EFFECT OF PRESSURE ON THE PHOTOCONVERSION PARAMETERS OF ANISOTYPE GaSe—InSe HETEROJUNCTIONS[1]

S.I. DRAPAK, M.O. VOROBETS

I.M. Frantsevych Institute for Problems of Materials Science, Chernivtsi Branch, Nat. Acad. Sci. of Ukraine
(5, I. Vilde Str., Chernivtsi 58001, Ukraine; e-mail: chimsp@unicom.cv.ua)

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Changes of the photoelectromotive force and the short-circuit current in n-InSe/p-GaSe heterojunctions stimulated by static pressure applied normally to the barrier plane have been studied. A pressure of about 35 to 40 kPa applied to optical InSe/GaSe junctions has been shown to result in almost the doubling of the open-circuit voltage and the increase of the short-circuit current by a factor not less than five. This allows us to forecast a capability to enhance the photoconversion efficiency of such heterojunctions up to 15—16%.

Photo diodes, developed on the basis of anisotype heterojunctions n-InSe/p-GaSe and fabricated making use of the optical-contact bonding method [1], are the analogs of silicon structures intended for operating under enhanced-radiation conditions [2]. The coefficient of photoconversion efficiency of such a heterojunction amounts to 0.7—3.2%, depending on the electric parameters of contacting semiconductors and on the design features of structures [3]. According to the results of work [4], the heterojunction InSe/GaSe is a semiconductor—insulator—semiconductor structure, where, despite the prevailing idea about the passivity of layered semiconductor surfaces to the sorption of foreign atoms from the atmosphere [5], the oxygen layer, being a nonequilibrium system with a long relaxation time, plays a role of an insulator. As was shown in work [4], semiconductor plates of InSe and GaSe, after their having been stored for a long time (10—14 years) and owing to the diffusive spreading of oxygen, come in a real close contact, the area of which is approximately 10% of the geometrical area of the heterojunction. The calculations carried out for such heterojunctions, manufactured of indium and gallium monoselenides with optimal electric parameters, which take into account the actual area of contact (i.e. the area, where the electrodes are in a close contact), result in the growing of the coefficient of efficiency from 3.2 to 11—12%. If the sites of close contact between InSe and GaSe emerge as a consequence of either partial "extrusion" of an "air interlayer" or "enveloping" the aggregates of adsorbed oxygen atoms under the action of the weight of the contacting semiconductors, it is reasonable to carry out a research of the influence of pressure upon the photoconversion parameters of the InSe/GaSe optical contact.

In this report, we present the results of the first researches of the influence of mechanical pressure applied perpendicularly to the plane of barrier localization on the photo emf (the open-circuit voltage) V_{oc} and the short-circuit current I_{sc} of the InSe/GaSe optical contact.

Unfortunately, we were lacking for indium and gallium monoselenide crystals at the moment of carrying out the researches to manufacture a heteropair with the maximal efficiency ($p_{\mathrm{GaSe}} = 5 \times 10^{16}$ cm^{-3} and $n_{\mathrm{InSe}} = 5 \times 10^{15}$ cm^{-3} at $T = 300$ K; the series resistance of the structure $R \approx 10^3\ \Omega$ [3]). We studied the structures, whose resistance R varied within the range $10^4 - 10^5\ \Omega$, depending on the charge carrier concentrations in contacting semiconductors ($p_{\mathrm{GaSe}} = 10^{14} \div 10^{15}$ cm^{-3} and $n_{\mathrm{InSe}} \approx 1 \times 10^{15}$ cm^{-3} at $T = 300$ K). The heterojunctions were undergone the action of a mechanical pressure directed perpendicularly to the

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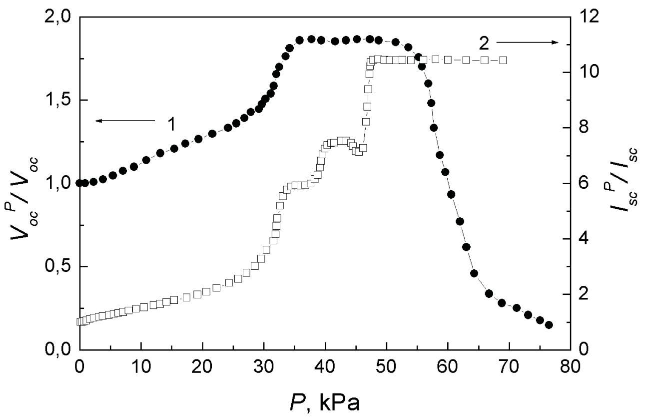

Fig. 1. Dependences of the open-circuit voltage $V_{\rm oc}$ (*1*) and $I_{\rm sc}$ (*2*) on the pressure P applied to a n-InSe/p-GaSe heterojunction. The superscript P denotes the relevant values for the structures under pressure

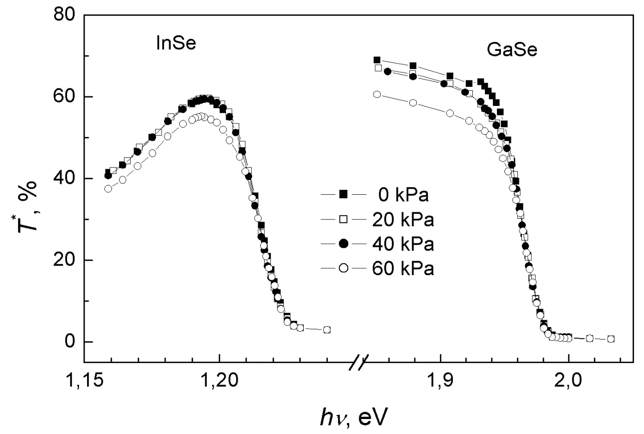

Fig. 2. Spectral dependences of the coefficient of optical transmission T^* of InSe (the thickness $d_{\rm InSe} = 230$ μm) and GaSe ($d_{\rm GaSe} = 240$ μm) plates at $T = 291$ K for various pressures P

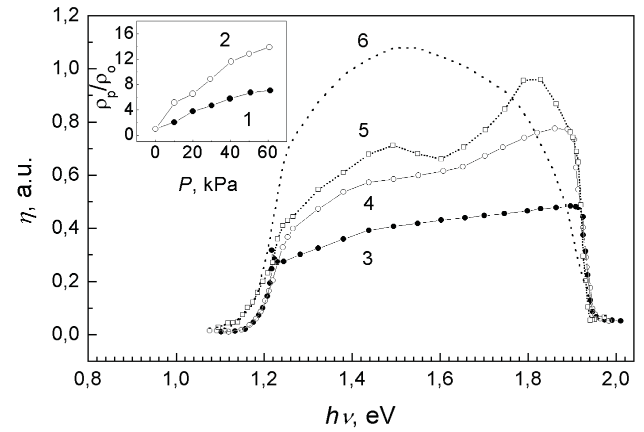

Fig. 3. Spectral dependences of the relative quantum efficiency η of the n-InSe/p-GaSe heterojunction for various values of pressure $P = 0$ (*3*), 20 (*4*), 40 (*5*), and 60 kPa (*6*). $T = 291$ K. The influence of pressure on the variation of the specific resistances of indium (*1*) and gallium (*2*) monoselenides is demonstrated in the inset

interface plane (along the symmetry axis c of InSe and GaSe crystals).

In Fig. 1, we display the dependences of the open-circuit voltage $V_{\rm oc}$ (curve *1*) and the short-circuit current $I_{\rm sc}$ (curve *2*) on the amplitude of a pressure P applied to a InSe/GaSe heterojunction. The analysis of the optical transmission spectra of indium and gallium monoselenides subjected to the uniaxial squeezing up to the pressure $P = 60$ kPa (Fig. 2) evidences for the absence of modifications in the energy spectra of those semiconductors, which is in a good agreement with literature data [6, 7]. For example, according to work [6], the narrowing of the energy gap E_g under the pressure action becomes appreciable at $P > 10^8$ Pa for GaSe. This circumstance provides the reasons to connect the changes of $V_{\rm oc}$ and $I_{\rm sc}$ of the n-InSe/p-GaSe heterojunction in the concerned range of pressure with, mainly, those changes that occur at the interface. An additional confirmation of such a conclusion is the hysteresis of the obtained dependences $V_{\rm oc}^P/V_{\rm oc}$ and I_{sc}^P/I_{sc} observed under the condition, when the pressure was first increased and then diminished to zero. For example, the values of $V_{\rm oc}$ and $I_{\rm sc}$ decreased after the pressure having been reduced but remained substantially larger as compared with those in the initial heterojunction.

From Fig. 1, one can see (curve *1*) that, under the action of the pressure $P \approx 35$ kPa on the InSe/GaSe heterojunction, the open-circuit voltage $V_{\rm oc}$ becomes almost twice larger and tends, as was predicted in work [4], to the magnitude of the contact potential difference φ_0 calculated in the framework of the Anderson model for perfect heterojunctions:

$$\varphi_0 = (\chi_p + E_{gp} - E_{{\rm F}p}) - (\chi_n + E_{{\rm F}n}), \qquad (1)$$

where χ_p and χ_n are the electron affinity of p- and n-semiconductors, respectively; E_{gp} the energy gap in the p-semiconductor; $E_{{\rm F}p}$ the energy of the Fermi level in the p-semiconductor reckoned from the top of the valence band; and $E_{{\rm F}n}$ the energy of the Fermi level in the n-semiconductor reckoned from the bottom of the conduction band. Nevertheless, the results of measurements of the volt-farad characteristics of the structures subjected to pressure testify to that the contact potential difference φ_{0p} does not reach the φ_0 level determined from the relationship for perfect heterojunctions (1), even if one takes into account a possible change of the Fermi level position in InSe and GaSe owing to the increase of their specific resistance, when the pressure grows up to $P \approx 70$ kPa (Fig. 3, curves *1* and *2*). This circumstance testifies to that it is impossible to entirely eliminate the intermediate layer of oxygen atoms adsorbed from the atmosphere by applying pressure. Nevertheless, contrary to heterojunctions which were not subjected to pressure and for which the open-circuit voltage considerably exceeded the contact potential difference (this is typical of structures that contain a dielectric layer at the interface [8]), in the case of the structures under pressure, the relationship

$$eV_{\rm oc} \leq \quad \varphi_{0p} \qquad (2)$$

is fulfilled, e being the electron charge, which evidences for a narrowing of the intermediate layer down to a thickness which can be neglected. At the same time, despite that the region of the spatial charge localization increases in thickness, which is caused by the growth of φ_{0p} determined from C—V characteristics, and that the specific resistance of contacting semiconductors also increases (Fig. 2, curves *1* and *2*), a substantial growth of $I_{\rm sc}$ is observed (by a factor of more than 5). This testifies to that the optical contact InSe/GaSe subjected to pressure can now be considered as an "intimate" heterojunction rather than the semiconductor—insulator—semiconductor structure. In the range of pressures $P = 35 \div 40$ kPa, the values of $V_{\rm oc}$ and $I_{\rm sc}$ saturate, which may result from the impossibility to reduce the thickness of the dielectric layer under the influence of the applied pressure. The further increase of pressure results in a jump-like increase of $I_{\rm sc}$, provided the constant value of $V_{\rm oc}$, which may be connected to the increase of the area of the heterojunctions concerned, owing to a more uniform distribution of the layer of oxygen atoms, which were adsorbed from the atmosphere, over the interface. An increase of $I_{\rm sc}$ in the range of the pressure $P = 40 \div 50$ kPa can also be connected with the variation of the parameters of contacting semiconductors, such as the minority charge carrier's lifetime or the diffusion length, under the influence of pressure. Nevertheless, this assumption demands carrying out the additional researches. A sharp recession of $V_{\rm oc}$ at $P > 55 \div 60$ kPa must be stimulated by a mismatch of the crystal lattice constants of contacting semiconductors (about 8%); the phenomenon starts to manifest itself, when the thickness of the dielectric layer diminishes, and may be responsible for the emergence of photosensitivity of the studied heterojunction beyond the band of intrinsic absorption of indium monoselenide (Fig. 3, curves *5* and *6*). The emergence of photosensitivity in the InSe/GaSe heterojunction under the action of pressure in a longer-wave region of the spectral distribution $\eta(h\nu)$ can also be a consequence of the increase of the structural defect number in semiconductors [9], which is evidenced for by the changes in the optical transmission spectra of indium and gallium monoselenides at $h\nu < E_g$ (Fig. 2). In this case, the growth of the structural defect number under the action of pressure results in a reduction of the majority charge carriers' mobility (scattering by defects), so that the specific resistance of either InSe or GaSe increases (Fig. 3, curves *1* and *2*). Owing to the pressure-induced enlarging of the amplitude of the diffusion-induced band bending φ_{0p} and the pressure-induced growing of the specific resistance of contacting semiconductors, the shape of the current-voltage characteristics (CVCs) of the heterojunctions is also modified (the results are in preparation for publication). We only note that, while the forward-bias branches of the CVCs of the initial specimens can be described by the expression $J \sim \exp(eV/nkT)$, where the diode factor n keeps its value close to 1 within the whole temperature range under investigation, for the structures, which are under the action of pressure, n exceeds 2 at room temperature.

Although we have made a lot of assumptions while interpreting the results obtained, the latter evidence for a possibility for the photoconversion efficiency of the n-InSe/p-GaSe heterojunction to grow substantially. At last, we should note that if the filling factor of heterojunctions subjected to uniaxial squeezing at $P = 30 \div 55$ kPa does not decrease substantially, one should expect an enhancement of the photoconversion efficiency in such structures with optimal parameters (the residual resistance $R \approx 10^3\ \Omega$, the coefficient of efficiency = 3.2%) up to 15—16%. We also note that the area of the n-InSe/p-GaSe heterojunction was spatially confined by the dimensions of quartz ampoules used for growing indium and gallium monoselenides, and amounted to approximately 1 cm^2 for the structures concerned. Casing the structures with such dimensions under the action of pressure $P = 35 \div 50$ kPa should not result appreciably in the quality of photoconverters.

1. *Bakumenko V.L., Chishko V.F.* // Fiz. Tekhn. Polupr. — 1977. — **11**, N 10. — P. 2000 — 2002.

2. *Ashirov E.G., Bakumenko V.L., Bonakov A.K. et al.* // Abstr. of All-Union seminar on radiation-induced effects in semiconductors and semiconductor devices. — Baku: Azernesher, 1980. — P. 91 (in Russian).

3. *Drapak S.I., Katerinchuk V.N., Kovalyuk Z.D., Manasson V.A.* // Fiz. Elektr. — 1988. — **41**. — P. 92 — 94.

4. *Drapak S.I., Orletskii V.B., Kovalyuk Z.D.* // Fiz. Tekhn. Polupr. — 2004. — **38**, N 5. — P. 566 — 569.

5. *Williams R.H., McEvoy A.J.* // J. Vac. Sci. and Technol. — 1972. — **9**, N 2. — P. 867 — 870.

6. *Landolt-Bornstein.* Numerical Data and Functional Relationships in Science and Technology New Ser. Group III: Crystal and Solid State Physics. 17, sv. F / Ed. by O. Madelung. — Berlin: Springer, 1983.

7. *Ulrich C., Olguin D., Cantarero A. et al.* // Phys. status solidi (b). — 2000. — **221**. — P. 777 — 787.

8. *Drapak S.I., Katerinchuk V.N., Kovalyuk Z.D., Manasson V.A.* // Phys. status solidi (a). — 1989. — **115**. — P. K35 — K37.

9. *Vavilov V.S.* Effects of Radiation on Semiconductors. — New York: Consultants Bureau, 1965.

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ВПЛИВ ТИСКУ НА ПАРАМЕТРИ ФОТОПЕРЕТВОРЕННЯ АНІЗОТИПНИХ ГЕТЕРОПЕРЕХОДІВ GaSe—InSe

С.І. Драпак, М.О. Воробець

Р е з ю м е

Досліджено вплив механічного тиску в напрямку, перпендикулярному до площини локалізації межі поділу гетеропереходів (ГП) *n*-InSe—*p*-GaSe, на зміну фото-ерс насичення та струму короткого замикання. Показано, що в оптичних контактах InSe/GaSe, які перебувають під впливом тиску $P = 35 \div 40$ кПа, спостерігається збільшення напруги холостого ходу майже в два рази та струму короткого замикання більше ніж у п'ять разів порівняно з вихідними зразками, що дозволяє прогнозувати можливість збільшення к.к.д. фотоперетворення таких структур до 15—16 %.