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PHOTODETECTOR BASED ON Al-As_2Se_3-Al BARRIER STRUCTURES

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The spectral measurements of the transient I-V characteristics and photoconductivity in the amorphous Al-As_2Se_3-Al barrier structures are presented. The photoconductivity was measured at room temperature by exciting with the IR light from the 0,8÷to 3.5 μm spectral region. The photosensitivity of the Al-As_2Se_3-Al barrier structures in the medium IR region is assumed to be determined by the optical transitions between the deep levels and extended states of the amorphous material with the subsequent thermal release of non-equilibrium holes to the valence band.

Keywords: Photoconductivity, Amorphous chalcogenide film, Deep levels, IR absorption

1. Introduction

The strong absorption of chalcogenide glass-like semiconductors (ChGS) in the visible and near infrared (IR) region of the spectrum contributes to their effective application in different photosensors and radiation detectors [1]. The technology of obtaining thin films of ChGS is extremely simple and does not require the use of especially clean material as in the case of crystalline semiconductor devices. Furthermore, amorphous chalcogenide films are resistant to the radiation [2].

The possibility of the direct detection of IR light (up to 1.5 μm) in a-As_2Se_3 films was demonstrated in [1]. In this book, the high coefficient of photoelectric amplification was attained due to the use of a rectifying contact, and the broadening of the depletion region to entire thickness of film. For expanding the wavelength range of the recording spectrum (up to 2 μm) into [1,3] was used the photostimulated optical absorption in the As_2S_3 fiber.

The coefficient of optical absorption of a-As_2Se_3 in the near IR range was measured mainly for studying the density-of-states distribution in the mobility gap of the material. It was brought out from the spectra of steady-state photocurrent, that the coefficient of sub-band gap absorption of amorphous semiconductor is considerably higher than its crystalline analog due to the optical transitions between the deep traps and the extended states in the valence band [4]. Recently new photodetectors based on heterojunctions SnO_2-$As_2(Se_{0.9}Te_{0.1})_3$ and SnO_2-$(As_{0.67}Sb_{0.33})_2Se_3$ were reported [5].

In this paper, we present the new results of investigating the photoconductivity of the thin a-As_2Se_3 films in the near- and medium IR spectral region (up to 4 μm) at room temperature. Photodetectors on the basis of the amorphous As_2Se_3 films, operating in the wavelength from 3 to 3.5 μm, can find wide application in photonics and optoelectronics.

2. Experimental details

The a-As_2Se_3 amorphous thin films (d~2 μm) were prepared by thermally evaporation in the vacuum onto the Al-covered glass substrate. Semi-transparent Al-layer was used as upper electrode (area A~0.56 cm^2). For photoelectrical measurements the sample was illuminated with the light spot from the specular monochromator SPM-2 with the projection quartz lamp (power of 78 W), and with prism from the fluoride of lithium (LiF). The spectral distribution of the intensity of light supplied to the sample was measured by the thermoelectric converter PTH-10 (0.6-2.7 μm) and pyroelectric receiver ПМ-4 (2-4 μm).

For measuring of the transient current-voltage (I-V) characteristics, the pulse of triangular voltage with a frequency of 10^{-2} Hz was applied to the sample. The rate of ramp voltage $\beta(=dU/dt)$ was about ±0.16 V/s on the forward (+) and back (-) front of pulse. The measured transient photocurrent was amplified by electrometer and then was recorded by the X-Y potentiometer. Before the measurements the sample was kept in the darkness at room temperature during the long time for establishing the stationary filling of deep traps.

3. Experimental results and discussion

3.1. The spectral distribution of photoconductivity

Fig. 1 illustrates the spectral response of Al-As_2Se_3-Al barrier structures, defined as the ratio of steady-state photocurrent to the intensity of incident light with the different values of the applied bias voltages (curves 1-3) and two values of the light intensity (curves 3-4). Relatively high sensitivity occurs in the range from 0.8 to 1.5 μm. Furthermore, is observed the growth of the photocurrent in the range from 3 to 4 μm, which indicates the unique possibility to detect the medium IR light by the amorphous chalcogenide film. Photoresponse can be associated with the presence in the mobility gap of the amorphous materials of the localized states with high concentration. For the comparison on the Fig. 1 are presented the spectral response of p-c-n stacked structure based on amorphous silicon (here "c" indicates the strongly compensated semiconductor), obtained into [6] from the measurements of low-frequency capacitance. In this work the spectral photoresponse in the medium IR range was explained by a change in defect occupancy due to IR absorption, which be present in the compensated a-Si:H material.

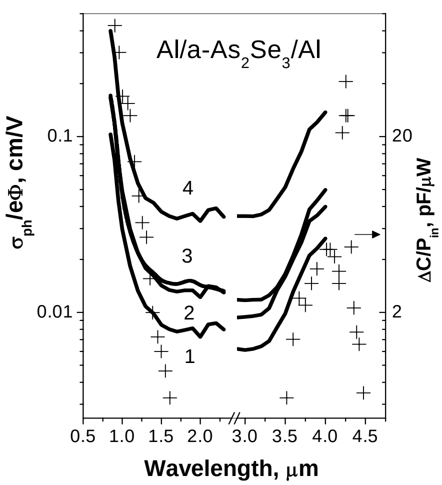

Fig. 1. The spectral distribution of the steady-state photoconductivity of Al/a-As_2Se_3/Al structure in the region of IR absorption measured for three values of potential on upper electrode U, V: 1- 0.5, 2- 2.0, 3, 4- 4.0 and two values of the light intensity Φ: 1, 2, 3-Φ_1, 4-Φ_2, $\Phi_1<\Phi_2$. For the comparison the spectral response of p-c-n structure on basis of a-Si:H, found from the measure ments of photocapacitance in [6] (symbols) is given.

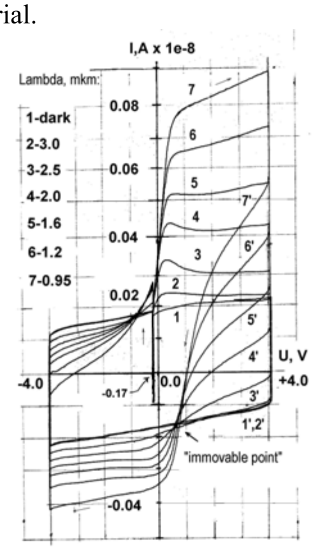

Fig.2. The transient I-V characteristics of Al/a-As_2Se_3/Al structure measured for the ramp rate $\beta\sim\pm0.16$V/s on the forward (+) and back (-) fronts of triangular pulse. The measurements were carried out in the darkness (curves 1,1') and also with the illumination by monochromatic light from the region of IR absorption (curves 2-7, 2'-7'). Arrows showed the direction of a variation of the voltage.

There is a standard picture for the energy distribution of the sub-band gap states (it is band tails and the deep levels of the charged defects) in the amorphous As_2Se_3 [4,7]. We suggest that in the range from 0.8 to 1.5 μm the positive photocurrent is determined by the electronic excitation of the localized states with the optical transitions of holes into the valence band (for $E>E_{g0}$, E_{g0} - optical band gap) or electrons into the conduction band, with the additional thermal ionization of electronic states (for $E<E_{g0}$). The spectral distribution of the photocurrent in this region

of wavelengths follows to the exponential Urbach law according to the optical absorption of the amorphous As_2Se_3.

Situation is not so obviously in the range from 3 to 4 μm, since here the photon energy $h\nu<E_{g0}/2$ is insufficient for the excitation of the holes, captured on the traps in upper half of the band gap. We think that because of the strong bend of bands in the contact M-ChGS the deep levels are partially filled with electrons and then, it is possible their excitation into the conduction band but with the smaller photon energy. This process is accompanied by the additional thermal ionization of non-equilibrium holes to the edge of valence band. As in the previous case, this leads to an increasing of the positive photocurrent.

Let us note that for ChGS is characteristic the low electron mobility and after light excitation immobile carriers remain in the high-field region until it is re-captured to the deeper traps. In this case negative fixed charge in the depletion layer increases. In both cases, the optical excitation yields to the redistribution of electric field in the amorphous film and to the increasing of the barrier capacitance. A similar mechanism was proposed in [6] for explanations of the spectral response in a-Si:H shown in Fig.1 by symbols.

3.2. Transient CV-characteristics

Fig. 2 shows the dependence of the transient I-V characteristics of Al/a-As_2Se_3/Al structures on the sign of the rate of ramp voltage in the absence of illumination (curves 1, 1') and also with the illumination of sample by IR light (curves 2-7, 2'-7'). With an increase in the positive voltage on the upper electrode, the current rapidly grows and at 0.1-0.3 V passes into the weak dependence on the voltage (curves 3-7). The current also grows with an increase in the photon energy.

After switching the sign of the rate of ramp voltage, the current drastically decreases, than it passes through zero and achieves saturation with the negative voltages on the upper electrode. The "Zero" position of the current depends on the photon energy and changes in the interval from 2 to 1 V for curves 4'-7'.

The remarkable feature of transient I-V characteristics in this range of voltage bias is the "immovable point", at which all curves intersect: this point lies on lower curve 1', measured in the darkness at ~0.6 V. A similar point exists also at the negative voltages, i.e., for the I-V characteristics, determined by the properties of the bottom contact.

The measurement of the transient I-V characteristics on the contact Al/a-As_2Se_3, in response to a pulse of triangular voltage, is the well approved technique for the study of deep states in the chalcogenide film. In the combination with the temperature measurements of transient current [8] and its dependence on the photon energy (with the illumination of sample from the range of near IR absorption) [9] were determined the energies of the thermal (~1.05 eV) and optical ionization (~1.4 eV) of deep state in the upper half of band gap of the amorphous semiconductor.

In the darkness the transient current is determined by the geometric capacitance of the thin film structure C_g ($=\varepsilon\varepsilon_0 A/d$), since it coincides with the estimation of the capacitance according to the value of $I/|\beta|$ ~1.1 nF (curves 1,1'). Under IR illumination, the behavior of transient current in the direct direction of voltage variation significantly differs from one for the case of opposite direction i.e. is characterized by hysteresis. The numerical calculations, carried out into [10] confirm that the hysteresis behavior of the transient I-V characteristics can be qualitatively explained by the presence of deep traps with the extremely long relaxation times, which prevent the establishment of thermal equilibrium in the contact.

According to the band diagram of the contact metal - strongly compensated semiconductor with the deep level (Fig.3), at the positive sign of the ramp rate $\beta>0$ the transient current may be determined by the slow process of the thermal release of the non-equilibrium holes, which are appeared under illumination (transitions 1).

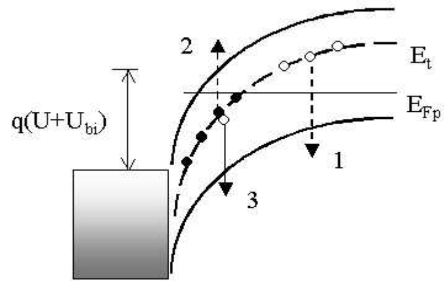

Fig. 3. The position of energy bands of the contact metal - strongly compensated semiconductor with the deep level under the reverse bias voltage. Arrows indicate the possible electron transitions under illumination from the region of IR absorption that give the contributions to the positive photocurrent. Transitions of the type 1 prevail in the range of wavelengths from 0.8 to 1.5 μm; transitions of the type 2,3 are actual for range from 3 to 4 μm; here continuous arrow 3 depicts thermal emission.

After switching of the sign of the ramp rate $\beta<0$ the rapid trapping process of the holes seems to be included in the current relaxation. This is caused by the excess concentration of holes that appears at the boundary with the quasi-neutral region of semiconductor, even with the small decrease of voltage bias. The further voltage decreasing leads to zero current at the point, where the rates of thermal emission and holes trapping are equal to each other. For the curves 4', 5' "zero" of current corresponds to the time constant of about 6-12 s from which can be evaluated the position of the Fermi quasi-level E_{Fp}~0.75-0.77 eV.

When the current becomes negative, the contact is included in the direct bias, despite the fact that the potential on the upper electrode remains positive. In this case the immovable point, at which intersect the curves of 2'-7' in the Fig.2 in the first approximation can corresponds to the built up potential U_{bi}, caused by a difference in work functions for the metal and chalcogenide film [1]. Indeed, on the equivalent scheme the contact can be represented in the form of the parallel resistance and capacitance chain of the quasi-neutral region connected in series with the barrier capacitance C_b. In an extreme case of $C_b >> C_g$, (which is realized at $U=U_{bi}$) the total capacitance of contact is determined by the geometric capacitance. The observed photosensitivity of a-As_2Se_3 film in the medium IR range can be associated with the optical excitation of the electrons, captured on D^+ centers if, of course, the time constant of optical ionization is lower than the transit time of defect into the meta-stable state ($D^+ + e \rightarrow D^0$) and/or - the time of the thermal emission of trapped carriers. The effect of the rate of optical ionization to the photoconductivity follows from the comparison of the curves 3 and 4 (Fig.1).

4. Summary

In this paper, we have demonstrated the possibility of the detection of IR irradiation in the range from 0.8 to 4 μm by the measurements of steady-state photocurrent at room temperature in the Al/a-As_2Se_3/Al structure. The measurements of the transient I-V characteristics under illumination by IR light show that the photosensitivity of the amorphous semiconductor is due to the electron transitions related to the thermal and optical ionization of the deep levels (D^+ centers).

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