Advanced Physical Research
Vol.6, No.1, 2024, pp.50-55
https://doi.org/10.62476/apr61.55

Jomard Publishing

STUDY OF INFRARED QUENCHING IN SILICIDE-SILICON-SILICIDE STRUCTURES

A.T. Mamadalimov[1], M.Sh. Isaev[1*], M.K. Karimov[2], F.M. Isaev[3], Z.A. Muminova[4], S.T. Karimova[4], M.R. Kayumova[4], G.T. Badalova[4], Kh.T. Abdurazzakov[4]

[1]National University of Uzbekistan, Tashkent, Uzbekistan
[2]Urgench State University, 220100, Urgench, Uzbekistan
[3]Almalik branch of Tashkent State Technical University, Uzbekistan
[4]Tashkent Institute of Chemical Technology, Uzbekistan

Abstract. Infrared quenching (IR Q) in silicide-silicon-silicide and silicide-silicon-metal structures has been studied. Silicides are obtained through the process of diffusion doping of silicon with manganese atoms. Infrared quenching was detected in the irradiation energy range of 0.31-0.75 eV when illuminated with local light $h\nu \geq E_g$. Attachment levels for electrons were found: E_c-0.31 eV, E_c-0.38 eV, E_c-0.51 eV. The long-wave limit of photoconductivity (PC) was established to be 0.38 eV by studying the spectral characteristics of silicide-silicon-silicide structures.

Keywords: *Diffusion, photoconductivity, structure, doping, quenching, photoresponse, adhesion levels, recombination, deep level, silicon.*

Corresponding Author: *Makhmudkhodja Isaev, National University of Uzbekistan, Tashkent, Uzbekistan, Tel.: +998935446040, e-mail: isayevmahmud02@gmail.com*

Received: *5 October 2023;* ***Accepted:*** *25 December 2023;* ***Published:*** *19 February 2024.*

1. Introduction

One of the pressing problems of microelectronics is the study of physical processes occurring in the surface and near-surface regions of silicon, diffusion doped with impurities creating deep levels (Daliev *et al*., 1990; Wang, 2013; Fistul *et al*., 1982; Utamuradova *et al*., 2022). Well-developed technology for growing monocrystalline silicon, planar technology for creating integrated devices based on it, a fundamentally new technology for creating objects of reduced dimensionality in silicon, modification of properties by various methods, as well as the discovery of new physical phenomena in the near-surface region that are not typical for bulk silicon, allows this area to be used as an active material for micro- and nanotechnology (Abdurakhmanov *et al*., 1998; Nematov *et.al*., 2023).

It has been experimentally proven that silicon doped with germanium and manganese atoms can be used for the development of infrared photodetectors operating in the wavelength range 1-8 μm and allow for more sensitive detection of infrared

---

[*] **How to cite (APA):**
Mamadalimov, A.T., Isaev, M.Sh., Karimov, M.K., Isaev, F.M., Muminova, Z.A., Karimova, S.T., Kayumova, M.R., Badalova, G.T., & Abdurazzakov Kh.T. (2024). Study of infrared quenching in silicide-silicon-silicide structures. *Advanced Physical Research*, *6*(1), 50-55 https://doi.org/10.62476/apr61.55

radiation and temperature by (Zikrillaev *et.al.*, 2023).

In the near-surface region of diffusion-doped silicon with manganese atoms, the formation of manganese silicides was revealed (Isaev *et al*., 2023a). In Bakhadyrkhanov et.al. (2013) there was found the autoquenching effect of photoconductivity (PC) in silicon with repeatedly charged nanoclusters of manganese atoms in the range of $h\nu$ = 0.4–0.5 eV.

As is known (Utamuradova *et al*., 2023b; Turgunov *et al*., 2023), transition metal silicides are becoming the base material for new promising technological schemes of future generations due to their resistance to aggressive environments and high temperature treatments. Therefore, a comprehensive study of the mechanism of impurity entry into the crystal volume and their interaction with both matrix atoms of the crystal and with technological impurities is relevant.

The phase states of manganese atoms in silicon have been studied using the X-ray diffraction method (Utamuradova *et al*., 2023a). It was found that the diffraction patterns of n-Si<Mn> and n-Si<Mn> samples with a SiO_2 film on the surface exhibit several selective structural reflections with different intensities.

From this point of view, the study of the formation of manganese silicides in the near-surface region of silicon during diffusion doping and the study of their thermal properties has of particular scientific importance in the context of creating new materials for micro- and nanoelectronics.

In this regard, in this work, the photoelectric properties of structures silicide-silicon-silicide and silicide-silicon-metal, which are necessary when creating semiconductor photovoltaic devices.

2. Experimental part

Manganese has a high diffusion coefficient in silicon, so we used the diffusion doping method (Abdurakhmanov *et al*., 1998). This method has a number of other advantages: 1) relative simplicity of technology; 2) the possibility of studying the influence of annealing temperature on the initial parameters of the crystal; 3) the possibility of regulating the concentration of electrically active chromium atoms by changing the temperature (Isaev, 2023b).

To dope silicon with manganese, single-crystal p-type silicon ingots of the KDB-10 brand, grown by the Czochralski method, were used. Their initial parameters: resistivity 10 Ohm·cm, hole mobility 430 $cm^2/V\cdot s$, hole concentration $1.5\cdot10^{15}$ cm^{-3}, oxygen concentration no more than 10^{17} cm^{-3}.

Silicon samples were ground using silicon carbide micropowder M-5, M-10, M-14. In order to remove the surface layer damaged during grinding, the samples were degreased in toluene at a temperature of 40÷50°C and subjected to chemical etching in a solution of 1HF:5HNO_3 for 1÷2 minutes, washed in deionized water and dried at a temperature of no more than 100°C. Silicon samples were placed in quantities of 4 in quartz ampoules previously washed in a solution of HNO_3: 3HCl and boiled in distilled water. Chromium powder in an amount of 5-6 mg was placed in an ampoule near the crystals. The ampoule with samples and diffusant was evacuated to a vacuum of ~10^{-3} mm Hg. and soldered it.

The ampoules were placed in a horizontal diffusion oven and annealed at a temperature of 950÷1020°C for 30 minutes to 2 hours. Temperature fluctuations in the working furnace did not exceed ±5°C. After annealing, the samples were quenched by cooling at a rate of 100-150 K/s by dropping the ampoules into a vessel with water rotating at 33 rpm and kept to room temperature.

After diffusion was completed, surface resistance was measured on all surfaces of the sample using the four-probe method (Pavlov, 1987). Due to the fact that the samples had a surface layer with high conductivity, to eliminate its shunting effect, the samples were ground off on three sides to a depth of 70-100 μm (Isaev & Gaibov, 2020; Kasymov & Isaev, 1997).

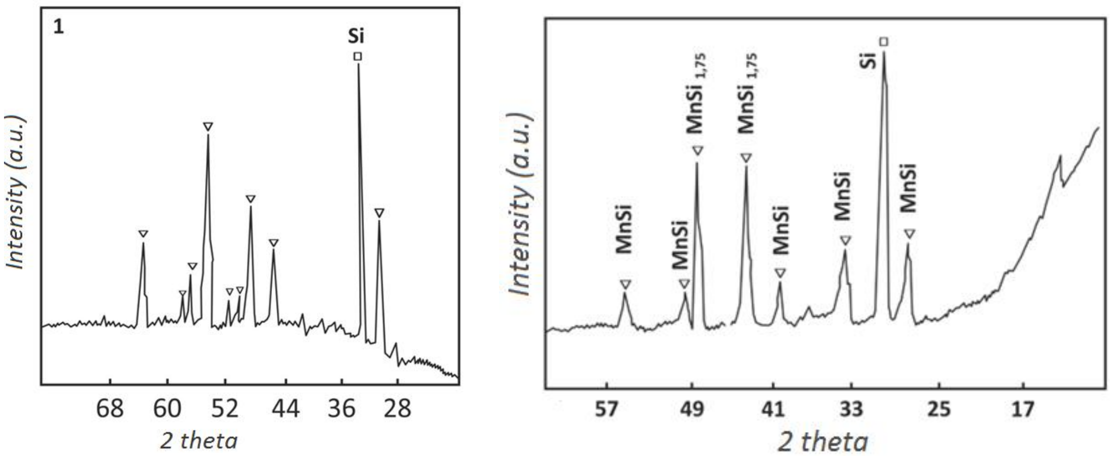
Parallel measurements of conductivity and the Hall effect (Pavlov, 1987) at temperatures of 70÷300 K showed that the surface layer has p-type conductivity, with a carrier concentration of $\sim 10^{21}$ cm^{-3} and a Hall mobility of 4-7 $cm^2/V\cdot s$ and the bulk layer has conductivity i - type, with carrier concentration $10^{10} \div 10^{12}$ cm^{-3} and mobility 300-350 $cm^2/V\cdot s$. Calculations have shown that the surface layer of Si <Mn> with a thickness of 1÷5 μm has a specific conductivity of $\sim(1.6\div 9.9)\cdot 10^3$ $Ohm^{-1}\cdot cm^{-1}$.

An X-ray diffraction pattern shows the formation of mono-, di- and higher manganese silicides in the near-surface region of diffusion-doped silicon with manganese atoms during a chemical reaction stimulated by heat.

Metal contacts were applied to the untreated edge in a gap and grooves 0.2 mm wide were opened in these gaps. In this case, the groove depth is at least 35 microns.

3. Results and discussion

Various samples were prepared for X-ray analysis: alloyed at different diffusion times and with different quenching rates, control samples. Figure 1.a shows an X-ray diffraction pattern of samples of silicon with manganese obtained by diffusion at a temperature of 1060 °C for 30 minutes.



a) b)

Figure 1. X-ray diffraction pattern of a silicon sample with manganese: 1-for diffusion-doped Si<Mn> T=1060 °C, t=30min, Cooling method=fastly (a), slowly (b)

Figure 1.b shows an X-ray diffraction pattern of a sample cooled in air after diffusion of manganese at a temperature of 1060°C for 30 minutes. This spectrum differs from the previous spectrum (Fig. 1.a) mainly in the intensity of the sample line and the line with interplanar distance. This means that the formation of manganese silicide on the crystal surface occurs at both fast and slow cooling rates.

The spectral dependence of the PC $p^{+} - i - p^{+}$ of the MnSi structure is shown in Fig. 2. Electrical parameters such a structure, i.e. $p^{+} - i - p^{+}$ structures at 300 K are as follows: p^{+} - region has a resistivity of 5÷10 Ohm·cm, i- region has a resistivity of 100,000 Ohm·cm.

In silicide-silicon-silicide and silicide-silicon metal structures, manganese silicide is a monopolar injecting contact - anode, and the metal is a blocking one cathode (Bakhadyrkhanov *et al*., 2021).

The manufactured device structures were subjected to irradiation tests in the visible and infrared regions at wavelengths of 0.5÷2.3 μm. In the energy range 0.31-0.75 eV, infrared quenching was detected (Figure 2).

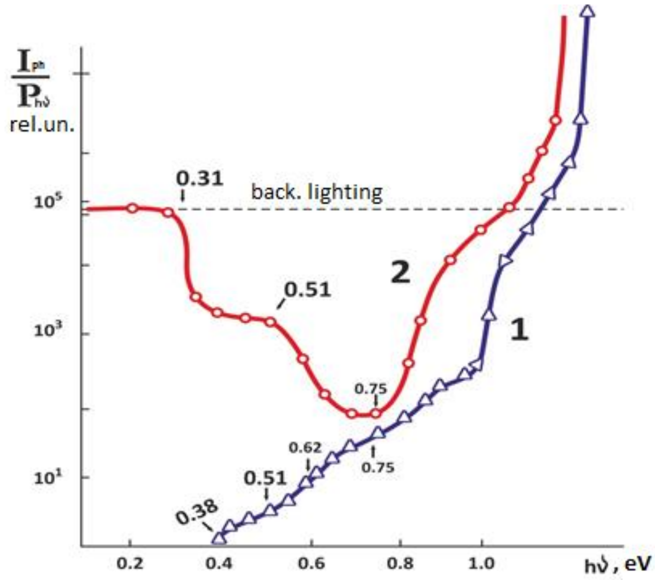


Figure 2. Spectral dependence of the PC p⁺ - i – p⁺ of the MnSi structure and IR Q PC at 77 K: 1 – after illumination with hν≥E_g; 2 – IR Q

By studying the spectral characteristics of $p^{+} - i - p^{+}$ structures, it was established that the long-wave limit of photoconductivity is 0.38 eV. When scanning towards higher energies, a photoresponse was detected at energies of 0.51 eV, 0.62 eV and 0.75 eV. In the band gap, there are levels of E_c - 0.31 eV, E_c – 0.38 eV, E_c – 0.51 eV. Under the influence of background illumination hν≥E_g, electrons from the valence band pass through the conduction band to levels of 0.31 eV; from this level, electrons pass through the conduction band to uncontrolled recombination levels, where they meet a hole and the current drops. After the release of electrons with E_c – 0.38 eV, the current increases, when electrons from the level E_c – 0.51 eV move to the conduction band and recombine with a hole at an uncontrolled recombination level (E_c – 0.51 eV), the current drops. When electrons move to levels E_c – 0.38 eV (E_V + 0.75 eV), from there to the conduction band, then the current increases.

The activation energies E_t=E_V+0.1 eV and the trap concentration N_t=2·10^{11} cm^{-3} were determined. It has been established that when the applied voltage changes in the range of 0.1 ÷ 1 V, the photocurrent under illumination $h\nu \geq E_g$ and intensity of 10^{14} quantum/cm^2 s increases by 10^4 times, and in the range of 1.5 ÷ 15 V – by 10^5 times, at 10 ÷ 15 V – 10^9 times.

4. Conclusion

As a result of the scientific research, we came to the following important scientific conclusions:

1. A method has been developed for obtaining $p^+ - i - p^+$ and $p^+ - i - m$ type structures based on diffusion-doped silicon with metal atoms during a single high-temperature annealing.
2. From a comparison of the current-voltage characteristics at two different voltage polarities for $p^+ - i - m$ structures, it was revealed that when a positive polarity is applied to the silicide layer, it is a monopolar injector for holes.
3. By studying the spectral characteristics of $p^+ - i - m$ and $p^+ - i - p^+$ structures, it was determined that the long-wave limit of photoconductivity is equal to 0.38 eV. When scanning light towards higher energies, a photoresponse was detected at energies of 0.5; 0.62; 0.9; 1.06 eV.
4. The effect of infrared quenching in these structures was discovered in the energy range of 0.31-0.75 eV.
5. It has been established that when the applied voltage changes in the range of $1.5 \div 15$ V under illumination with $h\nu \geq E_g$ and an intensity of 10^{14} quantum/cm^2·s, the photocurrent increases by 9 orders of magnitude.

References

Abdurakhmanov, K.P., Daliev, Kh.S., Utamuradova, S.B. & Ochilova, N.K. (1998). On defect formation in silicon with impurities of manganese and zinc. *Applied Solar Energy, 34*(2), 73-75.

Abdurakhmanov, K.P., Utamuradova, Sh.B., Daliev, Kh.S., Tadjy-Aglaeva, S.G. & Ergashev, R.M. (1998). Defect-formation processes in silicon doped with manganese and germanium. *Semiconductors, 32*(6), 606-607.

Bakhadyrkhanov, M.K., Isamov, S.B., & Zikrillaev, N.F. (2013). Infrared quenching of photoconduction in silicon with multicharge manganese clusters. *Surf. Engin. Appl. Electrochem.*, 49, 308–311. https://doi.org/10.3103/S1068375513040029

Bakhadyrkhanov, M.K., Ibodullaev, S.N., Zikrillaev, N.F. & Koveshnikov, S.V. (2021). An infrared radiation photoresistor based on silicon with nanoclusters of manganese atoms. *Technical Physics Letters, 47*(9), 641.

Daliev, Kh.S., Lebedev, A.A. (1990). *Properties of Doped Semiconductor Materials*. Moscow: Nauka.

Fistul, V.I., Kazakova, V.M., Bobrovnikov, Y.A., Ryabtsev, A.V., Abdurakhmanov, K.P., Zainabidinov, S. & Utamuradova, S.B. (1982). State of manganese impurity ions in silicon. *Soviet Physics Semiconductors-USSR, 16*(5), 603-605.

Isaev, M.Sh., Gaibov, A., Eshkulov, A., Mirkamilova, M. & Shukurova, D. (2022). Research of Surface and Near-Surface Region Diffusion Doped Silicon by Manganese. In *International School on Neural Networks, Initiated by IIASS and EMFCSC*, 681-690. Cham: Springer International Publishing.

Isaev, M.Sh. (2023b). Investigation of electrical and thermal properties of chromium silicides. *Science and World, 1*(113), 24-27.

Isaev, M.Sh., Gaibov, A.G. & Eshkulov, A.A. (2020, November). Investigation of parameters of Schottky diodes based on chromium silicides. *Journal of Physics: Conference Series*, *1679*(2), 022029. IOP Publishing.

Kasymov, A.K., Isaev, M.Sh. (1997). Thermoelectric properties of manganese silicide for thermoelectric converters of solar energy. *Applied Solar Energy, 33*(1), 54-58.

Nematov, D., Kholmurodov, Kh., Stanchik, A., Fayzullaev, K., Gnatovskaya, V., Kudzoev, T. (2023). A DFT Study of Structure, Electronic and Optical Properties of Se-Doped Kesterite Cu_2ZnSnS_4 (CZTSSe). *Letters in Applied NanoBioScience*, *12*(3), 67.

Pavlov, L.P. (1987). *Methods for measuring the parameters of semiconductor materials.* Moscow, High school.

Turgunov, N.A., Berkinov, E.Kh. & Turmanova, R.M. (2023). Accumalations of impurity Ni atoms and their effect on the electrophysical properties of Si. In *E3S Web of Conferences*, 402, 14018.

Utamuradova, Sh.B., Matchonov, Kh.J., Khamdamov, J.J. & Utemuratova, Kh.Y. (2023a). X-ray diffraction study of the phase state of silicon single crystals doped with manganese. *New Materials, Compounds and Applications*, *2*(7), 93-99.

Utamuradova, Sh.B., Daliev, Sh.Kh., Muzafarova, S.A., & Fayzullaev, K.M. (2023b). Effect of the diffusion of copper atoms in polycrystalline CdTe films doped with Pb atoms. *East European Journal of Physics*, 3, 385-390.

Utamuradova, Sh.B., Stanchik, A.V., Fayzullaev, K.M. & Bakirov, B.A. (2022). Raman scattering of light by silicon single crystals doped with chromium atoms. *Applied Physics*, 2, 33-38.

Wang, F.F. (2013). *Impurity doping processes in silicon*. Elsevier.

Zikrillaev N.F., Kushiev G.A., Isamov S.B., Abdurakhmanov B.A., & Tursunov O.B. (2023). Photovoltaic Properties of Silicon Doped with Manganese and Germanium. *Journal of Nano- and Electronic Physics, 15*(1), 01021(4).