects is expressed quantitatively through a considerable decrease of generation lifetime \( \tau_{g} \) values and an increase of a generation surface velocity \( S_{g} \). After the annealing we observed the lengthening of the relaxation time \( t_{r} \). Annealing temperature increase reveals a reduction of defects and decrease in their activity.

By comparison with the values of the generation surface velocity \( S_{g} \) (Tab.1) obtained from C-t measurements (Fig.5) we registered a good agreement with the results gained from quasistatic method (D0). Moreover we determined the magnitude of the capture cross-section \( \sigma_{c} \) which defines the electrical activity of traps [16].

\[
S_{g} = \sigma_{c} \nu \tau_{g}
\]

where \( \nu_{c} = 10^{16} \text{m}^{-3} \) is electron thermal velocity for silicon.

The values of \( D_{t} \) in Tab.1 were determined at 0.22 eV over the mid-gap (Fig.4). The non-irradiated sample D0 has the lower value of \( D_{t} \). The \( D_{t} \) increasing was observed on the Kr+ ions irradiated sample D1 (Tab.1). The higher value of \( D_{t} \) in comparison with the sample D1 detected on sample D2 was due to the same radiation with higher fluency. The highest value of \( D_{t} \) was observed on the sample D8 irradiated by Bi+ ions.

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The non-irradiated MOS structures (D0) were of a high quality, having a low density of defects. We detected only one deep energy level DL1 (0.66 eV) with a very low concentration 2.10^{15}cm^{-3} by DLTS measurements. This deep level corresponds to a presence of Au (0.59 eV). Fig. 7 shows typical DLTS spectra measured on the irradiated MOS structures before and after the isochronal annealing.

<table>
<thead>
<tr>
<th>Deep level</th>
<th>in sample</th>
<th>$\Delta E_{\text{meV}}$</th>
<th>Similar traps in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>D2</td>
<td>224</td>
<td>V'</td>
</tr>
<tr>
<td>L2</td>
<td>D2, D1</td>
<td>156, 170</td>
<td>A-centre</td>
</tr>
<tr>
<td>L3</td>
<td>D2, D1</td>
<td>121, 154</td>
<td>A-centre</td>
</tr>
<tr>
<td>L4</td>
<td>D1, D2</td>
<td>305</td>
<td>V'</td>
</tr>
<tr>
<td>L5</td>
<td>D1, D2</td>
<td>324</td>
<td>A-centre</td>
</tr>
<tr>
<td>L6</td>
<td>D2</td>
<td>407</td>
<td>V'</td>
</tr>
<tr>
<td>L7</td>
<td>D1</td>
<td>196</td>
<td>V'</td>
</tr>
<tr>
<td>D0, D6, D8</td>
<td>611</td>
<td>Au, 590 mV</td>
<td>[17]</td>
</tr>
<tr>
<td>D2, D6</td>
<td>523</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3, D6, D8</td>
<td>269, 300</td>
<td>V', V'</td>
<td>[18]</td>
</tr>
<tr>
<td>D4, D6</td>
<td>246</td>
<td>V', V'</td>
<td>[18]</td>
</tr>
<tr>
<td>D5, D8</td>
<td>171, 141</td>
<td>A-centre</td>
<td>[17]</td>
</tr>
<tr>
<td>D6, D8</td>
<td>143</td>
<td>A-centre</td>
<td></td>
</tr>
<tr>
<td>D7, D8</td>
<td>411</td>
<td>Dilation, 100, 200, 500°C</td>
<td></td>
</tr>
</tbody>
</table>

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ACKNOWLEDGEMENTS

REFERENCES

Abstrakt V článku sa uvádza polohové riadenie mechanizmu príjmu pohybových lineárnych synchronných motorov s permanentnými magnetmi. Koncepcia riadenia je založená na riadení s vznosou dynamiky, čo je formou lineárizácie spôsobu, ktorá generuje taký viacparametrový nečlný stacionárny režim, ktorý umožňuje dodržiavať predpísané lineárne dynamiku rýchlosti pohotovu, spolu so vzájomnou kolmouťou vektorov statorového prúdu s magnetického toku motora, čo je podmienku vektorového riadenia (s predpokladom vopredného odhadu parametov systému). Simulácie navrhnutého riadiaceho systému, ktoré obhavajú aj spôsoby výkonových elektroniky, potvrdzujú predpokladané vlastnosti pohotovu.

1. INTRODUCTION

There is an increasing use of linear motors for industrial position control systems. The paper develops position control system for linear permanent magnet synchronous motor (PMSM) based on forced dynamics control principles. Forced dynamic control is a relatively new control method for controlling of ac electrical drives based on the principle of feedback linearisation [1], [2]. The reason for utilising this method is that it is possible to design the position control system to be linear and have a prescribed second order transfer function. In the linear synchronous motor, mutual orthogonality of the force producing stator current vector and magnetic flux vector is maintained, as in conventional vector control [3], [4]. The control system has an inner speed control loop utilising a speed estimate and a external force estimate from an observer [5], [6] and outer position control loop. Speed control loop has linear first order dynamics with an adjustable time constant. An outer position control loop with an adjustable proportional gain is then closed via a suitable position measurement.