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Schottky- Matrices Based on Ultra-Thin Layers of Iridium Silicide - Silicon Used in Solar Cells

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Abstract: *The main advantage of Schottky diode matrices used in solar cells, in comparison with other multi-element matrices, is the high uniformity of the sensitivity of the receiving elements in the matrix. However, this is typical only for the stage of converting optical radiation into an electric charge directly in the photosensitive element. The final uniformity of the matrix sensitivity also depends on the uniformity of the process of reading signals from individual elements.*

Keywords: *IR - region, Schottky matrices, Schottky diodes, quantum efficiency, photosensitivity, Schottky barrier, internal photoemission.*

The parameters of receivers operating in the infrared region based on multielement Schottky diodes depend not only on the characteristics of the sensitive element, but also on the operating mode of the matrices. An increase in the quantum efficiency of Schottky diodes in the operating wavelength range can be achieved by increasing the long-wavelength border of the photosensitivity, which in turn is determined by the height of the Schottky barrier (SB):

$$\lambda = \frac{1{,}24}{\Phi_0} \qquad (1)$$

Where, Φ = hυ. Here Φ is the BS height, as described [1], depends on the work function of the metal and the electronic affinity of the semiconductor, and for Schottky diodes with an IrSi barrier is 0.173 eV, which corresponds to the long-wavelength photosensitivity limit of 7.18 eV. To reduce the efficiency of the Schottky barrier height, it was proposed to make it thinner (in the direction perpendicular to the junction surface), thereby creating conditions for the tunneling of photoexcited carriers through it [2]. Tunneling of photocarriers is facilitated by additional doping of silicon with a thin layer of ions near the metal-semiconductor interface. The dopant layer must have the same type of conductivity as the substrate material, and the dose of doping ions must provide a noticeable decrease in the barrier height. For example, doping with thallium made it possible to lower the PtSi barrier height from 0.267 to 223 eV and, accordingly, to shift the long-wavelength photosensitivity limit from 4.6 to 5.5 µm. An increase in the long-wavelength boundary by only 20% is said to have led to an increase in the quantum efficiency of the diode by a factor of 5.6–9.1, in the range of 3.4–4.2 µm.

It is also possible to significantly increase the quantum efficiency of Schottky receivers by manufacturing a photosensitive element in the form of an “optical cavity” (Fig. 1).

Figure 1. The structure of the photosensitive Schottky layer - a diode in the form of an "optical cavity".

The first Schottky photodiodes made of PtSi, Pd2Si have a rather thick metal layer (about 600A0) and a relatively low quantum efficiency. The creation of a Schottky receiver in the form of an “optical cavity” with a thin layer of silicide leads to an increase in the coefficient of quantum photoemission C, due to an increase in optical absorption due to multiple reflection of rays in the “cavity” formed by aluminum mirror and antireflection layers and the efficiency of internal photoemission of hot holes from a thin layer of iridium silicide into a silicon substrate, due to their multiple reflections at the silicide - dielectric and silicide - semiconductor interfaces. For the emission of a hot hole (electron) into a semiconductor to occur, the pulse of the photoexcited carrier in the direction normal to the silicide-silicon interface must correspond to a kinetic energy that is greater than the Schottky barrier height Φ0. As a result of the reflection of the hot hole from the interface, the angle between the direction of the photocarrier movement and the normal to the silicide-silicon interface changes. Since the moment in the direction of the normal is proportional to the cosine of this angle, then with multiple reflections, the probability of internal photoemission increases and due to this, the gain G increases, which is equal to the ratio of the probabilities of emission in thin and thick layers of silicide:

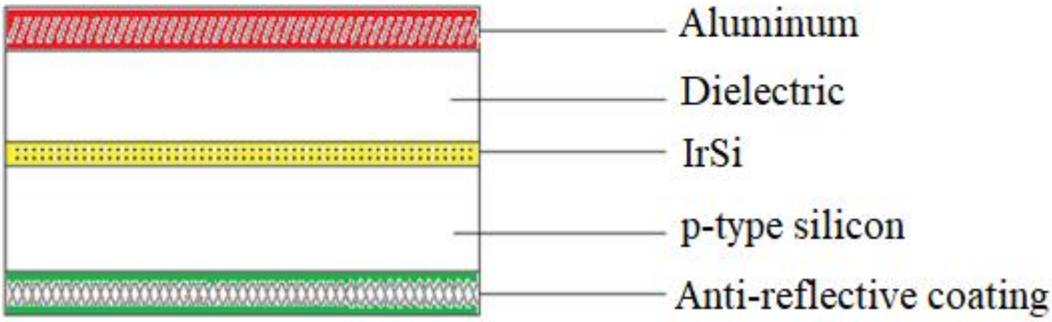

Figure1. *The structure of the photosensitive Schottky layer - a diode in the form of an "optical cavity".*

$$G = \frac{P_m(h\nu)}{P(h\nu)} \quad (2)$$

From general physical considerations, it is clear that the coefficient G is the higher, the greater the number of possible reflections of a hot hole from a silicide-dielectric or silicide-silicon surface. If we assume that the energy of the hot hole is conserved for each re-reflection, the angle of reflection is uncorrected with the angle of incidence, and the scattering of the hole energy in collisions with phonons and reflections at the boundaries of the silicide film can be described by the average length of energy scattering by the hot carrier L (in the direction perpendicular to the layer surface) , then the number of possible multiple reflections n depends on the hot hole energy E, the thickness of the silicide layer t, and the value of L:

$$E \cdot exp\left(-\frac{2nt}{L}\right) = \Phi_0 \quad (3)$$

It can be seen from the equation that the photoemission gain G should increase with an increase in the L / t ratio, and this dependence should be different for different photon energies E = hv. The maximum value of G corresponds to the case when all hot photocarriers are emitted into the silicon substrate, i.e. Pm (hv) = 1. In this way:

$$G_{max} = \frac{1}{P(h\nu)} \quad (4)$$

The degree of absorption of radiation in the “optical cavity” of the photosensitive structure of the Schottky diode depends on the thickness of the silicide layer, as well as on the thickness and material of the dielectric. This means that by choosing (for example, by calculating using Fresnel's formulas) the optimal thickness and material of the dielectric layer, one can significantly (several times) increase the absorption of radiation in the silicide layer and thereby increase the quantum yield of photoemission of Schottky diodes.

A photosensitive element on a Schottky barrier in the form of an “optical cavity” is formed by depositing a metal film, for example, iridium, about 60 nm thick through windows in an oxide film on the surface of p-type silicon doped with boron up to 10 ÷ 80 Ohm · cm. The formation of a Schottky diode between silicon and metal silicide is carried out after applying CCD contacts (charge-coupled devices) - a readout register with subsequent heat treatment at a temperature of 300-8000 C. Then the remaining iridium layer is removed so that the thickness of the silicide layer is 2 ÷ 10 nm, a dielectric layer is applied, and on top of it, aluminum. An antireflection layer is deposited on the back row of the substrate to reduce the reflectance of the surface on which the recorded radiation is incident. The magnitude of the dark current depends on the duration of the heat treatment that the diode undergoes during the manufacturing process. As it increases, the dark current decreases, however, the quantum efficiency and sensitivity of the diode simultaneously decrease. Experimental data show that the optimal ratio of the quantum efficiency and the dark current density is achieved with a heat treatment time of 8 hours.

According to the adopted division scheme, photodetector matrices made of Schottky diodes belong to monolithic structures. In such receivers, the conversion of optical radiation to an electrical signal and its primary processing take place in the same semiconductor material: silicon. For the implementation of the primary processing of the Schottky photo signal - receivers, which consists of element-by-element reading and output of the signal to the common output, CCD registers with a surface or covert channel are used. This structure can work in two modes: subtraction and without subtraction of the background signal. In the mode in which the background signal is not subtracted, the reset channels are not used, they are not involved in the operation of the device. When a high potential is applied to the electrode of the first phase of the shift register and a potential well is formed under it, a positive potential is applied to the readout gate, creating a potential UA under the gate electrode and on the floating diffusion region of the readout channel (Fig. 2).

Figure 2. Diagram explaining the operation of Schottky - photodiode in the mode without background subtraction (a) and with background subtraction (b) signal.

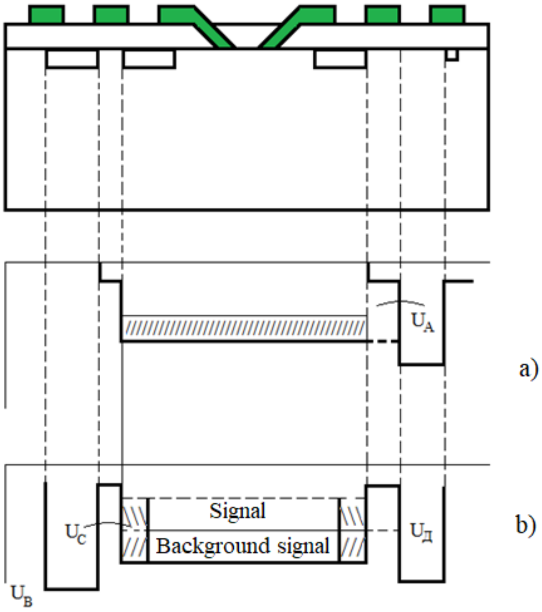

Figure2. *Diagram explaining the operation of the Schottky - photodiode in the mode without background subtraction (a) and with background subtraction (b) signal.*

The charge accumulated by this moment in the Schottky-barrier region passes into a deeper potential well under the electrode of the first phase of the readout register. After the termination of the read pulse at the read gate, this charge, which is a signal packet, is transferred in the usual way to the output device of the shift register to generate a video signal. After reading the special charge, the metal Schottky electrode - the diode is set under the floating potential UA and the signal charge accumulates on it, which will be read in the same way in the next frame. With this method of reading, the entire charge accumulated by the photosensitive element is transferred to the potential well of the shift register, both due to optical excitation by radiation from the recording object and due to excitation by background radiation (and thermal generation).

In the mode with subtraction of the background signal, the difference signal between the accumulated charge of the cell and the charge caused by irradiation with the average flux of background radiation is used as a signal charge. This charge, which is the same for all photosensitive cells of the matrix, does not contain useful information about the observed object and therefore may not participate in the formation of the video signal. This subtraction of the constant background signal is performed using a reset channel.

A high positive potential is applied to the reset signal bus, which forms a potential well under the reset bus with a depth of UD (see Fig. 2b). At the end of each frame, a reset pulse UC is applied to the dump gate, which sets the potentials of the diffusion regions of the dump and read channels, as well as the photosensitive Schottky region - the barrier, equal to UC. In this case, all the charge accumulated by the photosensitive area is transferred to a potential well under the dump bus and removed. The Schottky photodiode is charged up to the floating potential UC and is thus prepared for the accumulation of charge during the next frame. At the end of the signal integration time, before applying a reset pulse to the readout gate, a pulse is applied that sets the surface potential under the gate equal to UD. The charge that is accumulated in the potential well under the Schottky barrier is above this level and flows into the potential well under the shift register electrode. By choosing the value of the potential UD, it is possible to provide such conditions that only the charge that carries information about the change in the recorded radiation in relation to the average level of the background flux is transferred to the readout register for the formation of a video signal. The remaining constant background charge is removed after the transmission of the read pulse is stopped by opening the reset gate as described above. Thus, it is possible, firstly, to significantly increase the contrast of the image and, secondly, to more fully use the limited in magnitude capacity of the shift register phases, in order to provide a greater dynamic range of the receiving device.

From this point of view, the readout mode without subtracting the background signal is preferable. The nonuniformity of the signal can be caused by the nonuniformity of the oxide film in thickness and charge density in the oxide, as well as by the nonuniformity of the concentration of the dopant in the semiconductor, which leads to a spread in the values of the capacitance of individual elements and the surface potential under the gates. In the mode without background subtraction, the setting of the initial value of the floating potential of the sensitive element and the reading of the potential after the accumulation of the signal charge is performed using the same gate. Obviously, in this case, the possible difference in the values of the floating potential set between different cells does not lead to a spread in the level of the read signal, since it is determined only by the potential difference before and after the charge accumulation. In the mode with background subtraction, the initial value of the floating potential in each of the cells is set using the reset gate, and the read potential, using the reset gate, and the read potential, using the read gate. In this case, the spread in the level of the established potential by any of the gates leads to a difference in the signal being picked up and, thus, to unevenness of the matrix elements in sensitivity. Therefore, from the point of view of ensuring the greatest uniformity of sensitivity, the mode without subtracting the background signal is preferable.

CONCLUSION

It was revealed that, when used as a reading system CCD - registers, the composition of the multielement receiver should include electrodes for the transfer of charges and signal areas, electrodes of the reading gates, etc. for this reason, the relative proportion of the photosensitive area in multi-element Schottky arrays used in solar cells (sometimes called the fill factor) is small.

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