Influence of γ – radiation on the properties of silicon with clusters impurity atoms of manganese and nickel

Zlixa Saparniyazova[1], *Temur* Ismaylov[1], *Gulnaza* Abdireymova[1], *Gulnaz* Turmanova[1], *T Kh Hakimov*[2]

[1] Karakalpak State University, Nukus, Uzbekistan
[2]Tashkent State Technical University

Abstract. In works [1-4], it was shown that a number of new physical phenomena are observed in silicon with nanoclusters, such as high-temperature negative magnetoresistance (NMR), anomalously high impurity photoconductivity, giant residual photoconductivity, etc. All these phenomena are directly related to the presence of multiply charged, magnetic clusters of manganese atoms in the silicon lattice. It is shown that, on the basis of such materials, it is possible to create fundamentally new, highly sensitive magnetosensors, photodetectors of infrared radiation operating in the μm region and photomagnetic devices.

1 Introduction

As is known [5], g-irradiation in silicon creates primary radiation defects, such as vacancies (V) and interstitial atoms, as well as A centers. And with an increase in the radiation dose, i.e. when the concentration of such defects increases, secondary radiation defects can form. These are divacancies (V_2), trivacancies (V_3), vacancy pores, and, accordingly, various complexes of interstitial silicon atoms. Depending on the position of the Fermi level in the initial silicon, radiation defects can act as electrically neutral, singly, doubly charged (V^0, V^-, V^{--}), etc. Therefore, it is very important to study the interaction of clusters with radiation defects in silicon, depending on the position of the Fermi level [1-4].

This paper presents the results of a study of the effect of γ-irradiation on the properties of silicon with nanoclusters of manganese atoms. Such studies are of interest, on the one hand, for clarifying the features of radiation-induced defect formation and the interaction of defects with multiply charged clusters, and, on the other hand, for assessing the radiation resistance of such materials and devices based on them.

The influence of γ-irradiation of Co^{60} was studied in samples in which anomalously high NMR, impurity and residual photoconductivity were found. In these samples, before irradiation, the EPR spectrum consisting of 21 lines was clearly revealed, indicating the presence of nanoclusters of manganese atoms [6-7], and all of the above interesting phenomena were also found in them. Samples with nanoclusters, as well as samples with similar parameters doped with manganese, without nanoclusters, and samples without manganese with the same parameters were irradiated. After each stage of irradiation, the electrical and magneto-photoelectric properties of the samples were studied under identical conditions.

2 The mathematical statement of the problem

As shown by the results of the study, there is a critical radiation dose at which the electrical parameters, as well as the magneto-photoelectric properties of silicon samples with nanoclusters, change significantly. The value of $\Phi_к$ depends on the multiplicity of the charge state of nanoclusters and, with a decrease in the latter, shifts towards higher doses (Fig. 1, curves 1÷3). With a further increase in the irradiation dose to $\Phi_м$, the resistivity of the samples significantly decreases to ρ= 10 ÷15 Ohm×sm, i.e. the samples practically acquire the initial parameters of p-type silicon before the diffusion of manganese. The value of $\Phi_м$ also increases with decreasing multiplicity of the charge of nanoclusters (Fig. 1, curves 1÷3). At the same time, the effect of γ -irradiation on the electrical parameters of silicon samples doped with manganese without nanoclusters, as well as on the control samples, has a different character (Fig. 1, curves 4, 5). As can be seen from the figure, in these samples a noticeable change in the resistivity begins at sufficiently high doses , and with an increase in the irradiation dose, the resistivity does not decrease, as in the case of samples with nanoclusters, but increases to the value of intrinsic silicon [8-14].

Figure 2. the effect of γ-irradiation on the value of magnetoresistance in the samples is presented. As can be seen, starting with a dose, the value of the NMR in the samples with nanoclusters sharply decreases, and at $\Phi = \Phi_M$, the sign of the magnetoresistance (MR) is inverted from NMR to positive magnetoresistance (PMR). With a further increase in the irradiation dose, the PMR value increases slightly (curve 1).

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

 https://doi.org/10.1051/e3sconf/202128907020

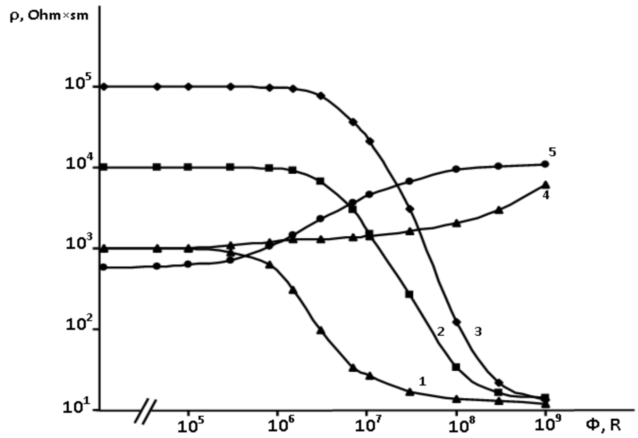

Fig. 1. Dependence of the resistivity of the samples on the dose γ - irradiation.

1, 2, 3 - Si <B,Mn> with nanoclusters with a charge state multiplicity of + 7, + 5, + 3, respectively, 4 - control sample, 5- Si <B,Mn> without nanoclusters [15-23].

PMR, which takes place in samples without nanoclusters doped with manganese, as well as in control samples, does not change sign and increases with an increase in the irradiation dose (curve 2). The study of the spectral dependence of the photoconductivity of silicon with nanoclusters before and after irradiation at $\Phi = \Phi_М$ is shown in Fig.3. As can be seen from the figure, after irradiation in such samples, photosensitivity in the impurity region is almost completely absent, and very weak photoconductivity is observed in the region of the intrinsic absorption spectrum.

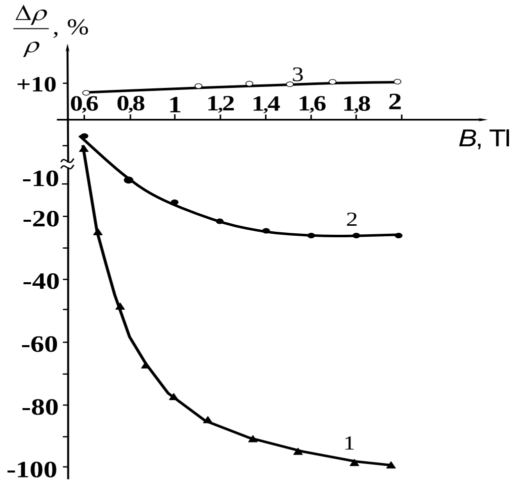

Fig.2. Dependence of the magnetoresistance of the samples on the dose γ - irradiation.

1 - Si<B,Mn> with nanoclusters, 2 –Si<B,Mn> without nanoclusters.

The results obtained show that, as a result of-irradiation, all new physical effects associated with the presence of nanoclusters in silicon disappear, and a change in the resistivity of such samples indicates that all introduced manganese atoms become electrically neutral. Comparison of these results with the data of silicon doped with manganese without nanoclusters and control samples makes it possible to assume that in the samples with nanoclusters at high irradiation doses $\Phi > \Phi_M$, there is no accumulation of radiation defects and their effect on the material properties is practically absent [24-30].

The results of the EPR study showed that in irradiated samples with a dose of $\Phi \geq 10^7$ R, the X-ray spectra associated with nanoclusters of manganese atoms are not observed, but there is a spectrum associated with the state of manganese atoms Mn^0 and Mn-. The obtained experimental data can be explained by the strong electrostatic interaction of radiation defects with multiply charged nanoclusters. As was shown in [2,3], when silicon is doped with manganese by the "low-temperature diffusion" method, almost all introduced manganese atoms participate in the formation of clusters. One of the main requirements for cluster formation is the presence of manganese atoms in the lattice in the Mn^+ and Mn^{++} states. Nanoclusters in the silicon crystal lattice consist of 4-manganese atoms in the nearest interstitial states around a negatively charged boron atom $[(Mn)_4{+}^nB^{-1}]^{+(n-1)}$ [5÷9].

The multiplicity of the charge of nanoclusters, depending on the ratio of the concentrations of boron and manganese atoms, varies in the range from +3 to +7. Therefore, around such clusters there is a sufficiently strong electric potential, the value of which depends on the multiplicity of the charge of the nanoclusters. If we take into account that the vacancies formed as a result of irradiation have a sufficiently large diffusion coefficient, low migration energy $\Delta E_v \approx 0{,}3эВ$ [10÷12] and can be in the lattice in a single and double negatively charged state, then the interaction between vacancies and nanoclusters will be the determining factor in the formation of a defect structure in such materials. As a result of the interaction, vacancies can capture manganese atoms (Mn^+, Mn^{++}), and this leads to the decomposition of nanoclusters and the formation of a manganese atom in the lattice sites in the form of an acceptor impurity atom. At the initial stage of irradiation ($\Phi < \Phi_к$), when the concentration of vacancies is less than the concentration of nanoclusters, the properties of the material are determined by nanoclusters. When the vacancy concentration becomes comparable to the concentration of nanoclusters, the nanoclusters disintegrate and the properties of the material are determined by the properties of manganese atoms located at the sites of the crystal lattice and by the concentration of boron atoms. The discovery of the electric levels created by manganese atoms at the lattice sites was not crowned with success. This may be due to the high ionization energy of the manganese acceptor levels, as well as the effect of a sufficiently high concentration of holes in the valence band [31-35].

3 Conclusions

The results obtained suggest that the formation of nanoclusters of manganese atoms not only significantly increases the photosensitivity of silicon in the impurity region, leads to the formation of an anomalously high NMR, but also controls the accumulation of radiation defects in the region of high radiation doses. This means that by creating nanoclusters based on manganese atoms in silicon with p-type conductivity. it is possible to obtain a radiation-resistant material for the region of high irradiation doses $\Phi > \Phi_к$, while maintaining its initial parameters measured before the formation of nanoclusters. It should also be noted that the magnetic and electrical properties of silicon with nanoclusters are sufficiently stable up to an irradiation dose of $\Phi = 10^6 \div 10^7$ R, and devices based on such materials also do not change their parameters at high irradiation doses.

References

1. M.K. Bakhadyrkhanov, G.Kh. Mavlonov, S. B. Isamov, K.S. Ayupov, H.M. Iliev O.E. Sattarov, S.A. Tachilin. Photoconductivity of silicon with multiply charged clusters of manganese atoms [Mn]4 // Surface Engineering and Applied Electrochemistry 46 (3), 276-280.
2. Ludwig G.W., Woodbury H.H., Carlson R.O. // J. Phys. Chem. Sol. 1959. V.8.P.490.
3. Kreissl, J. and Gehlhaff, W., Electron Paramagnetic Resonance of the Cluster in Silicon, Phys. Status solidi B, 1988, vol. 145, P. 609.
4. Bakhadyrkhanov M.K., Ismailov K.A., Ismaylov B.K., Saparniyazova Z.M. Clusters of nickel atoms and controlling their state in silicon lattice// Semiconductor Physics, Quantum Electronics & Optoelectronics, 2018 V. 21, No. 4. P. 392-396.
5. Watkins G.D. An E.P.R. Study of the lattice vacancy in silicon. J. Phys. Soc. Jap., 1963.18, No. III, P. 22-27.
6. Watkins G.D., Corbett I.W. Defects in irradiated silicon, electron paramagnetic of the divacancy. Phys. Rev., 1965, 138.
7. F.A.Hoshimov, I.I.Bakhadirov, M.S.Kurbanbayeva, N.A.Aytbayev. Development of specific standards of energy consumption by types of produced products of the spinning product // RSES 2020. E3S Web of Conferences. 216 (2020) 01169. https://doi.org/10.1051/e3sconf/202021601169
8. F.A.Hoshimov, I.I.Bakhadirov, A.A.Alimov, M.T.Erejepov. Forecasting the electric consumption of objects using artificial neural networks // E3S Web of Conferences. 216 (2020) 01170. https://doi.org/10.1051/e3sconf/202021601170
9. I.U.Rakhmonov, F.A.Hoshimov. Development of an algorithm for evaluating the dominant factors that have the greatest impact on the energy intensity of products // ENERGY-21. E3S Web of Conferences. 209 (2020) 07018. https://doi.org/10.1051/e3sconf/202020907018
10. Usmanov E.G. Stability in a parallel resonant circuit with active load // RSES 2020. E3S Web of Conferences. 216 (2020) 01160. https://doi.org/10.1051/e3sconf/202021601160
11. Usmanov E.G., Khusanov B.M. Phase relations in resonant circuits with a wide falling section on the amplitude characteristic // RSES 2020. E3S Web of Conferences. 216 (2020) 01161. https://doi.org/10.1051/e3sconf/202021601161
12. I.U.Rakhmonov, K.M.Reymov. Statistical models of renewable energy intermittency // RSES 2020. E3S Web of Conferences. 216 (2020) 01167. https://doi.org/10.1051/e3sconf/202021601167
13. I.U.Rakhmonov, N.N.Kurbonov. Analysis of automated software for monitoring energy consumption and efficiency of industrial enterprises // E3S Web of Conferences. 216 (2020) 01178. https://doi.org/10.1051/e3sconf/202021601178
14. F.A.Hoshimov, I.U.Rakhmonov, N.N.Niyozov. Technology to reduce energy costs in the electric steel melting shop // ENERGY-21. E3S Web of Conferences. 209 (2020) 07017. https://doi.org/10.1051/e3sconf/202020907017
15. A.Taslimov, F.Rakhimov, L.Nematov, N.Markaev, A.Bijanov, R.Yunusov. Economic load intervals for selecting 10 kV cable cross-sections for agricultural consumers // CONMECHYDRO – 2020. IOP Conf. Series: Materials Science and Engineering. 883 (2020) 012102. doi:10.1088/1757-899X/883/1/012102
16. A.Taslimov, M.Melikuziev, O.Matchonov, M.Ruzinazarov and M.Nasirov. Development of standard cable cross-sections of rural electrical networks // CONMECHYDRO – 2020. IOP Conf. Series: Materials Science and Engineering. 883 (2020) 012105. doi:10.1088/1757-899X/883/1/012105
17. I.Bakhadirov, N.Markaev, G.Aslanova, R.Tanatarov, S.Makhmuthonov. Differentiated tariffs of electricity for the improvement of steelmaking Uzbekistan // CONMECHYDRO – 2020. IOP Conf. Series: Materials Science and Engineering. 883 (2020) 012121. doi:10.1088/1757-899X/883/1/012121
18. A.D.Taslimov, A.S.Berdishev, F.M.Rakhimov and A.A.Yuldashev. Optimal tendency of selecting cable cross-sections for agricultural electrical networks // ICMSIT-2020. Journal of Physics: Conference Series. 1515 (2020) 022056. doi:10.1088/1742-6596/1515/2/022056
19. A.D.Taslimov. Selection of a complex of parameters of distribution electric networks with respect to technical limitations // ENERGY-21. E3S Web of Conferences. 209 (2020) 07013. https://doi.org/10.1051/e3sconf/202020907013
20. K.M.Reymov, G.R.Rafikova, L.A.Nematov, Sh.Esemuratova. Existing condition and prospects of making power balance and managing load of electric consumers in uzbek power system // ENERGY-21. E3S Web of Conferences. 209 (2020) 07015. https://doi.org/10.1051/e3sconf/202020907015
21. A.D.Taslimov, F.M.Rakhimov, A.O.Norkulov, A.A.Yuldashev. Research of the optimum scale of standard sections of agricultural purpose lines // E3S Web of Conferences. 216 (2020) 01158. https://doi.org/10.1051/e3sconf/202021601158
22. A.D.Taslimov., M.V.Melikuziev, A.M.Najimova, A.A.Alimov. Economic load intervals for selection of cable sections for agricultural purpose // E3S Web of Conferences. 216 (2020) 01159. https://doi.org/10.1051/e3sconf/202021601159
23. Olimjon Toirov,Kamoliddin Alimkhodjaev, Nurali Pirmatov and Aziza Kholbutaeva E3S Web of Conferences 216, 01119 (2020), https://doi.org/10.1051/e3sconf/202021601119
24. Hadha Afrisal, Budi Setiyono, Muhammad Fahmi Yusuf, Rose Mutiara Suin, Olimjon Toirov 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), pp. 41-46 (2020), https://doi.org/10.1109/ICITACEE50144.2020.9239228
25. Kamoliddin Alimkhodjaev, Olimjon Toirov, Mirzohid Taniev, Sharofiddin Alimkhodjaev Addressing Issues and Possibility of Introducing Renewable Energy Sources in the Conditions of Uzbekistan. JCR. 7(15), 1721-1728 (2020), doi:10.31838/jcr.07.15.231
26. Olimjon Toirov, Tulyagan Kamalov, Utkir Mirkhonov, Sardor Urokov, Dilnoza Jumaeva The mathematical model and a block diagram of a synchronous motor compressor unit with a system of automatic control of the excitation, E3S Web of Conferences, SUSE-2021 (2021)
27. Olimjon Toirov, Sardor Urokov, Utkir Mirkhonov, Hadha Afrisal, Dilnoza Jumaeva Experimental study of the control of operating modes of a plate feeder based on a frequency-controlled electric drive, E3S Web of Conferences, SUSE-2021 (2021)

28. Haqberdiev A., Toshov J. Analysis of the control system of electric motors of the running gear of self-propelled mine cars used in complex mining and technological conditions // E3S Web of Conferences 216, 01135 (2020), Rudenko International Conference “Methodological problems in reliability study of large energy systems” (RSES 2020), https://doi.org/10.1051/e3sconf/202021601135
29. K.M.Reymov, G.Turmanova, S.Makhmuthonov, B.Uzakov. Mathematical models and algorithms of optimal load management of electrical consumers // E3S Web of Conf. 216 (2020) 01166. https://doi.org/10.1051/e3sconf/202021601166
30. Yu.M.Bobozhonov, K.M.Reymov, B.T.Seytmuratov, T.Kh.Khakimov. Research of the dependence of the resistance of asynchronous generators with massive rotors on their design // RSES 2020. E3S Web of Conferences. 216 (2020) 01168. https://doi.org/10.1051/e3sconf/202021601168
31. A.N.Rasulov, M.R.Ruzinazarov, N.Toirova, T.Sh.Alibekova. Graphical-analytical method for constructing load characteristics // RSES 2020. E3S Web of Conferences. 216 (2020) 01171. https://doi.org/10.1051/e3sconf/202021601171
32. Yu.Bobozhonov, B.Seytmuratov, B.Fayzullaev, A.Sultonov. Study of the influence of different designs of massive rotor of asynchronous generator on their maximum power // RSES 2020. E3S Web of Conferences. 216 (2020) 01177. https://doi.org/10.1051/e3sconf/202021601177
33. Karimov R.Ch., Bobojanov M.K., Rasulov A.N., Usmanov E.G. Controlled switching circuits based on non-linear resistive elements (E3S Web of Conferences, 139, 01039, 2019), https://doi.org/10.1051/e3sconf/201913901039
34. Toshov J.B. The questions of the dynamics of drilling bit on the surface of well bottom// Arch. Min. Sci. - Poland. - Vol. 61 (2016), № 2, P. 279-287. DOI 10.1515/amsc-2016-0020
35. Toshov Zh.B. Ways towards optimization of washout components of rock cutting tools // «GORNYI ZHURNAL»/«MINING JOURNAL», Moscow, 2016, № 2, pp. 21–24. DOI: http://dx.doi.org/10.17580/gzh.