PERSISTENT PHOTOCONDUCTIVITY IN Cd$_{0.7}$Zn$_{0.3}$Se MIXED CRYSTALS

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Persistent photoconductivity (PPC) in Cd$_{0.7}$Zn$_{0.3}$Se mixed crystals is investigated. We report here the first experimental observation of PPC in Cd$_{0.7}$Zn$_{0.3}$Se at room temperature. In the temperature region 70 K $< T <$ 200 K, we found that the decay of PPC follows stretched-exponential behavior. PPC is not observable at temperatures below 70 K, in contrast to previously reported results on most materials which exhibits dominant PPC effects at low temperatures. Experimental results show strong evidence that random local potential fluctuations induced by composition fluctuations are the origin of PPC observed here.

One of the most interesting and important phenomena under intensive investigations in semiconductor materials is the slow relaxation of photoexcited carriers, which manifests itself as persistent photoconductivity (PPC). The PPC effect has been observed in a great variety of materials [1]. Several mechanisms have been proposed to explain the effect, one of which is the macroscopic barrier model [2], in which the spatial separation of photoexcited electrons and holes by built-in electric fields from macroscopic potential barriers due to band bending at a semiconductor surface or an interface leads to PPC. This model predicts a PPC decay essentially logarithmic in time for artificially constructed layered materials, which is consistent with experimental observation. However, PPC in bulk semiconductors is not yet well understood and usually cannot be described by this model. The alternative is the DX center model, which involves photoexcitation of electrons from deep level traps which undergo a large lattice relaxation [3,4]. The PPC is induced because recapture of electrons by DX centers is prevented by a barrier at low temperatures. This model explains the large Stokes shift observed in Al$_x$Ga$_{1-x}$As materials. The nature of the DX centers is still being investigated intensively [5].

In this paper, PPC phenomena in a Zn$_{0.3}$Cd$_{0.7}$Se mixed crystal are investigated at different temperatures. Decay behavior of PPC is also studied. Based on experimental results, we conclude that random local potential fluctuations induced by composition fluctuations are the origin of PPC observed here.

The sample used in this study is a Zn$_{0.3}$Cd$_{0.7}$Se mixed crystal with a dark room temperature resistivity of about 10^9 $\Omega \cdot$ cm. Gold leads were attached to the sample using indium solder and the junctions were

carefully tested for ohmic contacts. PPC measurements were performed in a closed-cycle He refrigerator. The sample was attached to a copper sample holder taking care to ensure good thermal contact, yet electrically isolated. A mercury lamp was used along with appropriate filters so that 435.8 nm and 546.1 nm lines dominated the output of the excitation light. To ensure that the data obtained at each temperature had the same initial condition, the system was always allowed to warm up to room temperature after each measurement so as to reach equilibrium, then cooled down in the dark to the desired temperature of measurement. The photon dose was about 2 × 10^{13} photons/cm^2 per second.

PPC decay behavior has been investigated at different temperatures. Figure 1 shows a typical decay curve taken at 170 K after 1000 s of light illumination. The curve is normalized to unity and dark current has been subtracted out. In the temperature region 70 K $< T <$ 220 K, we found that in full time range the PPC decay is well described by a stretched-exponential function,

$$I_{\mathrm{PPC}}(t) = I_{\mathrm{PPC}}(0) \exp\left[-(t/\tau)^\beta \right], \qquad (1)$$

where β and τ are two decay parameters. This is depicted by the perfect fit of experimental data with the solid line which is a plot of eq. (1) with $\beta = 0.77$ and $\tau = 740$ s. It is known that relaxation of a wide class of disordered systems towards equilibrium can be well described by a stretched-exponential function [6,7]. The PPC decay behavior thus implies the similarities of the present system to the disordered systems, which leads us to interpret the origin of PPC in terms of spatial separation of photoexcited charge carriers by local potential fluctuations induced by composition fluctuations in the sample. The similarity between the present sample and other disordered systems can be clearly seen if one notices that PPC decay is a process involving relaxation
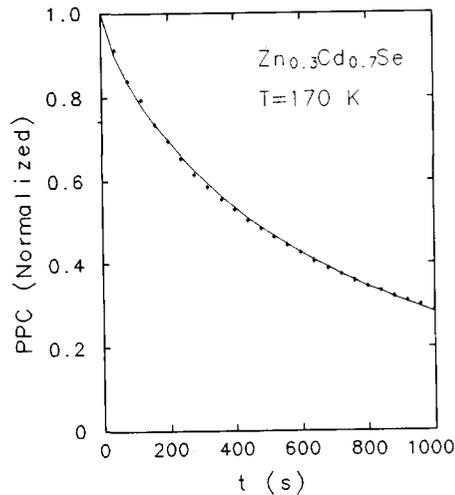
Fig. 1. PPC decay obtained at 170 K (* * *) for $Zn_{0.3}Cd_{0.7}Se$ mixed crystal for 1000 s light illumination. Photon dose is about 2×10^{13} photons/cm^2 per second. The curve is normalized to unity at $t = 0$, and the dark current has been subtracted out. Conductivity at $t = 0$ is 1.04 nA. Solid curve is a plot of a stretched-exponential function with $\beta = 0.77$ and $\tau = 740$ s.

of charge carriers which are localized in random potential sites, and the decay rate is determined by the separation distances of oppositely charged carriers. In mixed crystals large compositional fluctuations are well known [8], which cause local potential fluctuations in the sample.

Figure 2 shows the normalized PPC decay curve obtained at 293 K after 1000 s of light illumination. Dark current has been subtracted out. At temperatures
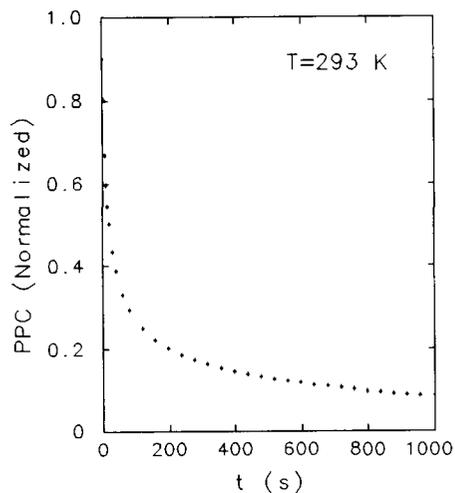
Fig. 2. Normalized PPC decay curve obtained at 293 K. Experimental conditions are the same as those in fig. 1. Conductivity at $t = 0$ is 3.66 nA.

$T > 220$, the relaxation of PPC states proceeds faster as temperature increases. The PPC decay as illustrated in fig. 2 has two components, and can be described by an initial rapid exponential decay followed by a slow stretched-exponential decay:

$$L_{PPC}(t) = A \exp(-t/\tau_1) + B \exp\left[-(t/\tau_2)^\beta\right]. \quad (2)$$

We see from fig. 2 that the PPC level is still 10% of its initial level after 1000 s of decay, and the tail of the slow decay component may extend to more than several thousands of seconds even at room temperature. In the description of the random potential fluctuation model, at higher temperatures ($T > 220$ K), thermal energy is sufficiently high so that some electrons can overcome the highest barriers to recombine with localized holes. This gives, the fast decay part, generally referred to as the photoconductivity (PC) component. The slow relaxation part corresponds to electrons in energy tail states contributing either to hopping or percolation conductance, and thus represents the PPC component. Fitting data from 320 and to 1000 s with the stretched-exponential decay yields the results that $\tau_2 = 107$ s, $\beta = 0.32$ and $B = 0.68$. Since the relaxation involves thermal activation of an electron to reach an available localized hole, we expect that the relaxation time of PPC to have an exponential temperature dependence in the temperature region $T > 220$ K [1] so the average recombination barrier height in the sample can be estimated using PPC decay results obtained in this temperature region. However, since the decay cannot be described by a single stretched-exponential function, the characteristic decay time constants cannot be defined. By defining a response time to be the time for I_{PPC} to decay to $1/2$ times $I_{PPC}(0)$, we obtain the recombination barrier height to be about 100 meV.

Additionally, we found that PPC is virtually unobservable below 70 K. However, a large increase in PPC is observed near 120 K. This is a consequence of the photoexcited carriers activated from localized to delocalized states. This observation further supports our interpretation that PPC is induced by local potential fluctuations in the sample. Below 120 K, electron transport occurs via activated hopping between localized states. At temperatures above 120 K, PPC is predominantly contributed by percolation conductance.

We also investigated the dependence of PPC decay on photon dose. In general, for a given temperature, before the photocurrent reaches saturation, relaxation times of PPC are found to be increased with an increase of the photon dose. The results obtained at room temperature for three different illumination times are shown in fig. 3. Similar behavior is also found for PPC measured at lower temperatures. Each curve is normalized to unity at $t = 0$, and only the PPC decay components are shown here. The observed results may be interpreted
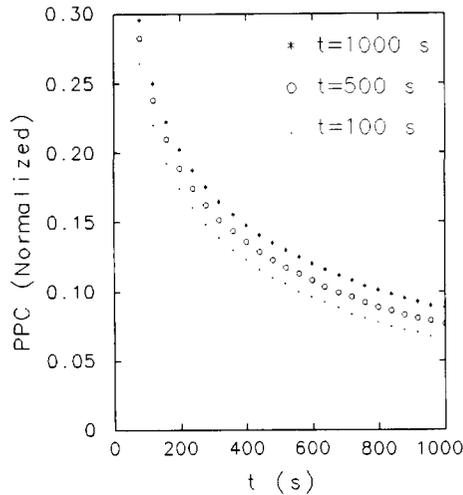
Fig. 3. Normalized decay curves after build-up by different illumination time at 293 K: a) 1000 s, b) 500 s, c) 100 s.

that random local potential fluctuations induced by composition fluctuations are responsible for the PPC observed in this type of crystal. PPC is only observable above 70 K yet still exists up to room temperatures, which is unexpected from both macroscopic barrier or DX center models. In the temperature region 70 K < T < 220 K, the PPC relaxation is well described by stretched-exponential decay. To data, there are no reported results on any other materials which exhibit well characterized PPC at room temperature. We believe that, for mixed crystals with larger composition fluctuations, well characterized PPC should be observed at room temperature, which is technologically important because such effects can be easily utilized.

in terms of the variation of the electron Fermi level with photon dose. For low photon dose, i.e., low electron concentration, the Fermi level in the local potential wells is low. However, the Fermi level increases as the electron concentration increases, and thus activation to percolation states is increased. Our measurements on the temperature dependent PPC decay yield the result that the relaxation of PPC by hopping transport proceeds faster than by percolation. Therefore, the photon dose dependent PPC decay may be a consequence of such an effect.

In conclusion, the PPC phenomena have been investigated for a $Zn_{0.3}Cd_{0.7}Se$ mixed crystal. We found

References

[1] M.K. Sheinkman and A.Ya. Shik, Sov. Phys. Semicond. 10 (1976) 128.

[2] H.J. Queisser and D.E. Theodorou, Phys. Rev. B33 (1986) 4027.

[3] D.V. Lang and R.A. Logan, Phys. Rev. Lett. 39 (1977) 635.

[4] D.V. Lang, R.A. Logan and M. Jaros, Phys. Rev. B19 (1979) 1015.

[5] D.J. Chadi and K.J. Chang, Phys. Rev. B39 (1989) 10063.

[6] R. Palmer, D.L. Stein, E. Abraham and P.W. Anderson, Phys. Rev. Lett. 53 (1984) 958.

[7] J. Kakalios, R.A. Street and W.B. Jackson, Phys. Rev. Lett. 59 (1987) 1037.

[8] J.A. Kash, Arza Ron and E. Cohen, Phys. Rev. B28 (1983) 6147.