Transition from negative to positive photoconductivity in *p*-type $Pb_{1-x}Eu_xTe$ films

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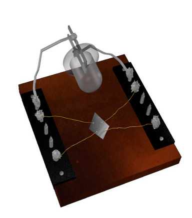
Introdutcion

The phenomenon of photoconductivity has been used as an important tool to investigate the presence of additional states within the band structure of semiconductors [1,2] and has provided basic knowledge that allowed the development of photodetector and sensor devices along the last decades [3]. Recently, the effect of negative photoconductivity, *i.e.*, the reduction of the electrical conductivity under illumination, has attracted some attention due to its potential application in the development on new photonic devices and non-volatile memories with low power consumption [2] .This work , the photoconductive properties of *p*-type $Pb_{1-x}Eu_xTe$ epitaxial layers were studied for *x* values varying from 0.06 to 0.1 and in the temperature range of 77 – 300K. In literature is well-known that a metal-insulator transition occurs around 0.05 at room temperature due to the disorder caused by the introduction of Eu atoms [1]. This study mainly focused on the study of the insulator regime, i.e., *x*>0.05, with physical description of the photoconductivity effect of *p*-type $Pb_{1-x}Eu_xTe$ films. In this insulator regime, it was observed that the photoconductivity suffers a transition from negative photoconductivity (NPC) to positive photoconductivity (PPC).

Experimental

In this work we investigated high quality samples of *p*-type $Pb_{1-x}Eu_xTe$ with *x* varying from 0.01 up to 0.07. The samples were grown in a Riber 32P molecular-beam epitaxy (MBE) system onto freshly cleaved (111) BaF_2 substrates. The films were grown at a substrate temperature of 208.5^{0}C during 2h, with a deposition rate of 3.9 Å/s, resulting in a 2.8 μm layer thickness. Three effusion cells with PbTe, Eu and Te_2 were used to grow the samples. Pb (Te) vacancies in PbTe crystals act as acceptors (donors), therefore it is possible to control the concentration and the type of carriers through the chalcogen source flux variation.

Results and discussion



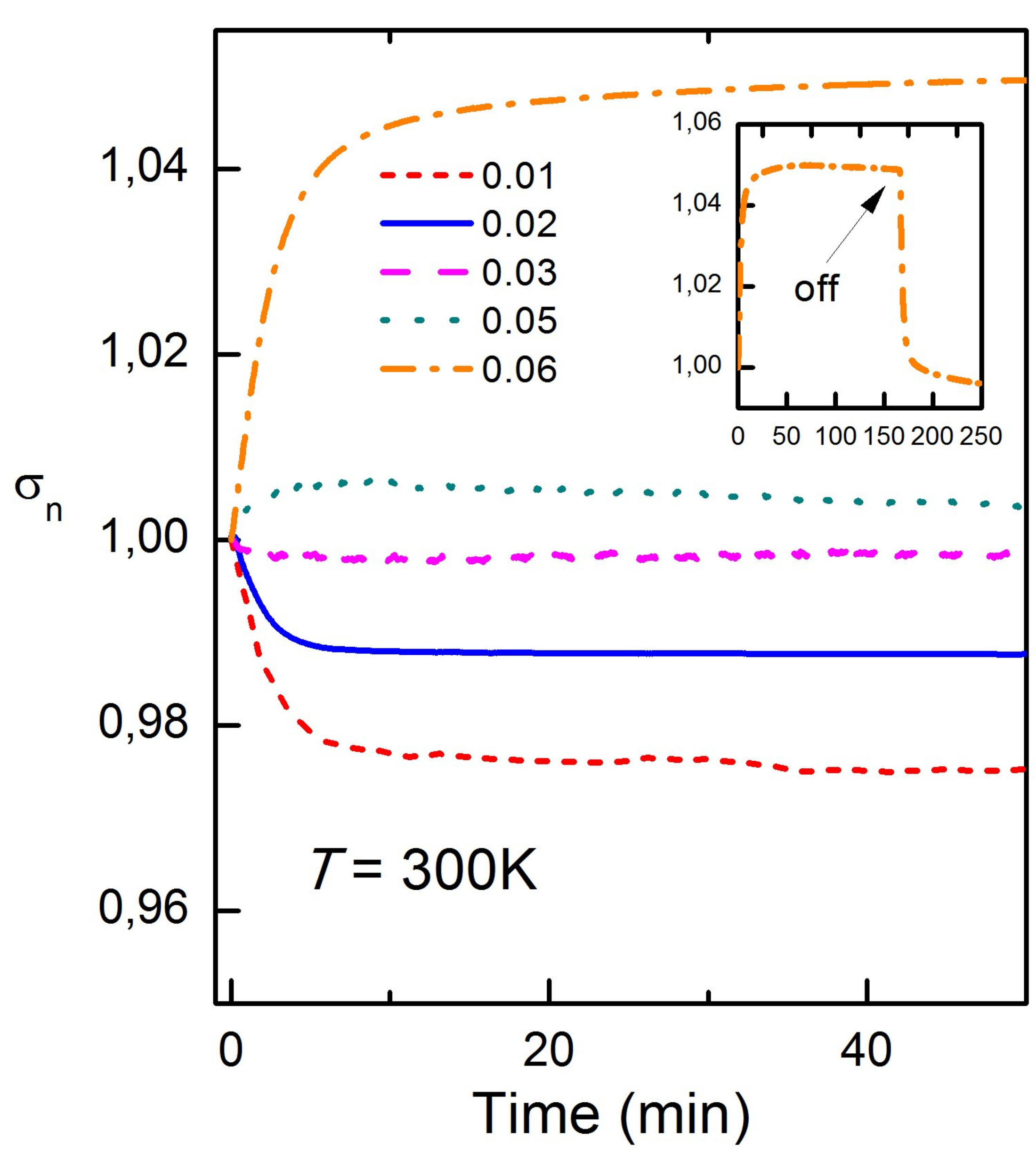


Figure 1. Photoconductivity curves obtained for *p*-type $Pb_{1-x}Eu_xTe$ films for *x*=0.01, 0.02, 0.03, 0.05 and 0.06 at *T*=300K, under IR light excitation. This figure shows a clear transition from negative to positive photoconductivity as the Eu content *x* is increased .

Figure 1 presents the photoconductivity measurements performed for *p*-type $Pb_{1-x}Eu_xTe$ films for *x*=0.01, 0.02, 0.03, 0.05 and 0.06 at *T*=300K.This figure shows a clear transition from negative to positive photoconductivity as the Eu content *x* is increased. For *x*=0.06, the photoconductivity amplitude reaches its maximum saturation value as compared to the other samples and also presents the effect of persistent photoconductivity, as observed in the inset, *i.e*, the signal takes several minutes to return to its original value after light is switched off (indicated by the arrow).

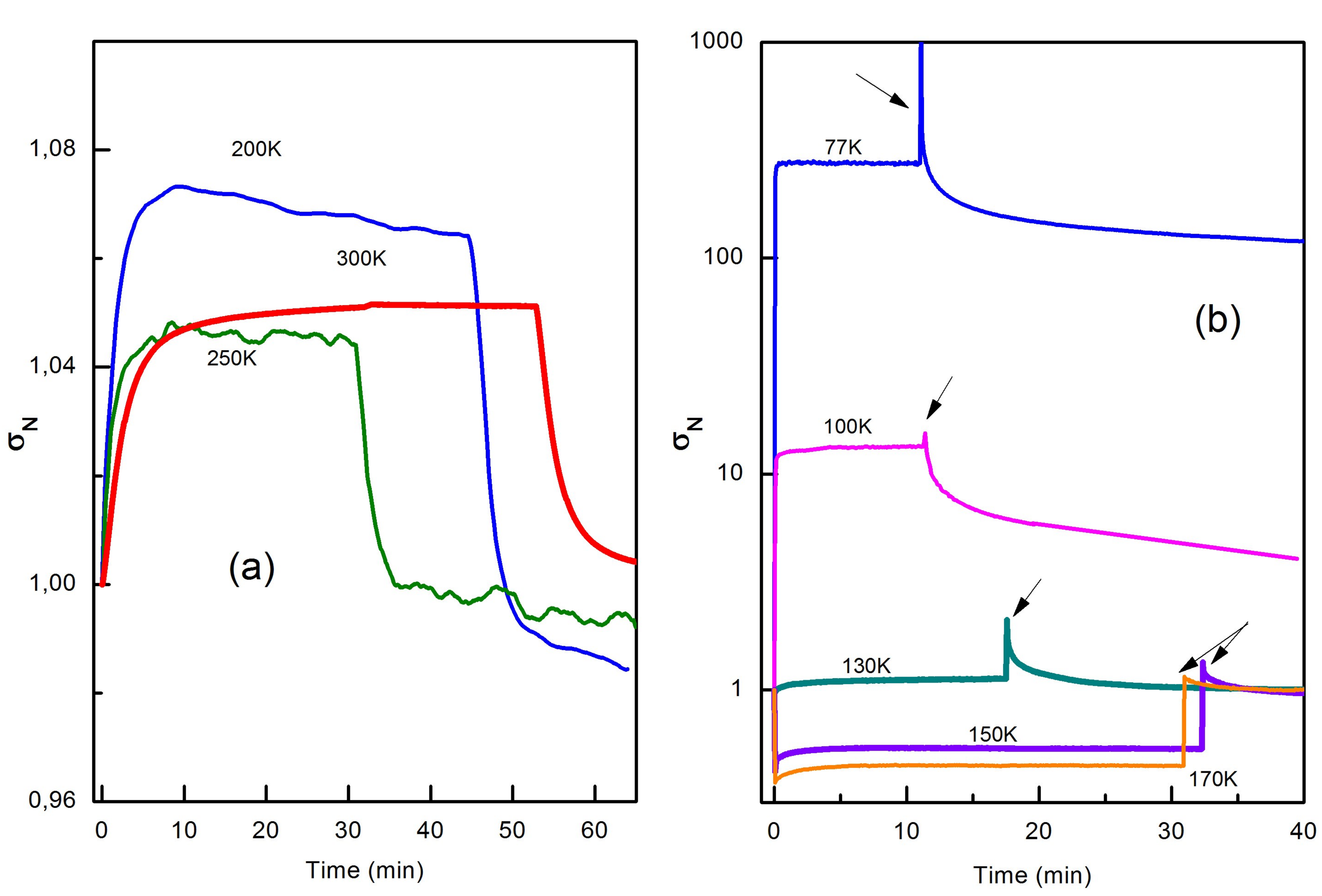


Figure 2. (a) and (b) show the photoconductivity measurements performed for the film with *x*~0.06, for the temperatures of 77, 100, 130, 150 and 170K.

Surprisingly, the sample presented additional transitions and a remarkable response for IR light, reaching a value 200 times higher than the original value in dark conditions at *T*~77K. Also, the sample presents a strong persistent photoconductivity effect for *T*<130K, revealing the existence of trap levels that are more effective at low temperatures .

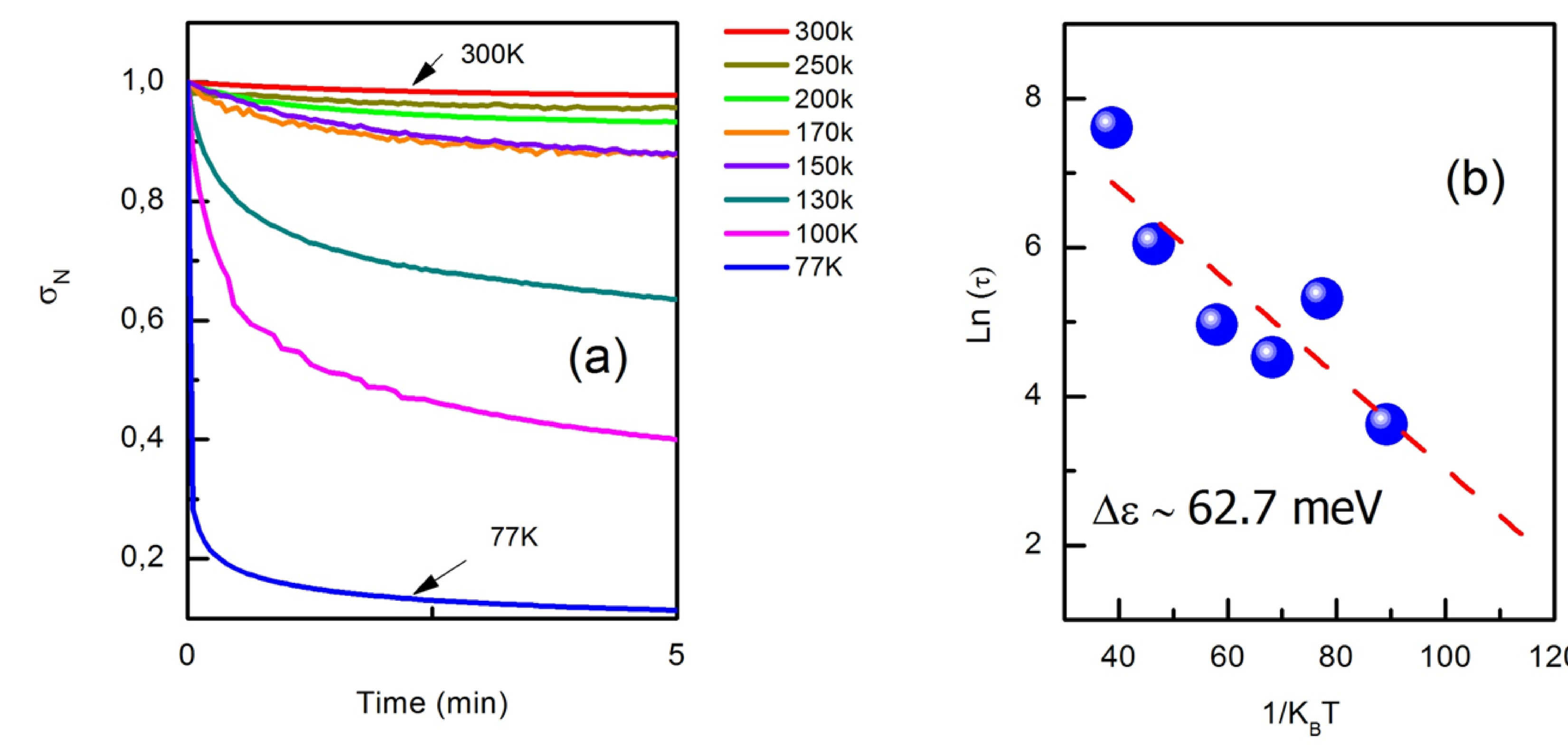


Figure 3.Decay curves for all temperatures obtained from the measurements presented in (a). (b) The values of the recombination times as a function of temperature in log scale.

From the decay curves, $\sigma(t) = \sigma_0 \exp(-t/\tau)$, it can obtain the recombination times as a function of temperature and hence the energy associated to the traps from the relation $\tau = -1/d\ln\sigma(t)/dt$ [3]. This energy value is in very good agreement to theoretical calculations to the position of the 4*f* levels inside the band *gap*.

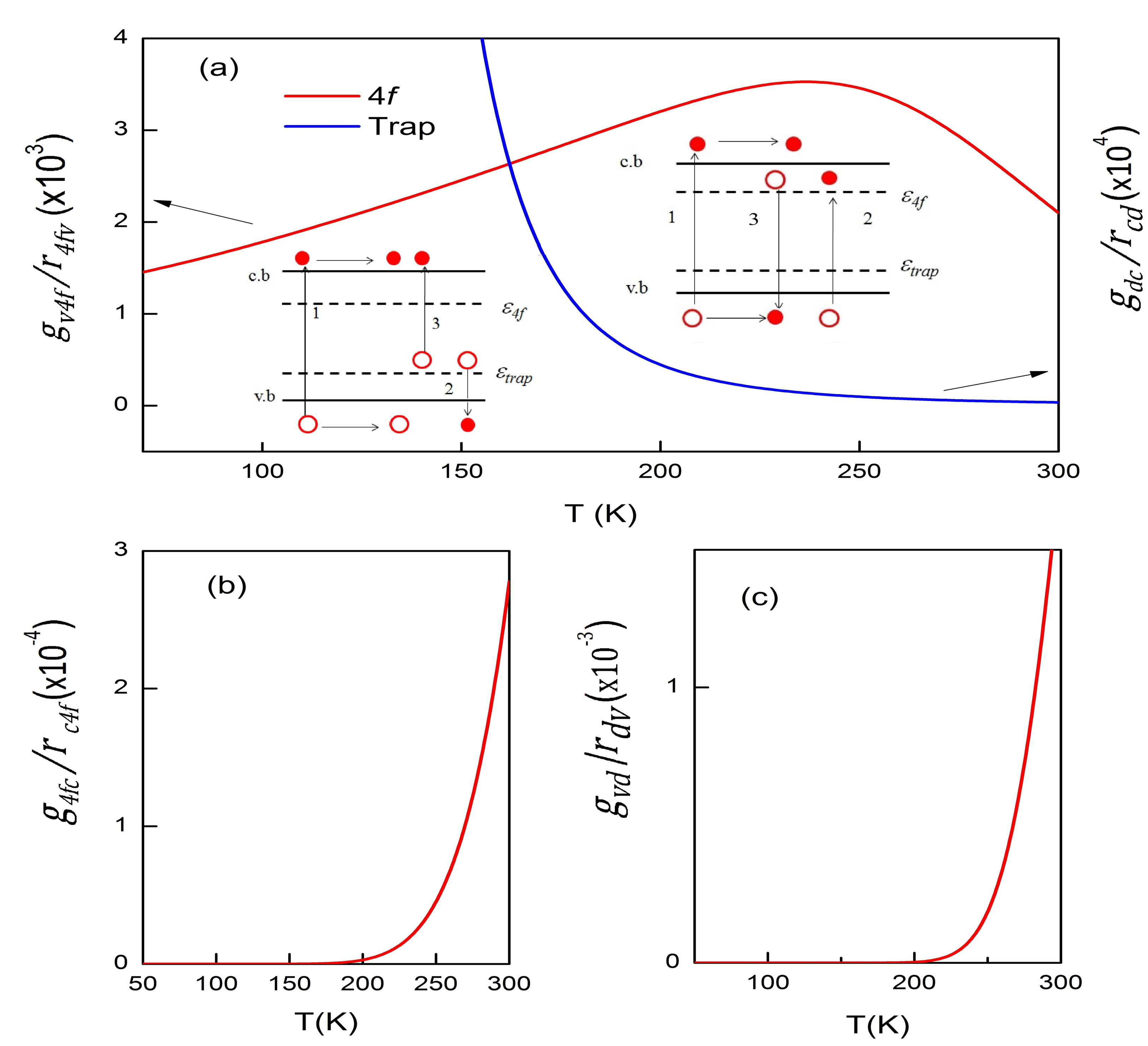


Figure 4. (a) The relation g_{v4f}/r_{4fv} calculated using the equations (3) and (5) and the relation g_{dc}/r_{cd} in the range of 77 – 300K. (b) Calculated values for the relation g_{4fc}/r_{c4f} using the equations (4) and (6). (c) Calculated values for g_{vd}/r_{dv} using equations (3) and (5). The insets present a pictorial representation of the generation and recombination processes (see text for further explanation).

The rates of the recombination and generation were calculated for equations descried in the reference 4. Comparing the analysis the experimental data to the calculated recombination rates, it was found that the NPC effect is a consequence of the reduction of electrons and holes in the conduction and valence bands, respectively, due to the influence of the trap level in dynamics of rates.

Conclusion

t was observed a clear transition from negative to positive photoconductivity for *p*-type $Pb_{1-x}Eu_xTe$ films for *x*=0.01, 0.02, 0.03, 0.05 and 0.06 at *T*=300K under illumination red LED light. This transition is related to the metal-insulator transition that occurs due to the disorder originated from the introduction of Eu atoms According with the analysis performed for *p*-type $Pb_{1-x}Eu_xTe$ film with *x*= 0.06, concluded that the PPC and NPC effect at different temperatures is a consequence of the reduction or increase of electrons and holes in the conduction and valence bands, respectively, due the influence of the two trap levels (4*f* and defect level) in the dynamics of recombination rates which also are deeply temperature dependent .

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Acknowledgments

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