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STUDY OF THE DISTRIBUTION PROFILE OF ION- IMPLANTED IN SILICON AND INFLUENCE THERMAL ANNEALING ON THE STRUCTYRE OF IRON SILICIDES

Annotation

The paper presents the results of studies of the distribution profiles of implanted iron atoms in silicon depending on the irradiation dose and annealing temperature by the RBS method. The obtained results confirm similar data obtained by SIMS. The influence of thermal annealing on the distribution of iron and other impurities, in particular oxygen, has been studied. The possibility of using the RBS method for the analysis of the concentration distribution and the interaction of impurities with each other is presented. At the same time, the crystal structure of the surface and the electrophysical properties of ion-doped layers were studied.

Key words: impurity, iron, silicon, thermal annealing, doping depth, concentration distribution, ion implantation.

ИЗУЧЕНИЕ ПРОФИЛЯ РАСПРЕДЕЛЕНИЯ ИОНОВ, ИМПЛАНТИРОВАННЫХ В КРЕМНИЙ И ВЛИЯНИЯ ТЕРМИЧЕСКОГО ОТЖИГА НА СТРУКТУРУ СИЛИЦИДОВ ЖЕЛЕЗА

Аннотация

В работе представлены результаты исследования профилей распределения имплантированных атомов железа в кремнии в зависимости от дозы облучения и температуры отжига методом RBS. Полученные результаты подтверждают аналогичные данные, полученные методом ВИМС. Изучено влияние термического отжига на распределение железа и других примесей, в частности кислорода. Представлена возможность использования метода RBS для анализа распределения концентрации и взаимодействия примесей друг с другом. Одновременно изучалась кристаллическая структура поверхности и электрофизические свойства ионно-легированных слоев.

Ключевые слова: примесь, железо, кремний, термический отжиг, глубина легирования, распределение концентрации, ионная имплантация.

KREMNIYGA ION IMPLANTATSIYA QILINGAN IONLARNING TARQALISH PROFILINI O'RGANISH VA TERMIK TOBLANISHNI TEMIR SILITSIDLARINING TUZILISHIGA TA'SIRI

Annotatsiya

Maqolada RBS usulida nurlanish dozasi va toblanish haroratiga qarab kremniyda implantatsiya qilingan temir atomlarining tarqalish profillarini oʻrganish natijalari keltirilgan. Olingan natijalar IIMS tomonidan olingan oʻxshash maʼlumotlarni tasdiqlaydi. Termik toblanishning temir va boshqa kirishmalarning, xususan, kislorodning tarqalishiga taʼsiri oʻrganildi. Konsentratsiyani taqsimlash va kirishmalarning bir-biri bilan oʻzaro taʼsirini tahlil qilish uchun RBS usulidan foydalanish imkoniyati taqdim etilgan. Shu bilan birga, sirtning kristall tuzilishi va ionli qatlamlarning elektrofizik xususiyatlari oʻrganildi.

Kalit soʻzlar: kirishma, temir, kremniy, termik toblanish, legirlangan chuqurlik, konsentratsiyaning taqsimlanishi, ion implantatsiyasi.

Introduction. Currently, ion implantation is a key stage in the technology of creating integrated circuits and many other semiconductor devices. In a narrow sense, ion implantation is a technological method of introducing accelerated ions into a solid target for the purpose of doping it. In a broad sense, this term means a scientific and technical direction located at the intersection of solid state physics, radiation physics, non-equilibrium thermodynamics, physical chemistry, mathematical statistics, using the achievements of vacuum technology and high voltage technology, the purpose of which is to control the properties of materials using ion beams; here, the introduction of ions is an episode in a long chain of processes occurring in a solid both directly during implantation and during its after-relaxation.

The greatest successes of ion implantation has been achieved in the field of planar technology of semiconductor devices and integrated circuits. The rapid development of microelectronics in recent decades is related to ion implantation to a large extent.

Implantation of silicon with iron, cobalt and nickel ions is used to create magnetic Nano clusters and metal silicide's [1–4]. Composite materials based on magnetic nanoclusters are used in the development of new information storage elements [5]. Metal silicide's are also used as materials for contacts and interconnects of integrated circuits. Thus, in silicon doped with elements of transition groups, in particular iron, a number of physical phenomena of scientific and practical interest are observed [5–6].

Ion implantation, depending on the dose and energy of irradiation, leads to a significant change in the composition, structures, and properties of semiconductor materials. In this regard, silicon single crystals doped with iron ions with the energy $E=20\div40$ keV are of special interest because at low doses of irradiation ($D<10^{15}$ cm^2) of high concentrations which is impossible to obtain by thermodiffusion method; at high doses of ions the metal silicide's with new physical properties are formed. However, such silicide's are currently obtained by MBE and SPE methods. Obtaining hidden conducting films of iron silicide's by ion implantation and studies of their physicochemical, electrophysical properties are still under development.

The purpose of the present study was to investigate the distribution profiles of implanted iron atoms in silicon as a function of the irradiation dose and annealing temperature.

Experimental technique. In this paper we present a number of new original results on the properties of the effect of annealing on the crystal structure of the surface of silicon doped with iron ions. Choice of iron as a compensating impurity is due to the fact that in a wide temperature range, the state of impurity atoms in the silicon lattice is quite stable (100-450^{0}C) and respectively parameters of silicon doped with it.

Experimental studies of concentration distribution profiles of iron atoms implanted in silicon with energy of E_0 = 40 keV with irradiation dose variation in the range of $10^{15}\div10^{17}$ ion/cm^2 were carried out. KDB silicon with specific resistance ρ=*10 Ohm· cm* was used as a starting material, the studies were carried out using the methods of secondary ion mass spectrometry, Rutherford backscattering and electron Auger microscopy methods.

Results and its discussion

Figure 2 shows the backscattering spectra of He^+ ions from a Si(111) single crystal implanted with Fe^+ ions at a dose of 10^{15} to 10^{17} ions/cm^2.

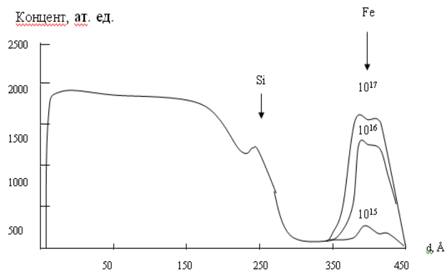


Figure 1. RBS spectr of He^+ ions on Si single crystal doped with 40 keV Fe ions and irradiation doses of 10^{15}-10^{17} ion/cm^2.

Figure 2 shows that the characteristic of Fe begins to appear in the spectrum at a dose of D≈10^{15} ion/cm^2. At the same time, the crystal structure of the surface and the electrophysical properties of ion-doped layers were studied.

The results of the experiments showed that at D≤10^{15} ion/cm^2, there is still no noticeable disordering of the near-surface layers, and the concentration of electroactive Fe atoms does not exceed ~$5\cdot10^{13}$ cm^{-3}. Increasing the dose to 5 $\cdot10^{15}$ ion/cm^2 practically does not lead to an increase in the concentration of electroactive Fe atoms. In this case, the near-surface region is partially disordered, and the backscattering peak from Fe becomes clearer and more intense. At an irradiation dose of D≈10^{16} ion/cm^2, amorphization of the near-surface layer and a significant increase in the Fe peak occur, and Fe + Si cluster phases begin to appear in some areas of the ion-doped layer. These changes occurred up to a dose of (8÷10) $\cdot10^{16}$ ions/cm^2. A further increase in the dose does not lead to a noticeable change in the relative intensity of the Si and Fe peaks. Therefore, the dose D≈10^{17} ion/cm^2 can be taken as a saturation dose.

In the above case, the highest concentration of electroactive atoms reached up to $5\cdot10^{14}$ cm^{-3}. Of interest is the nature of the depth distribution of metal atoms in Si as a function of the irradiation dose. At medium radiation doses (D≈$10^{15}\div$ 10^{16} cm^{-2}), the distribution profile has a very complex shape with several maxima. As an example, Fig. 3 shows the depth dependence of Fe and Si concentrations for an ion dose D≈10^{16} ion/cm^2.Figure 3 shows that the concentration of Fe on the surface in the region of the first maximum (d≈100Å) reaches up to 25÷30%.

Most of the implanted atoms are located in the near-surface region up to a depth of d≈300Å. At d≈400Å the iron concentration sharply decreases with increasing d, and at a depth of

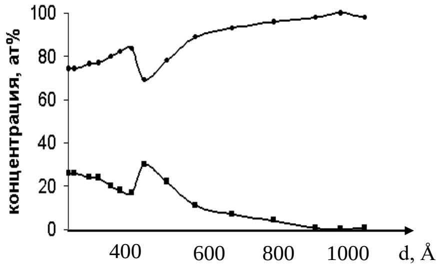


Figure 2. Fe distribution profiles in Si with 40 keV energy and of 10^{16} ion/cm^2 dose.

800 ÷850 Å its value does not exceed 1÷2%. At high doses of irradiation (D > 10^{17} ion/cm^2) instead of a few one maximums one maximum appears, and iron concentration on the surface sharply decreases. The latter can be explained by an increase in the sputtering rate of surface atoms.At D≈10^{17} ion/cm^2, the distribution of Fe has a Gaussian form, the maximum is formed in the near-surface layers d≈ 400 ÷450Å. The iron content in a maximum is egual ~ 30÷35 %. Further increase in a dose of ions leads to displacement of a maximum towards a surface its broadening.

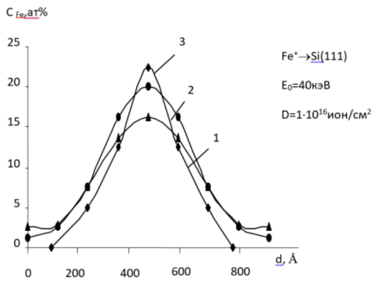
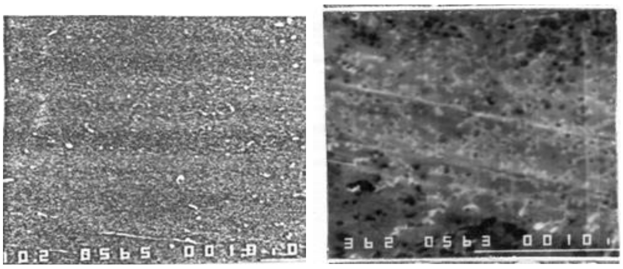


Figure 3. Distribution profiles of electroactive Fe atoms in Si with an implantation dose $1\cdot10^{16}$ion/cm^2: 1-room temperature; 2-T=800^{0}C; 3-T=1000^{0}C.

It is connected as with intensive pulverization of surface layers, and with increase in density of near-surface layers owing to formation of metal silicides. At the same time, the concentration of iron in the region of a wide maximum was 35÷40%. In these layers, compounds of the $FeSi_2$ type were formed predominantly [7–12]. Figure 4 shows the dependence of $C_{Fe}(d)$ irradiated after heating at different temperatures Si(111) doped with ions of Fe^+ c $D=10^{16}$ ion/cm^2.

It can be seen that after annealing at T=800 ^{0}C the concentration of electrically active iron atoms in the region of the maximum increases by 1.3 times. Increase of temperature up to 1000 ^{0}C. Ied to increase of iron concentration in the maximum up to 20 %. In case of silicon alloyed with $D=10^{17}$ ion/cm^2 , after heating the dependence $C^{Fe}(d)$ gets the P-shaped form. At T=1000^{0}C in these layers are formed $FeSi_2$ compounds with strict stoichiometry, which has a monocrystalline structure. Starting from T=1100^{0}C temperature increase leads to the decomposition of $FeSi_2$ film and evaporation of its components from the surface. The heat treatment carried out by a special procedure in the temperature range T=600÷1200^{0}C shows that at 600^{0}C appreciable activation of the iron atoms can be seen, as indicated by an increase in the surface resistivity of the samples. During isothermal annealing regardless of the temperature, the implantation efficiency increases as the implantation increases as the implantation dose increases. At the same time, the crystal structure of the surface and the electrophysical properties of the ion-alloyed layers were studied. Figure.5 shows the electronic patterns obtained from the Si surface before ion-alloying, after ion-alloying, and after heat treatment at different temperatures.



a) b)

Figure 4. Electron microscopic image of pure silicon surface (a) and Fe^+ ion-alloying silicon surface (b).

As can be seen from the figure, in the case of pure silicon the electron pattern is solid and uniform, since the samples were ground and polished (Figure 5, a). After ion doping, depending on the irradiation dose and the type of ions, the electronic pattern changes significantly. The pattern changes from a smooth surface to a rough or matte pattern (Figure 5, b).

Temperature annealing greatly affects the condition of the implanted samples. At small values of irradiation doses and thermal annealing in the case of Fe up to 800 ^{0}C there are no significant changes in the electronic pattern. At temperature 800 ^{0}C and above in the picture some rimmed areas characteristic for monocrystals are observed. Elemental analysis of these edgings by electron Auger spectroscopy showed that they consist mainly of Si and Fe atoms and partially oxygen. The amplitude state of the Auger peaks of silicon and iron allows us to argue that these areas are silicidesvof the $FeSi_2$ type. Similar patterns are observed in the case of Fe at a radiation dose of 10^{16} ion/cm^2 Fe ions edged regions appear at 800 ^{0}C and higher (Figure 6).

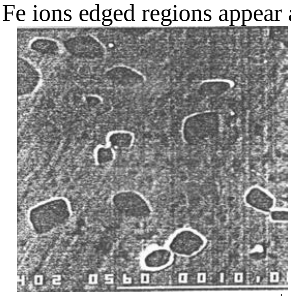


Figure 5. The electron microscopic image of the surface irradiated by Fe^+ ions with a dose of 10^{16} ion/cm^2, after thermal annealing at 800 ^{0}C.

The results of these experiments prove that complex surface processes depend on the type, temperature, and dose of alloying impurities[13–20]. Completely different results are obtained when silicon samples are doped with large doses. Figure 7 shows electronic patterns of silicon doped with Fe ions with a dose of 10^{17} ion/cm^2 after annealing at 800 ^{0}C. As can be seen from figure 7, rimmed areas as if merged, forming a continuous layer in the form of a single crystal with a large number of defects.

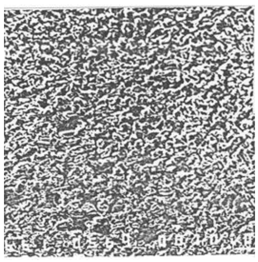


Figure 6. The electron - microscopic image of the surface doped with Fe^+ with a dose of 10^{17} ion/cm^2 after thermal annealing at 800 ^{0}C.

Conclusion. The results of the study of distribution profiles of iron in silicon after various heat treatments, choosing the temperature and duration of annealing for each dose of radiation, showed that it is possible to achieve a uniform distribution of iron in the crystal volume up to a certain depth.

The analysis of the obtained data confirms that during ion implantation, the maximum distribution of iron both on the surface and in the volume of the sample changes mainly due to the change in oxygen concentration. The introduction of iron ions into silicon displaces oxygen atoms.

The above assumption is justified in the case when oxygen in the silicon crystal is in the free interstitial state. The process of ion implantation affects not only the state of oxygen, but also the state of other defects.

The results are in good agreement with similar data obtained by SIMS methods. The possibility of using the RBS method to analyze the concentration distribution of alloying compounds and the interaction of mixtures was noted.

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