A method of obtaining high quantum efficiency in uncooled LWIR HgCdTe photodetectors

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***Abstract*—We have proposed the method to obtain high effective quantum efficiency in uncooled LWIR HgCdTe photodiodes. We have designed the stacked multi junction photodiodes working in non–equilibrium conditions. The effective quantum efficiency being the product of quantum efficiency and photoelectrical gain can achieve significant values, much greater than 100%, when the structure is reverse biased.**

I. Introduction

Conventional HgCdTe long-wavelength infrared (LWIR) photodetectors need to be cooled well below ambient temperature to reduce noise and leakage currents resulting from thermal generation processes [1]. Increasing the operating temperature of IR detectors without their performances deterioration has become a nearly universal goal in last two decades. A several new concepts of photodetectors to improve their performance have been proposed. Significant progress has been achieved with the use of heterostructure design of the devices [2,3] in which the active region (absorber) is sandwiched between wide gap layers that protect it against parasitic thermal generation at contacts, surfaces and interfaces. In the N^+-p-P^+ (a capital letter denotes wider band; the symbol + denotes strong doping) architecture, thermally generated charge carriers are extracted and excluded of from the active region under reverse bias was applied.

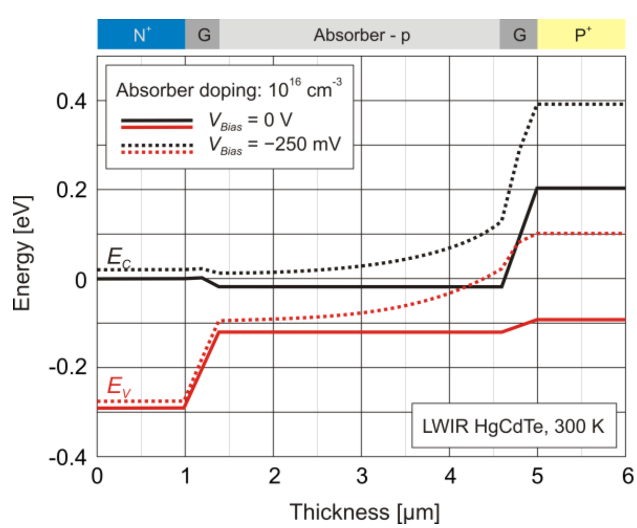
However, high-oparating temperature (HOT) LWIR photodetectors suffer from low differential resistance and poor quantum efficiency [4–6]. A method to increase the resistance and quantum efficiency is an idea of a device designed on the basis of multijunction structures monolithically connected in series [7]. In the analysis of detection parameters of photoelectric devices, it is convenient to use the photoelectric gain *g* which is understood as a number of electron charges passing contact per generated electron-hole pair. The idea of photoconductive gain was put forth by Rose [8] as a simplifying concept for the understanding of photoconductive phenomena.

In this paper, we discuss possible configurations and report numerical simulations of LWIR stacked multi-junction devices operating under non-equilibrium mode. We have analyzed the dependence of the photoelectrical properties on the thickness, and doping of the absorbing layer for a single N^+-p-P^+ heterojunction and n^+-p-p^+ photodiodes, as well as cells monolithically connected in series.

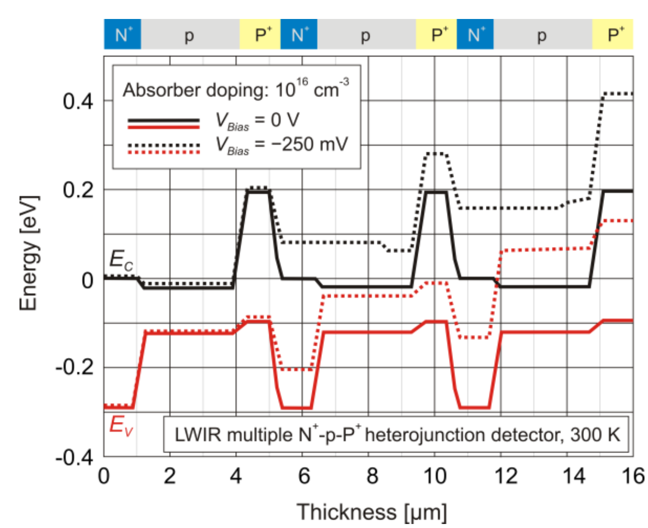
II. Results and discussion

Figure 1 shows calculated band structure of an unbiased and reverse biased single N^+-p-P^+ photodiode and multiple-junction photovoltaic detectors based on three N^+-p-P^+ cells.

The zero-bias resistance of all analyzed devices is quite small. The same is with the quantum efficiency which is



(a)



(b)

Fig. 1. Calculated band structure of an unbiased and reverse biased single N^+-p-P^+ photodiode (a) and multiple-junction photovoltaic detectors based on three N^+-p-P^+ cells (b).

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Tab. 1. The calculated parameters of single cell and multi-junction photodiodes operating at room-temperature and reverse-bias mode.

-250 mV (reverse-bias mode)		n^+-p-p^+ (homojunction)		N^+-p-P^+ (heterojunction)	
Device type	Absorber doping [cm^{-3}]	R_DA [mΩ·cm^2]	Quantum efficiency [%]	R_DA [mΩ·cm^2]	Quantum efficiency [%]
Single cell (d_{Abs} = 3 μm)	1×10^{16}	13.9	55	-33.9	50
	1×10^{17}	4.1	59	6.5	58
Triple cell (d_{Abs} = 3 × 3 μm)	1×10^{16}	13.2	40	-1.5	12
	1×10^{17}	3.9	26	-17.3	421

significantly below 10%. The reasons is poor absorption of IR radiation for the thin absorber layer. A method to increase the quantum efficiency in such devices is the operation under non-equilibrium mode by reducing the absorber carrier density below thermal equilibrium in reverse bias condition [2,3] what improves a collection of photogenerated-charge carriers.

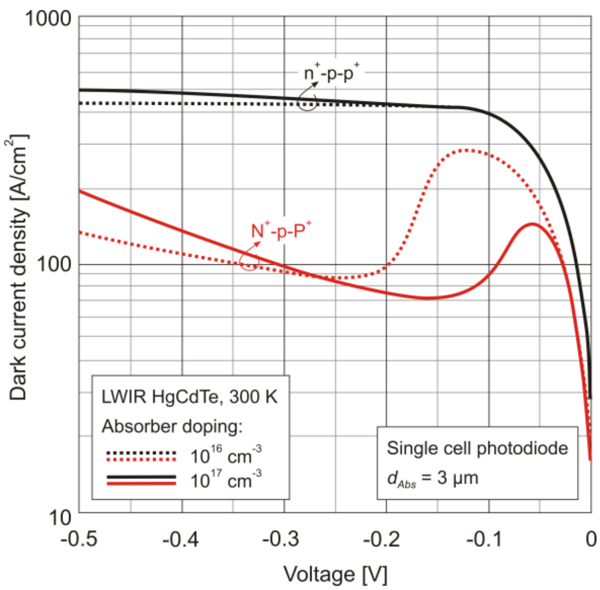

Fig. 2. Calculated current-voltage characteristics of a single N^+-p-P^+ heterojunction and n^+-p-p^+ homojunction photodiode cell at a temperature of 300 K.

Calculation parameters for the reverse bias mode are shown in Table 1. In the case of a single photodiode, both N^+-p-P^+ and n^+-p-p^+, the quantum efficiency is increased to about 50% because of improved collection of photogenerated-charge carriers. Multiple n^+-p-p^+ detector does not give better results than a single photodiode. However, for multiple N^+-p-P^+ herejunction detector with absorber doping at the level of 10^{17} cm^{-3}, the quantum efficiency increases up to 421%. Such high value is due to photoelectric gain in the absorber region. Devices with absorber doping at the level of 10^{16} cm^{-3} require a higher reverse bias voltage to increase the quantum efficiency.

Comparison of calculated current-voltage characteristics for N^+-p-P^+ and n^+-p-p^+ single cell photodiodes with 3-μm thick absorber layer is shown in Figure 2. N^+-p-P^+ device structures with combination of extraction (N^+-p) and exclusion (P^+-p) heterojunctions show smaller dark currents. Under reverse bias, the electrons are extracted from the absorber region by positive electrode connected to bottom N^+-layer. The electrons are also excluded from the absorber near the p-P^+ junction because they cannot be injected from negative electrode into P^+-layer. As a consequence, the hole concentration also decreases resulting suppression of Auger generation. The exclusion effect is limited by the level of acceptor concentration (due to the electrical carrier neutrality), as well as by thermal generation which restores the thermal equilibrium state.

III. Conclusions

We have carried out with advanced numerical analysis of photoelectric phenomena in stacked LWIR uncooled multijunction HgCdTe heterostructures to show that it is possible to obtain a high effective quantum efficiency during the detection process. The key to achieve it is reverse biasing of the structures enabled increasing of photoelectrical gain as well as decreasing of thermal generation rate due to exclusion of carriers in absorber regions. In stacked multijunctions an effective absorption region obeys the regions of a few (in considered structures of three) absorbers. Such construction leading to increasing the effective quantum efficiency. The quantum efficiency is effectively enhanced by high photoelectric gain, which increased when the structure is biased. The most promised results have obtained for triple N^+-p-P^+ cells with 3 μm p-type absorber regions.

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