HOT HgCdTe infrared detectors

P. Martyniuk
Institute of Applied Physics, Military University of Technology, 2 Kaliskiego Str.,
00-908 Warsaw, Poland (✉ pmartyniuk@wat.edu.pl, +48 22 6839673)

***Abstract*-Narrow band gap photon infrared detectors require cryogenic cooling to suppress the noise deteriorating the performance. Among the competitive materials and theoretical predictions favoring type-II superlattices (T2SLs) InAs/GaSb, HgCdTe has been still considered as the leader in terms of the fundamental parameters. The size, weight, power consumption and multispectral response of the infrared detection system play decisive role in fabrication of the higher operation temperature detectors. Several strategies have been implemented to improve the performance at elevated temperatures. The most efficient and used in HgCdTe technology are: non-equilibrium architectures and currently an idea of the barrier detectors. In this paper we present the comparison and short review of the nB_nn and pB_pp (B_n and B_p stands for n/p-type barrier) HgCdTe photodetectors.**

I. INTRODUCTION

Higher operation temperature (HOT) condition of the mid-wave (MWIR, 3−8 μm) and long-wave (LWIR, 8−12 μm) wavelength infrared radiation (IR) photodetectors are the most important research areas in infrared technology. The development of the new detector architectures has been driven by applications requiring multispectral detection, high frequency response, high detectivity, small size, low weight and power consumption (SWaP) and HOT conditions. Because of its physical properties, HgCdTe has evolved to become the most important and versatile material and can be used for devices operating in various modes: photoconductors, photodiodes and MIS detectors [1,2]. Additionally HgCdTe has inspired development of four generations of the IR detectors. The IR detector roadmap starting from 1959 when HgCdTe was used for the first time is shown in Fig. 1 [3]. The new concepts of IR technologies are marked in blue.

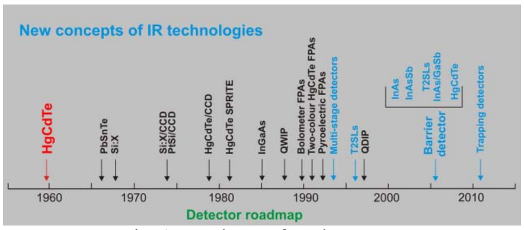


Fig. 1. Roadmap of IR detectors.

Third generation HgCdTe systems are now implemented and concept of development of the fourth generation system is undertaken to include: multicolour capabilities, optical coupling (plasmonic), large number of pixels, high frame rates and high thermal resolution. A revolutionary emergence of focal plane arrays (FPA) based on thermal detectors (bolometer, pyroelectric) has been observed but these devices are not expected to compete with the high-performance cryogenically cooled arrays (see Fig. 1).

A number of concepts to improve HgCdTe IR detecors' performance have been proposed, but significant improvements in reduction of the dark current has been reached by suppression of Auger thermal generation by implementing non-equilibrium conditions to the detectors structure [4,5]. In practice, most of HgCdTe $N^+p(\pi)P^+$ Auger suppressed photodiodes are based on complex graded gap and doping multi-layer structures in which the transport of majority and minority carriers is determined by barriers. 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 thermal generation mechanism [6]. A new strategy to achieve HOT detectors includes barrier structures launched by White and followed by Maimon and Wicks [7,8]. Barrier architecture was firstly implemented in $A^{III}B^{V}$ bulk materials (InAs, InAsSb), after in T2SLs InAs/GaSb and finally introduced into HgCdTe by Itsuno in both MWIR and LWIR ranges [9−11]. Itsuno presented nB_nn device being a prospect for circumventing of the p-type doping requirements in MBE technology related to an inconvenient *ex situ* As activation [12]. Since HgCdTe p-type material is much more favorable, MOCVD growth allowing both *in situ* donor and acceptor doping seems to be more attractive in terms of growth of pB_pp HgCdTe barrier structures [13]. The paper presents comparison and short review of the BIRD nB_nn and pB_pp HgCdTe detectors.

II. SIMULATION PROCEDURE AND RESULTS

Both nB_nn and pB_pp MWIR HgCdTe detectors were simulated with Apsys platform by Crosslight Inc. [14]. The simulation parameters were presented in Table 1 and modelled barrier structure is shown Fig. 2 (a). Interface barrier layers were assumed to be *x*-graded regions and represent the real structure which profile is shaped by interdiffusion processes during HgCdTe MOCVD growth.

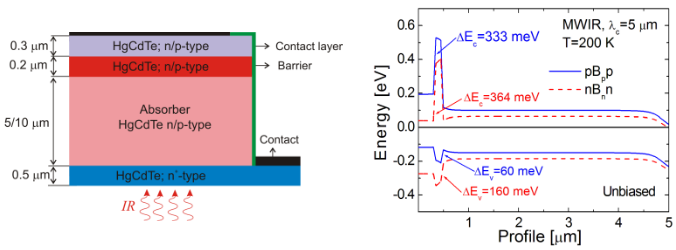
Table 1. Parameters taken in modeling of MWIR nB_nn and nB_pp HgCdTe detectors.

	Cap	Barrier	Absorber	n^+ contact
N_D/N_A [cm^{-3}]	$10^{14}\rightarrow5\times10^{16}$	7×10^{14}	7×10^{14}	2×10^{17} cm^{-3}
Gauss tail, dx	0.02			
x	0.33	0.33→0.7→0.2863	0.2863 (λ_c = 5 μm at T = 200 K)	0.2863
d [μm]	0.3	0.05→0.1→0.05	5/10	0.5
A [μm^2]	100×100			
T_s, field of view, θ	300 K, 20°			
F_1F_2	0.15			
E_{Trap}	$E_g/2$			
N_{Trap} [m^{-3}]	10^{10}			
SRH, τ_n, τ_p [μs]	10, 1			
Φ [W/m^2]	5			

The numerical simulations included: radiative (RAD), Auger, SRH GR and both: trap-assisted (TAT) and band-to-band tunneling (BTB) at barrier layer/absorber heterojunction. Both

nB_nn and pB_pp detectors require that the valence/conduction bands of the three constituent layers line up closely to allow minority carrier transport between the absorber and contact layers.

n^+ layer was added to assure proper contact properties to the p-type active layer in pB_pp barrier structure. Band diagram of the simulated structure is shown in Fig. 2 (b). The band energy discontinuity of both barrier layer and absorber layer seems to be the most decisive parameter influencing performance of barrier structure. Similarly to nB_nn, for pB_pp $\Delta E_c > \Delta E_v$.



(a) (b)

Fig. 2. Simulated nB_nn and pB_pp barrier structures (a); band diagrams (b).

J_{DARK} versus voltage is shown in Fig. 3 (a). pB_pp structure reaches lower dark current for > 175 mV. CL's doping to the level of 5×10^{15} cm^{-3} and ΔE_C dependence on voltage is responsible for the J_{DARK} increase with bias, while for pB_pp J_{DARK} saturates. pB_pp structure allows operation for unbiased conditions.

Since both HgCdTe n/p-type barrier height in conduction band was estimated to be within the range of ~400 meV, the SRH GR contribution is evident in HOT conditions. Crossover temperature for nB_nn was estimated at $T_C \approx 152$ K, while for pB_pp $T_C \approx 164$ K. (see Fig. 3 (b)). Barrier x_{Cd} composition influence on J_{DARK} and J_{PHOTO} is presented in Fig. 3 (c). Barrier x_{Cd} has no influence on J_{PHOTO} for pB_pp, while for nB_nn this behavior is observed for $x_{Cd} > 0.49$.

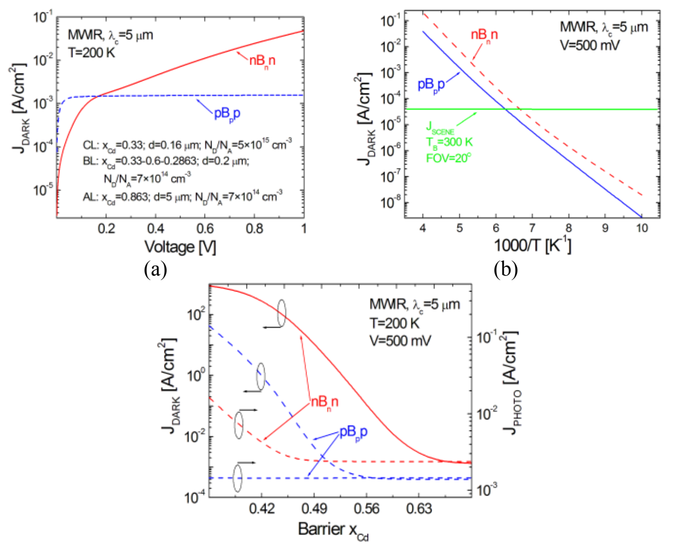
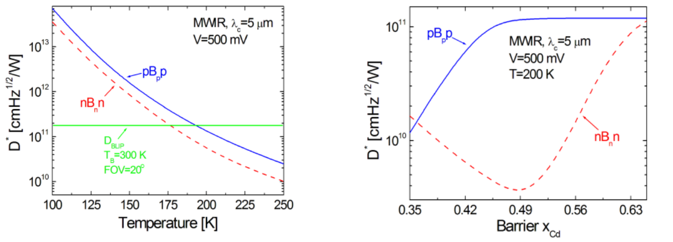


Fig. 3. J_{DARK} versus voltage (a); versus reciprocal temperature; J_{DARK} and J_{PHOTO} versus barrier Cd composition (c) for nB_nn and pB_pp barrier structures.

Detectivity versus temperature is presented in Fig. 4 (a). nB_nn reaches BLIP conditions at ~175 K, while for pB_pp at ~200 K. Detectivity dependence on barrier composition is presented in Fig. 4 (b). Barrier x_{Cd} should be higher than 0.49 for pB_pp structure, where D^* saturates, while for nB_nn, D^* increases with x_{Cd} for $x_{Cd} > 0.49$.



(a) (b)

Fig. 4. D^* versus temperature (a) and barrier composition (b) for nB_nn and pB_pp barrier detectors.

III. CONCLUSIONS

The barrier structure has been introduced to simplify the detector fabrication process and increase detector's operating temperature. Depending on the growth method, particular HgCdTe barrier architectures are favorable (nB_nn - MBE, pB_pp - MOCVD). pB_pp architecture allows to reach higher performance at MWIR range.

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