Structure design of HgCdTe mid-wavelength photon trapping infrared focal plane arrays

Peng Zhang,Zhen-Hua Ye,Chun Lin,Xiao-Ning Hu,Rui-Jun Ding,Li He
Key Laboratory of Infrared Imaging Materials and Detectors, Shanghai Institute of Technical Physics,
Chinese Academy of Sciences, Shanghai 200083, China
e-mail: zhye@mail.sitp.ac.cn

Abstract **Photon trapping structure in HgCdTe mid-wavelength infrared detectors is investigated in this study by exploiting the finite-difference time-domain (FDTD) technique. The quantum efficiency and the current-voltage characteristics have been numerically simulated, using commercial Technology Computer Aided Design （TCAD） software *Apsys*. Simulation results indicate that in contrast to the regular mesa structure, the photon trapping structure can reduce dark current and noise without degrading quantum efficiency.**

Keywords photon trapping structure; HgCdTe;FDTD

I. Introduction

Due to tunable absorption wavelengths, high quantum efficiency, and a wide operating temperature range, HgCdTe-based photodetectors are the promising devices of choice for many infrared thermal imaging systems [1,2]. As the third-generation detector development proceeds, device performance is being enhanced in a number of directions, such as array size, cooling temperature, readout capability and so on [3]. The photon trapping approach of reducing dark current without degrading quantum efficiency has been demonstrated in [4].

In this paper, the finite-difference time-domain (FDTD) method is utilized to calculate the optical energy distribution inside the device. Design of the photon trapping structure in HgCdTe mid-wavelength infrared detectors is mainly focused on the optimization of the aspect ratio and absorption layer thickness.

II. Model and Method

The detector pixel comprises an n+-on-p $Hg_{1-x}Cd_xTe$ mid-wavelength photodiode (x=0.29). Figure 1 and 2 show the relative energy density of the regular mesa structure and the photon trapping structure, respectively. The pitch of the regular mesa structure is 35μm and the pitch of the photon trapping structure is 5μm. The CdTe buffer layer between the active region and the substrate is 3-μm-thick. The donor density in the 2-μm-thick n-type region is $5\times10^{16}cm^{-3}$ and the acceptor density in the p-type absorption layer is $1\times10^{16}cm^{-3}$. The device is modeled to operate at zero bias, 77K with illumination source 4μm at the bottom.

At the first stage of simulation, light intensity distribution inside the device utilizes the FDTD algorithm. Then photoelectrical characteristics can be derived by simultaneously solving the Poisson equation and carrier continuity equations. Numerical calculations here are realized using finite-element modeling (FEM) simulator Apsys from Technology Computer Aided Design (TCAD) Software Crosslight.

III. Simulation Results

A series of simulations are carried out with p-type absorption layer thickness fixed at 5μm while aspect ratio changing from 0.25 to 5. The quantum efficiency and the current-voltage characteristics are depicted in Fig. 3. The volume fill factor is calculated as the volume of material remaining divided by the volume of the unit cell. With the same quantum efficiency, the volume fill factor of the photon trapping structure is much smaller than the regular mesa structure and i.e. the photon trapping structure can reduce the device noise without degrading the quantum efficiency. Correspondingly, the photon trapping approach of reducing the dark current without degrading the quantum efficiency is also demonstrated.

The quantum efficiency and the dark current of the photon trapping structure increase linearly with larger aspect ratio even that at certain ratio the quantum efficiency of the photon trapping structure exceeds the plane structure. Though the quantum efficiency of the photon trapping structure is in proportion to its aspect ratio, larger volume fill factor can introduce higher noise. With aspect ratio changing from 2 to 5, the increase of the quantum efficiency is 4%, much less than that of the volume fill factor, 29.1%. Hence, the photon trapping structure of fixed thickness can introduce lower noise and dark current when adopting lower aspect ratio.

Figure 4 presents the quantum efficiency and the current-voltage results of devices with aspect ratio fixed at 5 while thickness changing from 3μm to 7μm. The quantum efficiency of the photon trapping structure at 3μm exceeds the quantum efficiency of the plane structure at any thickness. The dark current of the photon trapping structure has a negligible variation with thickness. Therefore, the photon trapping structure of fixed aspect ratio can introduce lower noise by adopting lower thickness and i.e. smaller volume.

Simulation results are calculated on assumption that the surface condition is perfect, and only considering the bulk effect. At present the ideal state is difficult to reach, but the photon trapping structure will be useful with process improvements.

IV. CONCLUSION

The photon trapping structure in HgCdTe mid-wavelength infrared detector is designed. The quantum efficiency and current-voltage characteristics have been numerically simulated by exploiting the FDTD method with commercial TCAD software *Apsys*. Model results demonstrate that the photon trapping structure can reduce the noise and dark current while maintaining the quantum efficiency. Noise and dark current can be decreased further by the proper combination of lower aspect ratio and thickness.

REFERENCES

[1] Y. G. Chen, W. D. Hu, X. S. Chen, J. Wang, X. F. Wang, C. H. Yu, W. Lu, "Temperature dependence on photosensitive area extension in HgCdTe photodiodes using laser beam induced current." Opt. Eng., vol. 51, pp. 036401, 2012.

[2] J. Wang, X. S. Chen, W. D. Hu, L. Wang, W. Lu, F. Q. Xu, J. Zhao, Y. L. Shi, R. B. Ji, "Amorphous HgCdTe infrared photoconductive detector with high detectivity above 200 K," Applied Physics Letters, vol. 99, pp. 113508, 2011.

[3] A. Rogalski, "HgCdTe infrared detectors," Opto-Electronics Review,vol. 10(3), pp. 159–174, 2002

[4] J.G.A. Wehner, E.P.G. Smith, G.M. Venzor, K.D. Smith,A.M. Ramirez, B.P. Kolasa, K.R. Olsson, and M.F. Vilela, "HgCdTe Photon Trapping Structure for Broadband Mid-Wavelength Infrared Absorption", Journal of Electronic Materials, vol.40(8), 2011

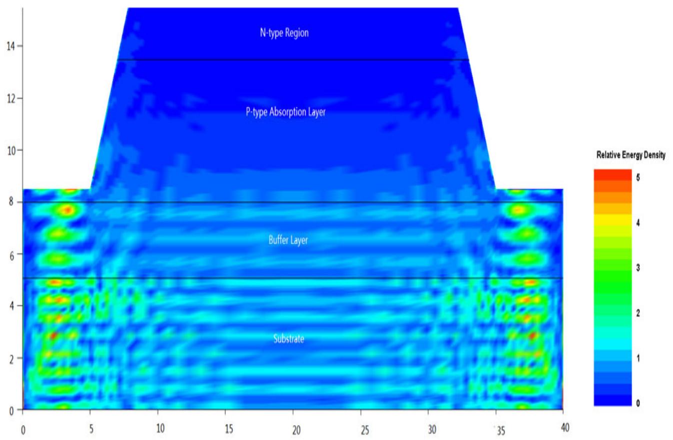

Fig. 1 Relative energy density of the regular mesa structure

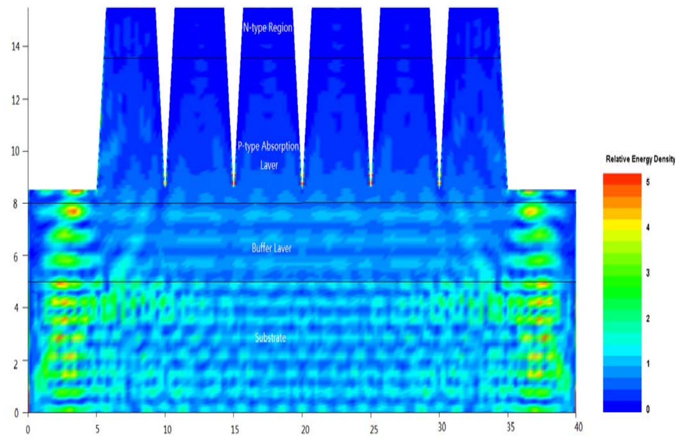

Fig. 2 Relative energy density of the photon trapping structure

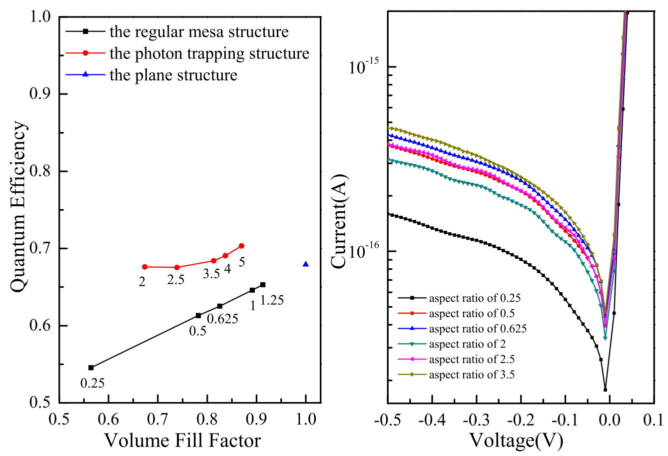

Fig. 3 Quantum efficiency and I-V curves related to aspect ratio

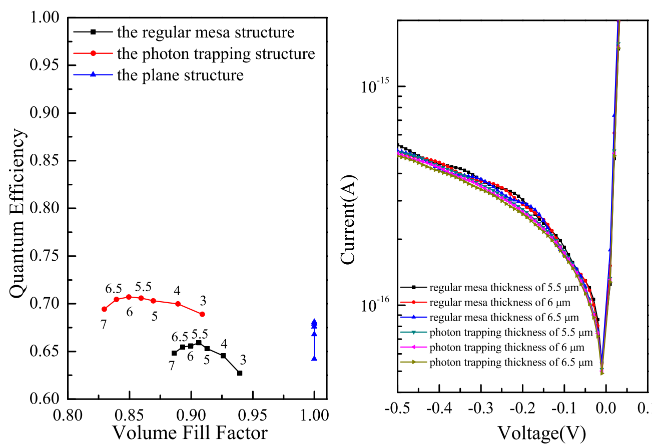

Fig. 4 Quantum efficiency and I-V curves related to thickness