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On the Optical Memory of a Thin-Film pInSb-nCdTe Heterojunction Obtained by Laser Pulsed Deposition

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ABSTRACT

Thin film pInSb-nCdTe heterojunctions (HJs) were produced using pulsed laser deposition (PLD) technique and their photoelectric properties were studied for various thickness of the CdTe layer at nitrogen temperature and under a background radiation the photo-EMF for which was around 1.5 mV. At radiative excitation of the HJ a photo-EMF is observed, which persists when the excitation is turned off. The optical memory (OM) effect is observed in an idling regime and in a wide spectral range: (0.37–1.37)μm with "recording" (0.37–0.575)μm, (0.75–1.37)μm, and "clearing" (0.575–0.75)μm sub-regions. The maximum OM signal is observed at λ=0.575μm while the minimum is at λ=0.768μm. In the spectral dependence of the OM signal at direct and reverse scanning of monochromatic irradiation an hysteresis is observed which is evident for the OM effect. The time dependence of OM signal is investigated at λ=0.575μm and at various intensities of the radiation source. Here, an effect of saturation is clearly observed, and the time during which the OM signal runs up to saturation, depends strongly on the incident light flow power and decreases drastically as the latter is increased. The external bias applied to the HJ enhances the OM on 2 orders over its value in the idling regime. The OM signal persists for a time period no less than 10^5 sec, either with or without an external bias. The actually obtained values of "recording" sensitivity and the "recording" time are U=0.66 μJ/mm^2 and $\tau=10^{-4}$ sec., respectively. The OM signal reaches its maximal value as the thickness of CdTe layer increases (up to d=0.45 μm). It is shown that the investigated HJ possess the property of integration of the radiation.

INTRODUCTION

It is well known that the effect of optical memory (OM) in semiconductors is related with the presence of inhomogeneities in a sample [1]. These inhomogeneities generally show a randomicity which results in drastic changes of main characteristics of the effect from sample to sample even for the same material. This complicates the experimental studies of quantitative trends of the OM effect. The problem of reproducibility of OM-based devices is even more complicated. Therefore, observation of these effects in artificial structures with controllable parameters is very important.

The presence of a recombination barrier in semiconductor is a necessary condition of OM in semiconductors. The simplest systems containing such barriers are p-n heterojunctions (other examples are p-n homojunctions, Schottky-barrier diodes, and MOS structures).

In this work, we have studied the I-V characteristics and photoelectric properties of PLD-grown [2] pInSb-nCdTe HJs.

EXPERIMENT

pInSb-nCdTe HJs were produced by laser deposition of nCdTe layers of various thickness on the polished substrates of partially compensated pInSb (N_A-N_D≈4.17×10^{14} cm^{-3} at T=77 ^{0}K). The ohmic contacts on InSb and CdTe are obtained by thermal evaporation of metallic indium. The contact film of In covers the whole surface of the pInSb layer, while on the CdTe layer it has a shape of 1mm-diameter round. Surface areas of obtained HJs are in the range (0.25–0.36) cm^2. Heterojunctions with the thickness of CdTe-layer (0.15, 0.45, 0.6, 1.2) μm were produced. In order to obtain large amplitudes of OM-signal the space charge region must take the large part of the conducting layer. The dependence of the cutoff voltage on the thickness of CdTe-layer was determined from the family of I-V curves at 77 ^{0}K (by extrapolation of the linear part of an I-V curve. The value of V_c corresponding to the total bend of energy bands of HJ materials saturates at thickness of CdTe layer, d ≥0.5μm. The thickness of W_n=0.45 μm corresponds to the maximum width of space charge region in CdTe. The latter is completely depleted at smaller thickness. Using the measured values of $V_c=V_D=V_{Dn}+V_{Dp}=0.45$ eV and W_n=0.45 μm, within the Anderson model, the concentration of donor impurities in CdTe, the space charge region in InSb, as well as the band curvature for each HJ material [3] were determined. The corresponding values are the following: $N_D=8.55 \cdot 10^{14}$ sm^{-3}, W_p=1.025 μm, V_{Dp}=0.2 eV, and V_{Dn}=0.25 eV.

The analyses of photoelectric properties of HJs were carried out on the monochromator MDP-3, and incandescent lamps were used as radiation sources. The HJ samples were placed in nitrogen cryostats. X-Y recorder, Endim, was used to record the output signal. The effect of optical memory was observed in InSb-CdTe HJ sample when irradiated from the side of wide bandgap CdTe with a monochromatic light of a certain wavelength. The exitation of HJ resulted in a photo-EMF, which persisted when the excitation was turned off. The effect was observed in a temperature range (77–165) ^{0}K, under the steady integral background radiation, the photo-EMF for which was 1.5 eV (idling regime).

The photomemory effect was observed also when an external bias was applied on the structure in accordance with I-V curves. In biased structure, the photovoltage was on 2 orders higher than that observed in idling regime. In difference with the work [4], the OM in our samples was observed either with or without an external bias, and in a wider spectral range: λ=(0.37–1.37) μm.

DISCUSSION

Figure 1 represents the spectral dependence of OM at direct and reverse scanning of the incident light spectrum, showing a hysteresis in this dependence. The studied wavelength range can be conveniently divided into 3 subranges:

a) λ=(0.37–0.575) μm, where the OM-signal enhances with increasing incident wavelength, i.e. a "recording effect" is observed (curve AB in figure 1);

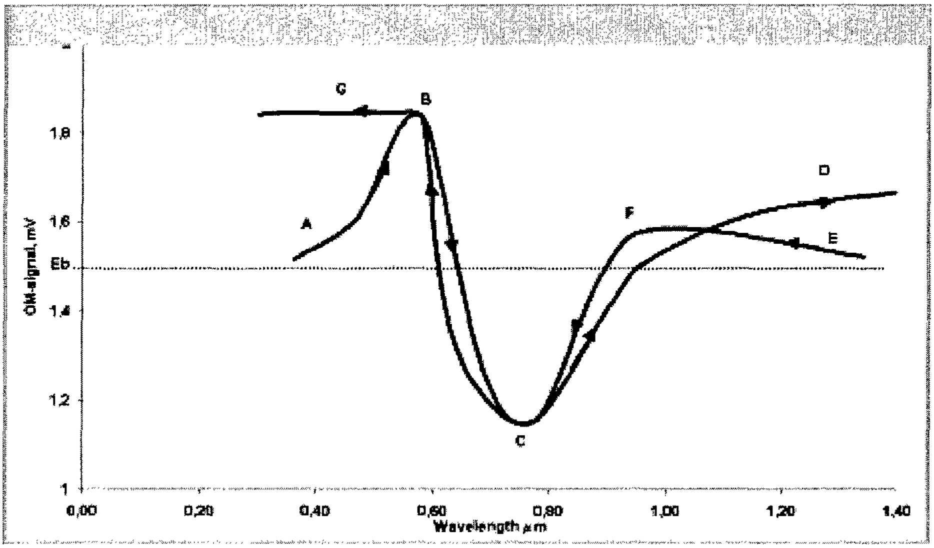

Figure 1. Wavelength dependence of optical memory signal (arrows indicate the scanning direction of external radiation).

b) λ=(0.575–0.768) μm, in which the OM reduces with increasing wavelength, i.e. "clearing effect" (BC curve);

c) λ=(0.768–1.37) μm, where the "recording effect" is again observed (CD curve).

The maximum of OM-signal is observed at λ=0.575 μm , while the minimum is at λ=0.768 μm. At larger thickness of the CdTe-layer the OM-signal enhances reaching a maximal value at d=0.45 μm. The further increase of d leads to decrease in OM-signal.

In figure 2, the time-dependence of OM-signal is shown at various intensities of incident radiation at λ=0.575μm. The effect of saturation is clearly seen on this dependence in accordance with the population of (finite) number of interface states (traps). The saturation start-time depends strongly on the power flow of the light and decreases drastically with its enhancement. We should mention that a certain intermediate value of OM-signal could be obtained also at constant radiation intensity, by simply varying the exposition time. It is also interesting that if after the first act of illumination the HJ is not returned to its initial state, instead an additional radiation-pulse is applied, the memory voltage increases from the initial to a new value. This continues until this voltage reaches a certain maximal value, which corresponds to the saturation of traps. Thus, the produced heterojunctions possess the property of integration of incident radiation.

For "recording" samples the achieved sensitivity to the incident radiation was ~0.66 $\mu J/mm^2$, and the "recording time" was $\tau_0 \sim 8.3 \cdot 10^{-4}$ sec. One should note, however, that the determined τ_0 is not limited to this value and depends on the experimental capabilities. The OM-signal persists in both biased and unbiased HJs no less than 10^5 sec.

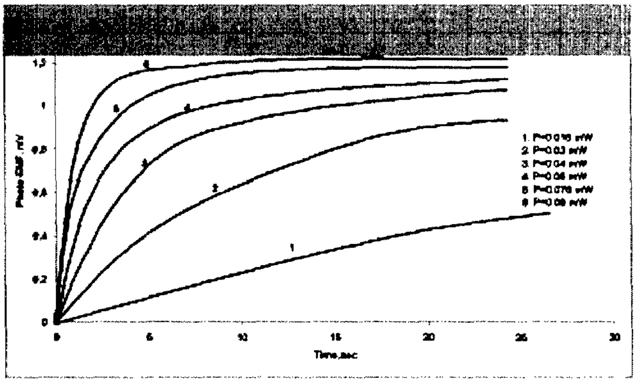

Figure 2. Time dependence of OM signal at various intensities of incident light. Incident wavelength is λ=0.575 μm.

The measurements of the memory photo-EMF depending on the reverse bias voltage were carried out at a fixed intensity of incident radiation at λ=0.575 μm. The applied voltages were in the range (100–1000) mV, where the resulting photo-EMF was in the range (9.15–65)mV (figure 3).

Thus, a reverse bias applied to the HJ increases the recombination barrier for non-equilibrium carriers (electrons) in CdTe resulting in an enhancement of memory photo-EMF more than 200 times.

The complex view of OM dependence on the incident wavelength results from the competing effects on the physical processes in HJ of such parameters as absorption coefficient, its frequency dependence, thickness of CdTe-layer, and geometrical sizes of space charge region.

The largest amplitude of OM-signal is observed in a sample with thickness comparable to the space charge region and with radiation penetration depth (the reciprocal absorption coefficient) to the incident wavelength.

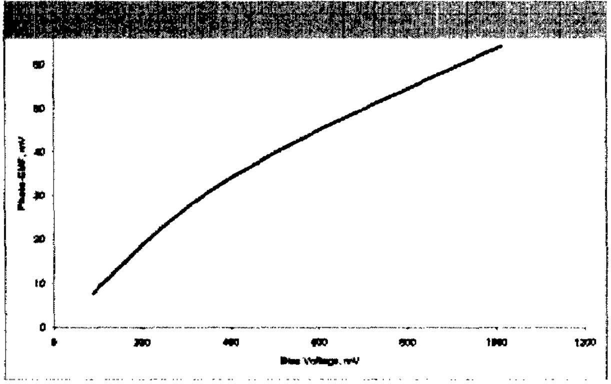

Figure 3. OM-signal in a biased sample. An incident light with fixed intensity at λ=0.575 μm is used.

It follows from the OM-signal vs. wavelength dependencies that the OM appears in both cases of fundamental and impurity-related absorption. Based on this fact we assume that the absorption in CdTe occurs at interband and interface states--conduction band transitions. The HJ field separates the electron-hole pairs created by incident light: electrons move to the CdTe contact, and holes move to CdTe-InSb interface. Holes are partially captured by deep interface states (another part of holes pass to InSb) resulting in an enhancement of positive charge on the interface. After the radiation is turned off this charge remains on the surface states creating an optical memory voltage (AB curve in figure 1).

In order to remove the photo-EMF it is necessary for electrons to be able to pass over the recombination barrier and recombine with holes on surface states. Electrons in CdTe do not possess such energy so they cannot contribute to this process. With increase of the radiation wavelength the radiation partially penetrates into the InSb at $\lambda \geq d$ creating electron-hole pairs, which again does the HJ field separate. The electrons with sufficiently high energies ($E \geq E_{rec}$) pass over the barrier and recombine with holes decreasing the memory photovoltage. Thus, a maximum of photo-EMF appears in wavelength dependence. With further increase of wavelength the number of electron-hole pairs increases in InSb while decreasing in CdTe. Besides, electrons still pass over the barrier and recombine decreasing the photo-EMF (BC curve, figure 1). The latter process continues until the absorption that is related with transitions from impurity states to conduction band, becomes appreciable. The increase of impurity-related absorption with wavelength leads to the enhancement in trap charge and in the OM amplitude. This can be explained by impurity-related absorption. The latter coefficient has a maximum in spectral dependence, and is described by an expression

$$k_{imp} \sim x^{1/2} \cdot (1+x)^{-4}, \qquad (1)$$

where $x = \dfrac{\hbar\omega - (E_g - \Delta E_a)}{\Delta E_a}$, ΔE_a is the depth of acceptor state, E_g is the bandgap width of CdTe, and ω is the frequency of incident radiation. As it is seen, k_{imp} has a maximum at $x_{max}=1/7$: $\hbar\omega_{\max} = E_g - \frac{6}{7}\Delta E_a$. Since the OM still increases with wavelength even when $\lambda<\lambda_{max}$ (λ_{max} corresponds to the maximum of the absorption coefficient), this can take place only if the energy of electrons created in InSb is not sufficient to pass over the recombination barrier. The OM amplitude continues to increase (charge accumulation occurs) and saturates. At reverse scanning of the incident wavelength after the HJ is returned to its initial state, the memory signal appears at $\lambda=1.37\mu m$ and increases with wavelength decrease, in accordance with the frequency dependence of the absorption coefficient, reaching a maximum at ω_l and then decreasing. The latter is possible when at frequencies $\omega>\omega_l$ the energy of electrons created in InSb is high enough to pass over the recombination barrier. Otherwise the OM amplitude would continue to increase until the saturation, though the absorption coefficient still increases. Further, the decrease in OM signal continues unless the interband transitions at $\lambda \leq \lambda_2$ turn on, when the intensities of electron and hole capturing equal. The OM signal passes the minimum and increases with further increase of absorption coefficient.

CONCLUSIONS

Optical memory effect was observed in pInSb-nCdTe heterojunctions produced by pulsed laser deposition. The wavelength dependence of photo-EMF signal has the form of a hysteresis in a spectral range 0.37 to 1.37μm. Optical memory signal was observed in unbiased, as well as in biased samples. In the latter case, the signal was on 2 orders of magnitude higher. The produced heterojunctions possess a property of integration of incident light power. Detailed description of physical mechanisms is given explaining the observed spectral and temporal dependencies of memory signal.

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