

PHOTOELECTRICAL PROPERTIES OF HETEROJUNCTIONS CONNECTED WITH VAN-DER-WAALS FORCES

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The layered structure of *InSe* with weak Van-der-Waals interlayer bonds allows: i) to get substrates of micron thickness with perfect mirror-like cleaved surfaces without any treatment; ii) to create high quality heterostructures by a simple method of thermal oxidation of the substrates; iii) to form simultaneously heterostructures on the opposite sides of the substrate with quasiidentical parameters and, therefore, realize the phototransistor effect. Here we investigate a double surface-barrier *oxide-InSe-oxide* heterostructure. The intrinsic oxide was grown in air at 450°C during 96 h. Owing to metallic conductivity and high transparency of the created oxides, the formation of a potential barrier with the crystal of about 0.55-0.6 V is provided. The current-voltage characteristic of the *oxide-InSe* heterostructure is close to ideal one and its photosensitivity was observed in the spectral range 0.6-1 μm. The photoelectrical properties of the double heterostructure with Van-der-Waals bond are investigated in dependence on substrate thickness. It is detected that the phototransistor effect is observed over the wide range of *InSe* thickness from 14 to 220 μm. At illumination of such kind phototransistor a high photocurrent density of about 60-100 mA/cm² is achieved that is evidence of amplifying electrical signal. The amplification factor depends on illumination level.

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1. Introduction

Crystals with a different type of the chemical bond between atoms acquire new properties in comparison to crystals with the same type of chemical bonding. For example, the simultaneous presence of the covalent and Van-der-Waals bond causes a layered structure of many materials. The layered structure, in turn, provides natural state of a crystal surface without dangling bonds and the possibility to manufacture by cleaving film-like substrates some micron thick. Therefore such crystals are of interest for photoelectronics due to an opportunity of creation of qualitative photosensitive structures of various applications.

The semiconductor compound *InSe* belongs to the specified type of layered crystals. At room temperature its energy gap E_g is equal to 1.2 eV and the fundamental edge absorption coefficient α is of the order of 10^3 cm^{-1} [1]. From the electrical properties one can conclude that intentionally undoped *InSe* crystals always are of n-type conductivity. A hole conductivity can be provided by doping with II group impurities (*Cd*, *Zn*, and *As*) of the periodic system. One more peculiarity of *InSe* crystals is a metallic conductivity and high transparency of their intrinsic oxides. This allows to create heterostructures under the certain time-temperature conditions with satisfactory photoelectric parameters [2]. The aim of this work is the manufacturing of *p-InSe* based double-side *oxide-InSe-oxide* heterostructure and investigation of its photoelectric properties for revealing phototransistor effect.

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2. Experimental

InSe crystals were grown by the Bridgman method. For receiving hole conductivity cadmium was added to the initial components before synthesis. From the Hall coefficient measurements it is established that the hole concentration in the grown crystals is approximately 10^{15} cm^{-3} .

Intrinsic oxide on cleaved surfaces of the crystal was created by thermal oxidization of the substrates in air [3]. As time-temperature regimes of oxidization those were chosen which provided forming the maximum possible potential barrier. The heterostructures with a saturated open-circuit voltage of about 0.6 V, that is half the quantity of E_g , were obtained at 450°C and a 96 h time exposure of the crystals [2].

The static dark and light current-voltage ($I - V$) characteristics of double *oxide-InSe-oxide* heterostructure were measured on a „Schlumberger SI” setup with a computer analysis of the data. Samples of different initial thickness were investigated.

3. Results and discussion

The obtained *n-p-n* structures are symmetric with respect to the polarity of applied bias. The phototransistor effect was observed in the case of a forward-biased *p-n*-junction which was illuminated (emitter). The second *p-n*- junction was reverse-biased and served as collector. A contact electrode to the base was absent. In the case of a change of bias polarity the double heterostructure is a series connection of the reverse-biased diode with the forward-biased one. Both situations of the connection of the double heterostructure are shown in Fig. 1.

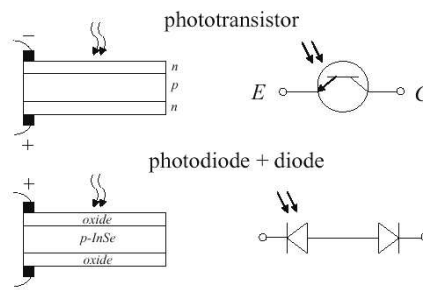


Fig. 1. A schematic drawing and equivalent circuit of *oxide-InSe-oxide* structure (E – emitter, C – collector).

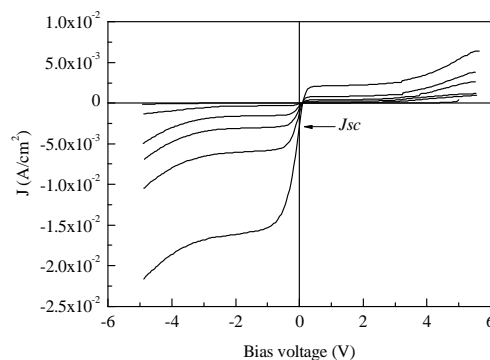


Fig. 2. Current-voltage characteristics of double *oxide-InSe-oxide* heterostructure for an initial 60 μm thick sample of p-InSe at different illumination levels.

Fig. 2 shows the current-voltage characteristics corresponding to both the above-considered cases of the connection of the *oxide-InSe-oxide* structure at different illuminations. As one can see from it, in a phototransistor regime the group of the $I - V$ characteristics begins from the origin of coordinates and at a change of the polarity of an applied voltage, i.e. in a regime of photodiode, they

are shifted along the ordinate axis by the value of short-circuit currents J_{SC} . As follows from this figure, the saturation photocurrents exceed the phototransistor collector current. A weak amplification of the phototransistor is caused by a small diffusion length L_n in comparison to the base thickness d which, in fact, can be considered as the thickness of initial *InSe* substrates. As it is known from reference [5], a magnitude of L_n lies between 10 and 20 microns.

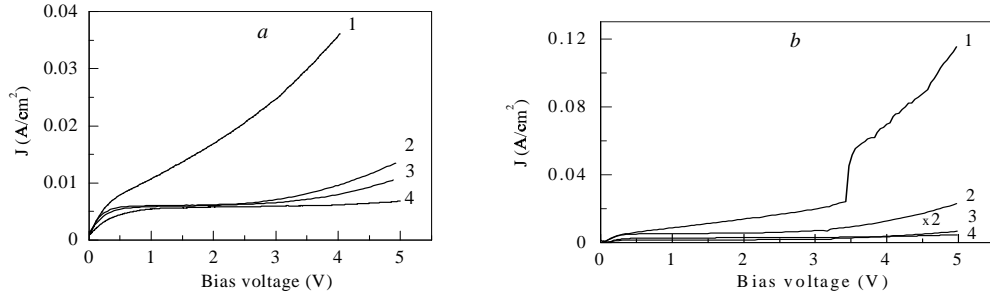


Fig. 3. Current-voltage characteristics of double *oxide-InSe-oxide* heterostructure in a photodiode (a) and phototransistor (b) regime at the same illumination level for the samples of different initial thickness: 1 - 14, 2 - 220, 3 - 60, and 4 - 93 μm . Curves 2 - 4 in fig. 3, b are shown in the 2:1 scale.

As the thickness of the base affects the amplification factor of phototransistor we have investigated the samples of different initial thickness. Such I – V characteristics at the same level of illumination and different directions of applied bias are shown in Fig. 3. The photocurrent of saturation of the photodiodes of different thickness is illustrated in Fig. 3, a. The coincidence of curves 2-4 shows that the *oxide-InSe* heterostructures prepared on different substrates have close characteristics. A sharp increase of photocurrent for the thinnest sample (curve 1) is due to some illumination of the back *oxide-InSe* heterostructure which in the considered circuit acts as a series resistance. The practically coincidence of the collector current for the different phototransistor samples we have also found in a phototransistor regime (Fig. 3, b). It takes place due to recombination of the carriers injected by the emitter in the thick base. A significant amplification of the photocurrent is observed only for the 14 μm thick sample. A peculiarity of such the amplification is the fact that depending on illumination level at some voltages the current density sharply increases and can achieve significant values of 60 - 100 mA/cm^2 . Fig. 4 shows the I – V characteristics of a phototransistor based on a 14 μm thick p-*InSe* sample. As one can see, at low illumination levels the phototransistor effect is not well manifested. At some voltages with increasing illumination level the phototransistor becomes switched from a high-resistive state to a low-resistance one.

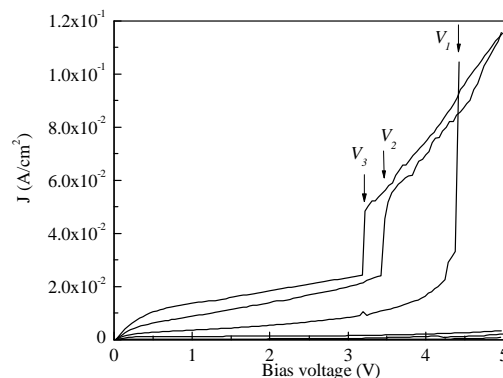


Fig. 4. Current-voltage characteristics of double *oxide-InSe-oxide* heterostructure for the initial 14 μm thick sample of p-*InSe* at different illumination levels.

At bias voltages V_1 , V_2 , and V_3 an essential increase of the collector current takes place due to increasing the base potential. It is caused by illumination of the emitter and partially collector that leads to additional injection of the minority carriers from the emitter and transfer of the holes into the base from the collector transition. As a result, the collector transition potential barrier decreases and the reverse breakdown of the phototransistor occurs. At the breakdown voltages the static coefficient of current transfer is equal to unit. As follows from Fig. 4, the phototransistor breakdown voltage decreases with increasing illumination level ($V_1 > V_2 > V_3$) and the behaviour of the current - voltage dependences goes from increasing vertical to sloped.

4. Conclusion

The possibility of manufacturing a qualitative *n-p-n* phototransistor on the basis of a double *oxide-InSe-oxide* heterostructure is established. A significant amplification of the phototransistor photocurrent occurs only for the thickness of the initial samples comparative to the diffusion length of the minority carriers. A peculiarity of the observed amplification is transition of the phototransistor from high-resistive to low-resistance state only at some applied voltages and illumination level. The higher is illumination level the lower becomes a voltage of such the transition. The current density through the phototransistor at such the transition can achieve 60 - 100 mA/cm².

References

- [1] Landolt-Bornstein. Numerical Data and Functional Relationships in Science and Technology. New Ser. Group III: Crystal and Solid State Physics. V. 17, sv.f / Ed. by O. Madelung. Berlin e.a.: Springer, 1983. 562 p.
- [2] Z. D. Kovalyuk, V. N. Katerinchuk, A. I. Savchuk, O. M. Sydor, Mater. Sci. Eng. B **109**, 252 (2003).
- [3] V. N. Katerinchuk, M. Z. Kovalyuk, Tech. Phys. Lett. **18**, 70 (1992).
- [4] S. M. Sze, Physics of Semiconductor Devices, 2-d ed., V.2, Moscow: Mir 382 (1984).
- [5] J. Martinez-Pastor, A. Segura, J. L. Valdes, A. Chevy, J. Appl. Phys. **62**, 1477 (1987).