ISOPERIODIC HETEROJUNCTIONS BASED ON $Pb_{1-x}Sn_xSe$, $PbSe_{1-x}S_x$ EPITAXIAL FILMS

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p-$Pb_{1-x}Sn_xSe$/n-$PbSe_{1-x}S_x$/BaF_2 isoperiodic epitaxial heterostructures have been obtained and peculiarities of growth and their electrical and photoelectrical properties have been investigated. Epitaxial films have been grown by molecular beams condensation method at 10^{-4} Pa of vacuum. The data on structure of films were obtained by electronographic, X-ray diffractometric and electron-microscopic methods. The heterojunctions are photosensitive in the spectral range 8÷12 μm. Maximum of the photosensitivity is observed at the wave length λ=11,8 μm. The observed displacement of the photosensitivity maximum in the short-wave length of the region of the spectrum is interpreted by the increase of the condensation temperature of the upper layer.

Persisting interest in $Pb_{1-x}Sn_xSe$ narrow gap solid solution and their use in different fields of optoeletronics stimulates all round research of their physical properties, playing a decisive role in development of the infrared photoreceiver in the atmospheric window from 8 to 14 μm based this material [1,2]. It is informed in [3] about photodiodes with the Shottky barrier based on $Pb_{1-x}Sn_xSe$ ($0.06<x<0.07$) layers, obtained on BaF_2 spallings, and the delectability is on one order higher than for photodiodes based on $Pb_{1-x}Sn_xSe$ monocrystals. In these layers the concentration of charge carriers is $(2\div6)\cdot10^{17}$ cm^{-3} at 77 K. Peculiarities of the growth and electrophysical properties of $Pb_{1-x}Sn_xSe$ (x=0.03÷0.07) epitaxial layers doped by indium (N_{In}=0.3÷0.05 weight.%) with various degrees of compensation, grown on BaF_2 spallings, were investigated in [4,5]. The optical absorption edge on the indium-doped ($N_{In}\leq0.08$ weight.%) $Pb_{1-x}Sn_xSe$ (x=0.07) epitaxial layers have been investigated in [6]. It is necessary to note that, until recently, there were not experimental works on the receipt and investigation of photovoltaic srtuctures on the base of $Pb_{1-x}Sn_xSe$ thin films of monocrystals or epitaxial films of $Pb_{1-x}Sn_xSe$ solid solutions. It is connected, apparently, with the absence of materials with the lowered concentration ($\leq10^{16}$ cm^{-3}). However theoretical analysis of $A^{IV}B^{VI}$ solid solutions demonstrates a number of advantages of $Pb_{1-x}Sn_xSe$ solid solutions for making of such structures. The same experimental work on making of $Pb_{0.93}Sn_{0.07}Se$/PbSe heterojunctions, and investigation of their electrical and photoelectrical properties for the first time was published in 1997 [8]. Heterojunctions were produced by the vacuum epitaxy method of PbSe films on the $Pb_{1-x}Sn_xSe$ monocrystals. However, for creation of monolithic matrix photoreceivers, producing isoperiodic heterojunctions based on epitaxial layers on the dielectrical substrates are very interesting. Such substrates allow to realize the electrical decoupling of separate functional elements at the creation of multi-elements devices. In this work we present results of investigation of electrophysical and photoelectric properties of p-$Pb_{0.93}Sn_{0.07}Se$/n-PbSe heterojunctions obtained on the basis of epitaxial films of above-mentioned solid solutions.

The films were grown by the molecular beams condensation method on the newly chiped off and polished sides of BaF_2 {111,100} substrate, under a vacuum of about 10^{-4} torr. Lattices constants of contacting pairs have the identical value ($a_{PbSnSe}=a_{PbSeS}$=6,19Å). Synthesized samples, doped by indium (In), were used for receipt of p-$Pb_{1-x}Sn_xSe$ films with low concentration of charge carriers ($p\leq10^{17}cm^{-3}$). Perfection of films structure was controlled by electronographic, X-ray diffractometric and electronmicroscopic methods. The spectral and volt-current characteristics have been investigated.

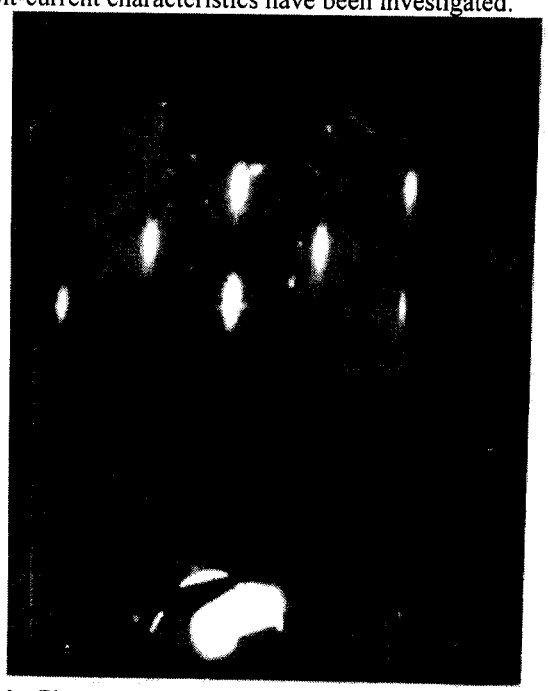

Fig. 1a. Electronogram and the electron microscopic photograph of $Pb_{0,93}Sn_{0,07}Se$ a) electronogram of the reflection,

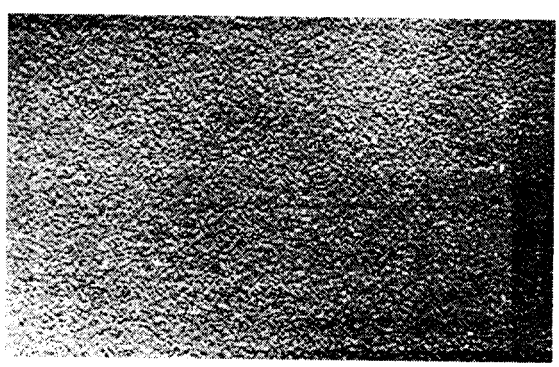

Fig. 1b. Electronogram and the electron microscopic photograph of $Pb_{0,93}Sn_{0,07}Se$ b) electron microscopic photograph of the surface.

For the making of heterojunctions, at first, the thin p-$Pb_{1-x}Sn_xSe$ films with the thickness about 1÷1.5 μm ($\upsilon_{cond.}$=7÷8 Å/s) were

ploted on BaF_2 {111,100} substrate at the temperature (400÷450)±0.5°C by the method [4]. Measurements of the half-width of X-ray diffraction swinging curves showed, that the structural perfection of films is on the level of best samples obtained by the method condensation of molecular beams ($W_{1/2}$=100÷150 angl.s.) and films grow in the plane parallel to the base according to [4-6]. Electronograms and electromicroscopic photographs also confirm this fact. Electronograms on reflection are characterized by reflexes stretched from the shade to the sample. It testifies on relative large dimensions of the blocks and on high crystalline perfection, respectively (fig.1.a). The smooth surface without second inclusions have been observed (fig.1.b) on the electron-microscopic photographs. p-$Pb_{1-x}Sn_xSe$ epitaxial films with the mobility $\mu=(2\div3)\cdot10^4 cm^2/V\cdot s$ and charge carriers concentration $p=2\cdot10^{16}\div3\cdot10^{18} cm^{-3}$ on the BaF_2 substrates, have been received with application of the additional compensating Se steam source at the growth process. The method with the additional source of selenium allowed to lower the concentration of charge carriers and to receive single phase films without second inclusions. Then $Pb_{1-x}Sn_xSe$ (x=0.12) epitaxial films of the n-type conductivity were grown without breakdown of the vacuum. Additional compensating selenium source was used during this growth. $Pb_{1-x}Sn_xSe$ films had the charge carriers concentration $n=3\cdot10^{17}\div4\cdot10^{18}$ cm^{-3} which was estimated on measurements of Hall effect and photomagnetic effect. The n-type $PbSe_{1-x}S_x$ films were received at temperatures of condensation T=(250; 300; 350)°C. Mask with the size of gaps about 0.3 mm was used for making of heterojunctions conducted in the united technological cycle in the process of films growth.

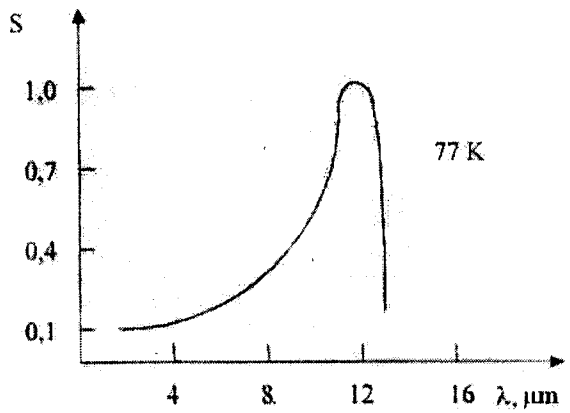

Fig.2. Volt-ampere characteristics of the p-$Pb_{0,93}Sn_{0,07}Se$/n-$PbSe_{0,88}S_{0,12}$ heterojunctions.

The obtained heterojunctions with charge carriers concentrations ($p=2\cdot10^{16}\div3\cdot10^{17}$ cm^{-3}; $n=3\cdot10^{17}\div4\cdot10^{18}$ cm^{-3}) have rectifying properties (fig.2). The volt-ampere characteristics of the heterojunctions show that the insulation current strongly depends on the degree of structural perfection of the p-layer. The straight branch of the volt-ampere characteristic at small displacements (U=30÷100 mV) is submited to the exponential law $J=J_o\cdot\exp(eU/\beta kT)$. The coefficient β changes in the range from 2.0 to 2.5 at T=77 K, that is characteristic for the generation-recombination process of the current leaking through the region of the space charge [10]. In the region of high straight displacements (U=100÷130 mV) the current leaking is determined by the tunnelling (β=9÷10). The spectral dependence of p-$Pb_{1-x}Sn_xSe$/n-$PbSe_{1-x}S_x$ photosensitivity at T=80 K is shown on fig.3. The reduction of the charge carriers concentration in $PbSe_{1-x}S_x$ thin film leads to the decrease of nonequilibrium defects in the n-type layer and, at the same, time stimulates appearance of the photosensitivity peak in the short-wave range of the spectrum with the maximum at λ=7,8 μm in the spectral characteristics of heterojunction photo reply.

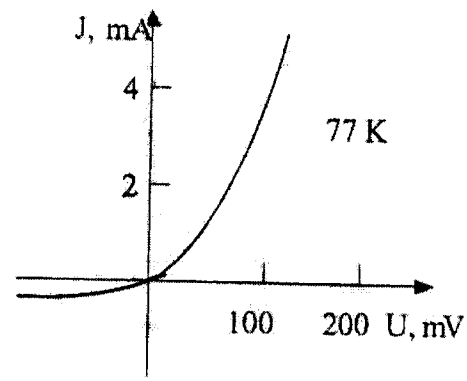

Fig.3. Spectral dependence of the p-$Pb_{0,93}Sn_{0,07}Se$/n-$PbSe_{0,88}S_{0,12}$ heterojunction photosensitivity.

The shift of the photosensitivity maximum to the short-wave region is observed with the increase of the condensation temperature (T_k) on the spectral characteristics of heterojunctions produced at T_k=(250; 300; 350)°C. Indeed, such increase of T_k leads to decrease of the concentration of nonequilibrium defects in the n-layers and, at the same time, stimulates processes of atomic diffusion in the contact region of heterojunction components. Apparently, in accordance with work [8], the diffusion of tin become noticeable from the base to the growing layer of $PbSe_{1-x}S_x$ at temperatures of condensation more than 300°C. As a result, the blurring of the metallurgical border occurs. In this case geometrical dimensions of blurring regions are comparable with the extent of regions of the spatial charge and the heterojunction acquires characteristics of the varizon structure that leads to the shift of the photosensitivity maximum of heterojunctions at the temperature growth of their making. Thus, for practical applications, heterojunctions are interesting, manufactured at the condensation temperature T_k<300°C with the spectral distribution of the photosensitivity determined by characteristics of heterojunction components in basic regions.

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$Pb_{1-x}Sn_xSe$, $PbSe_{1-x}S_x$ EPİTAKSİAL TƏBƏQƏLƏRİ ƏSASINDA İZOPERİODİK HETEROKEÇİDLƏR

BaF_2 altlqları uzərində p-$Pb_{1-x}Sn_xSe$/n-$PbSe_{1-x}S_x$ izoperiodik epitaksial heterokeçidlər alınmış, onların elektrik və fotoelektrik xassələri tədqiq edilmişdir. Epitaksial təbəqələr molekulyar dəstənin kondensasiyası metodu ilə 10^{-4}Pa vakuumda yetişdirilmişdir. Təbəqələrin struktur mükəmməlliyi elektronoqrafik, rentgendifraktometrik və elektronmikroskopik metodlar vasitəsi ilə öyrənilmişdir. Alınmıs heterokeçidlər spektrin 8÷12 mkm dalğa oblastında fotohəssadırlar. Fotohəssalığın maksimumu dalğa uzunluğunun λ=11,8 mkm qiymətinə uyğun gəlir. Göstərilmiş dir ki, yuxarı *n*-tip təbəqənin kondensasiya temperaturu artdıqca, fotohəssaslığın maksimumu qısa dalğalar oblastına tərəf sürüşür.

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ИЗОПЕРИОДИЧЕСКИЕ ГЕТЕРОПЕРЕХОДЫ НА ОСНОВЕ ЭПИТАКСИАЛЬНЫХ ПЛЕНОК $Pb_{1-x}Sn_xSe$, $PbSe_{1-x}S_x$

Получены изопериодические эпитаксиальные гетероструктуры *p*-$Pb_{1-x}Sn_xSe$/*n*-$PbSe_{1-x}S_x$/BaF_2, исследованы их электрофизические и фотоэлектрические свойства. Эпитаксиальные пленки выращены методом конденсации молекулярных пучков в вакууме 10^{-4} Па.

Структурное совершенство пленок контролировалось электронографическим, рентгенодифрактометрическим и электронномикроскопическим методами. Изготовленные гетеропереходы оказались фоточувствительными в области спектра 8÷14 мкм. Максимальное значение фоточувствительности наблюдается при длине вольны λ=11,8 мкм. Показано, что с увеличением температуры конденсации верхнего слоя максимум фоточувствительности смещается в коротковолновую область.

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