East European Journal of Physics. **4.** 305-310 (2024)
DOI:10.26565/2312-4334-2024-4-34 ISSN 2312-4334

CURRENT MECHANISMS IN ZINC DIFFUSION-DOPED SILICON SAMPLES AT T = 300 K

E.U. Arzikulov[a,c]*, M. Radzhabova[a], Xue Cui[c], Liu Teng[c], S.N. Srajev[a], N. Mamatkulov[b], Sh.J. Quvondiqov[a], Vasiliy O. Pelenovich[d,e], B. Yang[f]
[a]*Samarkand State University named after Sharof Rashidov, 140104, 15, University Blvd., Samarkand, Republic of Uzbekistan*
[b]*Samarkand State University Veterinary Medicine, Livestock and Biotechnologies,*
140003, 77, Mirzo Ulug Bek Str., Samarkand, Republic of Uzbekistan
[c]*School of Material Science and Engineering, Shenyang Aerospace University,* 37 Daoyi South Avenue, Shenyang**,** *China*
[d]*The Institute of Technological Sciences, Wuhan University, Wuhan, 430072, China*
[e]*Hubei Key Laboratory of Electronic Manufacturing and Packaging Integration, Wuhan University, Wuhan, 430072, China*
[f]*School of Power and Mechanical Engineering, Wuhan University, Wuhan, 430072, China*
**Corresponding Author e-mail: eshkuvata@gmail.com*

Received July 17, 2024; revised September 28, 2024; accepted October 9, 2024

This work is devoted to the study of current flow in diffusion-doped zinc silicon samples in the dark and when illuminated with light with an intensity in the range from 0.6 to 140 lx and at a temperature of 300 K. At T = 300 K and in the dark, the type of the *I–V* characteristic contained all areas characteristic of semiconductors with deep energy levels. It was found that when illuminated with light, the type of *I–V* characteristics of the studied Si samples depended on the value of the applied voltage, the electrical resistivity of the samples, the light intensity, and their number reached up to 6. In this case, linear, sublinear, and superlinear sections were observed, as well as the switching point (sharp current jump) and areas with negative differential conductivities (NDC). The existence of these characteristic areas of the applied voltage and their character depended on the intensity of the light. The experimental data obtained were interpreted in the formation of low dimensional objects with the participation of multiply charged zinc nanoclusters in the bulk of silicon. They changed the energy band structure of single-crystal silicon, which affected generation-recombination processes in Si, leading to the types of *I–V* characteristics observed in the experiment.

Keywords: *Doped silicon; I–V characteristic; Negative differential conductivity; Low dimensional objects; Zinc nanoclusters*
PACS: 72.8-,-r, 72.80. Cw

1. INTRODUCTION

The study of current flow processes in highly compensated (HC) silicon samples doped with zinc in a high non-equilibrium state, at room temperatures and in the presence of illumination, is of important scientific and practical interest. From a scientific point of view, such studies provide more information about the role of a particular center formed by impurity atoms on current flow processes. From a practical point of view, knowledge of the behavior of a sample under various conditions makes it possible to determine the optimal conditions for creating various sensors of external influences based on HC silicon samples.

It is known that zinc in silicon acts as a double acceptor with ionization energies $E_1=E_V+0.31$ and $E_2=E_V+0.50$ eV [1-3]. A study of the surface morphology using an atomic force microscope (AFM) and the photoelectric properties of diffusion zinc-doped silicon samples showed that nano-sized multi-charged clusters are formed in them [4]. These clusters significantly change the structure of the energy states of the zinc atoms in silicon. As a result, instead of the above two acceptor energy levels corresponding to a single zinc atom, other deep energy levels appear with the participation of zinc nanoclusters lying in the range of values $E=E_V+(0.16\div0.617)$ eV, which is consistent with the data [5].

2. EXPERIMENTAL METHODS, RESULTS AND IT'S DISCUSSION

To elucidate the mechanism of current flows in HC samples of silicon diffusion-doped with zinc with different types of conductivity and degrees of compensation, of both n- and p-type conductivities with resistivity lying in the range of $10^2\div10^5$ Ω·cm at T = 300 K were obtained using the high-temperature diffusion method according to the technology described in [6]. Ohmic contacts to the studied samples were created by laser soldering of copper wire with a diameter of 100 µm or by applying conductive silver paste [7].

The measurement of the *I–V* characteristics of diffusion-doped HC Si<P, Zn> samples of both p- and n-types, was carried out according to the method described in the [8]. Samples of p- or n- n-conductivity types in the form of parallelepipeds with dimensions of $10\times5\times0.3$ mm^3 were included in a circuit consisting of a series-connected load resistance R_L and a stabilized voltage source. The voltage generator mode ($R_S \gg R_L$) was performed regardless of the current flowing through the sample. An incandescent lamp, powered by direct current, served as a source of lighting.

Cite as: E.U. Arzikulov, M. Radzhabova, X. Cui, L. Teng, S.N. Srajev, N. Mamatkulov, Sh.J. Quvondiqov, V.O. Pelenovich, B. Yang, East Eur. J. Phys. 4, 305 (2024), https://doi.org/10.26565/2312-4334-2024-4-34

2.1 Results And Discussion

A study of the *I–V* characteristic of HC silicon samples diffusion-doped with zinc of both n- and p- types of conductivity and with electrical resistivity in the range of $10^2 \div 10^5$ Ω·cm at T = 300 K showed that the *I–V* characteristic in the dark contains three characteristic sections (Figure 1).

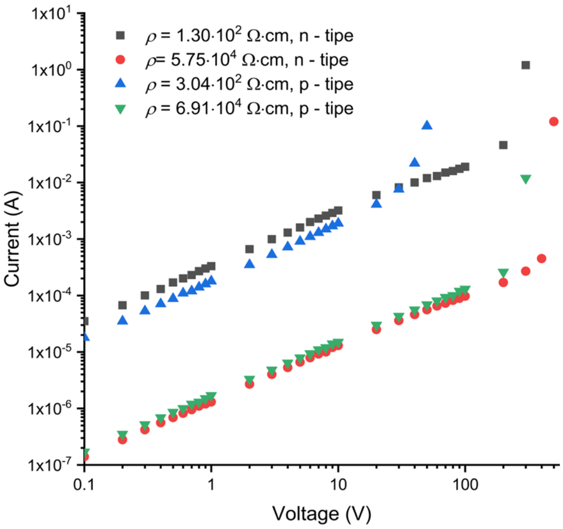

Figure 1. *I–V* characteristics of Si<P, Zn> samples with different specific electrical resistances and types of conductivity in the dark at *T* = 300 K

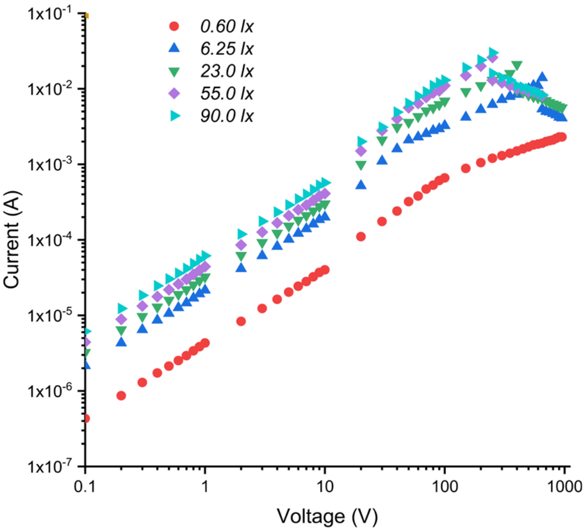

Figure 2. *I–V* characteristics of n–Si<P, Zn> samples with $\rho = 5.74 \cdot 10^4$ Ω·cm, *T* = 300 K

The first section in the dependence $I = U^{\alpha}$ is linear (the exponent α lies in the range 0.97÷1.03) for all studied samples whose length in voltage increases approximately 10 times with increasing ρ (for example, 0.1 ÷10 V for a sample with $\rho = 1.3 \cdot 10^2$ Ω·cm and 0.1 ÷ 100 V for a sample with $\rho = 6.91 \cdot 10^4$ Ω·cm). The second section is superlinear (the exponent is equal to the value 1.28 ÷ 1.97). The third section of the *I–V* characteristic is a section of a sharp increase in current from voltage. Here the value reaches up to 25.03. At first glance, the last section looks like an electrical breakdown. However, repeated measurements have shown that the experimental data is repeatable; therefore, we can say there is no electrical breakdown here. It should be noted that the exponent increases sharply in this section with increases of the ρ.

Figure 2 shows the *I–V* characteristics of n–Si<P, Zn> samples, also taken at room temperature and in the presence of illumination with an intensity of 0.6–90 lx.

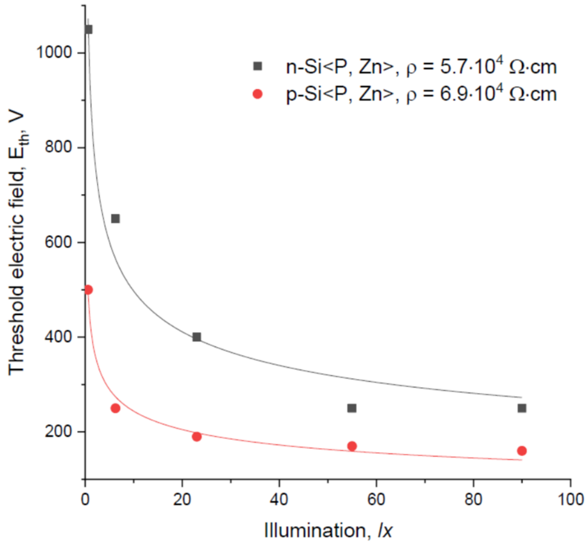

Figure 3. Dependence of the threshold voltage of the current jump on the illumination of the light

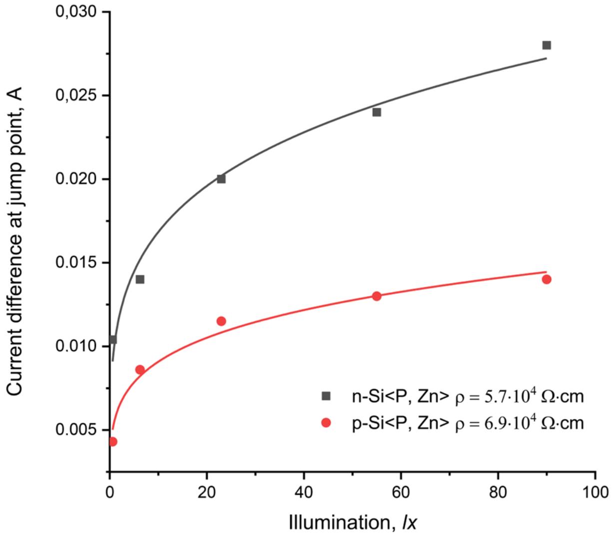

Figure 4. Dependence of the magnitude of the current jump on the illumination of the light

As can be seen from Figure 2 the *I–V* Characteristics of n–Si<P, Zn> samples taken at low illumination of light have three characteristic sections [9]. The first almost linear section with the exponent $\alpha = 0.99$ lies in the voltage range 0.10÷9 V, then follows the superlinear section with $\alpha = 1.24$ lying in the voltage range 10÷90 V, then follows the sublinear section with the exponent $\alpha = 0.554$ lying in the range 100÷950 V [10]. As the light irradiance value (LIV) increases, the number of characteristic areas and the nature of the $I = U^{\alpha}$ dependence changes. So, for example, at 6.25 *lx* the number of characteristic areas reaches six and this number is maintained for all LIV. In this case, the voltage extension of the first ohmic section is preserved for all values of the LIV. The nature of the second section does not change, i.e. it's always super linear. However, the degree of superlinearity increases from the beginning, and having reached a maximum ($\alpha = 1.77$), it decreases ($\alpha = 1.55$). The third section at low LIV is sublinear ($\alpha = 0.68$) and with increasing LIV the sublinearity decreases ($\alpha = 0.75$) with further growth of LIV it first turns into a linear dependence ($\alpha = 0.97$) and then becomes superlinear ($\alpha = 1.15$). The fourth section at relatively low LIV (6.25-23 *lx*) exhibits a superlinear dependence ($\alpha = 1.44÷2.04$), then, as in the third section, it first turns almost linear ($\alpha = 1.08$), and then a weak sublinear relationship ($\alpha = 0.90$). The fifth section is a section of a sharp jump in current downward in value. The threshold voltage corresponding to a current surge depends on the LIV. At low LIV, the jump occurs at higher values of voltage applied to the sample. With increasing LIV, the current sharply decreases, and, starting from 23 *lx*, the current jump does not depend on the LIV (Figure 3), but the magnitude of its jump ($\Delta I = I_{max} - I_{min}$) depends on the LIV. At low LIV, the value of ΔI is small and with increasing LIV it increases sharply, and, starting from LIV 23 *lx*, its growth slows down (Figure 4).

Figure 5 shows the *I–V* characteristics of HC samples p–Si<P, Zn> with $\rho = 6.91 \cdot 10^4$ Ω·cm taken at a temperature $T = 300$ K in the presence of illumination with an intensity lying in the range of 0.6÷100 *lx*.

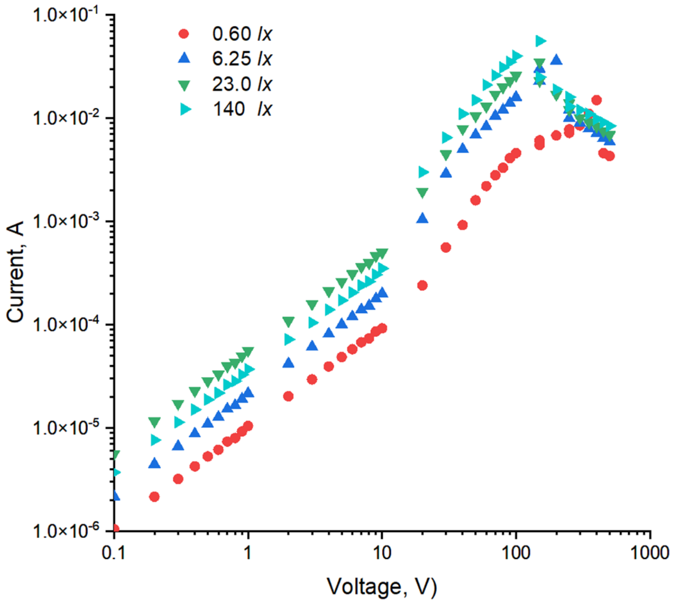

Figure 5. *I–V* characteristics of n–Si<P, Zn> samples with $\rho = 6.91 \cdot 10^4$ Ω·cm, $T = 300$ K

As can be seen from Figure 5, in contrast to n–Si<P, Zn> samples, the *I–V* characteristics of p–Si<P, Zn> taken at $T = 300$ K and low LIV contain 6 characteristic sections (instead of three). These are sections: the first almost linear section with the exponent $\alpha = 0.98$ lies in the voltage range 0.10÷9 V, and this dependence is preserved for all LIV, then follows the second superlinear section with $\alpha = 1.73÷2.08$, lying in the voltage range 10÷30 V, followed by the third sublinear section with the exponent $\alpha = 0.42$, lying in the range 40÷100 V. With an increase in the LIV, this section moves to a superlinear dependence with the exponent α, lying in the range 1.27÷1.45. Next comes the fourth superlinear section with $\alpha = 2.55$. With increasing LIV, this dependence becomes sublinear, and the value decreases. The fifth is a section of a sharp jump in current downward in value. The voltage corresponding to the current surge depends on the LIV. At low values of the LIV, the jump occurs at higher values of the voltage applied to the sample. With increasing LIV, the threshold voltage value decreases sharply, and starting from 23 *lx*, as in the case of p–Si<P, Zn> samples, it ceases to be affected by the LIV (Figure 3). In this case, the magnitude of the jump ($\Delta I = I_{max} - I_{min}$) also depends on the LIV. At low LIV, the value of ΔI is small, but with increasing LIV it increases sharply and, starting from LIV 23 *lx*, its growth slows down (Figure 4). It should be noted that in n–Si<P, Zn> both the value of the threshold voltage U_{th} and the value of ΔI are always greater than in p–Si<P, Zn>.

The nonlinearity of the *I–V* characteristic occurs not only in many semiconductor devices, in which the main working element is *p-n* junctions but also in many semiconductor materials in which *p-n* junctions are completely absent [11]. In semiconductor materials, if we exclude the influence of contacts, nonlinearity is most often due to the effects of strong fields. It is known that in strong electric fields, there is a dependence of mobility on the field strength until velocity saturation, NDC, impact ionization, and breakdown. However, in weak electric fields, the manifestation of nonlinearity of the *I–V* characteristic is also possible [12].

In [6], it was shown that in the silicon samples we studied, diffusion-doped with zinc at low voltages, the dependence of the current flowing through the sample on the applied voltage is linear. At higher voltages, nonlinearities appear in the

I–V dependence, which is described by the theory of limited space charge current (SCLC) by trapping holes at levels created by zinc atoms located in the band gap of silicon [13].

However, the exact reasons for the nonlinear nature of the *I–V* characteristics in semiconductors have not yet been unambiguously established [14]. According to [15], the nonlinearity of the relationship between excess carrier concentrations in compensated semiconductors leads to a complex dependence on the parameters that determine the shape of the *I–V* characteristics on the injection level. An important role in the formation of the *I–V* characteristics of the diode structure is played by the bipolar drift mobility and the effective diffusion coefficient. In the expressions that determine the above quantities, there is a function $v(p)=dn/dp$, the form of which is determined by the specific type of the system of deep impurity levels in the compensated semiconductor. At low and high injection levels, when carrier concentrations are related by a linear dependence and the value of $v(p)$ is constant, the influence of equilibrium parameters on the values of mobility and diffusion coefficient has a weak effect. When considering the mechanisms responsible for the behavior of the *I–V* characteristics of a compensated semiconductor, it is necessary to take into account the influence of simultaneous changes in the bipolar drift mobility and the effective diffusion coefficient, which is a difficult task in practice.

In our case, possible reasons for the nonlinearity of the *I–V* characteristics in Si<P, Zn> samples may be the following mechanisms: i) currents limited by space charges; ii) and ionization of impurity centers in strong electric fields [14, 16]. As was shown in [14], when a voltage is applied to samples with high resistance, an injection current appears in the circuit, which obeys the power law $J \sim E^2$. The nonlinear sections of the *I–V* characteristics in such samples containing shallow and deep traps were mainly associated with the possibility of implementing monopolar or double injection.

In the HC Si<P, Zn> samples we studied, there are *r*– (slow, associated with doubly ionized zinc atoms) and *s*– (fast, levels arising during high-temperature diffusion) recombination centers, as well as *t*– trap levels associated with shallow levels [17]. This suggests that in fields where a quadratic dependence $J \sim E^2$ is observed, the *I–V* characteristic exhibits a trap character of conductivity. The experimental data obtained in the corresponding sections of the *I–V* characteristic show that in p- and n-type Si<P, Zn> samples, the transport of charge carriers in electric fields with a strength of less than 10^2 V/cm is mainly due to monopolar injection and is consistent with Lampert's theory [9].

The sections of the *I–V* characteristic with $\alpha < 1$ that we studied for p- and n-type Si<P, Zn> samples can be satisfactorily explained within the framework of the theory of the "injection depletion effect" [13]. The appearance of sublinear sections of the *I–V* characteristic is theoretically possible only in the case of counter-directions of ambipolar diffusion of nonequilibrium current carriers and their ambipolar drift, which in our case is mainly determined by injection modulation of the charge of deep levels [18]. Due to the difference in diffusion coefficients, holes move slowly, and electrons run far ahead, which leads to their separation in space and an electric field arises between them, inhibiting their movement. A decrease in their speed causes a decrease in current, which in turn leads to the appearance of sublinear sections of the *I–V* characteristic.

Analysis of the results of experimental data obtained at relatively high electric field strengths (at $E > 10^2$ V/cm) shows that the increase in electrical conductivity with increasing E is associated with an increase in the concentration of excess charge carriers. This circumstance allows us to assume that the presence of a region of the sharper current growth in the *I–V* characteristic, where $\alpha > 3$, can be explained by the fact that in Si<P, Zn> p– and n-type samples at such E, depletion (or ionization) occurs traps stimulated by an electric field.

There is another mechanism that also leads to a strong change in the concentration of charge carriers. This may be due to a sharp increase in the degree of ionization of small donors or acceptors when free carriers are heated by an electric field. Such a sharp increase in the degree of ionization can be associated both with an increase in the rate of impact ionization upon heating of charge carriers and with the field dependence of the probability of their capture by similarly charged traps. This is only possible at very low temperatures. In fields of the order of 10^2 V/cm, almost complete release of charge carriers from traps occurs, which leads to sharp superlinearity of the *I–V* characteristic. At present, however, there is still no complete clarity regarding the specific mechanism of origin of the region responsible for NDC [10].

The origin of the fifth region, where a downward current jump is observed at certain values of voltage applied to the sample, is not yet completely clear. Such a current jump may be associated with the "opening" of a new additional recombination channel associated with zinc atoms. In this case, the capture cross section for nonequilibrium charge carriers at the center corresponding to this channel probably depends on the electric field strength. When the threshold voltage value is reached, this channel "opens", which leads to a sharp decrease in the number of current carriers and corresponds to a current jump down in value.

In [19], a model of a semiconductor with quantum dots (QDs) was used to explain the experimental data obtained. It is known that the presence in the band gap of a semiconductor of various traps for charge carriers associated with impurity atoms significantly affects the type of their *I–V* characteristics. This is especially evident in HC semiconductor materials. In this case, *S*- or *N*-shaped sections also appear on the *I–V* characteristic instead of a linear section, followed by quadratic and almost vertical dependencies. *I–V* characteristics with several NDCs or the simultaneous presence of *S*- and *N*-shaped characteristics are also possible [10].

The results obtained can be interpreted in such a way that zinc atoms in silicon, with strong compensation, form not only single deep levels but also an entire band of levels characteristic of nanoclusters (or quantum dots) with large carrier capture cross sections [7].

The value of the electrical resistivity of Si<P, Zn> samples of both n- and p-type conductivity with NC with different charge states, obtained by high-temperature diffusion lies in a wide range ($\rho \sim 10^2 \div 10^4$ Ω·cm), i.e. they are quite high-resistance. These NCs are deep traps for charge carriers. Unlike conventional traps, where carriers are at a fixed energy level, in NC they are not only bound but can also be at different quantized energy levels with different densities of states and capture cross sections. The nature of their distribution among levels depends on the degree of compensation, on injection, etc., in addition, the process of tunneling between NCs is possible. Therefore, it should be expected that the *I-V* characteristics in such materials should have their characteristics, which were experimentally discovered in the Si<P, Zn> samples with NC we studied [20].

It should also be noted that with a decrease in the resistivity of the samples, the value of the vertical section of the *I–V* characteristic also decreases. Knowing the charge carrier concentrations at a given temperature, we calculated the positions of the Fermi level in these samples at T=300 K, which are F_1=0.35 eV, F_2=0.43 eV, and F_3=0.49 eV, respectively. Therefore, it can be assumed that in these samples the NCs act as traps with different concentrations and ionization energies, which are higher than the Fermi level. We can consider that in the samples under study there are only NCs with different charge multiplicities and assume that the detected energy levels correspond to their different charge states.

3. CONCLUSIONS

Based on the studies of the electrical properties of silicon samples diffusion-doped with zinc, it was established that the *I–V* characteristic consists of several characteristic sections (the number of which can reach up to 6): linear, sublinear, superlinear, switching point, and section with NDC. Their number and voltage ranges depend on the temperature, degree of illumination, and resistivity of the sample.

The sublinear sections of the *I–V* characteristic observed in p- and n-type Si<P, Zn> samples can be satisfactorily explained within the framework of the theory of the injection depletion effect. The observed quadratic dependences $J \sim E^2$ in the *I–V* characteristic can be associated with the influence of traps on conductivity. In the p- and n-type Si<P, Zn> samples we studied, the transfer of charge carriers in electric fields with a strength of less than 10^2 V/cm is mainly due to monopolar injection and is consistent with Lampert's theory.

The presence of a region of sharper current growth in the I–V characteristic, where α>3, can be explained by the fact that in Si<P, Zn> p- and n-type samples at such electric field strengths, emptying (or ionization) of traps occurs, stimulated by the electric field.

The observed features in the *I–V* characteristic are mainly associated with the formation of nano-sized multiply charged clusters, which significantly change the structure of the energy states of zinc atoms in silicon. As a result, instead of the well-known two acceptor energy levels corresponding to atomic zinc, a whole spectrum of deep donor energy levels of zinc nanoclusters appears lying in the range $E=E_V+(0.16 \div 0.4)$ eV.

Acknowledgments

This study was supported by the Open Fund of Hubei Key Laboratory of Electronic Manufacturing and Packaging Integration (Wuhan University) (Grant No. EMPI2024017).

ORCID

Eshkuvat U. Arzikulov, https://orcid.org/0000-0001-9179-3402; **Vasiliy O. Pelenovich,** https://orcid.org/0000-0001-8663-3543

REFERENCES

[1] C.S. Fuller, and F.J. Morin, Phys. Rev. **105**, 379 (1957). https://doi.org/10.1103/PhysRev.105.379
[2] E. Merk, J. Hoyman, and E.E. Haller, Solid State Commun. **72**, 851 (1989). https://doi.org/10.1016/0038-1098(89)90412-2
[3] S. Weiss, N. Beckman, and R. Kassing, Appl. Phys. A, **50**, 151 (1990). https://doi.org/10.1007/BF00343410
[4] E.U. Arzikulov, M. Radzhabova, Sh.J. Quvondiqov, G. Gulyamov, East Eur. J. Phys. (3), 400 (2023). https://doi.org/10.26565/2312-4334-2023-3-43
[5] T. Abdulmecit, Turk. J. Phys. **44**(4), 302 (2020). https://doi.org/10.3906/fiz-2007-11
[6] M.K. Bakhadirkhanov, N.F. Zikrillaev, and E.U. Arzikulov, Tech. Phys. Lett. **17**, 1 (1991). (in Russian)
[7] M. Neul, I.V. Sprave, L.K. Diebel, L.G. Zinkl, F. Fuchs, Y. Yamamoto, C. Vedder, *et al*., Phys. Rev. Materials, **8**, 043801 (2024). https://doi.org/10.1103/PhysRevMaterials.8.043801
[8] N.F. Zikrillaev, and E.U. Arzikulov, Report. Uzb. Acad. Sci. **11**, 27 (1991). (in Russian)
[9] M.A. Lampert, and P. Mark, *Current Injection in Solids*, (Electrical Science, 1970).
[10] M.C. Ozdemir, O. Sevgili, I. Orak, and A. Turut, Mater. Sci. Semicond. Process. **125**, 105629 (2021). https://doi.org/10.1016/j.mssp.2020.105629
[11] S. Boughdachi, Y. Badali, Y. Azizian-Kalandaragh, and S¸ Altindal, J. Elec. Mater. **47**, 12 (2018). https://doi.org/10.1007/s11664-018-6593-y
[12] E. Schöll, *Nonequilibrium Phase Transitions in Semiconductors. Self-Organisation Induced by Generation and Recombination Processes*, (Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, 1987).
[13] V.E. Lashkarev, A.V. Lyubchenko, and M.K. Sheikman, *Nonequilibrium processes in photoconductors*, (Nauk. Dumka, Kiev, 1981). (in Russian)
[14] D. Degler, U. Weimar, and N. Barsan, ACS Sens. **4**, 2228 (2019). https://doi.org/10.1021/acssensors.9b00975
[15] M. Labed, J.Y. Min, A.B. Slim, N. Sengouga, C.V. Prasad, S. Kyoung, and Y.S. Rim, J. Semicond., **44**(7), 072801 (2023). https://doi.org/10.1088/1674-4926/44/7/072801

[16] P. Vivek, J. Chandrasekaran, V. Balasubramani, A. Manimekalai, and T.G.V. Prabhu, Surfaces and Interfaces, **37**, 102689 (2023). https://doi.org/10.1016/j.surfin.2023.102689
[17] H. Chouaib, M. Aouassa, and M. Bouabdellaoui, J. Mater. Sci: Mater. Electron. **34**, 1815 (2023). https://doi.org/10.1007/s10854-023-11171-6
[18] B.I. Shklovsky, and A.L. Efros, *Electronic properties of doped semiconductors*, (Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1979).
[19] N.N. Gerasimenko, and Yu.N. Parkhomenko, *Silicon - Nanoelectronics Material*, (Technosphere, Moscow, 2007). (in Russian)
[20] M.A. Rafiq, J. Semicond. **39**, 061002 (2018). https://doi.org/10.1088/1674-4926/39/6/061002

МЕХАНІЗМИ СТРУМУ В ЗРАЗКАХ КРЕМНІЮ, ЛЕГОВАНОГО ДИФУЗІЄЮ ЦИНКУ, ПРИ Т = 300 К

Е.С. Арзікулов[a,c], М. Раджабова[a], Сюе Цуй[c], Лю Тенг[c], С.Н. Срасв[a], Н. Маматкулов[b], Ш.Дж. Гувондіков[a], Василь О. Пеленович[d,e], Б. Янг[f]
[a]*Самаркандський державний університет імені Шарофа Рашидова,*
140104, Університетський бульвар, 15 Самарканд, Республіка Узбекистан
[b]*Самаркандський державний університет ветеринарної медицини, тваринництва та біотехнологій,*
140003, вул. Мірзо Улуг Бек, 77, Самарканд, Республіка Узбекистан
[c]*Школа матеріалознавства та інженерії Шеньянського аерокосмічного університету,*
37 Південна авеню Даої, Шеньян, Китай
[d]*Інститут технологічних наук Уханьського університету, Ухань, 430072, Китай*
[e]*Ключова лабораторія виробництва електроніки та інтеграції упаковки в Хубеї, Уханьский університет, Ухань, Китай*
[f]*Школа енергетики та машинобудування Уханьського університету, Ухань, Китай*

Дана робота присвячена вивченню протікання струму в дифузійно легованих зразках цинкового кремнію в темряві та при освітленні світлом з інтенсивністю в діапазоні від 0,6 до 140 лк і температурі 300 К. При Т = 300 К і в темряві вид ВАХ містив усі ділянки, характерні для напівпровідників з глибокими енергетичними рівнями. Встановлено, що при освітленні світлом вид ВАХ досліджуваних зразків кремнію залежав від величини прикладеної напруги, питомого електричного опору зразків, інтенсивності світла, а їх кількість досягала 6. при цьому спостерігалися лінійні, сублінійні та суперлінійні ділянки, а також точка перемикання (різкий стрибок струму) і області з від'ємною диференціальною провідністю (НДП). Наявність цих характерних ділянок прикладеної напруги та їх характер залежали від інтенсивності світла. Отримані експериментальні дані інтерпретовано при формуванні низькорозмірних об'єктів за участю багатозарядних нанокластерів цинку в об'ємі кремнію. Вони змінили енергетичну зонну структуру монокристалічного кремнію, що вплинуло на процеси генерації-рекомбінації в Si, що призвело до типів ВАХ, які спостерігалися в експерименті.

Ключові слова: *легований кремній; ВАХ; негативна диференціальна провідність; малорозмірні об'єкти; нанокластери цинку*