Photosensitive Structure with Schottky Barrier Based on Nickel-Silicon Silicon Contact

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I. Introduction

In a metal-semiconductor contact, depending on the ratio between the values of the electron yield work in the metal ψ_m and in the semiconductor $\chi + V_n$, electrons as a result of internal emission may pass from metal to semiconductor or vice versa. In this case, a part of electrons from the metal (silicide) goes to the semiconductor (Si) until thermodynamic equilibrium occurs and the Fermi levels in the metal and in the semiconductor are equalized [1,2].

In the vicinity of the semiconductor-metal interface in the semiconductor an area of depleted charge carriers arises, an area of bulk charge of uncompensated negative acceptor ions whose electric field prevents the further emission of electrons from metal to semiconductor, the semiconductor energy bands bend downwards.

If the thickness of the intermediate layer is atomic distance, then the magnitude of the curvature of the height of the potential barrier equals the contact potential difference

$$\psi_{mS} = \Phi_S - \Phi_m + (E_f - E_v) = X + E_g - \Phi_m,$$

where, the second term is the difference between the yield work of the metal and the electron affinity of the semiconductor.

Under the influence of IR radiation two types of electronic transitions can take place in such a structure. If the incident photon energy $h\nu \geq E_g$, then electron-hole pair generation occurs when it is absorbed in the semiconductor. In this case, as well as in an ordinary photodiode on a p-n junction, carriers of different sign on the junction field separate and photo-electric power arises. It is obvious that the long-wave limit of such a process cannot be less than the band gap width of the semiconductor, and from this point of view the Schottky barrier photodiodes do not differ from p-n photodiodes or their own photoresistors. If $h\nu < E_g$ then infrared absorption in a metal film excites valence electrons to states above the Fermi level, leading to holes, some of which have energy greater than the barrier height Ψ_{ms}. Then either the hole is emitted from the metal to the semiconductor, or the electron moves from the semiconductor to the metal, filling the empty state [3,4]. To overcome the metal-to-semiconductor barrier, the energy of the excited hole must be greater than the height of the barrier. The long-wave boundary of such a process can be changed by selecting the appropriate metal. Therefore, from the point of view of creating silicon-based IR photodetectors the greatest interest is the photoemission from metal to semiconductor.

a) Experiment

In the first step, the 0,5 μm thick SiO_2 oxide layer was grown on p-type (100) silicon wafers (KDB-10). Before this operation the silicon wafers were degreased with trichloroethane, acetone and alcohol and cleaned in a CCl_4 boiling solution. Before metal (Ni) sputtering, windows of 2·2 mm and 4·4 mm were opened in the SiO_2 film using photolithography techniques. Metal sputtering was carried out thermally in a vacuum of 10^{-5} mmHg. The substrate temperature was maintained at 200^0 C. Immediately before loading into the vacuum chamber Si wafers were pickled by buffer solution of HF (34,6%NH_4F + 6,8%HF + 58,6%H_2O) with the following washing of wafers in deionized water and drying in isopropyl alcohol vapor. After metal deposition the silicon wafers were annealed at $T_{ann} = 510^0$ C and $T_{ann} = 900^0$ C for t = 30 min in N_2 atmosphere to obtain NiSi - Si and $NiSi_2$ - Si structures. Fig. 1 shows the cross-section of the investigated structures. Photoconductivity spectra of the obtained NiSi - Si and $NiSi_2$ - Si structures with the Schottky barrier were studied.

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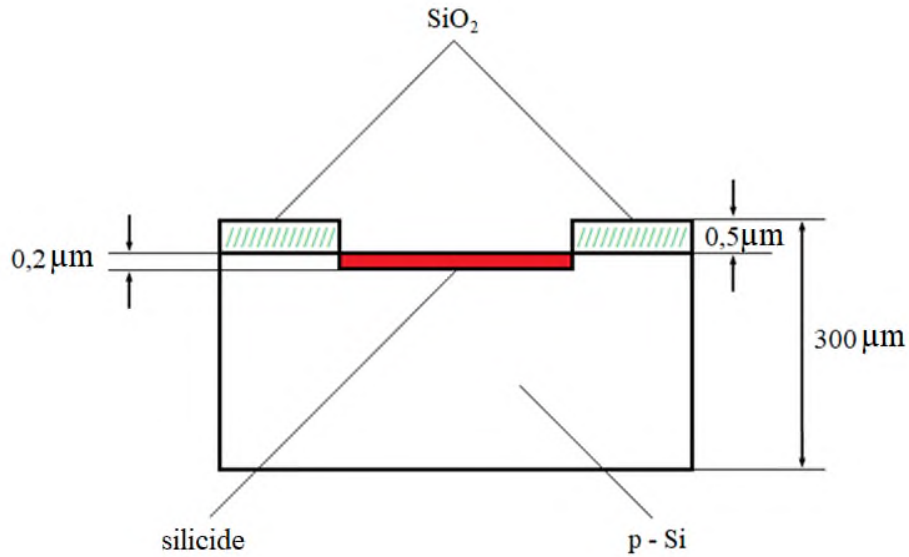
Figure 1: Cross Section of Nickel Silicon-Silicide NiSi - Si Structure

II. Discussion of Results

Figures 2 and 3 show the V- Icharacteristics of the NiSi - Si and NiSi$_2$ - Si structures, and figures 3 and 4 show the inverse V- I characteristics of the NiSi - Si structures in the absence of incident radiation. 3 and 4 the inverse V- I characteristics of NiSi - Si structures in the absence and presence of incident radiation. Figures 2 and 3 show that the V- I characteristics of NiSi - p - Si and NiSi$_2$ - p - Si structures at room temperature are very different.
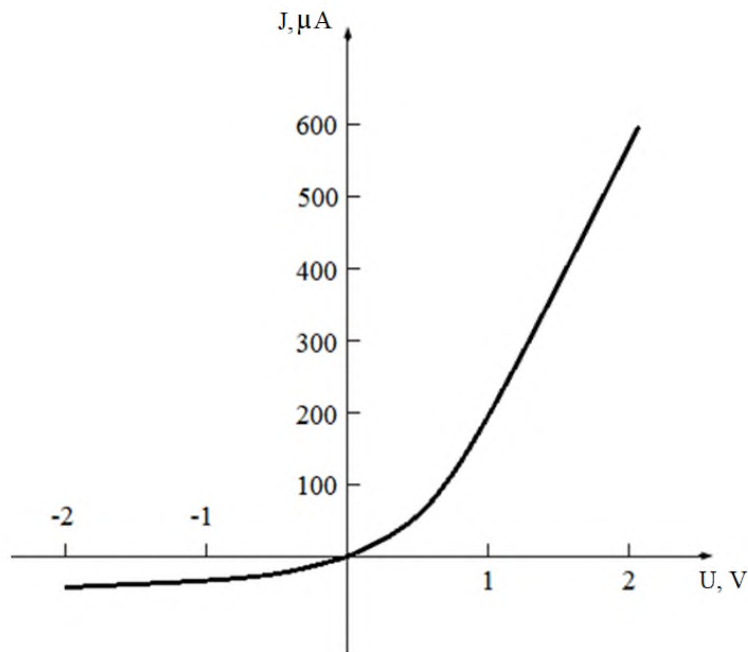

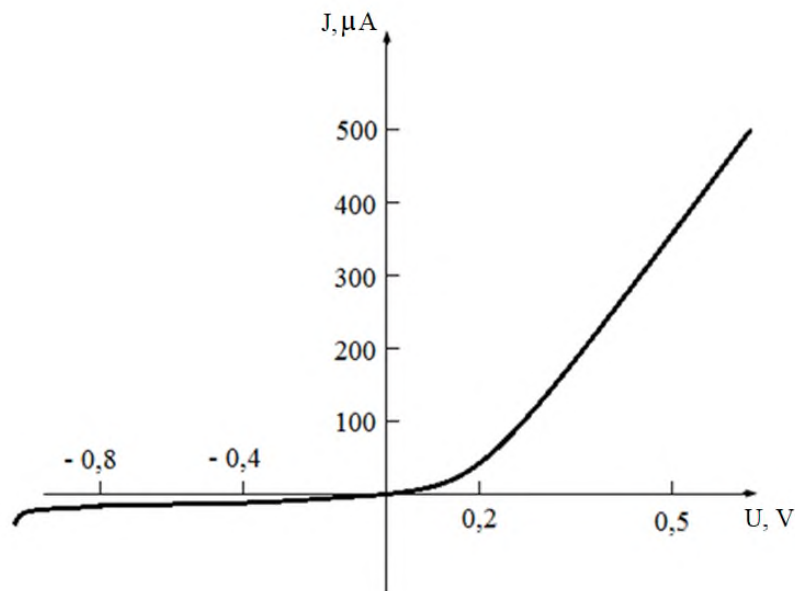*Fig. 2:* The V- I Characteristic of NiSi - p - Si Structure at T = 300 K

Fig. 3: The V- I Characteristic of NiSi$_2$ - p - Si Structure at T = 300 K

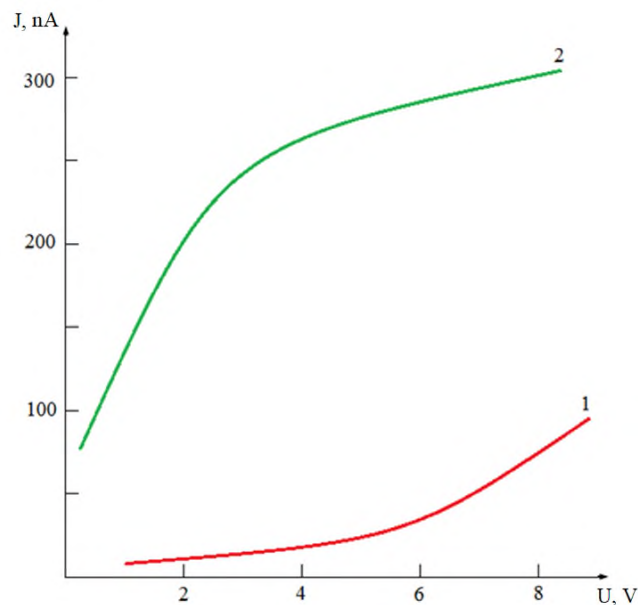*Fig. 4:* Inverse V- I Characteristics of NiSi - p - Si Structure: 1 - in Absence of Illumination, 2 - with Light Illumination λ = 2 μm

Inverse currents differ by more than an order of magnitude and it was found that for the NiSi$_2$ - p - Si structures the V- I characteristic does not change its appearance up to frequencies of 100 kHz, but for the NiSi - p - Si structures at frequencies above 1 kHz strong distortions of the V- I characteristic are observed. A spectrophotometer IKS-14A tuned to a wavelength λ = 2 μm was used as a light source. The light hits the silicide from the Si side (back illumination).
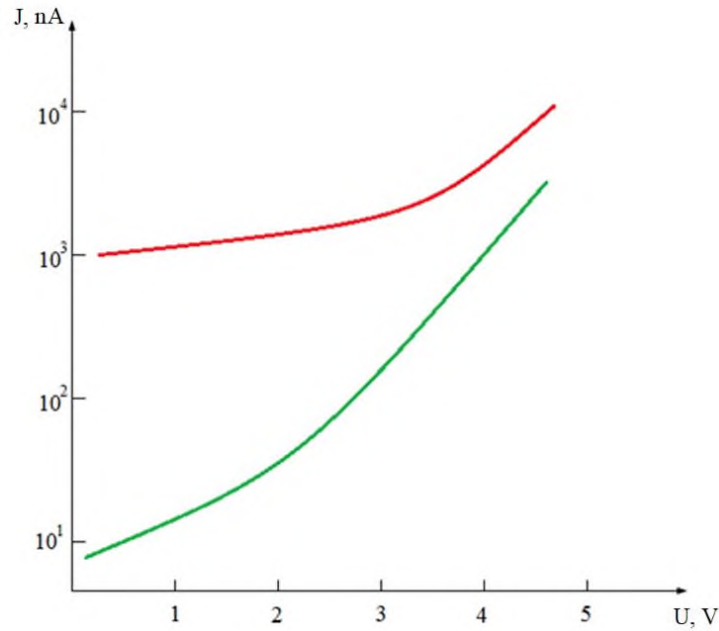
Fig. 5: Inverse V- I Characteristicsof NiSi$_2$ - p - Si Structure: 1 - in Absence of Illumination, 2 - with Light Illumination λ = 2 μm

As can be seen from fig. 4 and 5 a considerable change of a current through the investigated structures at illumination is observed: the current through the investigated structures at illumination increases in 100 - 200 times at small values of the applied reverse voltage (V$_R$ = 200 - 800 mV), in 10 - 50 times at higher reverse biases (V$_R$ = 1 - 2 V); at voltages 4 - 6 V a current change makes only 1,1 - 5 times, i.e. the best mode of structures with the Schottky barrierNiSi - p - Si V$_R$ = 1 - 2 V. At higher voltages the leakage currents increase and also breakdown of investigated samples occurs. For structures NiSi - p - Si and NiSi$_2$ a considerable change of current at illumination at wavelength λ = 2 μm at various values of applied reverse bias (V$_R$ = 0,1 - 5 V) was observed.
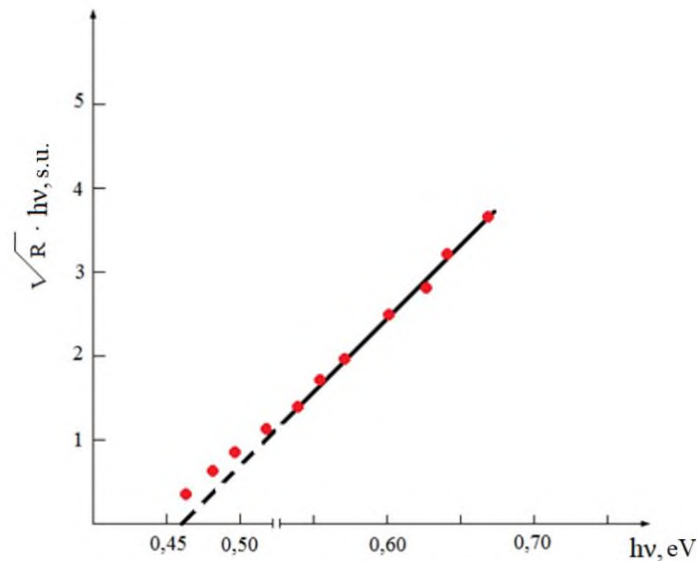

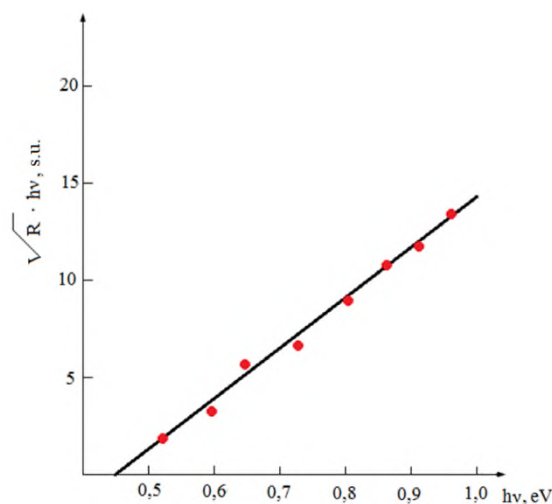*Fig. 6:* Dependence of R$^{1/2}$·hν Value on Barrier Height for NiSi - p - Si Structures: T = 80 K; V$_R$ = 154 mV

Fig. 7: Dependence of $R^{1/2} \cdot h\nu$ Value on Barrier Height for NiSi - p - Si Structures: T = 80 K; V_R = 380 mV

The experimental results for photosensitivity are in accordance with the refined Fowler formula [5]. These data were used to determine the Schottky barrier height. Figures 6, 7 and 8 the dependences $R^{1/2} \cdot h\nu$ on the incident photon energy $h\nu$ are plotted. The point of intersection with the energy axis gives the barrier height, which is for NiSi - Si structures Ψ_{ms} = 0.46 eV.
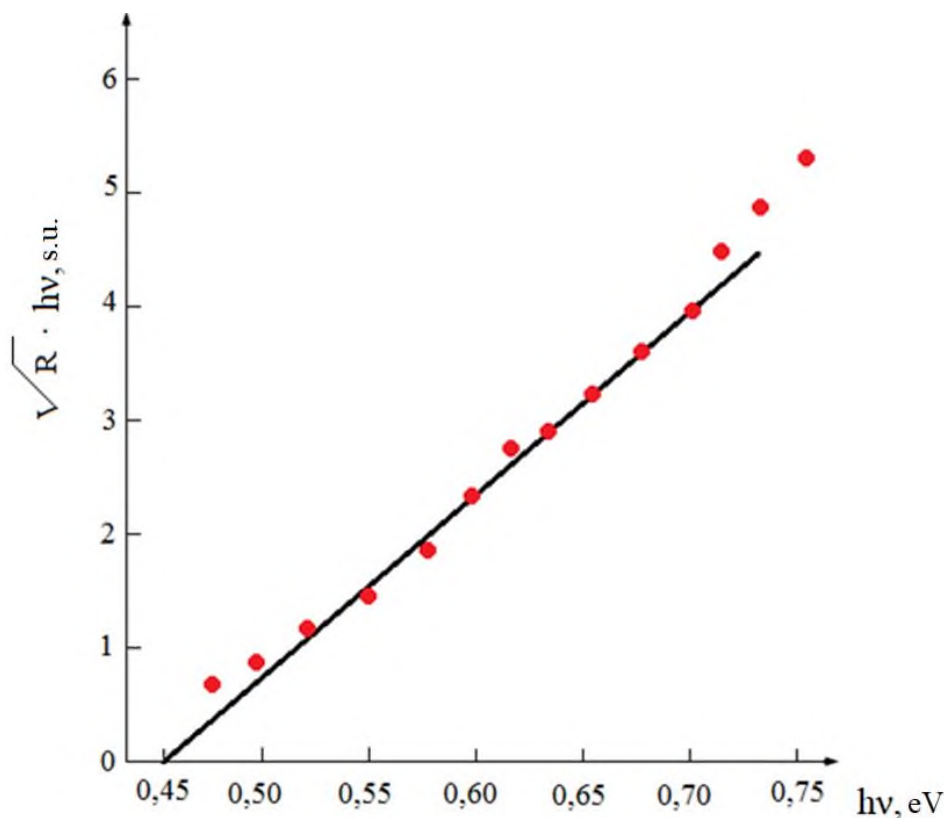

Fig. 8: Dependence of $R^{1/2} \cdot h\nu$ Value on Barrier Height for NiSi - p - Si Structures: T = 80 K; V_R = 0 mV

Figures 9, 10 and 11 show experimental dependences of sensitivity of structures PdSi - p - Si, Pt_2Si - p - Si and PtSi - p - Si at temperature T = 77(80 K) at constant incident radiation power. The measurements were made on a spectrophotometer IKS-31 (temperature of the global bar T = 500 ^{0}C).

Samples PdSi - p - Si and PtSi - p - Si were made according to previously described technique. Figures 9, 10 and 11 show that the wavelength dependence of photosensitivity is approximately described by Fowler formula.

The Schottky barrier height determined from the photoelectric measurements obtained from the

dependence $R^{1/2} \cdot h\nu = f(h\nu)$ was $\Psi_{ms} = 0{,}38$ eV for PdSi - p - Si and $\Psi_{ms} = 0{,}26$ eV for PtSi - p - Si (fig. 11). The values of the Schottky barrier heights obtained in this way were also confirmed by photoelectric measurements. A study of the annealing temperature dependence for the PtSi - p - Si and PtSi - n - Si structures has shown that φ_B for the first type structure weakly depends on the annealing temperature, while for the second type structure this dependence passes through a maximum. The latter character of the dependence has found its explanation in the multicontact theory [6,7].
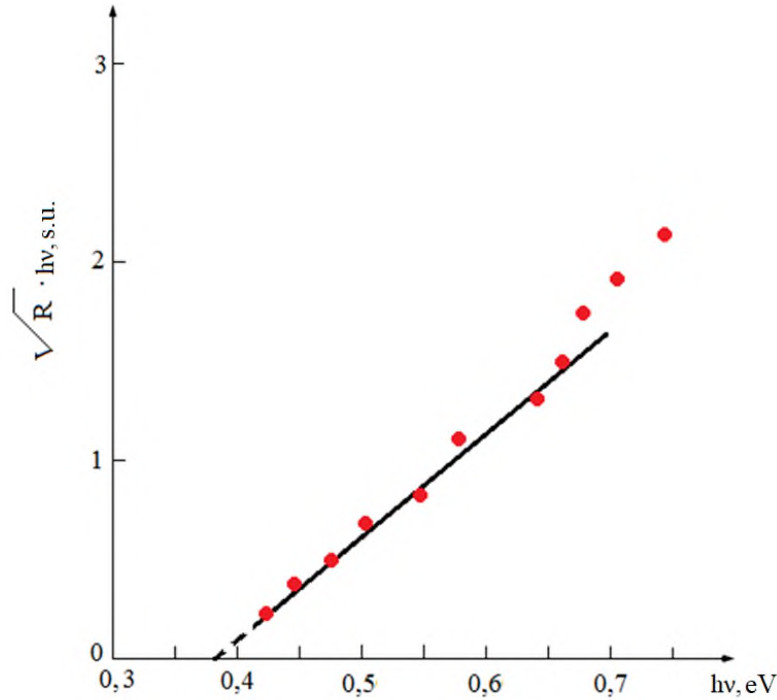

Fig. 9: Dependence of $R^{1/2} \cdot h\nu$ Value on Incident Photon Energy for PdSi - p - Si Structure at $T = 77^0$ K
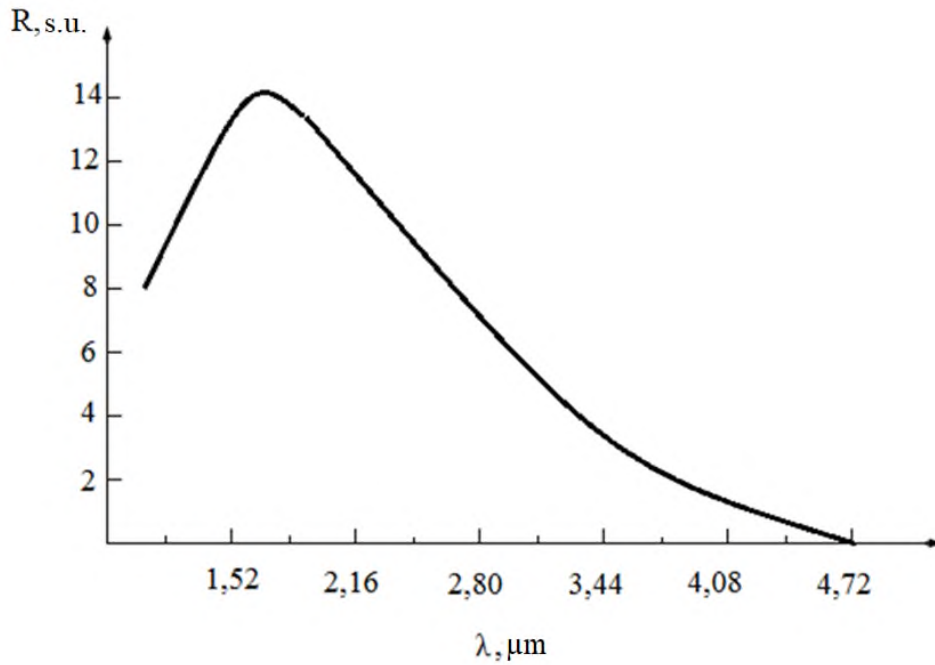

Figure 10: Spectral Dependence of Sensitivity of Pt_2Si - p - Si Structure at $T = 80$ K
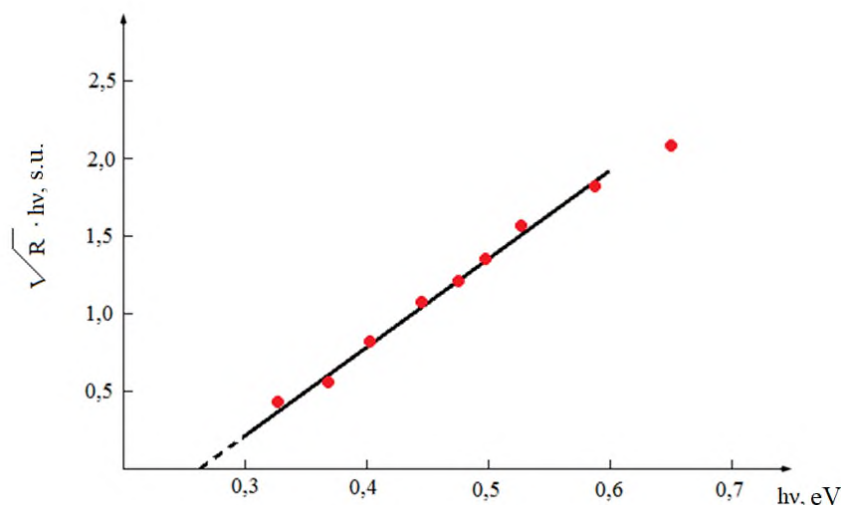
Fig. 11: Dependence of $R^{1/2}\cdot h\nu$ Value on Energy of Incident Photons for PtSi - p - Si Structure at T = 80 K

It is shown that the direct currents of these structures are proportional to their active area. It is found that all characteristic parameters of contacts made on Si substrate (111) are somewhat lower than those of contacts made on Si substrate (100).

III. CONCLUSION

It is found that the sensitivity of the NiSi - p - Si structure is significantly higher than that of the NiSi$_2$ - p - Si structures. In addition, an increase in sensitivity with decreasing nickel silicide thickness was observed. The optimum mode of operation of the NiSi - p - Si structure and its photosensitivity at a wavelength of 2 μm, which was R = 0,05 – 0,1 mA/W, were determined.

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