ISSN NO: 2770-4491
Date of Publication:24-08-2022

Features of the temperature dependence of the photoconductivity of the base of Mn_4Si_7-Si<Mn>- Mn_4Si_7 structures

N.F.Zikrillaev[1], A.J.Khusanov[2], K.K.Kurbonaliyev[2]
1. Tashkent state technical university
2. Kokand pedagogic institute

Abstract: In this article the influence of infrared radiation and temperature on the parameters of higher silicides of manganese on the surface of silicon created on the basis of impurity manganese atoms is studied. It is shown the possibility of creating effective thermal converters and photodetectors based on structures Si_xMn_{1-x}-Si<Mn>- Mn_xSi_{1-x}.

Key words: manganese, silicide, silicon, impurity atom, thermobatteries, monocrystalline silicon, structure, semiconductor devices, quenching, diffusion technology

Introduction

As production technologies of modern electronic devices improve, the demand for semiconductor materials and devices based on them with stable electro-physical parameters to external influences grows. During operation of semiconductor devices (ultra-large integrated circuits, microprocessors) in practice, relatively large heat values are emitted, which negatively affects operational parameters of devices. This requires continuous cooling of such devices. During development, scientists and specialists need to eliminate certain physical mechanisms of heat generated in high-power semiconductor devices. For cooling of such semiconductor devices, in addition to created coolers and other cooling means, thermal batteries based on higher manganese silicide on monocrystalline silicon structures may well be used. During operation of such powerful semiconductor devices in practice they emit not only heat related to the Joule effect, but also heat related to the Petle effect. In a thermopile installed directly to a high-power semiconductor device, a thermoelectric voltage (TEV) is generated when heat is generated based on the Petle effect. The study of the possibility of creating thin that work on the basis of the heat generated in such semiconductor devices is a very urgent problem of electronics. Thermal batteries based on the structures of higher silicides of manganese on silicon make it possible to create sources with low voltage values, microcoolers with small sizes, as well as highly sensitive photodetectors with low inertia and temperature and infrared radiation sensors operating in a wide range of IR radiation and temperatures.

Material and Methods

Contacts of a metal or silicide with a high resistance semiconductor are known to create potential barriers, which have a great influence on the measurement results and on the operating parameters of semiconductor devices. This is due to the fact that when an external voltage is applied, one contact shifts in the forward direction and the other shifts in the opposite direction.

Requirements for operating parameters of thermobatteries based on thin layers of higher silicides of manganese on monocrystalline silicon are the same as those of thermal batteries developed on solid-state semiconductor compounds with improved parameters. In solid-state thermocouples the heat transfer is carried out on the basis of metal electrodes set in the semiconductor. In contrast, in thin thermocouples and thermobatteries, the heat is transferred by the substrate in which the thin layer has been produced. In thermobatteries based on higher silicides of manganese, due to their small thickness of the formed layer, the heat transfer takes place rapidly. Therefore, studying the parameters of thermobatteries and the mechanism of heat to electricity conversion based on higher silicides of manganese with the use of modern units and devices is the most important task in electronics. Showing the possible applications of thermobatteries based on higher silicide of manganese - silicon structures is also an urgent problem today.

ISSN NO: 2770-4491
Date of Publication:24-08-2022

Diffusion alloying technology of impurity manganese atoms to produce higher silicides of manganese on silicon surface from gas phase, possibilities of impurity manganese atoms concentration control during formation of higher silicides of manganese, obtaining different layers (with different electrophysical parameters and thickness) of higher silicides of manganese on silicon surface. The methods and capabilities of modern installations which have been used to fulfil the task of this work are described in detail. A scientific analysis of the results obtained is given with comparisons with existing scientific data, which had a good agreement, confirming the validity of the scientific results obtained.

During the diffusion of impurity manganese atoms from the gas phase into monocrystalline silicon, initially a thin solid phase layer is formed on the silicon surface with a low concentration of manganese atoms. This is followed by the process of diffusion to form Mn_xSi_{1-x} type silicides on the silicon surface. In this process, the diffusion of manganese atoms on the silicon surface is the main one. In the near-surface layer, which is formed in the second diffusion step, the concentration of manganese atoms evenly distributed over the volume will grow closer to the silicon surface.

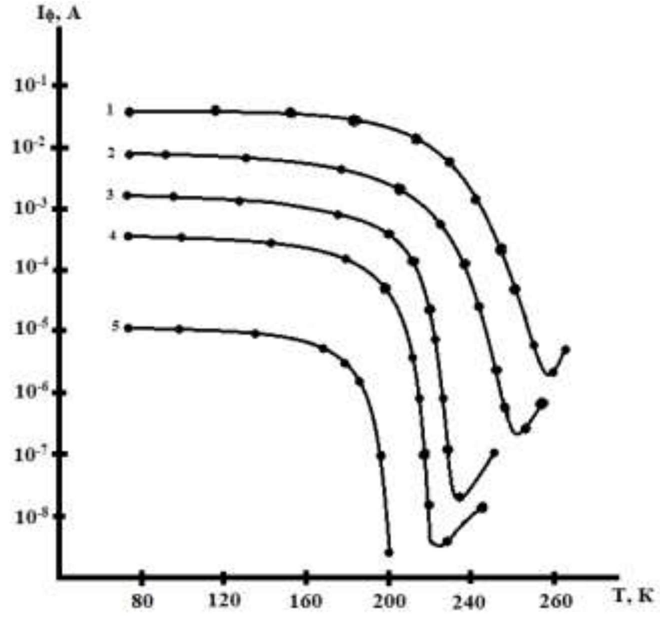
Results

Si_4Mn_7-Si<Mn>-Si_4Mn_7 structures with a high resistivity base based on the initial silicon of KDB-10 grade was obtained to investigate the temperature quenching photoconductivity. Temperature quenching photoconductivity is a thermoelectric feedback between the value of current and temperature at the interface between higher silicides of manganese (HSM) and silicon doped with impurity manganese atoms Si<Mn> under illumination and applied a certain value of electric field strength. To explain the physical mechanism it is necessary to consider the band diagram of the studied structure [1-3]. The base region of the Si<Mn> structure at low temperatures and illumination by its own light becomes a quasi-equilibrium hole conductivity with a concentration of current carriers $p \geq 10^{14}$ cm^{-3}. In this state the Fermi quasi-level for hole-E_{Fp} in the forbidden zone of silicon is close to the ceiling of the valence band and takes the value $E_v + E_{Fp} = 0{,}18$ eV. The Fermi quasi-level for electrons-E_{Fn} due to electrons sticking to the levels of singly ionized impurity manganese Mn atoms will rise from the middle of the forbidden zone to the value of $E_v + E_{Fn} \leq 0.3$ eV. In such a quasi-nonequilibrium state, a small applied voltage leads to a linear heating of the photocurrent of the obtained structures in such structures depending on the temperature value of two sections, which are very different from each other.

The first section (increasing) has a slope characterized by the activation energy of the level on the lower half of the forbidden zone of silicon $F_v + 0.18$ eV. When the structures are heated in the base region, electrons are generated from the valence band with transition to the $E_v + 0.18$ eV level, since the Fermi quasi-level E_{Fp} is below this level, which leads to emptying from electrons. At certain illumination intensities, the lower level is filled with electrons and the Fermi quasi-level for holes E_{Fp} shifts upwards (to the middle of the band gap E_g). In this case there is an increase in the concentration of holes in the valence band increasing the temperature of the structures studied. In the process of heating the base simultaneously shifts the Fermi quasi-level of electrons - E_{Fn} to the middle of the band gap E_g. However, energy values of acceptor level and donor levels of manganese differ almost two times. A change in the photocurrent leads to an increase in the temperature of the silicon-based structures doped with manganese atoms, which affects each level in the corresponding temperature region. It was found that such electronic transitions in Mn_4Si_7- Si<Mn>-Mn_4Si_7 structures occur in the temperature range T=77 ÷ 180 K.

The second section, relating to the rapid decrease in the photocurrent with increasing temperature value in the interval T = 180 ÷ 220 K, can be explained as follows. With increasing temperature the Fermi quasi-level of electrons-E_{Fn} begins to intersect with the manganese level, further shifts to the middle of the silicon E_g band gap. This leads to thermal emission (thermal ejection) of electrons from Mn levels into conduction zone with their subsequent recombination through uncontrolled level- N_r with valence zone holes. This leads to a decrease in the concentration of holes and, consequently, to an increase in the resistance of the base region of the structure, i.e., the temperature extinguishing of photoconductivity. The increase of resistance in the base region of structures, in turn, leads to redistribution of electric field in the transition region of contact with potential barrier in the region of its base, resulting in acceleration of current reduction rate by more than 5÷7 orders of magnitude (pic. 1).

ISSN NO: 2770-4491
Date of Publication:24-08-2022



Picture 1. Temperature quenching of photoconductivity under different background illuminations in Mn_4Si_7- Si<Mn>-Mn_4Si_7 with $\rho_6=8\cdot10^4$ Ohm·cm,

E=40 V/cm, 1-25 lux, 2-10 lux, 4-1 lux, 5-0,1 lux

Discussion

Based on the above, we can assume that the nonlinear features of the photovoltage ampere characteristic (PVACH) are associated with thermal quenching of photoconductivity due to self-heating by joule heat. In the dynamic mode the obtained curves of photocurrent depending on the applied voltages made it possible to understand the mechanisms of photocurrent rise and quenching. This characterizes the nature of photocurrent saturation and emergence of negative differential photoconductivity (NDPC) in heterojunctions of Mn_4Si_7-Si<Mn>-Mn_4Si_7 or Mn_4Si_7-Si<Mn>-M (metall) [4,5].

In the process of carrying out this work the diffusion of impurity manganese atoms into silicon was carried out by two mechanisms. In the first mechanism the diffusion of impurity manganese atoms occurs by displacement of uncontrolled impurity atoms, which are deposited in the vacancies of the crystal lattice of silicon. In the second mechanism, the manganese and silicon atoms are interconnected to form higher of silicides manganese between the lattice junctions.

Conclusion

From the analysis of the literature it is known that if in semiconductors the number of vacancies and the number of inter-nodal atoms are equal, then under such circumstances (conditions) both diffusion mechanisms are observed simultaneously.

The analysis of the results of the study of the photo-electric characteristics of the obtained structures Mn_4Si_7-Si<Mn>-Mn_4Si_7 and Mn_4Si_7-Si<Mn>-M at different radiation densities and applied electric field strength from 50 to 200 in the temperature range T = 77÷250 K showed that with increasing radiation intensity in the area of photocurrent saturation the area of negative differential photo-conductivity (NDPC) appears. It is also shown that the area of NDPC shifts towards lower values of temperature with decreasing intensity of radiation [6-8].

These conditions once again showed the unique physical properties of the obtained structures and the possibility of creating thermobatteries, IR photodetectors and temperature sensors based on them.

References

1. Клечковская В.В., Камилов Т.С., Адашева С.И., Худайбердиев С.С., Муратова В.И. Особенности кристаллической структуры плёнок высшего силицида марганца, выращенных на кремний. Кристаллография, 1994 г., Т.39, №5 с. 894-899

ISSN NO: 2770-4491
Date of Publication:24-08-2022

2. Камилов Т.С., Клечковская В.В., Шарипов Б.З., Эрнест И.В., Зайцев В.К. Электрические и фотоэлектрические свойства четырёхфазных структур на основе кремния и силицидов марганца. Ташкент, MERIYUS, 2014 г., с.180.
3. Бекпулатов И.Р., Хайриддинов Б.Э., Хужаниязов Ж.Б. Структура и физические свойства наноразмерных пленок силицидов металлов. // Монография. Ташкент. «Adad plyus», 2017 г., с. 230.
4. Рисбаев А. Тонкие наноразмерные силицидные плёнки: получение и свойства. // Монография, Ташкент 2013 г., с.210
5. T.S. Kamilov V.V., Klechkovskaya A.S., Orekhov Sh.Kh., Dzhuraev A.S., Kasymov Influence of structural defects in silicon on formation of photosensitive heterostructures Mn_4Si_7-Si<Mn>-Mn_4Si_7 and Mn_4Si_7-Si<Mn>-M. // Eurasian Journal of Physics and Functional Materials, Vol. 2 (4), Kazakstan-2019. p. 360-366.
6. M.K., Bachadyrchanov, S.B., Isamov, N.F., Zikrillaev, E.U., Arzikulov. Infrared quenching of photoconduction in silicon with multicharged manganese clusters. Surface Engineering and Applied Electrochemistry, 2013, 49(4), pp. 308-311.
7. M.K., Bakhadirkhanov, S.B., Isamov, N.F., Zikrillaev, … S.V., Koveshnikov, S.N., Ibodullaev. Functional Capabilities of Silicon with Nanoclusters of Manganese Atoms. Surface Engineering and Applied Electrochemistry, **56**(6), 2020, pp. 734-739.
8. M.K., Bakhadyrkhanov, S.B., Isamov, N.F., Zikrillaev, M.O. Tursunov. Anamalous Photoelectric Phenomena in Silicon with Nanoclusters of Manganese Atoms. Semiconductors, 2021, **55**(6), pp. 542-545.