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THE INJECTION PHOTO DIODE ON THE BASIS OF *n*Si-*n*CdS-n^+CdS HETEROSTRUCTURES

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It is shown that the *n*Si-*n*CdS-n^+CdS heterostructures in operative (carrying) direction of current, while being exposed to low intensity radiation, operate as injection photodiodes. Their current sensitivity is $S_\lambda \approx 2.12$ A/W at $\lambda = 0.625$ µm, which effectively represents a 4.2 increase in compare to spectral sensitivity of the ideal photo receiver at small wavelength of irradiation.

Keywords: heterostructure, film, spectrum, injection.

ИНЖЕКЦИОННЫЙ ФОТОДИОД НА ОСНОВЕ *n*Si-*n*CdS-n^+CdS ГЕТЕРОСТРУКТУРЫ

И.Б. Сапаев

Показано, что гетероструктуры *n*Si-*n*CdS-n^+CdS в пропускном направлении тока при малых уровнях освещения работают как инжекционный фотодиод. Они обладают токовой чувствительностью $S_\lambda \approx 2.12$ A/W при $\lambda = 0.625$ µm, что в 4.2 раза превышает спектральную чувствительность идеального фотоприемника при этой длине волны излучения. Высокие значения S_λ обеспечивают высокую эффективность превращения световой энергии в электрическую при малых уровнях освещенности.

Ключевые слова: гетероструктура, пленка, спектр, инжекционный.

ІНЖЕКЦІЙНИЙ ФОТОДІОД НА ОСНОВІ *n*Si-*n*CdS-n^+CdS ГЕТЕРОСТРУКТУРИ

І.Б. Сапаєв

Показано, що гетероструктури *n*Si-*n*CdS-n^+CdS у пропускному напрямку струму при малих рівнях освітлення працюють як інжекційний фотодіод. Він має струмову чутливість $S_\lambda \approx 2.12$ A/W при $\lambda = 0.625$ µm, що в 4.2 разів перевищує спектральну чутливість ідеального фотоприймача при цій довжині хвилі випромінювання. Високі значення $S_л$ забезпечують високу ефективність перетворення світлової енергії в електричну при малих рівнях освітленості.

Ключові слова: гетероструктура, плівка, спектр, инжекційний.

Injection photodiodes based on n^+-*n* transitions or Schottky barrier are normally made of high resistance semiconductors characterized by large length of diffusive displacement, whereas thickness of the base area (distance from the injected contact to the second one) tremendously exceeds (several times) the diffusive displacement length – “long diodes” [1]. Such type photodiodes operate in the mode of high levels of injection. The carrying capacity of their base area is determined by injected carriers. The injection photodiodes are developed and investigated on various types of semiconductors (doped Germanium and Silicon, Gallium Arsenide and Indium Antimonide, solid alloys of A^2B^5 compounds and other materials) [2]. However, there is virtually no information in the literature on how to develop injection photodiodes based on Si-CdS heterostructures. Such structures are characterized by astonishing interrelation of electrical and photoelectrical properties both of pertinent Si and CdS. Such structures are characterized also by direct optical transitions that help to obtain a high efficiency of generation of electron-hole pairs.

The photosensitive n^+CdS-*n*CdS-*n*Si structure has been created by dusting of CdS-powders (in quasi-closed system in vacuum 10^{-5} torr) on the surface of silicon plate of *n*-type with the specific resistance $\rho \approx 15$ Ohm·cm and thickness of 300 – 400 мм. Thus the source temperature was (CdS) $T_{\text{source}} \approx 800 - 850$ °C, and on the substrate (*n*Si) it was supported in limits $\approx 250 - 270$ °C. The carried out researches by means of microscope MII-4 have shown, that films CdS consist of columnar grains to be focused in the direction of the films growth and disarranged on an azimuth. It has been established, that the size of crystallites strongly depends on technological modes and first of all on temperature of Si substrate. For example, made at $T_{\text{substrate}} =$

250 °C films CdS had the size of crystallites ≈0,8 – 1 мм which completely penetrated all thickness of films $d \approx 1$ μm. Thus, grown up CdS films were high-resistant with specific resistance $\rho \geq 10^8$ Ohm·cm. Further, on CdS film was formed n^+CdS layer by thickness ~500 Å and current-collecting "П" – figurative contact by means of vacuum evaporation In.

The spectral distribution of the photocurrent of such structure consists of two parts and its spectral range stretches from $\lambda \approx 460$ nm to $\lambda \approx 1200$ nm (fig. 1). In the first and the second parts of spectral distribution the photocurrent has different polarity that is caused with return inclusion of the barriers created between n^+CdS-nCdS and nCdS-nSi.

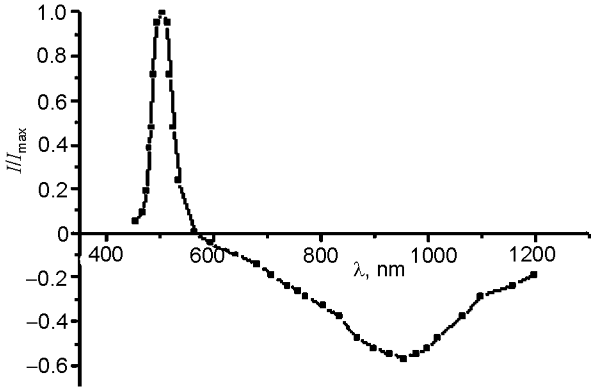

Fig. 1. Spectral distribution of a photocurrent of n^+CdS-nCdS-nSi heterostructure.

Besides the curve of spectral distribution of photosensitivity shows, that between sulphide of cadmium and of silicon with electronic conductivity is available an isotype heterojunction containing a small density of superficial conditions on section border. Acknowledgement to that is that the structure has the straightening factor of more than two orders, and occurrence of maximum in curve dependence I/I_0, λ at $\lambda \approx 955$ nm; and tangent, made to it on recession in long-wave area of the spectrum cuts on abscissa axis the length of the wave, corresponding to width of the forbidden zone of silicon.

The developed n^+CdS-nCdS-nSi – heterostructure is characterized by rectification properties, whereas the rectification coefficient defined as a ratio of direct and reverse current at fixed voltage – $K = I_{forward}/I_{back}$ ($V = 5$ V) makes up 2 orders (refer to fig. 2). The direct direction of current in the structure is deemed to occur when "+" potential is applied on the contact of Silicon surface whereas "–" potential is applied on the reverse surface. The analysis of the direct line of dark current-voltage of n^+CdS-nCdS-nSi heterostructures [3] clearly demonstrates that the base of the structure is of high-resistance and the ratio of thickness of base to the length of diffusion of the minority current carriers amounts ~4 at base thickness of (nCdS) ~ 1 μm, that corresponds to the diffusive length of minor carriers – electrons 0.26 μm. Thus, it is determined that n^+CdS-nCdS-nSi – heterostructures meet the requirements set out for injection photodiodes [4]. Besides, the structure investigated is photo-sensitive.

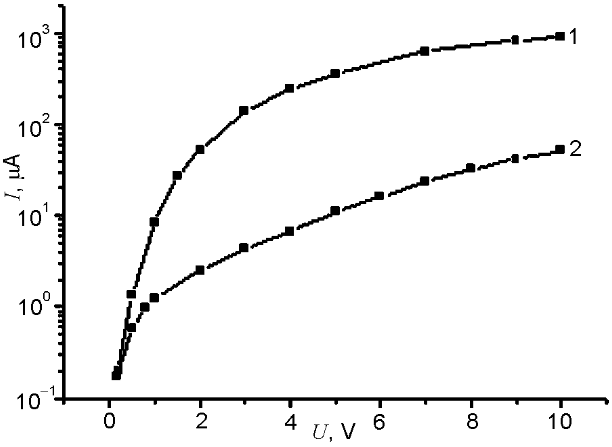

Fig. 2. Conventional direct (1) and reverse (2) sections of current-voltage characteristics of nSi-nCdS-n^+CdS heterostructure in semi-log scale at room temperatures.

Research of their current-voltage characteristics in direct and reverse directions shows that there is the strengthening of photocurrent. As one can judge from fig. 3, the direct line of current-voltage characteristics obtained in darkness and while exposed to light, practically do not differ from one another judging by the shape of the line. However, the values of photocurrent and dark current do indeed differ.

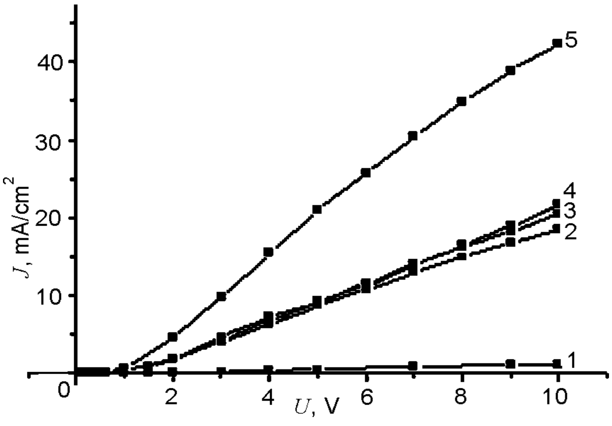

Fig. 3. Dark and light current-voltage line of nSi-nCdS-n^+CdS heterostructure: 1 – dark, 2 – 0.05 Lux, 3 – 1.25 Lux, 4 – 4 Lux, 5 – 20 mW/cm^2.

Comparing values of photocurrent and dark current was done at the same voltage ($V = 10$ V). They are reflected in tabl. 1. This table also reflects

Table 1

Dependences of the photocurrent (I_{Ph}) and integrated sensitivity ($S_{current\ sensitivity}$) from light exposure (E_{lux})

E, 10^{-2} lux	I_{dark}, mA/cm^2	I_{Ph}, mA/cm^2	$S_{current\ sensitivity}$, A/lm	$S_{current\ sensitivity}$, A/W
0	0.91	–	–	–
5	–	18.6	3720	$4.1 \cdot 10^5$
125	–	20.5	164	$1.8 \cdot 10^4$
400	–	22	55	$6 \cdot 10^3$

the photocurrent values and the current sensitivity ($S_{current\ sensitivity}$) at different levels of illumination (E, lux). The data in the tabl. 1 clearly demonstrates that the integrated sensitivity in the investigated heterostructures has a high value. Moreover, it has a maximum value at luminous flux of $E = 0.05$ Lux, wherby $S_{current\ sensitivity} = 3720$ A/Lm. For comparison we should mark that the best industrial photo receivers FD-7, FD-11 are characterized by $S_{current\ sensitivity} = (4 - 5)$ mA/lm [5].

Nevertheless, the current sensitivity still remains high even at illumination with monochromatic light of laser with the wavelength of $\lambda = 0.625$ μm and power of 20 mW/cm^2, reaching ~2.1 A/W. One can incidentally conclude that we are actually witnessing the photocurrent strengthening. This is further evidenced by the fact that the current sensitivity of such structure tends to be ≈2.1 A/W, whereas the ideal photo receiver at similar wavelength has the current sensitivity of ≈0.5 A/W [5]. Under the ideal photo device, we understand the one, which is free of effect of reflection from surface, has the internal quantum efficiency ≈1 and all generated carriers participate in the process of photocurrent formation. Usually such photo receivers are absent as they are idealized. That is why it is possible to think that nSi-nCdS-n^+CdS – heterostructure has high spectrum sensitivity in the result of inner strengthening of photocurrent.

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