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EFFECT OF ANNEALING OF STATE OF ION-IMPLANTED ATOMS OF Mn in Si

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Abstract: The paper reports a number of experimental results related to the study of the effect of temperature of annealing and dose of irradiation applying the technique of Rutherford backscattering spectroscopy (RBS) on profiles of distribution of implanted atoms of Mn in Si. The results are proved by similar experimental results obtained by using Secondary Ion-Mass Spectrometry. The influence of thermal annealing on Mn and other impurities (especially oxygen) distribution profile was studied. The authors have identified how RBS technique could be implemented for determination of distribution profiles of concentrations of doped impurities and their interaction with each other in the bulk of material.

Keywords*: impurities, profiles, influence, thermal annealing, depth, concentration distribution, dose of irradiation, temperature of activation.*

As is known in silicon, doped with an element of transition groups, in particular manganese, a number of physical phenomena are observed that are of scientific and practical interest [1-2].

The production of thin layers in the near-surface region of Si with specified electro physical properties and a certain thickness is of great interest both from the point of view of technology and for the creation of various sensors and devices of high sensitivity. The most interesting in this area are dopants of elements of transition groups, in particular manganese. From a technological point of view, it is impossible to create thin layers in silicon with a limited depth and sufficient concentration by the diffusion method due to the large value of the diffusion coefficient of these elements. Therefore, they resort to the method of ion-beam doping.

However, in the literature, there are practically no works on ion implantation and depth distribution profiles of manganese in silicon. Since the Mn impurities in Si can be located at both the sites and interstices of the crystal lattice, and interact with lattice defects, their distribution during ion implantation and the mechanism of their activation are of certain interest. The aim of this research is to study the distribution profiles of implanted manganese atoms in silicon depending on the radiation dose and annealing temperature.

As is known, for studying the distribution profile of ion-implanted layers, the traditional methods are secondary ion mass spectrometry and Auger — electron spectroscopy with layer-by-layer removal. However, these methods do not provide high accuracy of quantitative characteristics, although accurate quantitative data on the concentration of dopants are necessary for dosage in order to obtain thin layers with desired electrophysical properties.

Therefore, in this work, the Rutherford backscattering (RBS) method is applicable to study the distribution profiles of Mn dopants and the effect of the activation temperature on their distributions.

For the study, we used KDB monocrystalline silicon plates with p = 10 ohm cm. The implantation of Mn and ions in silicon was carried out on an ILU-3 setup at an ion energy of 40 keV along the crystallographic axis (111). The implantation dose (N) was varied in the range of 10-15 -10-17 ion / cm2. The resistivity of the samples was measured by the 4-probe method.

Figures 1a-1c show the distribution profiles of implanted manganese ions in silicon with 40 keV at different implantation doses. Regardless of the implantation dose, the distribution is described by a Gaussian function. In this case, the depth of the projected path (Rp), depending on the radiation dose, lies within 398 A-410 A. This is in good agreement with the data of the study of these samples by other methods, for example, SIMS [3].

RBS studies for Si samples after Mn implantation with a dose of 10-15 ions / cm2 gave results on the surface of the silicon sample - 82.7%, oxygen - 10%, manganese - 2% in atomic units. Within the limits of sensitivity, Mn is observed down to a depth of 600 A, and oxygen - 900 A. For silicon wafers after ion implantation with Mn 10-16 ion / cm2, the percentage of silicon, oxygen and manganese in atomic units on the surface is Si -69%, 0-29%, Mn -2%. A significant change in the percentage is observed at a depth of about -400 A, where the following ratios are observed: Si -76%, 0-18%, Mn - 6%. Within the sensitivity of the method, Mn is observed down to a depth of -650 A. From this depth on, there is a rare change in oxygen content. At a depth of 900 A, oxygen is practically not felt.

When Mn is implanted with a dose of 10-17 ions / cm2, the following picture is observed: on the sample surface Si -64%, 0-34% and Mn -2%. At a depth of 400 A, Si -82%, 0-3%, Mn -15% in atomic units.

An analysis of the data obtained shows that during ion implantation, both on the surface of the sample and at the depth of the maximum of the Mn distribution, the oxygen content is mainly. It can be assumed that the incorporated Mn ions into the ubiquitous displace oxygen. This assumption is justified if oxygen in a silicon crystal is in a free state [4-5].

The influence of thermal annealing on the behavior of dopants, in particular, on the depth distribution, is of great scientific and practical interest. Below are the results of the effect of thermal annealing on the depth distribution of Mn for Si samples for 30 min - Fig. 2. As can be seen, thermal annealing at 600 ° C has a significant effect on the depth distribution of impurities. The strong effect begins at temperatures of 900 ° C.

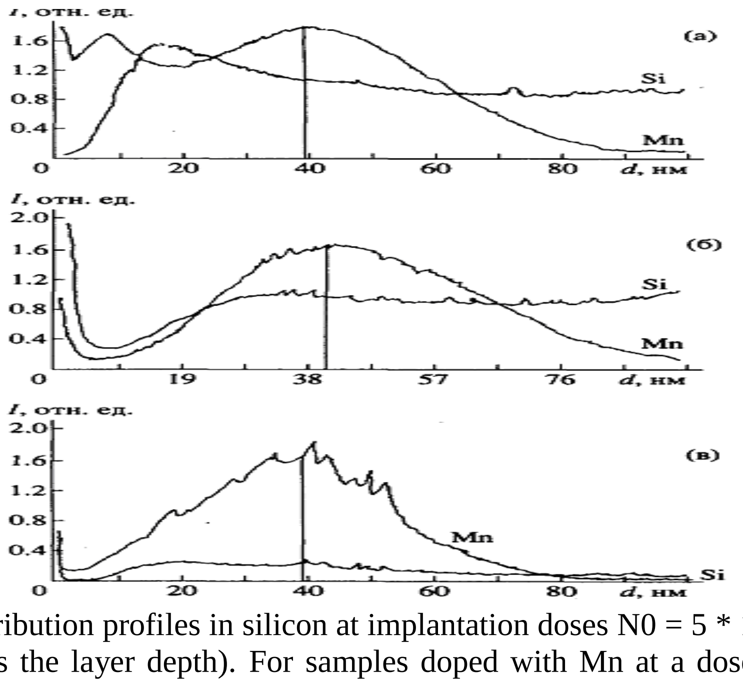

Fig. 1. Manganese distribution profiles in silicon at implantation doses N0 = 5 * 1015 (a), 5 * 1016 (b), 5 * 1017 ion / cm2 (c) (d is the layer depth). For samples doped with Mn at a dose of 10-15 ion / cm2, the

distribution maximum moves to a depth of -800 A, practically has a content of up to 2 at% - Fig. 3. At the same time, it does not feel the Mn content on the surface, oxygen decreases to 27 at%, and does not feel oxygen at a depth of 800 A.

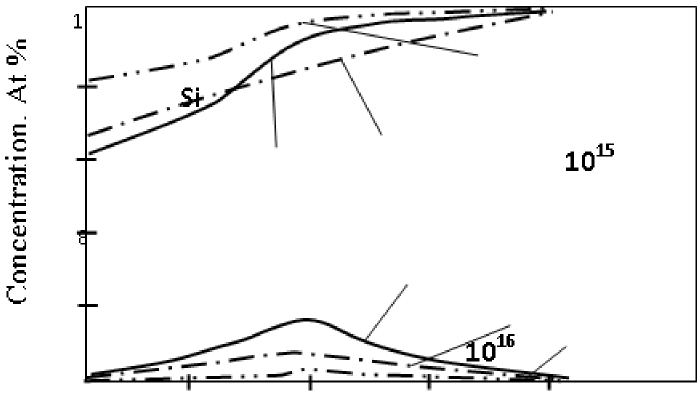

Fig. 2. Depth distribution of Mn concentration in Si at an irradiation dose of 1015 - 1017 ion / cm2

For samples doped at a dose of 10-16 ions / cm2, annealing for 30 min at a temperature of 600 ° C practically significantly affects the Mn distribution. A breaking of the maximum is observed. At an annealing temperature of 900 ° C, the distribution maximum moves to a depth of 800 A with a decrease in the maximum to 5% at.

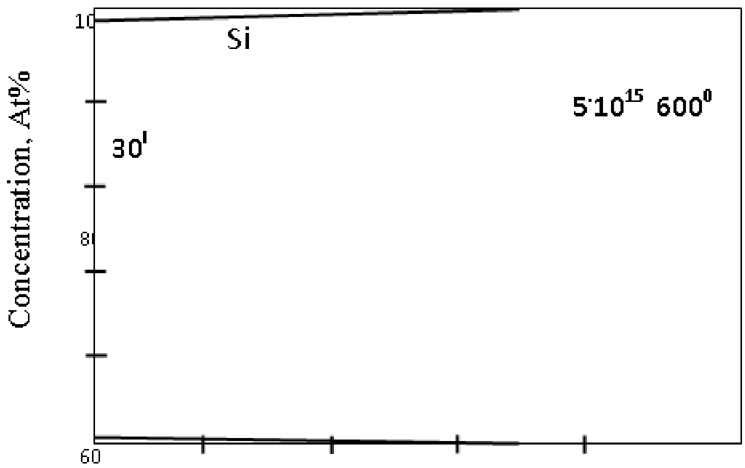

Fig. 3. Depth distribution of Mn concentration in Si at an irradiation dose of 1015 ions / cm2 after annealing at a temperature of 6000C for 30 minutes.

The distribution of impurities for samples doped with Mn with a dose of 10-17 ions / cm2 undergoes significant changes during thermal annealing. Thermal annealing at 600 ° C for 30 min to a shift of the distribution maximum to a depth of 380 A and a slight increase in the content on the surface. Thermal annealing at 900 C for 30 min strongly affects the Mn distribution. The maximum shifts to a depth of 600Å. The shape of the distribution becomes flatter, Mn is observed up to a depth of about 1200 Å within the range of up to 5 at%

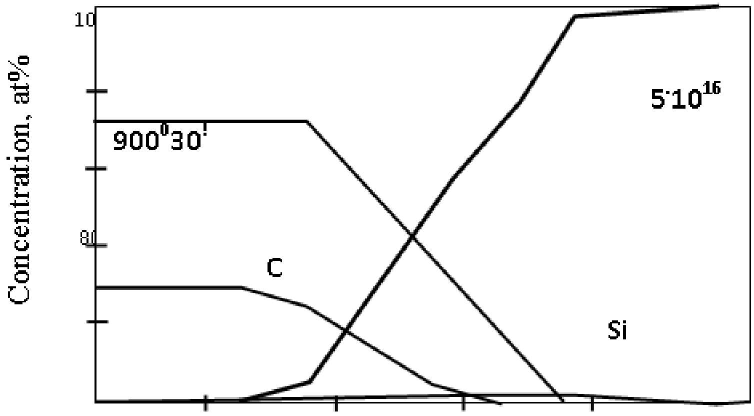

Fig. 4. Depth distribution of Mn concentration in Si at an irradiation dose of 1016 ions / cm2 after annealing at a temperature of 9000C for 30 minutes

Analysis of the data obtained gives grounds to assert that with the help of RBS, one can obtain not only information on the distribution of impurities over the depth of the samples, but also obtain quantitative characteristics.

In our opinion, the connection between the distribution of manganese and oxygen in silicon crystals is interesting. Comparison of these distributions shows that in the depth of the maximum of the manganese distribution, the oxygen content is minimum, and vice versa, in the places of the maximum oxygen content, the manganese concentration has a minimum.

For undoped initial Si samples, there is a distribution of oxygen with a certain excess on the surface; with a monotonic decrease in the depth of the sample; then, a uniform distribution takes place.

After ion implantation, this distribution undergoes a strong change. The concentration on the surface and near-surface regions increases, in the region of the maximum of the Mn distribution, a sharp decrease in its concentration is observed. This change occurs for all samples with different radiation doses.

Based on the results obtained, it can be argued that manganese during ion implantation mainly replaces oxygen. This statement will be real if oxygen is in an unbound state inside the Si volume.

The ion implantation process not only affects the state of oxygen, but also the state of defects. The created defects, both on the surface and at the depth of Si, open up free radicals that attract free particles, in particular, O.

Thus, the distribution profiles in Mn with different irradiation doses in Si have been studied by the RBS method. The results obtained are in good agreement with similar data obtained by SIMS. The effect of thermal annealing on the distribution of Mn and other impurities, in particular, oxygen, has been studied. The possibility of using the RBS method for analyzing both the concentration distribution of dopants and the interaction of impurities with each other is noted.

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