Modeling of HOT (111) HgCdTe MWIR Detector For Fast Response Operation

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***Abstract*—The paper reports on photoelectrical performance of the mid-wave infrared (MWIR) (111) HgCdTe high operating temperature (HOT) detector for the fast response conditions. Detector structure was simulated with software APSYS by Crosslight Inc. The detailed analysis of the time response as a function of device architecture and applied bias is performed pointing out optimal working conditions.**

I. Introduction

Higher operation temperature (HOT) condition of the mid-wave (3-8 μm) wavelength photodetectors is the most important research area in infrared technology [1]. The development of the new detector architectures has been driven by applications requiring fast response. This requirement stays in contradiction with reaching high detectivity as for as detector's optimization is concerned. The best way to achieve a short response time of the detectors is high recombination decay in absorber region and fast transport of the photogenerated carriers to contacts. In this case a special heterostructure designs are developed where *p*-type absorber is advantageous due to both high diffusion and drift ambipolar mobility what is consider as a must to achieve fast and efficient collection of charge carriers. The recombination mechanism is important for forward, zero and weak reverse conditions while transport removal is important for higher reverse biases. Additionally, *p*-type HgCdTe active regions are characterized by the best compromise between requirement of the high quantum efficiency and a low thermal generation driven by the Auger 7 generation-recombination (GR) mechanism [2].

In practice, most of photodiodes with short time response are based on heterostructures to prevent parasitic thermal generation at contacts, surfaces and interfaces. Complex multi-layer structures in which the transport of majority and minority carriers is determined by barriers has been used with great success for MWIR photodiodes operating at HOT conditions. The photodetectors architecture has been improved by graded gap layers. The main modification in comparison with the standard three-layer $N^+\pi P^+$ structure is programmed grading of band gap and doping level at interfaces [3–9].

In this paper we present the theoretical modeling of the photodetector for fast response conditions based on epitaxial multi-layer graded gap structures. Detector structure was simulated with software APSYS by Crosslight Inc. The voltage and structural dependences of the dark current, and time response characteristics including both TAT and BTB processes at the heterojunctions were modelled. The time response of the MWIR HgCdTe detector with 50% cut-off wavelength of $\lambda_c \approx 5.3$ μm at $T = 200$ K was estimated at the level of $\tau_s = 2.5$ ns for $V = 100$ mV.

II. Simulation Procedure

The devices presented in this paper were fabricated in joint laboratory run by Vigo Systems S.A. and Military University of Technology (MUT). The (111) HgCdTe layers were grown on 2" inch, epiready, semi-insulating (100) GaAs substrates in a horizontal MOCVD AIX 200 reactor.

The interdiffused multilayer process (IMP) technique was applied for the HgCdTe layer's deposition. The $P^+/\pi/N^+$ structures has been expanded with interfaces 1/2/3 and p^+-n^+ (layers 13/14/15) tunnelling graded gap junction (Fig.1). Interface layers were assumed to be *x*-graded regions and represent the real structure which profile was shaped using interdiffusion processes during $Hg_{1-x}Cd_xTe$ growth.

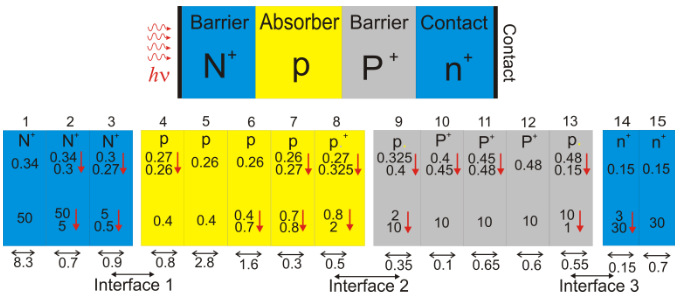

Fig. 1. Simulated graded gap HgCdTe heterostructure. The layer number, type of doping, composition grading, doping grading $\times 10^{16}$ cm^{-3}, and thickness of the layers in μm are marked. Red arrow presents composition and doping grading respectively.

The doping profiles were simulated by applying gauss tail model [10]. The p^+-n^+ graded gap junction bas been applied for improvement of electrical contact property between P^+ barrier region and metallization.

III. Results

Band diagram of the simulated structure is shown in Fig. 2. Two heterojunctions were found to be decisive as for as photoelectrical performance is concerned. The applied voltage drops mostly on the interface 1 (layer 3/4) while interface 3 is forwardly biased which was presented in Fig. 3.

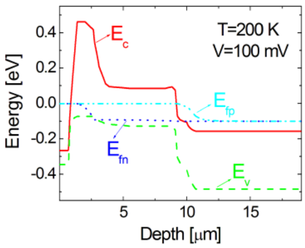

Fig. 2. Simulated band diagram of graded gap HgCdTe heterostructure.

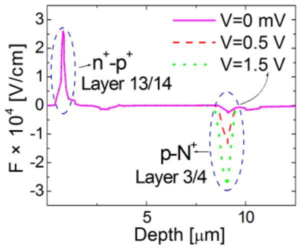

Fig. 3. Electric field along the sample for selected voltages

n^+-p^+ (layer 13/14) heterojunction is directly responsible for time response of the modelled detector and should be optimised by proper choice of composition (x) and doping. The lowest composition in both layer 14 and 15 the better as for as time response is concerned.

Figure 3 presents J_{DARK} versus applied voltage. For V > 250 mV the dark current density is mostly driven by TAT and BTB on interface 1. Green dashed line presents J_{DARK} without influence of tunneling mechanism on interfaces 1 and 3. The energy band gap of the layers 13/14/15 ≈ 0.041 eV for x = 0.15 and T = 200 K which means that under proper voltage there is no barrier for holes moving to the left contact. Situation changes when composition of the layers 13/14/15 increase to 0.34 when the hole transport to the left contact is disturbed by higher energy gap at the Interface 3 (see dotted pink line in Fig. 4).

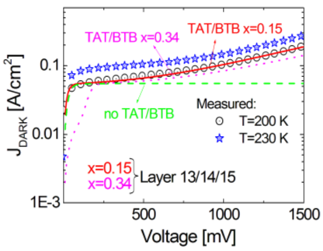

Fig. 4. J_{DARK} versus voltage for selected temperatures and layer 13,14,15 composition.

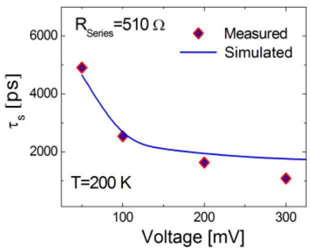

Fig. 5. Time response versus voltage for selected temperatures.

Modeled time response characteristic versus voltage for T = 200 K is presented in Fig. 5 (solid blue line). The fitting to the experimental result presented in Fig. 4 and 5 was reached with the series resistance R_{Series} = 510 Ω attached to the detector's structure.

The time response was measured with Optical Parametric Oscillator (OPO) producing 25 ps pulses. The proper agreement to the experimental results was reached in the range < 300 mV. We believe that parasitic resistance exhibits non-linear behavior versus voltage.

The time response dependence on the layer 14/15 doping was simulated for selected R_{Series} is shown in Fig. 6. Once R_{Series} increases the shape of the τ_s curves changes. Assuming, the structure without R_{Series} and high doping in layer 14/15, τ_s ≈ 300 ps. For low doping < 5×10^{15} cm^{-3} τ_s increases for every analyzed parasitic resistance.

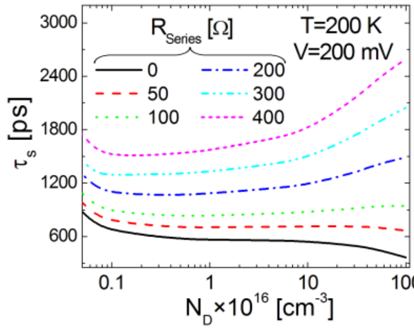

Fig. 6. Time response versus doping of the layer 14 and 15 (see Fig. 1) for V = 200 mV.

IV. Conclusions

Time response could be minimized by both enhanced recombination decay and faster collection of the carriers (n^+-p^+ graded gap junction plays decisive role). Elimination of the parasitic resistances allows to decrease of the time response nearly by 10 times.

Acknowledgment

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