Numerical analysis of HgCdTe dual-band infrared detector

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***Abstract*—In this paper we describe recent progress in the MOCVD growth of HgCdTe multilayer heterostructures on GaAs substrates for photodetectors operated above 200 K. We present example of design and characterization of the new classical N^+-n-P^+-p-N^+ back to back HgCdTe dual-band photodiode structure, that operates within the MWIR band in sequential mode. A numerical modelling was used for investigation of the device design on the current responsivity and dark currents. The program based on the solution of the system of the carrier transport equations including the whole spectrum of various generation and recombination mechanisms consisting of Shockley–Read–Hall (SRH), Auger and radiative generation-recombination (GR) terms. Additionally, tunneling effects such as band-to-band and trap-assisted tunneling models are included in the continuity equations by incorporating them as additional generation–recombination processes.**

I. Introduction

Two-color detectors have the ability to detect two different infrared (IR) bands or two different wavelengths in the same band separately and independently. Dual-band detection can greatly improve overall system performance: it provides an additional dimension of contrast that is available for signal processing allowing determination of the temperature of the scene, assuming constant emissivity in the entire spectral range [1].

The architecture of the device is implemented in such a way that the long-range photodiode is placed physically directly behind the photodiode at shorter wavelengths. Such detector can operate in both sequential and simultaneous modes.

II. Device design

The investigated bias-selectable dual-band HgCdTe detector adopts a multi-layer heterostructure grown by metaloorganic chemical vapour deposition (MOCVD). The growth has been carried out in Aixtron AIX-200 system on 2 inch, epiready, semi-insulating (100) GaAs substrates, oriented 2° off toward nearest <110> using the interdiffused multilayer process (IMP) technique.

Device architecture is a simplified configuration of N^+-n-P^+-p-N^+ (where lower case letters refer to the absorber regions, while upper case letters refer to higher Cd mole fraction layers, symbol "+" denotes strong doping) as presented in Figure 1. The detector consists of two back-to-back photodiodes. Both photodiodes detect in the MWIR spectral band, with responds between 3.0~4.2 μm for the first wave band and between 4.2~5.2 μm for the second band. For a photodiode of a more short-wave range, the active area (MW1) is a layer of non-intentionally doped (n.i.d.) material. Due to the residual background concentration at 1×10^{15} cm^{-3}, the first absorber is characterized by the n-type conductivity. In a more long-wave photodiode the active area (MW2) is the p-type layer doped with arsenic at the level of 5×10^{15} cm^{-3}. First absorber with a Cd molar composition of 0.32 act as an optical window for IR radiation reaching the second abrorber with a Cd molar composition of 0.28. Both absorbing layers are separated by the barrier doped with arsenic at the level of 5×10^{17} cm^{-3} and adjustable thickness, and composition. Contacts are created to the wide-bandgap n-type layers doped with iodine at the level of 2×10^{17} cm^{-3}. By switching the bias voltage from a negative to a positive value, it is possible to detect the signal in first or the second absorber.

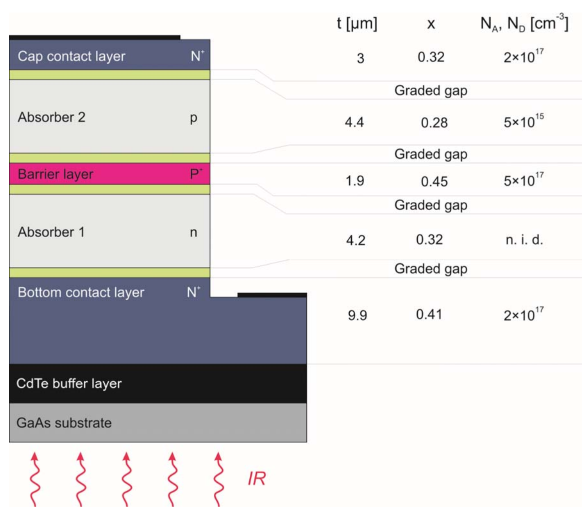

Fig. 1. Cross-section scheme of a HgCdTe two-color IR detector

At the layer interfaces are the *x*-graded regions created by interdiffusion processes during HgCdTe growth at 350°C. Compositional gradients were introduced to reduce the influence of misfit dislocations, mainly at the heterojunctions.

III. Results and discussion

Figure 2 shows the spectral photoresponse for the integrated HgCdTe two-color IR detector illustrated in Figure 2, where the corresponding two spectral bands with cut-off wavelengths of 4.1μm and 5.05 μm at 230 K are evident. The cut-off wavelength of the MW1 photodiode is close to the cut-on wavelength of the MW2 diode. The simulated spectral

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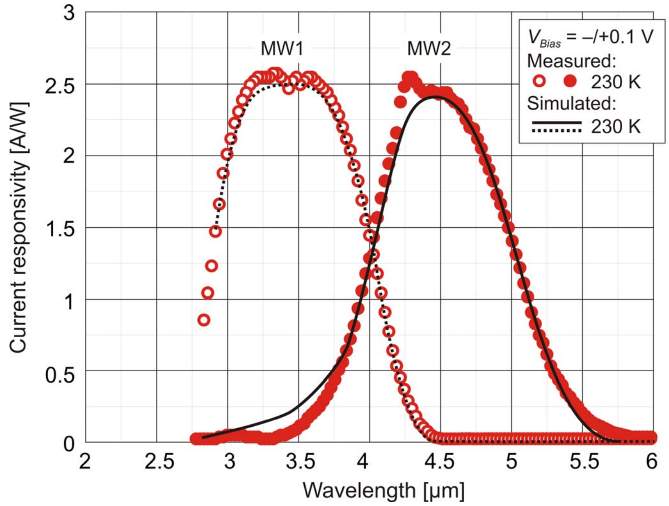

Fig. 2. Measured (points) and simulated (lines) spectral photoresponse of HgCdTe dual-band IR detector operated at 230 K.

photoresponse is also compared to that of experimental results showing that the simulation and experiment are in good agreement.

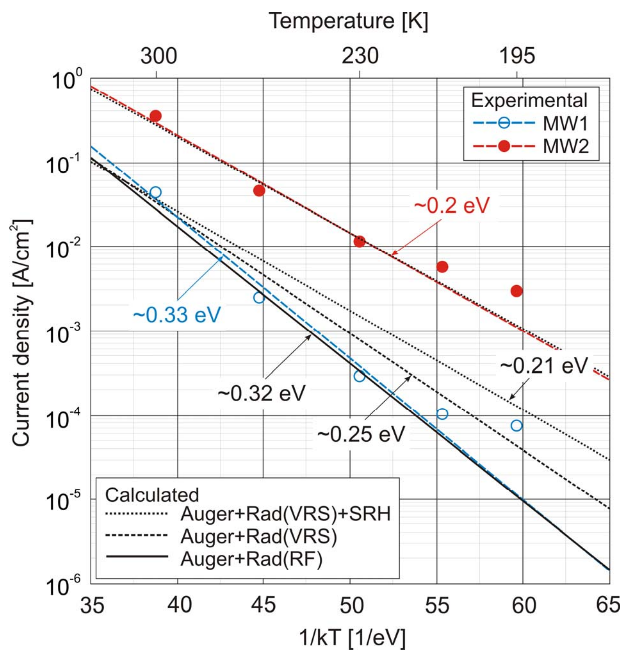

Fig. 3. Arrhenius plots for HgCdTe dual-band IR detector.

The current-voltage (I-V) characteristics of the photodiodes are influenced by various GR mechanisms occurred in semiconductors. One of the methods of analyzing these mechanisms is numerical modeling of dark currents and comparing them with experimental results. The calculations were made taking into account Auger, radiative and SRH mechanism occurring through trap states related to metal (mercury) vacancies and dislocations. The assumed mercury vacancies density is $N_T = 5\times10^{13}$ cm^{-3} with the ionization energy of the $E_T = 0.75E_g$ above the top of the valence band. The density of dislocations was assumed at the level of $G_{DIS} = 1\times10^{6}$ cm^{-2} with the energy of activation of the dislocation band of $E_{DIS} = 0.32E_g$ above the top of the valence band.

The current dependence (at the bias voltage of –/+0.2 V) of the analyzed detector on the temperature is presented in Figure 3. The experimental results show a non-linear dependence of the dark current density in the low temperature range, especially for the MW1 photodiode. This is probably due to the presence of photocurrent originating from the background. Arrhenius plots allow us to determine the activation energy of GR processes.

For a MW2 photodiode, the specific activation energy, based on both experimental and theoretical results, is about 0.2 eV, which is smaller than the $Hg_{0.72}Cd_{0.28}Te$ bandgap at 300 K, which equals 0.264 eV. It corresponds to the value of about $0.75E_g$ and shows GR behavior. For a MW1 photodiode, the activation energy of 0.33 eV determined from experimental results corresponds to the $Hg_{0.68}Cd_{0.32}Te$ bandgap, which at 300 K is 0.318 eV. Activation energy determined from theoretical calculations assuming all GR mechanisms amounts to 0.21 eV and is much smaller than the experimental one.

In order to further clarify the discrepancy, the dark current calculation for a MW1 photodiode was made for the case when the influence of the SRH mechanisms was not taken into account. In the case when the dark current is limited by the interband Auger processes and the radiative mechanism calculated using the classic Van Roosbroeck and Shockley (VRS) theory [2], the determined activation energy of 0.25 eV is larger, but still much lower than the value determined from the experimental results. Further calculations of dark currents for a MW1 photodiode were made including in the radiative recombination model the effect of photon reabsorption (PR) [3]. RF causes an increase in the effective carriers lifetime. The determined activation energy is 0.32 eV and is similar to the activation energy determined from the experimental results.

IV. Conclusions

A numerical analysis was used to investigate the influence of different GR mechanisms on dark currents of dual-band HgCdTe detector. Results shows that a more long-wave photodiode is limited by the SRH mechanisms while shorter-wave photodiode is diffusion limited – dark currents are limited by fundamental Auger processes radiative one.

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