Dependence of laser beam induced current on geometry of the junction for HgCdTe photodiodes

A. L. Feng, G. Li*, S. W. Shi, M. Z. Wu, G. He and Z. Q. Sun

School of Physics and Materials Science, Anhui University, Hefei 230601, China

Abstract

The dependence of laser beam induced current (LBIC) on the junction structure of n^+-on-p HgCdTe photodiode has been numerically investigated. The simulated LBIC profiles are in good agreement with the experimental data. It is found that the peak LBIC magnitude is close to a linear relationship with both junction depth and length. In addition, the shape between two peaks becomes more flat with the increasing junction depth. A lateral and vertical current flow competition mechanism is proposed to explain the junction structure dependence of the LBIC signal.

I. INTRODUCTION

HgCdTe is the preferred material for infrared focal plane arrays (IRFPAs) [1- 3]. Currently, typical HgCdTe photodiodes operating at cryogenic temperatures are on the basis of n^+-on-p planar junction [4]. The appropriate depth and position of p-n junction are critical to ensure the highest performance of photodiodes. For heterojunction photodiodes, the p-n junction needs to be in the narrow band gap material. The appearance of p-n junction in the wider band gap layer may render a blind device [5]. If nondestructive characterization could be performed to identify the poor performance device at an earlier stage in the fabrication process, significant cost savings would be expected in HgCdTe IRFPAs. One technique as a candidate for such characterization is LBIC which has been proved to be useful to examine electrically active features in a qualitative manner [6]. In this technique, a focused low power laser beam scans across the HgCdTe sample and then the induced current flowing through two remote contacts at opposite sides of the sample is collected. The LBIC image is a two-dimension mapping of obtained current as the function of the laser beam position, as illustrated in Fig.1.

In this paper, we systematically study the dependence of LBIC on the junction depth and length for typical n^+-on-p HgCdTe photodiode.

II. DEVICE DESCRIPTION AND DISCUSSION

This paper considers the typical n^+-on-p photodiode structure with doping density of N_d=1×10^{17} cm^{-3} and N_a= 8×10^{15} cm^{-3}. The p-type region consists of the length of 250μm and the thickness of 8μm. The length of n-type region is 56μm with the depth of 2μm.Two-dimensional steady-state numerical simulations presented here are performed using the Sentaurus Device. For the plain drift-diffusion simulation, the well-known Poisson equation and continuity equations are used. The carrier generation-recombination process is composed of Shockley-Read-Hall, auger, radiative and optical generation-recombination terms. Photo generation is simulated by raytracing [7, 8]. The wavelength of the laser is 0.63μm and the spot diameter is 1.5μm.

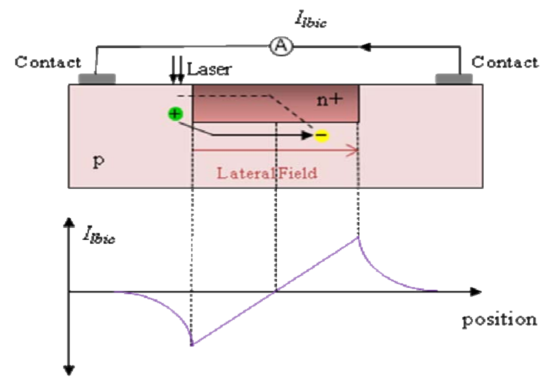


Fig.1. LBIC schematic structure and the corresponding LBIC profile showing the typical bipolar nature.

III. RESULT AND DISCUSSION

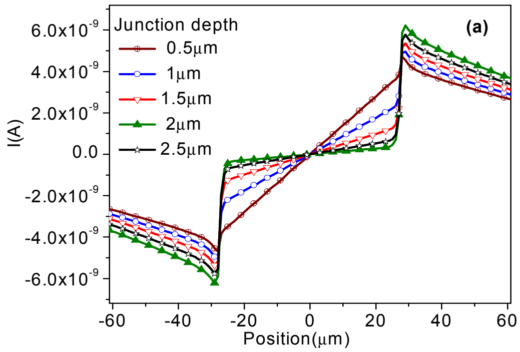
In order to understand the sensitivity of the LBIC signal on device junction structure, the effects of junction depth and length on LBIC profiles are numerically investigated for $Hg_{0.69}Cd_{0.31}Te$ photodiodes at 170K.

The simulated LBIC profiles with different junction depths are shown in Fig. 2(a). It can be found that the peak magnitude and shape of LBIC vary with the junction depth in good agreement with the reported experimental data [9]. The peak magnitude of LBIC monotonously increases with increasing junction depth, but the slope in the n-type region decreases. The properties are determined by where carriers are generated and how they diffuse [10]. For carriers generated in the p-type region, when the junction depth, the vertical junction length, increases, more minority carriers in the p-type region can be swept across the junction, giving rise to a larger signal at two remote contacts. However, when the incident illumination on the surface of the n-type region with a deep junction, more carriers diffuse to the vertical side-junction and only a small fraction of generated carriers reach the lateral junction contributing to the LBIC signal. Therefore, a flat portion in the n-type region is observed.

Fig. 2 (b) shows the simulated LBIC profiles with different junction lengths using a fixed contact separation *s* (denoted in Fig.1, *s* = 80μm). It can be seen that the sensitivity of LBIC

* Corresponding author: liguang1971@ahu.edu.cn (G. Li)

signal in response to the reduced junction length is obvious. It is noted that the peak LBIC magnitude almost linearly increases as the junction length increases. Fig. 3 shows that the current flow lines from two identical devices with the junction length of 20μm and 50μm, respectively. It is found that the contact-to-contact or lateral current is larger in the device with longer junction length. The reason is that in the device with shorter junction length, much more current flows through the vertical junction making no contribution to LBIC signal because of the form of inner circular current. Hence, the LBIC peak magnitude increases with increasing the junction length.



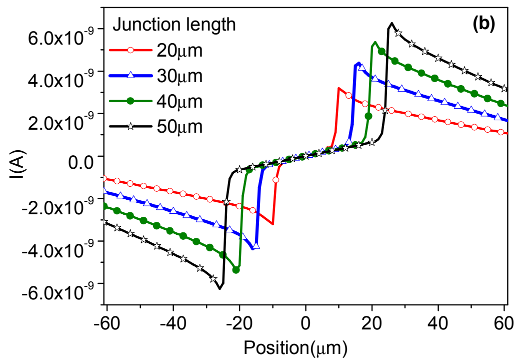


Fig.2. (a) LBIC profiles with different p-n junction depths. (b) LBIC profiles with different p-n junction lengths.

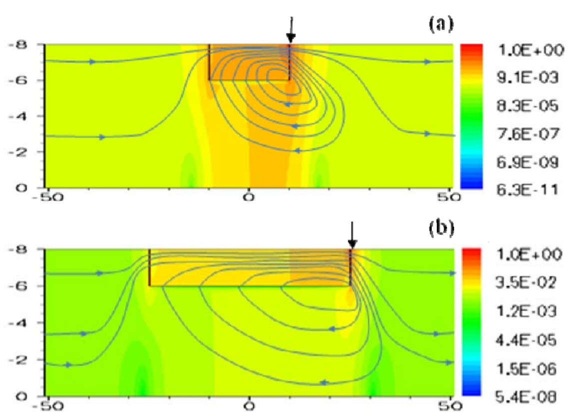


Fig.3. The contour of the laser induced current density and the steady-state current flow lines. (a) the junction length of 20μm. (b) the junction length of 50μm.

IV. Conclusion

In conclusion, the sensitivity of LBIC to the junction depth and length is investigated for n^+-on-p HgCdTe photodiode. The simulated LBIC profiles are in good agreement with the experimental data. A lateral and vertical current flow mechanism is proposed to discuss the structural size dependence of LBIC. The peak LBIC magnitude appropriately linearly increases with increasing both junction depth and length. Additionally, the slope in the n-type region decreases with the increasing junction depth. The results are helpful for us to understand the performance of HgCdTe photodiodes at an earlier stage.

Acknowledgements

This work was financially supported by National Natural Science Foundation of China (11174002) and by '211 Project' of Anhui University.

References

[1] V. Garber, A. Dust, E. Baskin, B. Spektor, and G. Bahir, "Estimation of the p-n Junction Depth in LWIR HgCdTe Detectors from the Spatial Profile of the Lateral Photocurrent and Transverse Photovoltage Induced by an Infrared Small Spot," J. Electron. Mater. vol. 30, pp. 690-695, 2001.

[2] W. D. Hu, X. S. Chen, Z. H. Ye, W. Lu, "A hybrid surface passivation on HgCdTe long wave infrared detector with in-situ CdTe deposition and high-density Hydrogen plasma modification," Appl. Phys. Lett. vol. 99, pp. 091101, 2011.

[3] E. Bellotti and D. D. Orsogna, "Numerical analysis of HgCdTe simultaneous two-color photovoltaic infrared detectors," IEEE J. Quantum Electron. vol. 42, pp. 418-426, 2006.

[4] W. D. Hu, X. S. Chen, Z. H. Ye, Y. G. Chen, F. Yin, B. Zhang, and W. Lu,"Polarity inversion and coupling of laser beam induced current in As-doped long-wavelength HgCdTe infrared detector pixel arrays: Experiment and simulation," Appl. Phys. Lett. vol. 101, pp.181108, 2012.

[5] A. E. Gluszak, S. Hinckley, and K. Eshraghian, "Determination of junction depth and related current phenomena using laser beam induced curren," Proceedings of SPIE vol. 5274 (SPIE, Bellingham, WA), 2004.

[6] D. A. Redfern, C. A. Musca, J. M. Dell, and L. Faraone, "Characterization of electrically active defects in photovoltaic detector arrays using laser beam-induced current," IEEE Trans. Electron Devices vol. 52, pp. 2163-2174, 2005.

[7] F. Yin, W. D. Hu, B. Zhang, Z. F. Li, X. N. Hu, X. S. Chen and W. Lu, "Simulation of laser beam induced current for HgCdTe photodiodes with leakage current," Opt. Quantum Electron. vol. 41, pp. 805-810, 2009.

[8] W. D. Hu, X. S. Chen, Z. H. Ye, and W. Lu, "An improvement on short-wavelength photoresponse for a heterostructure HgCdTe two-color infrared detector," Semicond. Sci. Technol. vol. 25, pp. 045028, 2010.

[9] C. A. Musca, D. A. Redfern, E. P. G. Smith, J. M. Dell, L. Faraone, and J. Bajaj, "Junction Depth Measurement in HgCdTe Using Laser Beam Induced Current (LBIC)," J. Electron. Mater. vol. 28, pp. 603-610, 1999.

[10] C. A. Musca, D. A. Redfern, J. M. Dell, and L. Faraone, "Laser beam induced current as a tool for HgCdTe photodiode Characterization," Microelectron. J. vol. 31, pp. 537–544, 2000.