Numerical simulation of HgCdTe nBn long-wavelength infrared detector

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***Abstract*—HgCdTe nBn device is a kind of unipolar barrier layer in which the B layer is a wide band gap barrier layer with a thickness of several tens of nanometers, and could effectively reduce the dark current and the process difficulty of HgCdTe device. The photoelectric properties of HgCdTe nBn infrared detectors are studied by two-dimensional numerical simulation. The energy band structure of the nBn structure and the influence of the structural parameters on the performance of the device are theoretically calculated, which provides guidance for designing or optimizing the structure of HgCdTe nBn infrared detector.**

Keywords—HgCdTe, dark current, nBn structure, numerical simulation

I. INTRODUCTION

HgCdTe has become one of the most promising materials in the field of infrared photodetectors with the advantages of high absorption coefficient, high quantum efficiency and adjustable band in the whole infrared band [1-5]. However, HgCdTe device with conventional structure faces many problems. The high dark current and the difficulty of P doping technology greatly restrict the development of HgCdTe devices [6-8].

As a unipolar barrier layer device, nBn structure has been proposed to solve these problems [9-14]. This structure completely abandons the P-type doping, and could obtain the characteristics similar to PN junction only by N-type doping and the energy band engineering [15, 16]. Compared with the traditional PN junction structure, the nBn structure has a low requirement for surface treatment technology and can effectively control the leakage of the surface. What's more, nBn can effectively reduce the tunneling current and the production-compound current, especially the SRH composite current [17-20]. By ingenious designing the energy band, the conduction of majority carriers can be prevented and thus effectively reduce the dark current of the device, which is very helpful to the realization of high temperature devices. In this paper, the photoelectric properties are studied by numerical simulation, and the parameters of each layer in the nBn structure can be optimized by the energy band reduction calculation.

II. SIMULATION RESULTS

The schematic diagram of HgCdTe nBn structure used in numerical simulation is shown in Figure 1, including heavily doped n-type cap layer, barrier layer (B) and n-type absorption layer. The detailed material parameters used in numerical simulation are shown in Table 1.

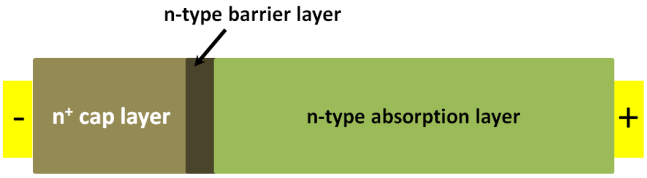

Fig. 1 Schematic of HgCdTe nBn

Table. 1 Parameters of the HgCdTe nBn structure used in the simulation

Layer	Cd Composition	Thickness	Doping
Cap	0.33	3μm	$10^{17}cm^{-3}$
Barrier (B)	0.39~0.57	0.1μm	$10^{15}cm^{-3}$~$10^{17}cm^{-3}$
Absorption	0.23	7μm	$10^{15}cm^{-3}$~$10^{17}cm^{-3}$
SRH lifetime (electron)		10μs	
SRH lifetime (hole)		1μs	

The simulation results of the band structure of the nBn device are shown in Figure 2. Between the barrier layer and the cap layer, a conduction barrier with a height of 0.15eV can effectively block the movement of the electrons from the cap layer into the absorption layer, thus reducing the dark current. However, it can be seen that there is a hole barrier on the valance bane at the interface between the absorbing layer and barrier layer, which will obstruct the collection of photo-generated holes in the absorption layer. Our simulation results show that this hole barrier can be reduced by applying a suitable bias, however the band bending caused by excessive bias can significantly reduce the barrier on conduction band and seriously damage the electron blocking effect.

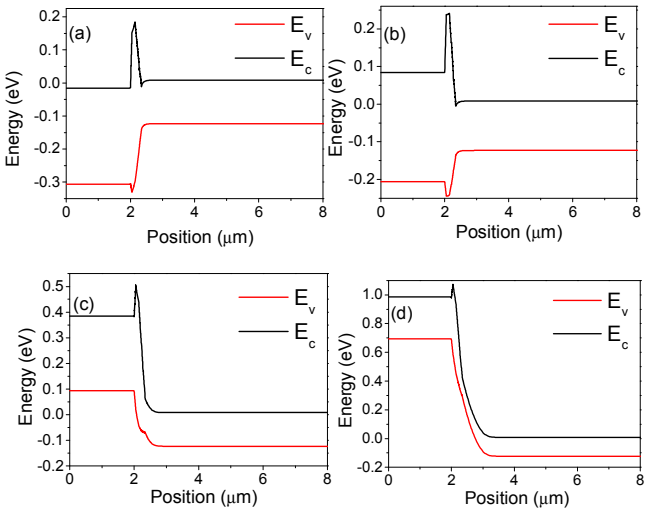

Fig. 2 Simulated energy band of HgCdTe nBn at the bias of (a) 0V (b) 0.1V (c) 0.4V (d) 1V

The influence of the structure parameters of the nBn device on the performance of the device has been calculated as shown in Figure 3. Our results show that the doping concentration of the B region and the absorption region and the components of the barrier layer can be the main influencing factors. The increase of the doping concentration of both the barrier layer and the absorption layer will bring a significant increase to the dark current. Therefore, one of best effective methods to reduce the dark current is to reduce the doping concentration of the barrier layer and the absorption layer.

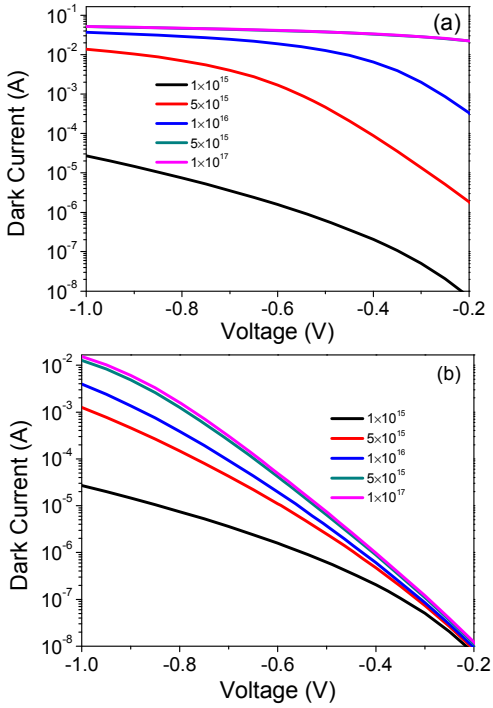

Fig. 3 Dependence of the dark current changing on (a) the doping of barrier layer (b) the doping of absorption region

One of the problems in the process is that the component of the barrier layer will diffuse to the cap layer and absorption layer when annealing, which resulting in the decrease of barrier height and the increase of SRH current. The effect of component barriers decrease caused by component diffusion is shown in Figure 4. It can be seen obviously that the diffusion of components leads to the increase of dark current. As a result, the annealing process should be optimized as good as possible to reduce the dark current.

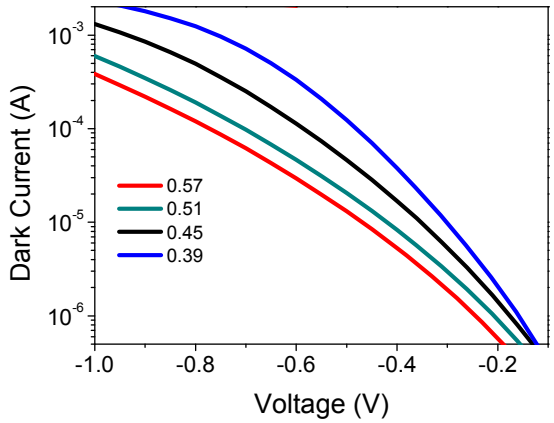

Fig. 4 Influence of component diffusion on dark current

III. CONCLUSION

In conclusion, we have studied the structure of HgCdTe nBn by two dimensional numerical simulations. The simulation results of the band structure show that the nBn device needs to work under a suitable bias to increase the light response as much as possible while maintaining the suppression of the dark current. In addition, the effects of the structure parameters on the performance of the device are also simulated. We found that both the doping concentration of barrier region and absorption region as well as component diffusion will effectively affect the dark current.

REFERENCES

[1] Rogalski A. Recent progress in infrared detector technologies[J], Infrared Physics & Technology, 2011, 54 (3) :136- 154

[2] Qiu W, Hu W. Laser beam induced current microscopy and photocurrent mapping for junction characterization of infrared photodetectors[J], Science China-Physics Mechanics & Astronomy, 2015,58(2) : 027001

[3] Gopal V, Qiu W Hu W. Modelling of illuminated currentvoltage characteristics to evaluate leakage currents in long wavelength infrared mercury cadmium telluride photovoltaic detectors[J], J. Appl. Phys, 2014, 116: 184503.

[4] J. H. Chu, and Arden Sher. Physics of Narrow Band Semiconductor. Science Publisher[B], Beijing, 2005.

[5] D. L. Polla and C. E. Jones. Deep level studies of Hg1-xCdxTe. I: Narrow-band-gap space-charge spectroscopy [J]. J. Appl. Phys., 1981, 52:5118–5131.

[6] L. He, L. Chen, Y. Wu, et al., MBE HgCdTe on Si and GaAs substrates [J]. J. Cryst. Growth 2007, 301: 268-272.

[7] P. Tribolet, J. P. Chatard, P. Costa, A. Manissadjian. A Progress in HgCdTe homojunction infrared detectors [J]. J. Cryst. Growth, 1998, 185:1262–1271.

[8] T. Tung, M. H. Kalisher, A. P. Stevens, et al. Liquid-phase epitaxy of Hg1-xCdxTe from Hg solution: a route to infrared detector structures [C]. Mat. Res. Symp. Proc. 1987, 90:321–56.

[9] Anne M Itsuno, Jamie D Phillips, et al. Unipolar BarrierIntegrated HgCdTe Infrared Detectors[J], IEEE, 2012,978-1-4673-1164-9: 257.

[10] Itsuno A M , PhillipsJD , et al Design and Modeling of HgCdTe nBn Detectors[J], J. Electron. Mater. 2011,40(8) .

[11] Itsuno A M Phillips,JD , et al. Design of an Auger-Suppressed Unipolar HgCdTe NBvN photodetector[J], J. Electron. Mater. 2012,Vol. 410, No. 10 .

[12] P. Norton. HgCdTe infrared detectors [J]. Optoelectronics review, 2002 (3): 159-174.

[13] S. Maimon, and G. W. Wichs. nBn detector, an infrared detector with reduced dark current and higher operating temperature [J]. Appl. Phys. Lett. 2006, 89:151109.

[14] A. M. Itsuno, J. D. Phillips, and S. Velicu. Design and Modeling of HgCdTe nBn Detectors [J]. J. Electron. Mater. 2011, 40(8): 1624-1629.

[15] Maimon S ,Wicks G W ,[J] Appl. Phys. Lett. 2006, 89:151109- 1.

[16] PedrazzaniJR , Maimon S , Wicks G W ,[J] Electron.Lett. 2008,44: 1487.

[17] G. R. Savich, J. R. Pedrazzani, D. E. Sidor, et al. Benefits and limitations of unipolar barriers in infrared photodetectors [J]. Infrared Physics & Technology, 2013, 59: 152-155.

[18] M. I. Anne, D. P. Jamie, and V. Silviu. Mid-wave infrared HgCdTe nBn photodetector [J]. Appl. Phys. Lett. 2012, 100: 161102.

[19] M. Kopytko. Design and modelling of high-operating temperature MWIR HgCdTe nBn detector with n- and p-type barriers [J]. Infrared Physics & Technology. 2014, 64: 47–55.

[20] M. Kopytko and K. Jo´z´wikowski. Numerical Analysis of Current–Voltage Characteristics of LWIR nBn and p-on-n HgCdTe Photodetectors [J]. J. Electron. Mater. 2013, 42(11):3211-3216.