Polarization photosensitivity of n-p-CdSiAs₂ photodiode

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Abstract. The work is devoted to the study of natural photopleochroism of n-p-CdSiAs₂ structures. In this paper the main results of polarization studies about photosensitivity of n-p-CdSiAs₂ based diode structures (electrochemical cells and fine structure), are presented. We also conclude that such structures can be used as polarimetric photodetectors for optical communications lines and photonics

1. Introduction

It is well known that intensity and polarization are basic characteristics of a light wave. A complete analysis of polarized radiation with the help of polarization insensitive photodetectors is possible only after the recorded radiation is converted with the help of an external polarization device, as a result of which the polarization characteristics of the radiation are calculated from the measured intensity. The use of polarization insensitive photodetectors for determining polarization parameters requires that the polarization element be spectrally matched with the photodetector, which gives rise to additional losses of radiation. A photodetector which does not require external polarization devices – a polarimetric photodetector – is obviously most suitable for such purposes.

The importance of such studies has increased in recent years because of the fact that the method developed for performing polarization studies of photoconductivity has proven to be very useful for studying the electronic spectrum of anisotropic semiconductors and the perfection of their structure and has opened up the possibility of creating such device with new functional possibilities. It turns out that in order to create polarization sensitive photodetectors it is no longer sufficient to establish the general characteristics of the polarization photosensitivity (PS): the effect of the nature of the positional ordering of the atoms, the behavior of specific impurities, and the characteristic parameters of semiconductors and instrumental structures must also be studied in detail.

The cadmium silicium diarsenide CdSiAs₂ (Figure 1) is the electronic analog of gallium arsenide. The paper presents a comprehensive study of the polarization photosensitivity straight forward uniaxial crystals CdSiAs₂ (E₀= 1.55 eV at 300 K). These single crystals are of interest from the point of view of creation of new optical systems in which the state of polarization of incident radiation becomes the main parameter (Figure 2). It is found that deviation of the composition of stoichiometric CdSiAs₂ toward an
increase in the concentration of As or Cd is accompanied by formation of additional radiative and non-radiative recombination centres, causing quenching of recombination radiation, and especially of exciton band. These single crystals can be used as the basis for sources of linearly polarized radiation and other functional devices that could not be produced with gallium arsenide crystals with isotropic crystal lattice.

Optical system is an optoelectronic product, which includes polarimetric photodiode that is designed to convert the input optical signals to electronic equipment in electrical. A typical block diagram of such a system (Figure 3) includes an optical radiation source, a modulator, a polarizer, a fiber optical line, polarimetric photodetector, an amplifier. As such, the device allows converting optical signals coming from optical linear path, electrical signals in crucial device, for example, electronic equipment reception station. Using the phenomenon of photopleochroism this allows detecting the change of the coefficient photopleochroism at the slightest change in the polarization of the incident radiation.

Figure 1. The crystal lattice of chalcopyrite for CdSiAs₂, where a-lattice constant, c is a tetragonal compression of the lattice.

Figure 2. The diagram of the optical interband transitions with k=0 (where A-transitions 1.55eV (at 300K) and 1.85 eV (at 77K), B-transitions 1.74eV (at 300 K) and 1.85 eV (at 77K), and C-transitions 1.99 eV (at 300 K), 2.07 eV (at 77K).
Figure 3. The block diagram of the optical system with polarimetric photodiode: (1) emitter, (2) modulator, (3) polarizer, (4) polarimetric photodiode, (5) amplifier.

2. The method

Electrochemical cells were prepared on (100) oriented uniform monocristalline wafers of CdSiAs2 doped by In. This method made it possible to reproducibly grow crystals with holes concentrations of $10^{11}$-$10^{23}$ cm$^{-3}$ at room temperature. When compared with undoped crystals ($\rho$=10$^{16}$ to 10$^{17}$ cm$^{-3}$) in cell employing CdSiAs2:In a higher photosensitivity could be reached as shown by the measurements. Following orientation, the plates were mechanically and chemically polished. An ohmic contact was made by chemical deposition of copper and a current lead soldered with In. The side bearing the ohmic contact was protected with a non-conducting varnish, then the plates were put into a cuvette containing an electrolyte. The measuring cell comprised a platinum counter electrode of large area facing the side of the semiconductor-electrolyte boundary on which the radiation was incident. Distilled water was usually taken as an electrolyte.

Under illumination a photo e.m.f. is generated in the H$_2$O-CdSiAs2 structures. It is positive with respect to the electrolyte if a p-type photoelectrode is used. The sign of the photo-e.m.f. does not change with variation of the illumination intensity or incident photon energy, nor does it change from point to point on the structure. The open circuit photovoltage is logarithmic in intensity and it high intensities tends to saturate, which gives an estimate of the band bending value from 0.8 to 1.0 V for different electrodes. The maximum voltage photosensitivity of H$_2$O-CdSiAs2:In reached 10 V/W at room temperature. The diodes were produced by heat treatment of p-type plates with a free holes concentrarions 10$^{16}$ cm$^{-3}$ at room temperature. The heat treatment was carried out in evacuated quartz ampules. The method allows for conversion of the conductivity type to a specified depth. To be able to study the anisotropy of photosensitivity homojunctions were obtained on the (100) and (001) oriented plates of CdSiAs2. The experimental apparatus for studying polarization photosensitivity induced falling along the normal to the receiving plane of CdSiAs2 oriented plates [1].

3. Results and discussion

Under illumination, normal to the (100) surface of the photoelectrode, with linearly polarized light in the energy range of the A-transition (band-to-band) the photocurrent in found to depend on the orientation of the polarization plane of incident radiation relative to the tetragonal e-axis of the CdSiAs2 crystal in electrochemical cells [2, 3]. This dependence follows to the Malus periodic law. The peak position on the polarization indicatrixs of the photocurrent exactly corresponds to the polarization $E_{II}$ c. In this respect such structures are identical to their solid state analogues. The photocurrent spectra of the H$_2$O-CdSiAs2:In structures also give evidence of the anisotropy of the photoactive absorption. In the region of impurity absorption and interband A-transition of the photoelectrode material the photocurrent in the structure is larger at polarization $E_{II}$ c the long-wavelength exponential edge is split and the photocurrent difference at two polarizations is positive and has a peak at $h\nu$=$E_A$.

A typical spectral dependence of the coefficient of natural photopleochroism for such structure is given in Figure 4. As to the value and sign of natural photopleochroism, these structures are similar to their solid-state analogues. The most important feature of the photopleochroism spectra of such barrier is that
the absolute maximum at $h\nu=1.47$ eV as well as the long-wavelength peak at $h\nu=1.35$ eV both fall in the range of impurity absorption of CdSiAs$_2$. Hence, doping of the photoelectrode material is always accompanied by an increased polarisational photosensitivity in the long-wavelength region whereas features of the photopleochroism spectra inside the fundamental absorption region experience nosubstantial changes compared with undoped crystals.

Also we find that in electrochemical cells based on indium doped CdSiAs$_2$ crystals a maximum azimuthal photosensitivity of $\approx 10^3$ V/WK may be reached near $h\nu=1.55$ eV at $T=300$K. Such structures could be used as photodetectors for LPL. [4-7].

The polarization indicatrices of a photocurrent suggest that in n-type diffusion layers the structural perfection of the original p-type plates as maintained. When illuminated along (001), the photocurrent is polarization – independent, such n-p transitions corresponding functionally to GaAs diodes. CdSiAs$_2$ diodes prepared on (001) plates exhibit polarization indicatrices of photocurrent in agreement with the generalized Malius law [8-10].

The natural photopleochroism spectra exhibit an extremely specific reaction as long as the exciton features are manifested in photosensitivity processes in the form of two narrow peaks in the photoconversion efficiency spectra, each predominant in a certain polarization. In the example of an n-p-CdSiAs$_2$ homodiode containing a thin film of n-type of conductivity, during illuminations from the side of the p-type conductivity substrate, a sharp oscillation of the photopleochroism arises on the photopleochroism spectrum near the energy position of the fine structure which determined from the photosensitivity spectrum before. Here the maximum of the positive photopleochroism lies near energy position belongs to the A interband transition, and its short-wavelength decay is due to the onset of B interband transitions, which are allowed predominantly in the $E_{\perp c}$ polarization. As it follows from Figure 5, the lowering of the temperatures causes a parallel displacement of the photopleochroism spectra and the energy position of photopleochroism oscillations in accordance with a value of $dE_C/dT$ for CdSiAs$_2$ single crystals. We have found that the azimuthal light sensitivity of such diodes reaches 36 mA/W• deg, which indicates the prospects of their use as photoanalyzers of linearly polarized light.

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**Figure 4.** Spectral dependence of the coefficient of natural photopleochroism of a H$_2$O-CdSiAs$_2$:In photodiode at 300 K.
Figure 5. Natural photopleochroism spectra for n-p-CdSiAs$_2$ eliminated from the p-type substrate (curve 1 - at 300 K, curve 2 - at the T=77 K).

4. Conclusion
We conclude that such based on n-p-CdSiAs$_2$ homodiode structures can be used as polarimetric photodetectors for optical communications lines and photonics.

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