nBn HgCdTe infrared detector with HgTe/CdTe SLs barier

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***Abstract*-Several strategies have been implemented to improve the performance of infrared single pixel detectors at higher operating temperature condition. The most efficient and effective in HgCdTe technology are: non-equilibrium architectures and currently an idea of the barrier detector to include unipolar and complementary structures. Valence band offset between active layer and barrier impeding the minority carrier transport is considered to be the most important issue to overcome. Currently, implementation of the Cd composition and doping graded interfaces has been proposed. In this paper we present the performance (dark current) of the nBn detector with HgTe/CdTe superlattice barrier. The superlattice barrier is believed to decrease valence band offset between active and barrier layers.**

I. INTRODUCTION

Currently, the infrared detector industry is dominated by mercury cadmium telluride (HgCdTe) detectors. A number of concepts to improve HgCdTe IR detecors' performance have been proposed, but significant improvement in reduction of the dark current has been reached by suppression of Auger thermal generation by implementing non-equilibrium conditions [1]. In practice, most of HgCdTe $N^+p(\pi)P^+$ Auger suppressed photodiodes are based on complex, technologically difficult to grow graded gap and doping multi-layer structures [2]. A new strategy to achieve higher operating temperature (HOT) detectors includes the barrier structures [3]. Itsuno *et al.* presented nBn HgCdTe bulk device being a prospect for circumventing of the p-type doping problems in MBE technology [4]. Valence band offset (VBO) between active layer and barrier blocking the minority carrier transport is considered to be the most important issue to overcome. Currently, implementation of the Cd composition and doping graded interfaces have been proposed [5,6]. An alternate approach for reduction of the VBO is to use a HgTe/CdTe superlattice (SLs). HgTe/CdTe SLs have a type-III band alignment. Considered SLs is composed of alternating layers of semimetallic HgTe and semiconductor CdTe. The HgTe layers are the wells and the CdTe layers form the barriers for both types of carriers: electrons and holes. Band engineering capability may be introduced by incorporation of Hg into the barrier layers. The C1 and HH energy difference of SLs is controlled by the thicknesses of the HgTe well layers allowing fitting to the absorber in terms of VBO. The transport properties of carriers in HgTe/CdTe SLs are completely different in comparison to HgCdTe alloys, meaning that the SLs in-plane transport properties are noticeably different from those in the growth direction. The transport in the growth direction is of greatest importance for the device presented in this paper. The numerical simulations predict that the effective masses of electrons and holes can be tuned over a considerable range by varying the CdTe barrier layer widths. The effective mass of electrons is expected to exceed up to an order of magnitude the effective mass in alloys with the same bandgap reducing the tunneling currents by several orders of magnitude in the SLs-based detectors [7].

In this paper we present the simulation of the dark current characteristics of the nBn barrier detector with HgTe/CdTe SLs barrier at T = 155 K for mid-wave infrared range (MWIR). The SLs barrier is believed to decrease VBO between active and barrier layers.

II. SIMULATION PROCEDURE

The device presented in this work were grown (by MBE) and fabricated in Microelectronics Research Group, The University of Western Australia. The schematic of a typical nBn detector structure with HgTe/CdTe SLs barrier design intended to operate in the MWIR (absorber layer Cd composition, x = 0.3, T = 155 K, λ_c = 4.8 µm) spectral region is shown in Fig. 1. The detector structure was grown on a CdZnTe substrate and CdTe undopped buffer layers (d = 0.8 mm). The first layer of the devices was bulk absorber grown with a thickness of 4 µm and Cd composition 0.3, n-type doped with I (n = 10^{14} cm^{-3}). Next the non-intentionally doped (n.i.d) HgTe/CdTe SLs (CdTe barrier d = 9 nm and HgTe well d = 2.5 nm) barrier layer was grown with a thickness of 50 nm. After the barrier layer a 0.3-µm thick bulk HgCdTe n-type contact doped with I ($n = 10^{17}$ cm^{-3}) was grown. The device diameter is 500 µm.

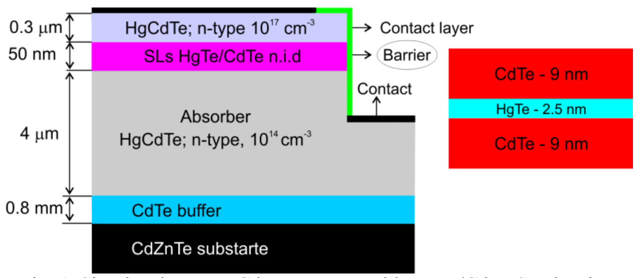

Fig. 1. Simulated nBn HgCdTe structure with HgTe/CdTe SLs barrier.

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This heterostructure design was chosen to block the majority carriers (electrons) while the minority carriers can flow with no impedance due to an assumed lack of VBO between absorber and barrier layer. The barrier was found to be thick enough to prevent electron tunnelling between the top contact layer and active layer.

nBn HgCdTe with barrier HgTe/CdTe SLs detector was simulated with Apsys platform by Crosslight Inc. [8]. The bulk based model was used in modeling of the device's transport properties. The applied model incorporates both HgCdTe bulk and barrier HgTe/CdTe electrical properties to estimate device performance taking into consideration radiative (RAD), Auger (AUG), Shockley Read-Hall (SRH) generation recombination (GR) mechanisms. RAD and AUG parameters for SLs layer were assumed to correspond to the bulk HgCdTe material with the same energy band gap (E_g). The carrier mobility dependence on bias was calculated in accordance with Canali (Beta) model [9], while low field carrier mobility was assumed according to the paper by Scott respectively [10]. The SLs was treated as an artificial material where C1 and HH1 effective masses were calculated using advanced 8×8 kp model in equilibrium condition incorporated in APSYS numerical platform (Crosslight Inc.). Affinity of HgTe/CdTe barrier was assumed 3.8 eV, while for HgCdTe absorber and contact layer 4.03 eV to reach zero VBO between barrier and absorber layer. The simulation parameters used for SLs HgTe/CdTe in 8×8 kp were presented in Table 1.

Table 1. Parameters taken in modeling of SLs HgTe/CdTe in 8×8 kp [11,12].

Parameter	HgTe	CdTe
E_g (eV) (Bandgap)	-0.302	1.6
Δ (eV) (Spin-orbit coupling)	1.00	0.91
F (Kane parameter)	0.0	0.0
γ_1 (Luttinger parameter)	4.3675	1.540
γ_2=γ_3 (Luttinger parameter)	1.034	0.015
a (eV) (Hydrostatic deformation potential)	3.5	x
b (eV) (Shear deformation potential)	-1.5	x
m^* (γ) (Effective mass in the γ band)	0.026	0.087
C11 (Gpa) (Elastic constant)	53.61	53.8
C12 (Gpa) (Elastic constant)	36.6	37.4
C44 (Gpa) (Elastic constant)	21.23	20.18
a (Å) (Lattice constant)	6.462	6.482
c (%) (Strain)	0.3	x

III. RESULTS

The calculated dispersion curves in growth direction for C1 and HH1 are presented in Fig. 2. The VBO between HgTe and CdTe was assumed 350 meV. The HgTe/CdTe SLs band gap energy was estimated at the level 548 meV.

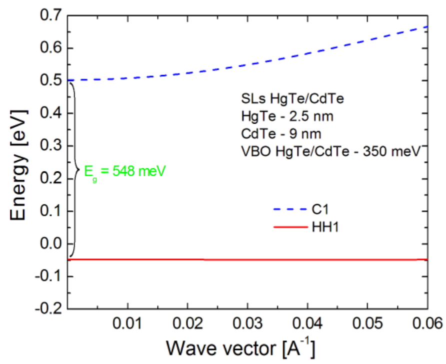

Fig. 2. Typical dispersion relation for C1 and HH1 in growth direction for HgTe/CdTe SLs at T = 155 K, VBO = 350 meV.

In growth direction effective masses were extracted from dispersion curves and taken to the bulk based model, i.e. $m_e = 0.082m_0$ and $m_{hh} = 1.15m_0$ respectively.

Measured and calculated dark current (I_{DARK}) and dynamic resistance (R_D) versus voltage are shown in Fig. 3. Oscillations in I_{DARK} characteristics in vicinity of 1 and 2 V are believed to be related to the dependence of energy barrier in conduction band (ΔE_c) versus voltage. For unbiased condition energy barrier $\Delta E_c \approx 300$ meV.

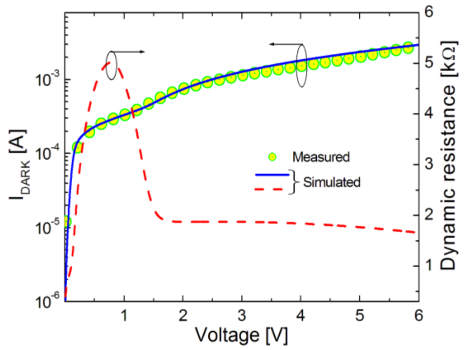

Fig. 3. I_{DARK} and R_D versus voltage for nBn detector with SLs HgTe/CdTe barrier at T = 155 K.

CONCLUSIONS

nBn detectors based on bulk HgCdTe naturally present a potential barrier in the valence band, which significantly reduces the performance. SLs HgTe/CdTe barrier gives an opportunity to reduce VBO in nBn structures leading to unimpeded transport of the photogenerated carriers to the contacts.

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