ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

Some features of photoelectric characteristics of silicon photodiode structure

Feruza Giyasova

Senior research scientists, Physical-technical scientific institute, Tashkent, Uzbekistan

ABSTRACT: The results of a study of the mechanisms of the current transfer of a silicon photodiode structure as a function of the total voltage and the stresses incident on each transition. The model explaining the manifestation of a one-way photovoltaic effect in a silicon two-barrier photodiode is analyzed.

I. INTRODUCTION

Photodetectors (photodiodes) based on silicon are widely used in microelectronic and optoelectronic devices. The trends in the development of photodiodes can be classified into three main areas: microminiaturization using hetero-junctions to produce avalanche and injection photodiodes; improvement of photodiode structures with planar metal-semiconductor contacts; creation of photodiode structures with integrated semiconductor and metal-semiconductor junctions [1-3]. The study of photodiodes with nanoinclusions [4], cluster formations [5] began to be used. However, studies of structures with combined properties dependent on switching modes and methods are remains without due attention. In particular, photodiodes that combine photovoltaic and photodiode effects remain poorly understood. In addition, existing semiconductor lasers and light-emitting diodes require the development of matched photodetectors not only based on gallium arsenide, but also on the basis of widely mastered silicon [6]. Interest silicon is due to a unique combination of its properties, as well as a high level of technology for obtaining both the material itself and the devices based on it. Further development of silicon technology and the development of new structures based on silicon, especially photovoltaic devices such as photodiode and phototransistors are an urgent task.

In this paper, the results of an investigation of the current characteristics of silicon photodiode structures with rectifying barriers are represented.

II. MAIN PART

The investigated photodiodes were obtained on the basis of silicon of n-type conductivity with carrier concentration 1×10^{15} cm^{-3}. Straightening contacts were obtained by vacuum deposition of Au on both nSi surfaces, on one of which a thin SiO dielectric layer was formed, followed by annealing at 350 ° C. The thickness of the base area was 300 μm, and the square was 0.54 cm^2. Here it should be noted that the formation of rectifying two barriers is due to the possibility of reducing the capacity of the structure [7]. At the same time, as shown by the example of the arsenide-gallium structure [8], the frequency range of the photodiode increases.The height of the potential barrier determined from the spectral characteristics is 0.49 eV (Fig. 1).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

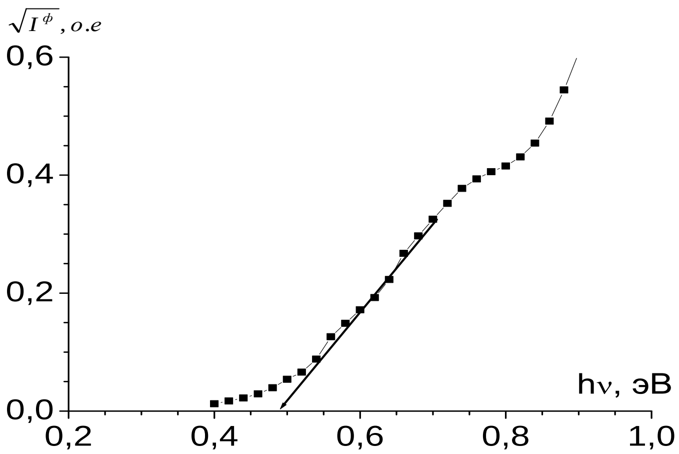

Fig. 1. Dependence of the photocurrent root on Photons energy of the Au-nSi transition

The contact difference of the Au-nSi transition potentials is 0.27 V. The thickness of the space-charge layer at the metal-semiconductor transition is 0.60 µm according to the calculated data:

$$W = \sqrt{\frac{2\varepsilon\varepsilon_0 U_{\hat{E}}}{qN}}$$

The resulting structures, having a two-sided sensitivity, due to the relatively higher concentration of the base carriers, exhibit a photovoltaic effect. The short-circuit photocurrent from the intensity of the integral illumination up to the illumination of 300 lux increases, and then starts to become saturated with 500 lux, and forms a shelf up to 2000 lux, and then decreases. With respect to the open circuit voltage, it can be noted that it increases from the illumination intensity to 300 lux and then acquires a decreasing character, as shown in Fig. 2.

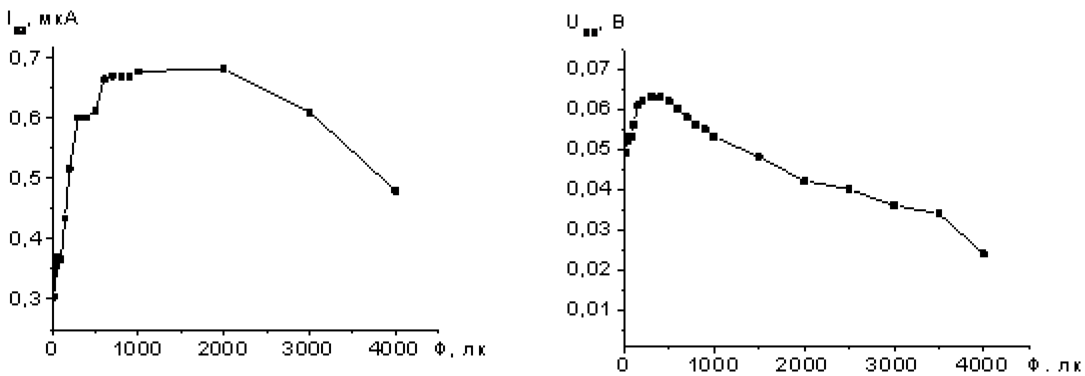

Fig.2 Dependences of short-circuit current (a) and idle voltage (b) from the intensity of integrated lighting

During illumination from either side, a photoelectric emitter with a positive pole appears on the same terminal. When the illuminated surface changes, the photocurrent has different values. When the voltage is applied with positive polarity to the electrode producing a positive polarity, the EMF (Electromotive Force) of the dark and light currents have a greater value, and when the polarity of the voltage is changed, the values of both the light photocurrent and the

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

dark current are lower (Figure 3). Here a branch with a large current is taken as a straight line. In principle, on the voltage applied in the direction (+) Au-SiOnSi-Au (-), on the current-voltage characteristic we have the dark current of the lock-in transition nSi-Au (curve 1), since the Au-SiOnSi transition is switched in the positive direction (Fig. 3a).

During change of applied voltage polarity (-)Au-SiO_2 nSi-Au(+), we have reverse current for locking Au-SiO_2 nSi transition. Thus, in both directions we have reverse currents. Reverse current of nSi-Au is more than Au-SiO_2 nSi transition. Saturation currents are also different (Fig. 3b)

With zero bias, a photomultiplier is created from the backlight, the magnitude of which is compensated by the direct shifting voltage, and further the light current assumes an increasing character (curve 2), as well as the dark current of the other transition (curve 1). In the other direction in the locking mode, the light current (curve-4) is limited by a locked photogenerating junction with a lower dark current (curve 3).

Thus, in Au-SiOnSi-Au-structure under illumination from the transition with a low saturation current, photovoltaic EMF is created, the magnitude of which is larger than at the transition with a high saturation current. The sign of the photoelectric power does not change when the illuminated surface is changed. To explain the observed effect, let us consider the band diagrams in the corresponding modes and analyze the model scheme.

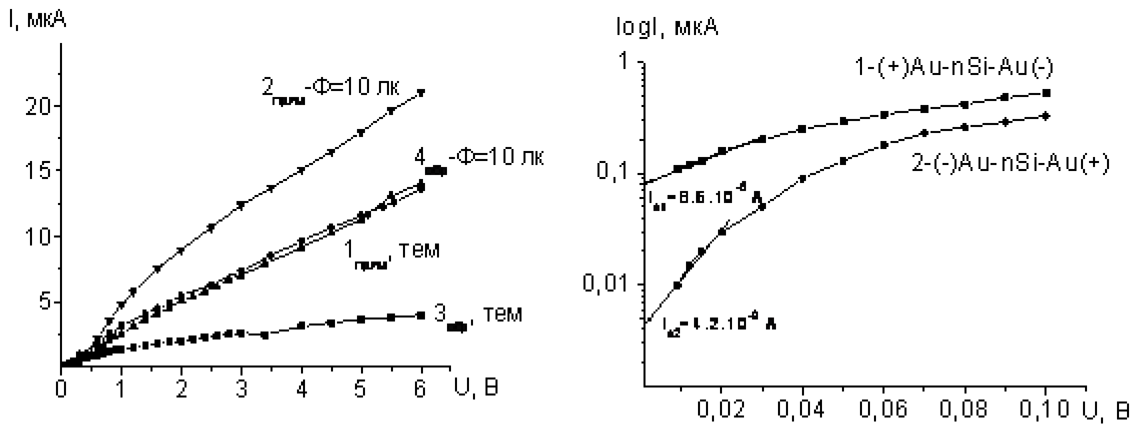

Fig. 3. Dependences of dark and light currents from working voltage: 1,3-dark; 2.4-light for 10 lx (a) and dark current of the initial section for different modes of switching (b)

Based on the energy band diagram of the Au-SiOnSi-Au structure constructed on the basis of the experimental and calculated data obtained above, it is possible to analyze the model explaining the manifestation of a one-way photovoltaic effect in a silicon two-barrier photodiode (Fig. 4).

In the equilibrium state, under illumination from the Au-SiOnSi junction, photovoltaic EMF with a positive polarity is created on the Au electrode and negative polarity in the base due to separation of photocarriers, as shown in Fig. 4a. However, our meter with a negative terminal is connected to the second terminal of the nSi-Au transition electrode, so this structure can be taken as one. In order to obtain information on the second transition, we simulate it in the form of an additionally connected diode in the same direction. As a result, we get a model two-barrier diode, and when we use the diode to explain the area diagrams, we can do without an additional diode, since in this case physical processes under external influences and mode changes can be traced. In the equilibrium state, the band diagram of the two-barrier diode is symmetric. When both terminals are short-circuited and illuminated from the side of the potential Au-SiOnSi barrier, a photovoltaic EMF with positive polarity at the Au terminal and negative polarity in the base region will be generated in this transition. Since this transition has a common base, the negative pole will be connected to the n-region of the second nSi-Au transition, and the positive pole to the terminal of Au. As a result, all the generated EMF will be applied to the nSi-Au transition, which will lead to a direct shift of this transition, that is, both transitions will be directly displaced, as shown in Fig. 4b. Therefore, in the short-circuit mode, a photocurrent is created in the circuit.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

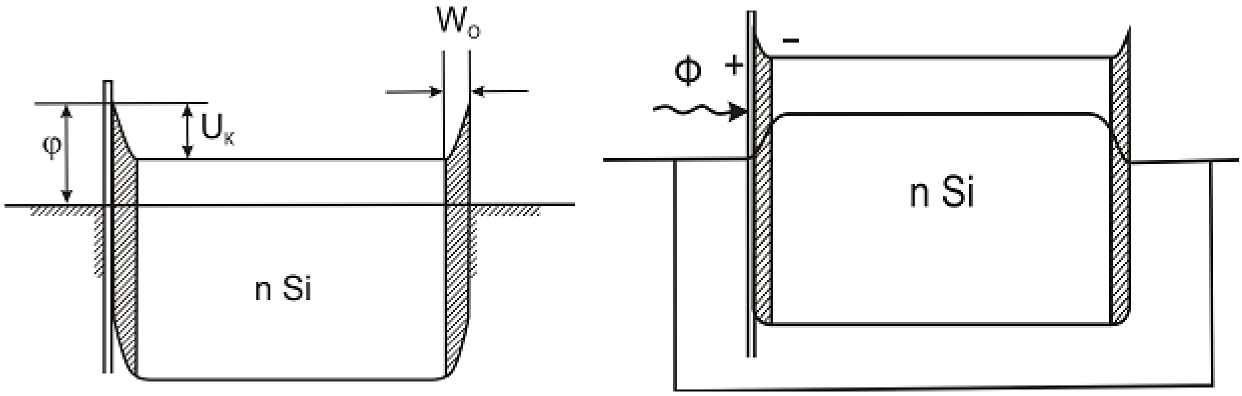

Fig.4. The energy band diagram of silicon Au-SiOnSi-Au-structure in the equilibrium state (a) and during exciting from the Au-SiOnSi barrier (b)

Under different switching modes, the energy band diagram of the silicon Au-SiOnSi-Au structure has a different form (Fig. 5). Here we note that when a low voltage is applied from a power supply unit with a locking Au-SiOnSi junction (Fig. 5a), electron-hole pairs with a current direction coinciding with the dark current will be generated in its space-charge region. In this case, the thickness of the space-charge region of this transition and its resistance decrease. As a result, the voltage incident in the other directly shifted transition will increase, leading to a noticeable change in the light. With large locking voltages, the illumination resistance also decreases, and the voltage redistribution will be less relative to the change in the direct-shifted transition. That is, the slope of the current characteristic will decrease.

Turning to the mode of direct bias of the Au-nSi junction (Fig. 5b), it should be noted that the direct resistance of the illuminated junction will decrease from the illumination, which will lead to the displacement of the operating point to the region of high currents due to a redistribution of the voltage increase to the blocked junction. In this case, as the operating voltage increases, the voltage increment, i.e., the difference between the voltage falling at a given current in the dark and under illumination, will pass to the locked transition increasing the value of the current. Accordingly, as the operating voltage increases, we will have an increase in the light current and a simultaneous increase in the generation of the dark current of the locked transition due to an increase in the thickness of the depletion region.

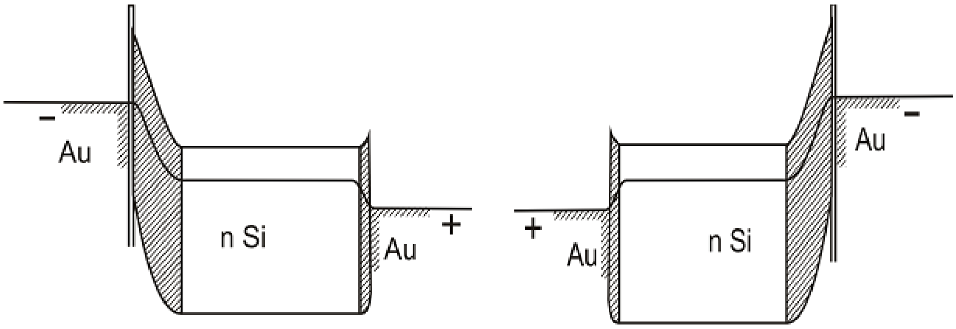

Fig.5. The energy band diagram of a silicon Au-SiOnSi-Au structure at various modes of voltage applied: a) (-) Au-SiOnSi-Au (+) - locking mode; b) (+) Au-SiOnSi-Au (-) - Direct Bias Mode

In the experiment, these positions can be traced on the model representation using an equivalent diode circuit. The observed independence of the polarity of the photovoltaic effect from the illuminated surface can be explained by the fact that a photoelectric emitter with a large value is created from the side of the surface with positive polarity, and on the other transition we have a low value of the photoelectric power with the opposite polarity. That is, when illuminated from the other side, the radiation reaches the region of generation of the photocurrent of a high-efficiency transition, whose EMF compensates for the low value of the photoelectric power generated in the lighted

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

transition. As the illumination intensity increases, the values of the emf generated at each transition approach each other, compensating each other.

The equivalent circuit of the two-barrier structure will be two diodes, one of which creates a photo-EMF and, when the terminals are closed, a short-circuit photocurrent is produced. In this case, the second diode serves as a load, and the current through it passes unhindered. When an increasing voltage is applied from an external power supply, the photo-emf appearing in the vicinity of the zero is compensated by a voltage of opposite polarity, and the current in the circuit will increase as the voltage increases due to the injection of the carriers through the direct-shifted illuminated junction. When the polarity of the power source is changed, the illuminated transition is locked and enters the photodiode mode, resulting in a photogenerating current that is summed with the dark current. To verify this model representation, an additional diode with the same direction was applied to the side of the opposite photogenerating EMF of the transition (Fig. 6) and investigated the dependence of the light current and the incident voltage on the operating voltage.

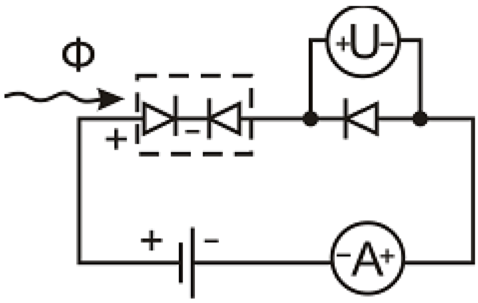

Fig. 2.6. Electrical circuit for checking of model representation of the Au-SiOnSi-Au structure

As studies have shown, with zero bias from the illumination from the side of the direct-shifting generating photoelectric transition, a current of negative polarity is created with respect to the ammeter. When the rising voltage is applied, the generated photo-EMF will be compensated at the very beginning and the current passing through zero takes a positive sign, and as a result we get an increase in the voltage of the incident on the additional diode, and if the polarity of the operating voltage changes, the incident voltage takes a negative sign, as shown in Fig. 7 In this case, the lockable Au-SiOnSi junction enters the photodiode mode, and shifts in the opposite direction, limiting the photocurrent.

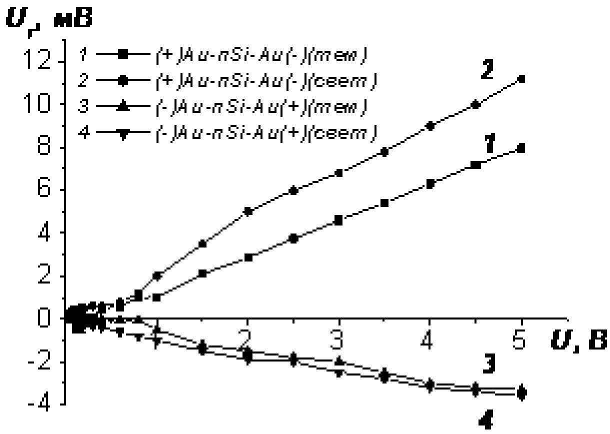

Fig. 7. Falling voltage on the series-connected additional diode at different switching modes: 1,3-in the dark; 2,4-at illumination

III. SCOPE

Thus, the photogeneration of carriers is more intense in the metal-semiconductor transition with a lower saturation current. In the mode of direct displacement of the photovoltaic transition in a locked transition, the current from the voltage has an increasing character, that is, this current does not sharply limit the current, as a result, carrier illumination is carried out through the direct shifting transition and redistribution of the voltage to the locked transition.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 10 , October 2017

However, when the polarity is reversed, the current through the diode is limited, which leads to low photocurrent values.

REFERENCES

[1]. Averin SV, Kuznetsov PI, Chusov II Ultra-high-speed photo-detectors for broadband optical information systems // Exhibition Center of the Russian Academy of Sciences, IRE.-Moscow, 2005.
[2]. Akhmetoglu MA, Andreev IA, Kunitsyna EV, Mikhailova MP, YakovlevYu.P. Electrical properties of isotypicheterojunctions // Physics and Technology of Semiconductors. - Sankt-Peterburg, 2007. - Vol. 41. - Vol. 2. - P. 154-159 .
[3]. Karimov AV, Yedgorova DM, Giyasova FA, Azimov TM, Buzrukov UM, Yakubov AA Features of photoelectric characteristics of photoelectro-transformational structures // Technology and design in electronic equipment. - Odessa, 2007. - No. 4 (70), - P. 23-28.
[4]. Silicon nanostructures for photonics / P. Bettotti, M. Cazzanelli, L. Dal Negro, B. Danese, Z. Gaburro, C.J. Oton, G. VijayaPrakash, L. Pavesi // J. Phys.: Condens. Matter. – 2002. – V. 14. – P. 8253-8281.
[5]. Efremov MD, Arzhannikova SA, Volodin VA, Kamaev GN, Marin DV Nanometer clusters and nanocrystals of silicon. Bulletin of NSU Series Physics. 2007. T.2. Issue. 2. P.51-60.
[6]. Godovanyuk VN, DobrovolskyYu.G., Ostapov S.E., Rarenko I.M., Photius V.D. State and prospects of the microphotoelectronic complex in the Chernivtsi region of Ukraine // Applied Physics. - 2003. - No. 3. - P. 72-83.D. Huang, T. Xing, and H. Wu, "Mobile Cloud Computing Service Models: A User-Centric Approach," IEEE Network, vol. 27, no. 5, Sept.–Oct. 2013, pp. 6–11.
[7]. Abdulkhaev OA, Asanova GO, Yedgorova DM, Yakubov EN, Karimov AV Investigation of the effect of potential barriers on the mechanisms of current transfer in meetings of two-barrier silicon structures. FIP. 2011, v. 9, No. 3.
[8]. Yedgorova D.M. The effect of photocurrent amplification in a photodiode structure with direct and reverse transitions // Technology and design in electronic equipment. - Odessa, 2010. - № 1. - P. 3-5.