Reduction of the Low Frequency Noise and Negative Photoconductivity in HgTe Quantum Wells

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***Abstract*—Negative photoconductivity and reduction of noise under illumination are found in HgTe/CdHgTe quantum wells with electrons dominated conductivity. These effects are explained by electron-holes' pairs generation outside the quantum well. Electrons and holes are separated by the built in electric field. Holes, which get inside the quantum well, recombine with electrons there and reduce the conductivity. A fraction of holes is captured by those traps which cause the noise. Change of occupancy function of these traps provides the noise reduction.**

Keywords—HgTe, noise, negative photoconductivity, noise reduction.

I. INTRODUCTION

The band gap in the meV range and high electron mobility make HgTe/CdHgTe quantum wells (QWs) structures promising for the terahertz applications. Detection by different mechanisms and emission in the terahertz frequency range were already demonstrated in several publications [1-11]. The low-frequency noise presents in all kinds of electronic materials and devices [12-25]. The knowledge of noise properties of HgTe QWs is important for the understanding of the current flow mechanisms and judgement about possible applications.

II. RESULTS AND DISCUSSIONS

The HgTe/CdHgTe QW structures were grown by molecular beam epitaxy (MBE) on GaAs substrate (013) with the thickness of d = 7 – 7.5 nm, corresponding to the inverted band structure at 4 K and normal band ordering at 300 K [26]. Figure 1 shows the schematic view of the quantum well structures. Composition profile of the studied structures is shown in Fig.2. Hall measurements at 4K indicated that all structures had electrons dominated conductivity with the mobility and concertation $\mu = (4 - 70) \cdot 10^3$ cm^2/Vs and $n = (2 - 10) \cdot 10^{11}$ cm^{-2}, respectively.

At 300 K, all structures demonstrated negative photoconductivity under ambient visible light illumination, i.e. the resistance increased under illumination. In order to be sure that the contacts are not involved in the effect, the resistance was measured in 4-probe configuration. The characteristic times of the transient processes with light on and off were in the range of hundreds of seconds (Fig. 3). As seen from Fig. 3, the fast change in the resistance is followed by a long non exponential tail. Existence of the long relaxation times is a sign of the deep traps with small capture cross section. This trap also should contribute to the low frequency noise. This kind of negative "persistent" photoconductivity is known for other types of heterostructures [27-29] but to the best of our knowledge it has not been yet reported for HgTe QWs.

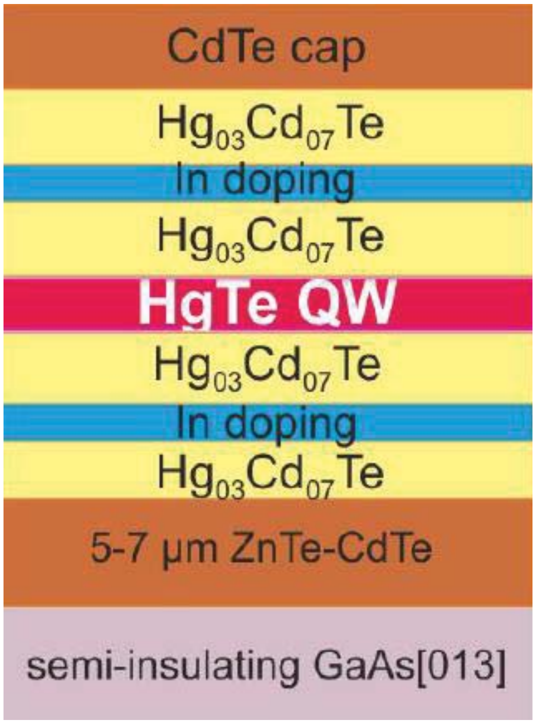

Fig.1. Schematic view of the quantum well structures

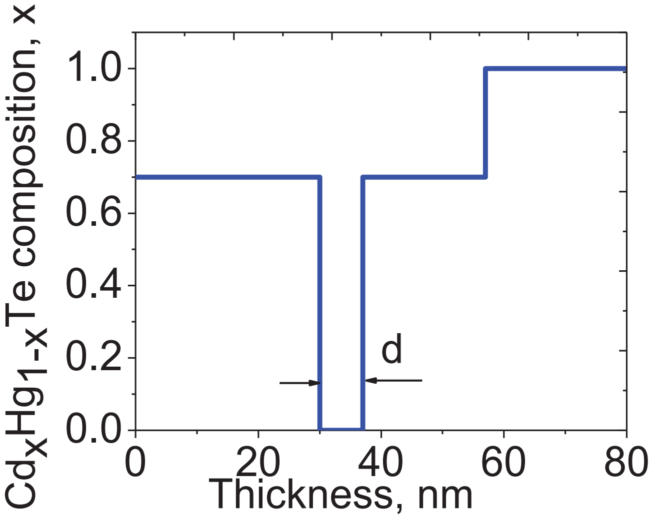

Fig. 2. Composition profile of the studied structures. Quantum well width *d* =7 nm.

Several mechanisms were discussed for negative photoconductivity. In quantum well structures the most realistic one is the separation of electrons and holes generated in the barrier layer ($Cd_{0.7}Hg_{0.3}Te$ in our case) by built in electric field. Electrons go to the surface and are trapped by the deep states. Holes go inside the quantum well where they recombine with electron reducing their concentration and, therefore the conductivity.

Figure 4 shows the spectral dependence of the negative photoconductivity. Although the amplitude of the resistance change under illumination increases slightly with wavelength decrease, the dependence is weak owing to small thicknesses of the layers in the nanometer range (Fig.2)

The low frequency noise was measured at room temperature in the dark and under illumination. Figure 5 shows the dependence of noise on current for several samples. As seen the spectral noise density of the current fluctuation is proportional to the current squared. This confirms that the noise is due to the resistance fluctuations and the current does not affect these fluctuations.

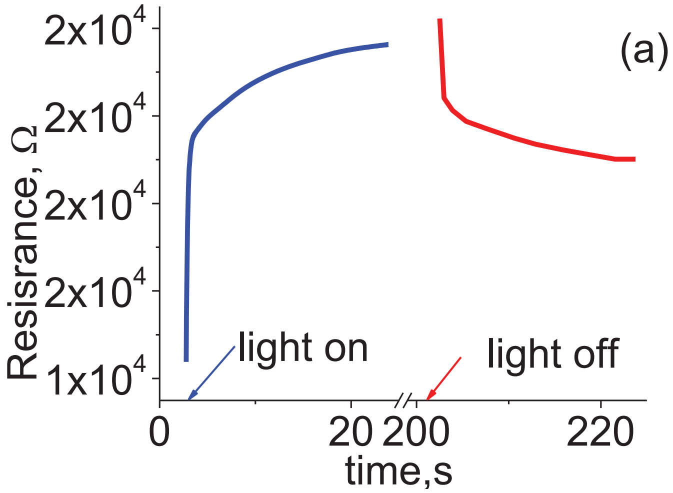

Fig.3. Transient processes in HgTe/CdHgTe quantum well as a result if illumination

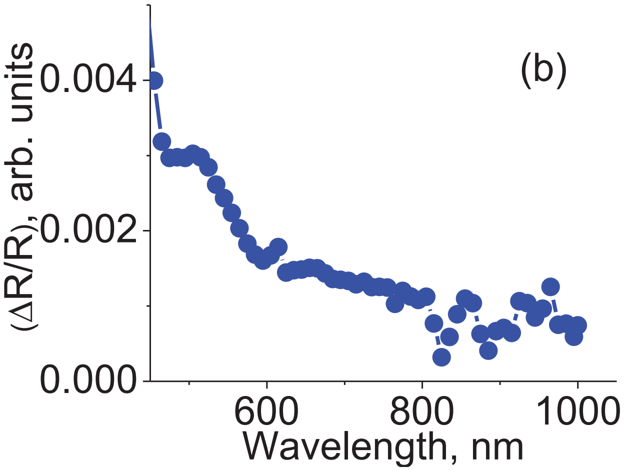

Fig. 4. Transient processes of the resistance change under illumination (a) and spectral dependence of the negative photoconductivity (b).

Figure 6 shows the noise spectra at low voltage $V = 10$ mV. As seen, the spectra in the dark has the form of the $1/f$ noise. Illumination leads to the change of the noise spectra shape and to overall reduction of the noise at frequencies 1 Hz $< f <$ 100 Hz.

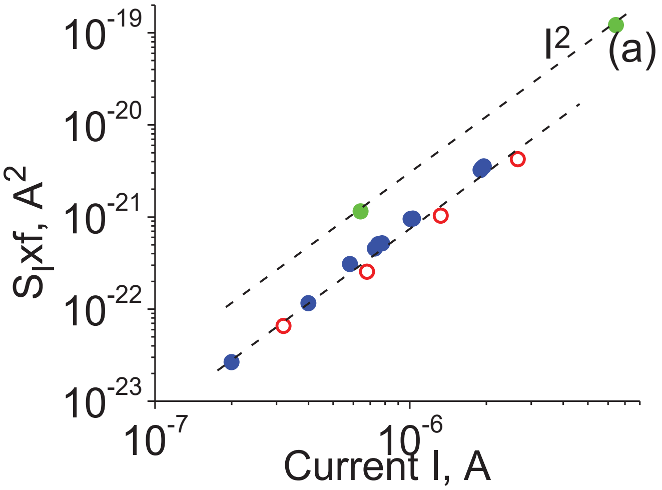

Fig.5. Spectral noise density of current fluctuations at f=1Hz as a function of current for several samples.

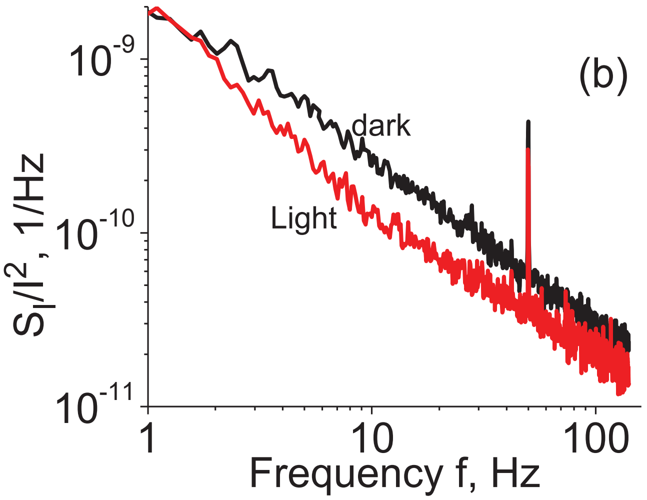

Fig.6. Dependence of noise on current (a) and noise spectra of CdHgTe quantum well structure in the dark and under illumination (b). $T = 300$ K.

In order to characterize the amplitude of noise, the effective trap density responsible for noise can be calculated based on the McWhorter model [30,31]:

$$\frac{S_I}{I^2} = \frac{kTN_t}{\gamma f WLn_s^2}, \tag{1}$$

where k is the Boltzmann constant, T is the temperature, N_t is the effective trap density f is the frequency, WL is the channel area, n_s is the concentration and γ is the attenuation coefficient of the electron wave function under the barrier:

$$\gamma = \frac{4\pi\sqrt{2m^*\Phi}}{h}. \tag{2}$$

Here m^* is the electron effective mass, h is Planck's constant, and Φ is the tunneling barrier height seen by the carriers at the interface. In Si MOSFETs the γ value is usually taken to be $\gamma=10^8$ cm^{-1}. In the studied system the effective mass of electrons and tunneling barrier height are both about one order of magnitude smaller than in Si MOSFET. Therefore, the estimate for the attenuation coefficient in the studied system yields $\gamma \cong 10^7$cm^{-1}. With known amplitude of noise and electron concentration from the Hall measurements trap density estimated based on McWhorter model for different samples is $N_t = 10^{18} - 10^{20}$ cm^{-3}eV^{-1}.

Reduction of noise under illumination in semiconductors is usually explained by the model which includes the capture of the minority carriers by the traps responsible for the carriers' number fluctuations [32-40]. As a result, the occupancy of these levels changes. It is well known that the generation-recombination (g-r) noise amplitude is proportional to $F(1-F)$, where F is the noisy level occupancy function. It is clear that depending on F value in the dark, illumination can either increase or decrease the noise. The strong enough illumination always leads to the noise reduction [32-40]. If we assume that the $1/f$ noise is a superposition of several g-r processes, this scenario explains the noise reduction and change of the noise spectra. It is important to note that in HgTe QWs, contrary to the previous studies, the noise reduction under illumination is accompanied by the negative photoconductivity.

CONCLUSIONS

In conclusion, the amplitude of the noise in HgTe quantum wells is within the range found for Si MOSFETs. Similar noise level is reported for other low dimensional structures, like graphene and MoS_2. Noise reduction under illumination and negative photoconductivity is explained by electrons and holes generation in the $Cd_{0.7}Hg_{0.3}Te$ layer followed by holes' recombination in quantum wells. These results are in favor of the number of carriers fluctuations mechanism of noise.

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