EFFECTS OF SPACE CHARGE AS DETERMINED FROM THE TRANSIENT PHOTOCURRENT WAVE FORMS

V.I.Mikla, V.V.Mikla, V.Yu.Slivka

Uzhgorod State University, Voloshina st.54, 88000 Uzhgorod, Ukraine

Transient photoconductivity technique (realized via conventional electrodes time-of-flight experiments) is used to probe the existence and/or formation of bulk space charge in pure amorphous selenium (a-Se) and alloyed with branching additives. The compositions studied are shown to be extremely suitable for such a purposes due to relatively well-defined signal shape and long carrier lifetime. It is observed that band gap irradiation of photoconductors mentioned results in a formation of bulk space charge. The spatial distribution of the space charge density can be estimated from the shape of the transient photocurrent.

1. Introduction

The use of time-of-flight (TOF) measurements on amorphous selenium samples for direct studying of charge transport and trapping dates back to early seventies. The technique was first pioneered by W.Spear [1]. He ascribes the principles, some of the important aspects and experimental realization for drift mobility to be determined. In the following, the method was further improved by M.Abkowitz [2], J.M.Marshall [3] S.Kasap [4] and others. Recent modifications of TOF technique such as delayed and interrupted TOF experiments, as well as xerographic mode of operation are also exploited [5].

One of the most important representatives of a large class of non-crystalline materials is pure amorphous selenium. Due to its importance as a xerographic photoreceptor, many of the properties (especially photoconductive) of a-Se have been widely studied and well documented (see [4] and references cited therein].

This work presents a relatively simple method of examining trapped space charge in typical photoconductors. We have use the TOF technique as a probe for exploring any existing initially or induced bulk space charge distribution in a-Se based photoconductors.

2. Principles

At the beginning it should be noted that the TOF measurement monitors the transient photocurrent in the external circuit due to the motion (drift) of photoinjected carriers through the photoreceptor sample. The transport of hole photocarriers in a-Se has been studied by numerous authors [4]. It is established that the process is shallow-trap controlled and nearly nondispersive at room temperature region. This in turn means that in the absence of deep trapping a TOF wave form exhibits a constant current level. Consequently, the presence of space charge (irrespective to the polarity of charge carriers) affected the electric field. Thus, one faced with decaying or increasing wave form, from which the spatial distribution of trapped charge can be estimated.

For the simplicity, we will consider in the following hole transport. The photocurrent detected in external circuit is proportional to the number of charge carriers drifting as well as their average velocity (both of this are time dependent). The transient photocurrent is then given simply by

$$I_{ph} = N(t)\, V_d(t) = e\, p_0 V_d = e\, p_0\, \mu_d \qquad (1)$$

Where V_d is the average drift velocity at time t, N(t) is the number of charge carriers drifting in the transport state at time t, p_0 is the density of holes in the charge packet, μ_d is the hole drift mobility and E is the electric field. Note that p_0 is assumed constant. If we differentiate both sides with respect to time and take into account Poisson's equation then we obtained

$$dj_{ph}/dt = e\, p_0\, \mu_d\, (dE/dx)(dx/dt) = e\, p_0\, \mu_d(\rho/\varepsilon) = j_{ph}\, \mu_d\, (\rho/\varepsilon) \quad (2)$$

The latter equation can be rewritten as

$$\rho = \varepsilon/\mu_d\, 1/i_{ph}\, (di_{ph}/dt) \quad (3)$$

The current i, it derivatives and t can be obtained from Fig.1. The relationship gives ρ as a function of transit time for charge carriers. The conversion t - x can easily be performed by the following way. Using equation (1)

$$\mu_d E = (dx/dt)\, j_{ph}/(e\, p_0) \quad (4)$$

This gives

$$x = (d/Q_0)\, i(t^*)\, dt^* \quad (5)$$

The shaded region of Fig.1 shows the integration results. Therefore, one can obtain space charge profile ρ(x) ~ f(x) using equation (3) and (5).

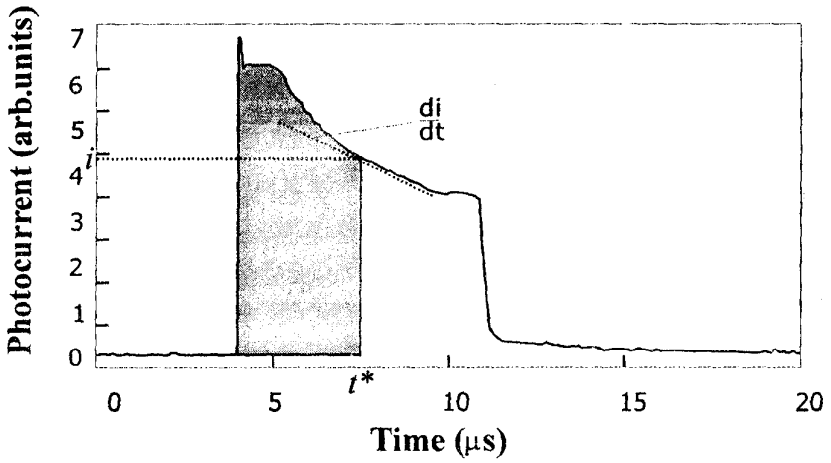

Figure 1. Typical TOF wave form exhibiting bulk space charge effects induced by band- gap illumination. For details see the text.

3. Experimental

To examine, bulk space charge effects on TOF wave forms, simple devices were fabricated in a sandwich-cell configuration on glass substrates, with the chalcogenide alloy as deposited between a top and bottom electrode. In the present study, we used pure amorphous selenium and a-Se alloyed with 2-10 % As(Sb). Glassy As_xSe_{1-x} alloy source material was prepared by conventional melt-quenching technology in a similar fashion to that described previously [8,9]. Amorphous Se and As_xSe_{1-x} films with small amounts of As additives were deposited onto glass substrates by conventional vacuum deposition techniques. The glass substrates were previously coated with SnO_2, which forms the bottom electrode. The thickness of pure a-Se and a- As_xSe_{1-x} films ranged from 5 to 50 μm. The substrate temperature during the deposition process was 300 K. A semitransparent Au electrode was sputtered on the uniform thickness region to complete a sandwich structure: Me/(a-Se)/SnO_2. To limit possible heating of amorphous films, evaporation times were restricted to less than 1 min. The contact area (0.1 cm^2) was defined by the crossover of the two (bottom

and top) electrodes. Prior to any measurement, the samples fabricated in the laboratory were naturally aged in the dark for nearly two weeks to allow their structure and corresponding physical properties to equilibrate.

The experimental TOF technique has been described in the literature by a number of authors [1,6-9]. In a-Se –based materials, it is more useful to measure time-resolved transits in the current mode of operation because of the relatively long transit at low fields. In the present case, we used a nitrogen gas laser to photoexcite the carriers. The nitrogen gas laser provided a short light pulse of duration ~10 ns at a wavelength of 337 nm. Because the photocarriers are generated at the sample surface due to the high absorption coefficient of Sb_xSe_{1-x} glasses at 337 nm ($\alpha>10^4$ cm^{-1}), the species of drifting carriers can be chosen by changing the polarity of applied voltage across the sample. The transient current was amplified and displayed on a single-event storage oscilloscope. The TOF measurement was carried out under the single-shot mode of operation and between each measurement, the sample was short-circuited and stored (relaxed) in the dark to allow any bulk space-charge build-up to decay. Small-signal conditions were maintained throughout all the measurements.

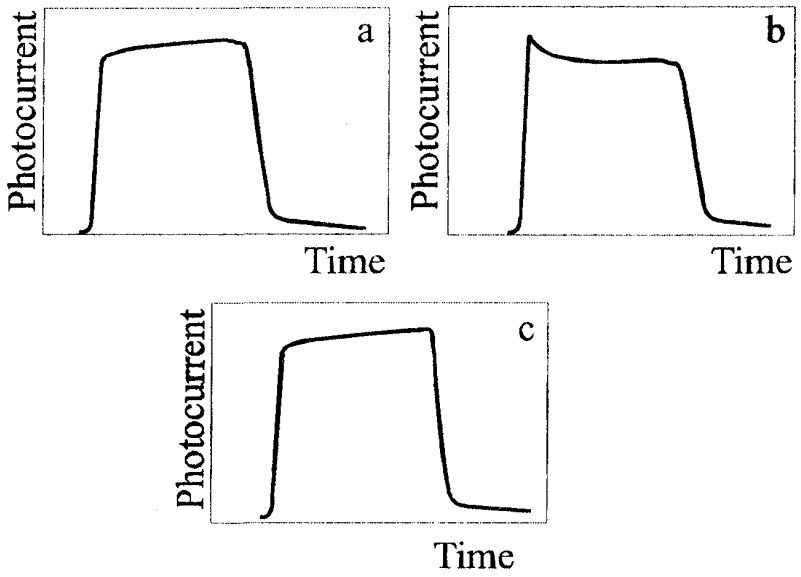

Figure 2. The effect of band-gap illumination on the TOF wave form in $As_{0.015}Se_{0.095}$. (a) dark-rested sample, (b)immediately after irradiation, (c) annealed sample.

Figure 2(a) illustrates the initial, space charge free, TOF wave form that was determined on dark-rested amorphous film. Figure 2(b) exemplifies the effect of pre-illumination of a sample with band-gap light. As it is clearly seen, an initial TOF waveform has the decay (see pre-transit, top portion of j_{ph}). The origin of such a decay might be:

the formation of new set of traps (or modification of preexisting) due to illumination of the sample. The traps under consideration immobilize holes from the propagating charge packet. This process can cause the photocurrent to decay. Examining the integrated change in both the initial (Fig.2a) and final, after irradiation, wave form we find them identical. This in turn ruled out the photogenerated traps as a cause of photocurrent decay;

the TOF probe itself (via electron – hole recombination). In such a case, one observes decreasing signal in successive cycles of photogeneration. Additionally, the amount of charge collected in repetitive mode of operation diminishes;

non uniform electric field formation inside the sample.

It seems that the latter case, (c), is the real origin of light-induced space charge

Applying the method described above we find the density profile of trapped charge through the amorphous sample immediately after exposure with band-gap light (Fig. 3). One can discern the photocurrent to decay exponentially from the top (illuminated) surface of the device. As exposure increases, the amount of trapped charge also increases. At the same time, by varying the time after illumination (delay time) the trapped space charge is decaying in expectable way, i.e. at the same rate for each exposure.

Finally, we mention several conditions necessary for the above method to be applied.

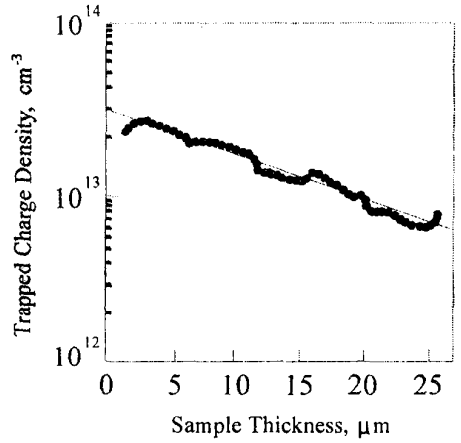

Figure 3. Trapped space charge distribution across the As_xSe_{1-x} amorphous film.

1. The transport should be nondispersive. In other words, the photoinjected carrier packet when drift through the sample suffers only Gaussian dispersion. That is it exhibit a constant, well defined, drift velocity of form $V_d = \mu E$, where μ is the corresponding mobility and $E = V_0/d$ is the applied electric field.

2. The injected photocarriers must have a long Shubwegs ($\mu\tau E$ product) comparatively to the photoconductor thickness d. Therefore, the photocarrier lifetime is much longer than the transit time.

3. The major drawback of the method shown is associated with differentiation noise. This can be minimized by the use of respective modern technique.

The discharge rate is temperature dependent and increases with temperature increasing. Such a behavior is expected for the case of thermally activated detrapping process

$$(\tau_r)^{-1} = \nu \exp(-E_t/kT) \qquad (6)$$

where τ_r is the average release time, ν is a phonon frequency, k is a Boltzmann constant and E_t is the trap depth. Here it is necessary to emphasize that previously similar method (xerographic TOF) was used [5,10] by S.Berger and S.Kasap to probe space charge in selenium photoconductors.

Deep light-induced electron traps are located in a-Se – based alloys near the midpoint of mobility gap (e.g. 0.9-1.0 eV below the conduction band in pure a-Se). The fact that the carriers giving rise to space charge were indeed trapped at the above defect states may be a strong argument in favor of our hypothesis. Different processes including the absorption profile of band-gap light can affect the space charge profile. Our preliminary estimations show that the former is steeper in comparison with the latter.

4. Summary

Time-of-flight experiments were used to probe bulk space charge in a-Se-based films after irradiation with band-gap light. To extract the charge density profile from the TOF wave form an analytical method was applied. The method involves derivative and integral of the transient photocurrent. The distribution of space charge of negative sign through the a-Se-based layer was established. The study shows that the space charge formation can be considered as special case of light-induced effect: trapping of drifting carriers on some light-created deep species of states. This is a possible origin for TOF wave form to change. The traps under consideration are mid –gap mobility states and are located in the range 0.6-0.9 eV.

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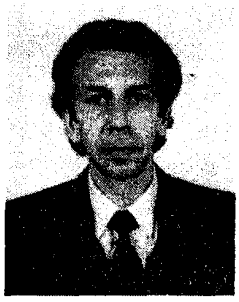
ЕФЕКТИ ПРОСТОРОВОГО ЗАРЯДУ ТА ФОРМА КРИВИХ НЕСТАЦІОНАРНОГО ФОТОСТРУМУ В ЕКСПЕРИМЕНТАХ ПО ВИМІРЮВАННЮ ДРЕЙФОВОЇ РУХЛИВОСТІ

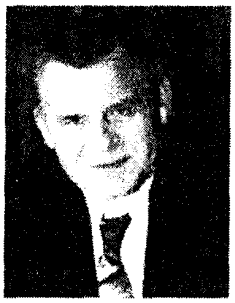
В.І.Мікла, В.В.Мікла, В.Ю.Сливка

Ужгородський держуніверситет, м.Ужгород, вул.Волошина, 54

Розглянуто аналітичний метод розрахунку розподілу просторового заряду для високоомних аморфних фотопровідників. Метод базується на аналізі форми перехідного фотоструму часопрольотних вимірів. Апробація зазначеного способу проведена на прикладі фотоіндукованих ефектів, що відбуваться в аморфних селенідах. Вказано переваги та окремі недоліки такого способу визначення профілю просторового заряду.



Віктор Іванович Мікла – професор кафедри фізики напівпровідників
Народився в 1953 р. Закінчив фізичний факультет УжДУ у 1975 ., кандидатську дисертацію захистив у 1983 р., докторську – у 1997 р.



Володимир Юлієвич Сливка – ректор Ужгородського державного університету
Народився в 1943 р., в 1965 р. закінчив УжДУ, кандидатську захистив у 1970 р. , докторську – у 1982 р. професор, доктор фізико-математичних наук.
Лауреат Державної премії України в галузі науки і техніки 1989 р.