High frequency response of LWIR HgCdTe photodiodes operated under zero-bias mode

M. Kopytko, P. Martyniuk, P. Madejczyk, K. Jóźwikowski, J. Rutkowski
Institute of Applied Physics, Military University of Technology, 2 Kaliskiego St., 00-908 Warsaw, Poland

***Abstract*—High frequency response is an important capability of infrared detectors in many applications. High-temperature long wavelength infrared HgCdTe heterostructure photodiodes exhibit sub-nanosecond time constants while operating under reverse bias. However, the noise, as well as the high current requirements are severe obstacles to their widespread applications. Thus, the present efforts are focused on a zero-bias operation of infrared detectors.**

A numerical modelling was used for investigation of the device design on the response time and current responsivity of HgCdTe photodiodes operating at 200 K and zero-bias mode. The program based on the solution of the system of the carrier transport equations including the whole spectrum of various generation and recombination mechanisms. To determine the response time of devices, the Fourier expansion method was applied.

I. Introduction

Near-room operation of long-wavelength infrared (LWIR) photodetectors is one of the hot topics of IR technology and their fast response found numerous practical applications, such as long-range free space communications, ultrafast spectroscopy, gas leak detection in civilian applications or weapon control and missile guidance systems in military applications.

During last three decades, high-operating temperature (HOT) HgCdTe detectors have been developed in Poland [1] and they are manufactured by VIGO System. So far, HOT HgCdTe heterostructure photodiodes exhibit sub-nanosecond time constants while operate under reverse bias. However, non-equilibrium devices exhibit excessive low frequency $1/f$ noise that extends up to MHz range which is severe obstacle to their widespread applications. Present efforts are focused on a zero-bias operation of HgCdTe photodiodes. Unfortunately, the time constant of unbiased detectors is still at the level of several ns.

In this paper, we discuss a possible configurations of LWIR HgCdTe photodiodes and report on numerical simulations of a dependence of the response properties on the thickness, and doping of the absorbing layer.

II. Method of Analysis

The Fourier analysis method [2] is based on describing carrier transport equations in a complex numbers space and computation of all the photoelectric parameters of the structure including flowing currents in steady state condition at definite bias voltage. Then, after activating the structure by a small harmonic optical pulse in the form of $\Phi(\omega) = \Phi_0\exp(i\omega t)$, where Φ_0 is the amplitude and indicates the imaginary part, ω is the frequency, and t is the time, the complex amplitude of the detector's responsivity is calculated. Real part of the obtained current responsivity R_i and can be approximated by equation:

$$R_i = \frac{R_{i0}}{(1+\omega^2\tau^2)} . \tag{1}$$

In the simplest detector's case, the time constant τ defined by the cutoff frequency f_T at –3-dB line can be calculated as:

$$\tau = \frac{1}{2\pi\, f_{T(-3dB)}} . \tag{2}$$

There are more complex cases if the detector time response is limited by different mechanisms such as different carrier recombination mechanisms, space charge and diffusion capacitance [3].

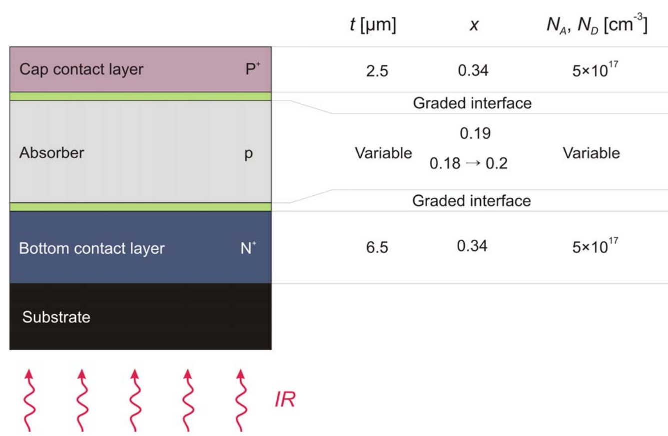

Fig. 1. P^+-p-N^+ diode architecture and structural parameters taken in modeling.

III. Results and Discussion

We have analyzed two possible configurations of N^+-p-P^+ $Hg_{1-x}Cd_xTe$ photodiodes:

- with a constant Cd alloy composition in the absorber layer, x_{Abs} = 0.19 was chosen for 11.6 µm cut-off wavelength at 200 K, and
- with a graded composition in the absorber layer, ranges from 0.18 to 0.20, and adjusted to maintain a constant peak wavelength (about 9 µm) at a temperature of operation in comparison to the device with constant composition.

978-1-5090-5323-0/17/$31.00 ©2017 IEEE

The absorber layer is surrounded by a wider band gap, highly doped contact layers to suppress dark current generation from these regions and to suppress tunneling current under reverse bias.

The main objective of this study was to achieve a tradeoff between contradictory requirements of reaching high current responsivity and fast response time under zero-bias conditions. Structural parameters such as absorber doping and thickness were changed in calculations (Figure 1) to obtain optimal architecture of the device.

Figure 2 shows the time constant and peak current responsivity as a function of the absorber doping of N^+-p-P^+ HgCdTe photodiodes operated at zero bias. Calculations have been done for a two thickness values of the absorber layer. For the concentration of acceptors in the absorber up to the intrinsic concentration (in this case, the intrinsic carrier concentration is of about 10^{16} cm cm^{-3} at 200 K), the time constant of the photodiodes assumes a relatively high values of about 5 ns for a 5-μm and 0.8 ns for a 1-μm thick absorber layer. Then, the time constant decreases with a higher p-type doping. A higher doping in the absorber region also improve the current responsivity of the photodiodes. Devices with a graded composition in the absorber layer achieve better performance for doping below $p \approx 2n_i$, while devices with a constant Cd alloy composition in the absorber layer are better for the higher doping.

Figure 3 shows the time constant and peak current responsivity as a function of the absorber thickness of the analyzed photodiodes. Calculations have been done for two doping levels of the absorber. As expected, the time constant of the photodiode decreases with a reduction of thickness of the absorption region. For $p = 0.1n_i$ doping level, the time constants below 1 ns can be obtained with thin absorption region. For high doping level ($p = 10n_i$), the time constants below 1 ns is reachable for the absorber thickness less than 5 μm. Regardless of the doping level, the devices show a relatively low values of current responsivity for a 1-μm thick absorber layer due to the only partial absorption of incoming photons. On the other hand, the absorption region cannot be too thick for the near-intrinsic material. In LWIR range, the minority carrier lifetime is quite short, mostly due to the Auger 1 process. The maximum current responsivity is reached by devices with 3-μm thick absorber layer doped at a low level. For thicker absorbers, a significant portion of the carriers recombine before reaching the contacts. For higher doping, the current responsivity assumes almost constant values for absorbers thicker than 5 μm.

IV. Conclusions

A formulation of carrier transport equations for HgCdTe heterostructure photodiodes is presented in Fourier space method in order to analyze spectrum characteristic of currents generated by harmonic optical signals. The method is valid in describing the high frequency response of LWIR photodiodes based on HgCdTe multilayer heterostructures.

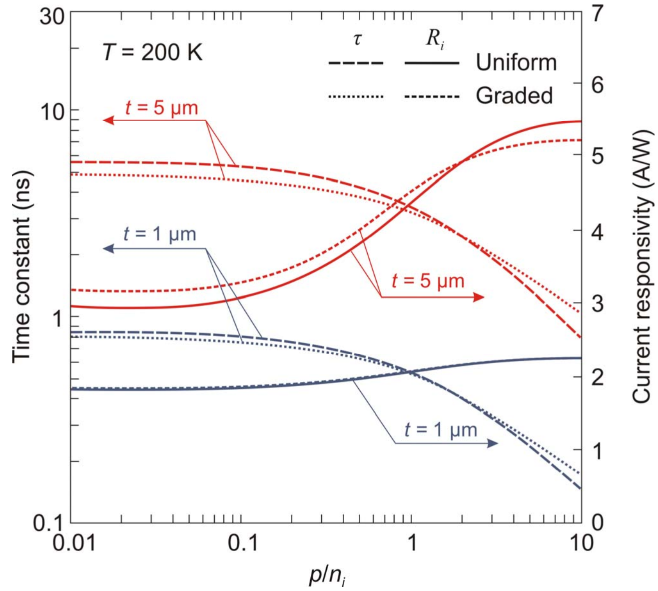

Fig. 2. Time constant and peak current responsivity of analyzed photodiodes as a function of absorber doping at zero bias operation.

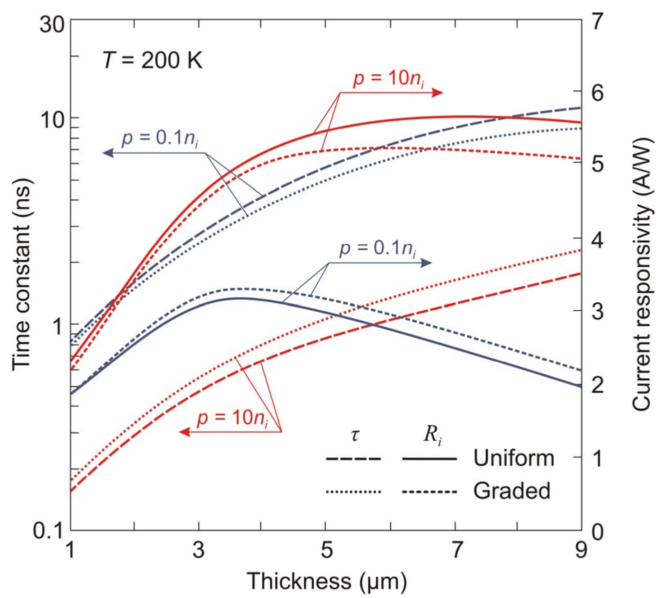

Fig. 3. Time constant and peak current responsivity of analyzed photodiodes as a function of absorber thickness at zero bias operation.

Acknowledgment

This work was supported by the National Centre for Research and Development (Poland) as research project No. TANGO1/2665576/NCBR/2015.

References

[1] J. Piotrowski and A. Rogalski, "High-Operating-Temperature Infrared Photodetectors," SPIE, Bellingham (2007).

[2] M. Kopytko, K. Jóźwikowski, A. Rogalski and A. Jóźwikowska, "High frequency response of near-room temperature LWIR HgCdTe heterostructure photodiodes," *Opto-Electron. Rev.* 18, 277–283 (2010).

[3] T.J. Phillips, and N.T. Gordon, "Negative diffusion capacitance in auger-Suppressed HgCdTe heterostructure diodes," *J. Electron. Mater.* 25(8), 1151–1156 (1996).