PARALLEL TRANSPORT IN PbTe/PbEuTe QUANTUM WELLS

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1. INTRODUCTION

PbTe is a narrow gap semiconductor which exhibits interesting properties that differentiate it from other semiconductors [1]. PbTe based materials have being widely used in the fabrication of infrared devices [2] and its electrical properties are well investigated in literature. Concerning to photoconductivity effect, very few information have being reported in structures base in this compound.

2. STATEMENT OF WORK

In this work, we present photoconductivity measurements performed in *n*-type PbTe quantum wells (QW) under infrared (IR) illumination. The measurements revealed that at high temperatures the photoresponse has small amplitude which increases as temperatures reduces reaching a maximum value which is 1000 times higher than the original value. Unexpectedly, when temperature reduces, the photoconductivity amplitude starts to decrease again. We show that this effect is a result of parallel transport that occurs between the barriers and the quantum well even if the barriers are insulators.

3. EXPERIMENTAL

The PbTe/$Pb_{1-x}Eu_xTe$ QW samples were grown by molecular beam epitaxy on (111) cleaved BaF_2 substrates consisted of the PbTe well embedded between two $Pb_{1-x}Eu_xTe$ buffer of a 30 nm thick layer as illustrate in Figure **1a**. These barriers are doped with bismuth, which guarantee an n-type character for these samples. The samples have $x\approx12\%$ and $x\approx10\%$ of Eu and width of the QW is 10nm and 14.5nm for the 6072 and 7111 samples respectively.

For photoconductivity and Hall experiments, these samples with Indium contacts in Van der Pauw geometry are connected in the sample port with gold thin wires and a near IR commercial *LED* as illustrate in Figure **1b**. The samples are cooled in a system with temperatures between 77k e 300K and electrical characterized with and without *LED* radiation. The band diagram of this quantum well is depicted in Figure **1(c)**, with a barrier energy height of 295meV for the conduction band (ΔEc) and 242meV for the valence band (ΔEv).

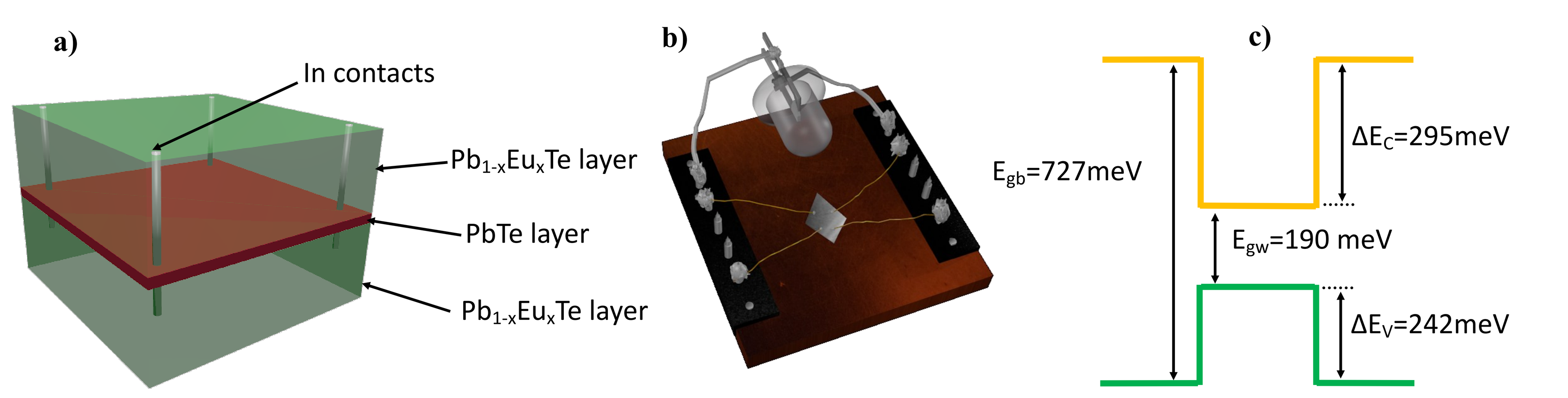

Figure 1. Illustration of a) PbTe/$Pb_{1-x}Eu_xTe$ QW with In contacts. b) sample port with a sample connected with gold thin wires and a *LED*. c) energy band diagram in units of meV, where Egb is the energy gap of barrier, Egw is the energy gap of the well, ΔEv and ΔEc are the energy high of valence and conduction band respectively.

4. RESULTS

Figure **2(a)** presents the normalized photoconductivity for 6072 QW. At high temperatures, sample presents small amplitude (<1%) but, as temperature reduces, a huge increasing of photoresponse is observed reaching the maximum amplitude (T=100K) which is 100 times higher than the original value before illumination. Further decreasing of temperature leads to a decrease of photoconductivity amplitude. This effect can be related to the QW structure that can allow transport via combination of two channels like in a parallel association of resistors. Figure **2(b)** presents the electrical resistance R as a function of temperature. Under dark conditions, we can see a change of channel transport from the barrier to the well, beginning at 127K exhibiting a metallic like behavior. For sufficient low temperatures, a spontaneous carriers transference from barriers into the QW can occur. This situation can be verified comparing the thermal energy at T=127K (kBT≈10.9meV) to the Fermi level energy of the barrier (εF≈10.6meV) located above the minimum of conduction band. Under light conditions, the obtained Fermi level energy is 23.5meVmeV for the barrier this corresponds to a thermal energy of T≈270K. The inset in Figure **2(b)** shows the full profiles of photoconductivity for temperatures of 77K and 150K. When light is switched off the curve measured at 77K exhibits strong persistent photoconductivity effect while curve at 150K returns much faster to its original position. It is known that trap levels are present in films of PbEuTe[3].

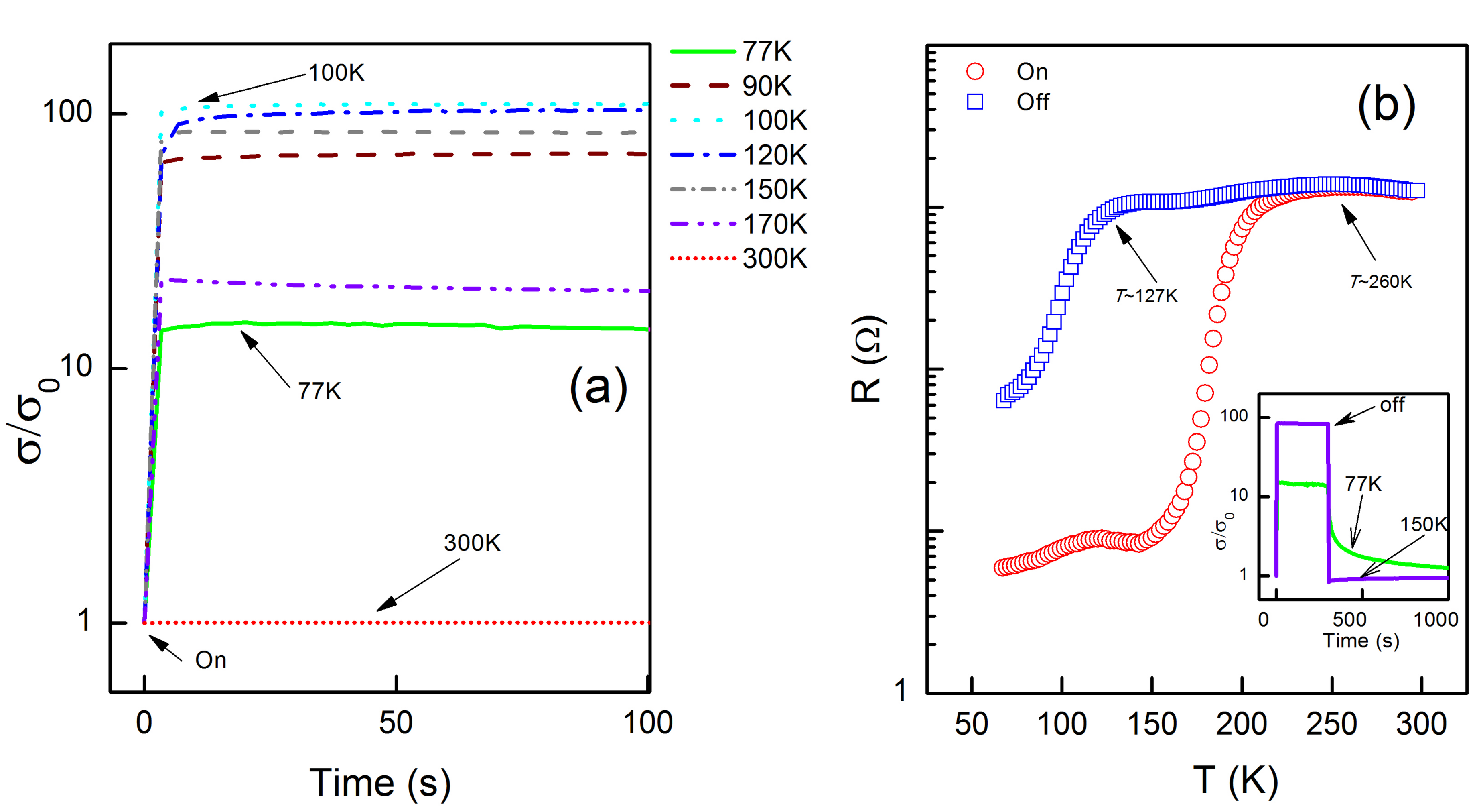

Figure 2. (a) Presents the normalized photoconduction under IR irradiation, for temperatures in the range 300-77K. (b) The resistance in function of temperature showing the change of conduction channel from the barrier to the well, the insert I contain the behavior of conductivity when the LED is on and off, for temperatures of 77K and 150K.

In Figure **3(a),** it is clear the difference between the decay profiles in different temperature regions indicating the mixed conduction via barriers and QW. Applying the Arhenius plot as presented in Figure **3(c)** it is possible to obtain the trap depth energy (Δε=37meV (±6meV) by fitting the curve. We can consider the model of random inhomogeneities and derive the energy associated to the barrier potential using the expression $E_t=e^2N^{(2/3)}/\varepsilon n^{(1/3)}$, where $N\approx2.5\times10^{25}m^{-3}$ obtained from magnetoresistance (MR) measurements as presented in figure **3(b).** With these values we obtain Et~30.5meV. Figure **4** presents the Hall measurements performed under light and dark conditions. Shadow areas represent the region where the carriers majority are transferred to the QW, according to the previous discussion. in Figure 4**(b)**, there is a visible drop in carrier mobility. The reduction of carrier mobility can be a consequence of electron-electron scattering due to the excess of electrons photogenerated.

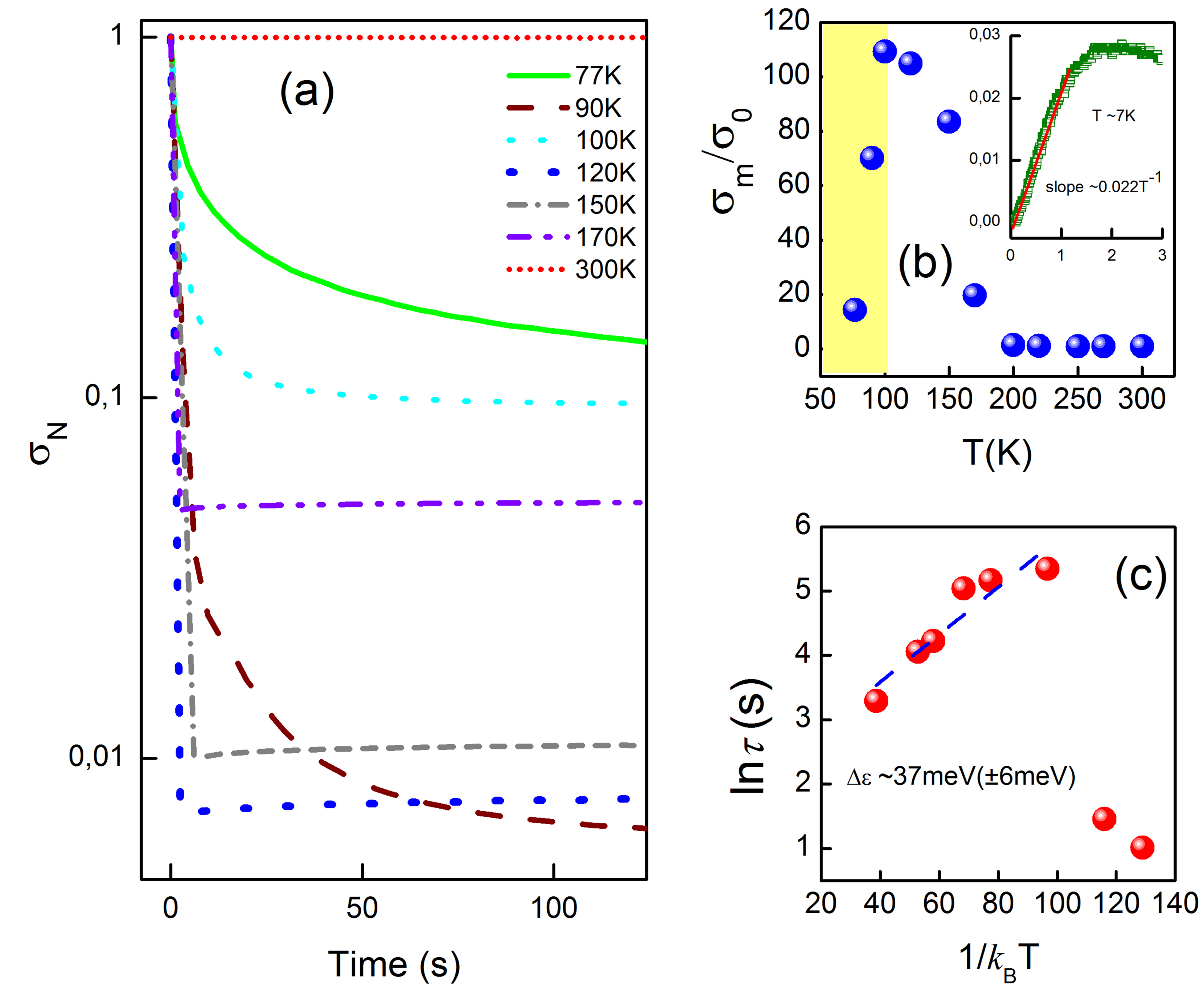

Figure 3. (a) Normalized photodecay, when LED is turn off for 6072 sample and (b) the peak of normalized photoconductivity under IR irradiation in function of temperature in the range of 300-77K, the inset shows the slope of the magnetoresistance curve for $Pb_{0,88}Eu_{0,12}Te$ film with 2.3µm of thickness and (c) decay time in function of $1/k_BT$ and linear fit, getting the activation energy for this film.

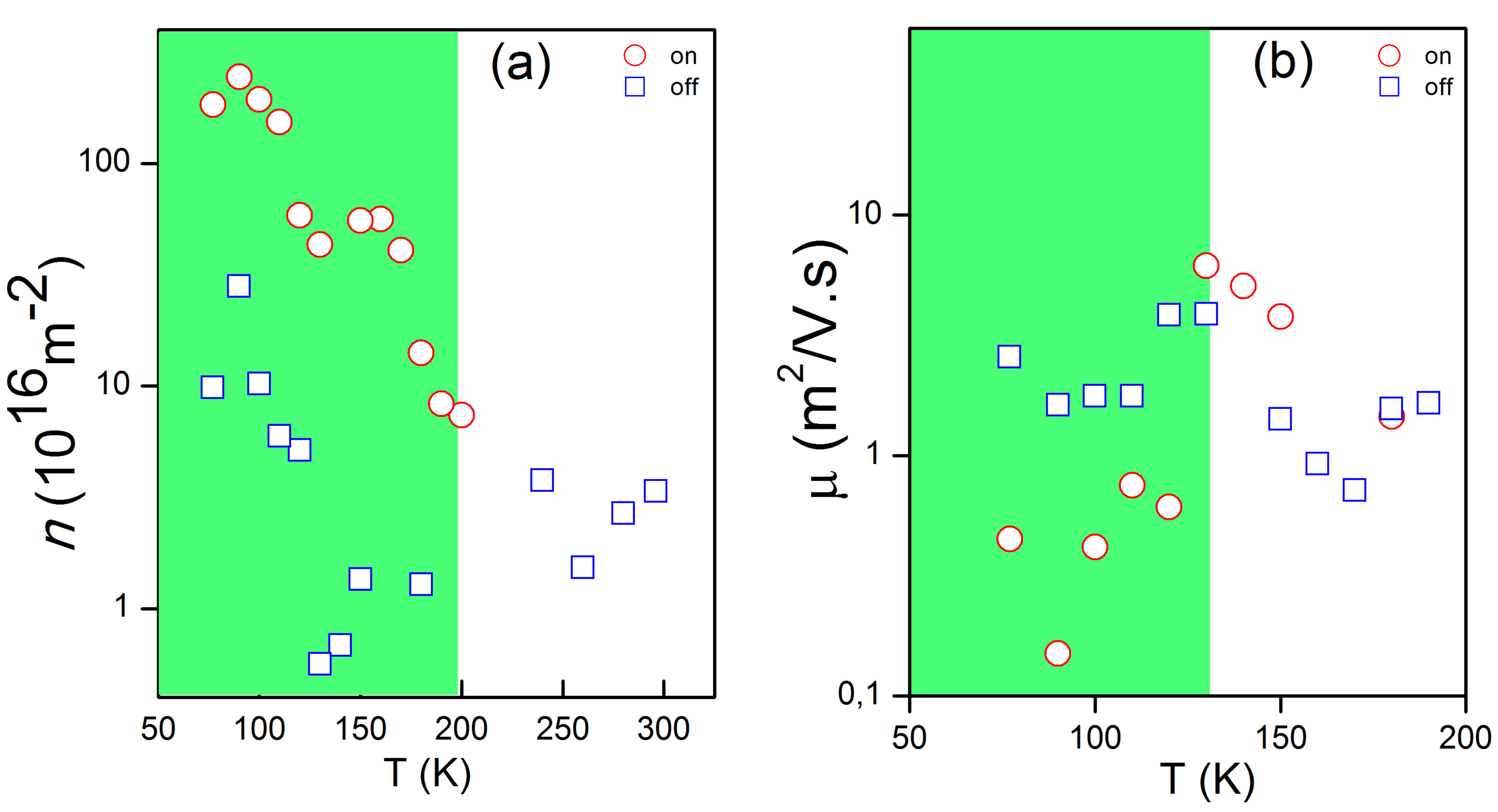

Figure 4. Presents the data found with Hall measurements in the 6072 sample, (a) the charge density and (b) the carrier mobility, with and without illumination.

The photoconductivity profiles observed in Figure **5(a)** for 7111 sample are the same as those observed in Figure **1 (a)** and **3(a)**. Also, in Figure **5(b)** we observe an increasing of σm/σ0 as temperature decreases from 300K down to 100K, and a decreasing of σ_m/σ_0 for temperatures below 100K. This observation is also in agreement to the observed profiles presented in Figure **3(b)**. It is important to point out that in this sample the maximum photoconductivity amplitude reaches a value about 1000 times higher than the value before illumination. This amplitude is one order higher than that observed in the 12nm QW.

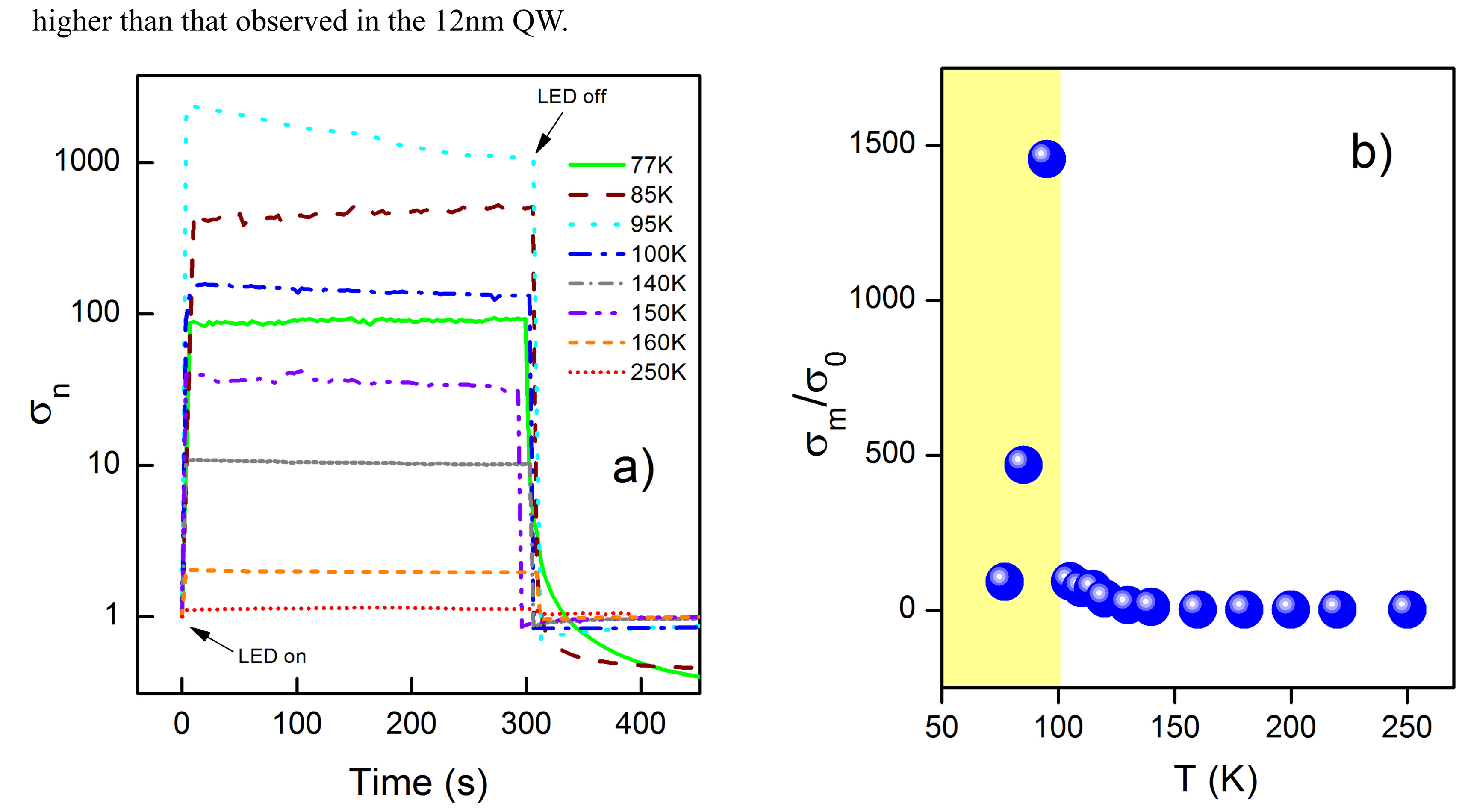

Figure 5. (a) Presents the normalized photoconductivity, when LED is turn on and off for. (b) The peak of normalized photoconductivity under IR irradiation in function of temperature. Those data is for 7111 sample and temperatures are in the range of 300-77K .

5. CONCLUSIONS

In conclusion, we found that photoresponse to IR light have contributions from barriers and the QW. We verified that the contribution from each channel depends on the temperature region and that for high temperatures, the transport via barriers is more effective. We also found the presence of persistent photoconductivity effect in the whole range of temperatures measured and we calculate the depth trap energy in the barriers from the experimental data and compare to the random potential model. On the other hand, we showed that the decreasing of photoconductivity amplitude for temperatures below ~100K is due to the reduction of carriers mobility and suggest that the reduction is a consequence of electron-electron scattering due to the excess of electrons photogenerated.

6. REFERENCES

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