Optimization of InSb Infrared Focal Plane Arrays

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Abstract

The quantum efficiency (QE) for mid-wavelength InSb infrared focal plane arrays has been numerically studied. Effects of the absorption length and thickness of p-region on device QE have been investigated. Our work shows that the optimum thickness of p-region is largely dependent on the absorption characteristics of the InSb.

I. Introduction

InSb which is a narrow-bandgap compound semiconductor has a response cutoff wavelength of 5.5µm at 77K. Due to its excellent absorption ability in the spectral range of 3µm-5µm and superior fundamental properties, InSb has been widely used in military and civil fields[1-8]. Therefore, it is particularly important to fully understand the photoresponse mechanisms of InSb to improve device performance[9]. In this paper, effects of the absorption length and thickness of p-region on the device QE are numerically investigated. The optimum thickness of p-region is largely dependent on the absorption characteristics of the InSb.

II. Simulation Models

For plain drift-diffusion simulation, the well known Poisson equation and continuity equations are self-coupled. The carrier generation-recombination process consists of SRH, Auger, and optical generation-recombination terms. Additionally, the tunneling effect is implemented in the continuity equations[10-13].

III. Result And Discussion

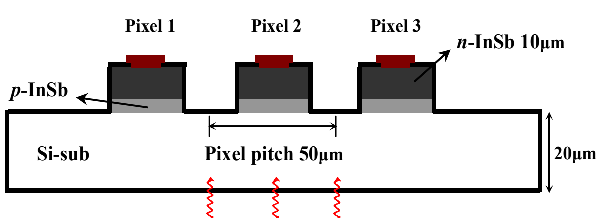

Figure 1. Schematic of linear InSb infrared focal plane arrays.

The InSb focal plane arrays discussed in this study are composed of three pixels, as shown in Figure 1. The n-region with the doping density of 10^{15}cm^{-3}, has a thickness of 10µm. The p-region is doped with 10^{17}cm^{-3} and its thickness is an adjustable parameter in the simulated process. The pixel pitch and filling factor are 50µm and 92% respectively. It should be noted that each element including an individual p-n junction forms an island on the 20-µm-thick Si substrate. During the simulation, only the center pixel is front-side illuminated using a 5µm incident light under 77K background, i.e., the optical energy is incident on the p-region. And the effect of antireflection coating is not taken into consideration. Finally the QE curve from pixel 2 is obtained.

For the conventional InSb detectors, the infrared radiation is incident on the n-type bulk InSb substrate. The photo-generated minority carriers will diffuse a long distance to p-n junction to be converted into electrical response. However, it is impossible to limit all inter-pixel migration of carriers. Some of them diffuse into neighboring junctions to form the crosstalk[14]. In our calculations, the light is directly incident on the thinner p-region instead of n-region. The carriers can diffuse to junction more easily with less recombination to lead a higher QE[15]. Moreover, all of the diodes are spaced from each other and the effect of crosstalk can be significantly reduced.

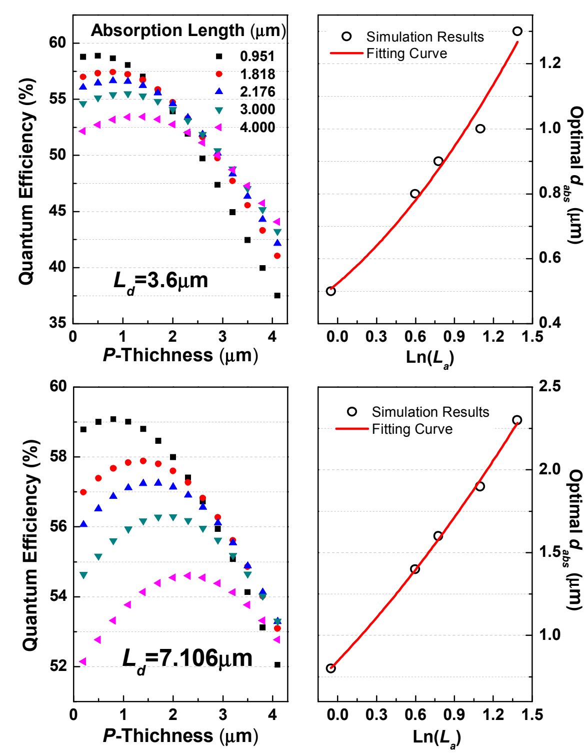

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Figure 2. QE vs. p-region thickness with L_a changing from 0.951 to 4.0μm for different L_d, i.e., 3.6, 7.106μm (left column). Fitting curve of the optimum thickness of p-region as a function of L_a (right column).

However the light can not be fully absorbed in the p-region due to its thinner thickness. Some of optical energy penetrates through the p-region into the n-region where still more minority carriers are generated[16]. Part of these additional carriers will diffuse back to the junction to contribute to the response. So the QE is dependent on not only carrier diffusion length L_d but also light absorption length L_a. In this paper, L_d refers to electrons diffusion length and that of holes is fixed at 81.2μm.

Figure 2 shows the simulated QE as a function of the p-region thickness with L_a changing from 0.951 to 4.0μm for different L_d, i.e., 3.6, 7.106μm (left column). By fitting the curve of the optimum p-region thickness d_{abs} as a function of L_a (right column), two empirical formulas which have the same polynomial format for different L_d are obtained:

$$d_{abs} = 0.52472 + 0.34239 \times \ln(L_a) + 0.13974 \times \ln^2(L_a) \quad \text{for } L_d = 3.6\mu m$$

$$d_{abs} = 0.8449 + 0.83016 \times \ln(L_a) + 0.14969 \times \ln^2(L_a) \quad \text{for } L_d = 7.106\mu m$$

IV. CONCLUSION

The quantum efficiency of mid-wavelength InSb infrared focal plane arrays has been numerically simulated with a two-dimensional simulator. Effects of the absorption length and thickness of p-region on device quantum efficiency have been investigated. The empirical formulas about the optimum thickness of p-region and the absorption length are obtained.

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REFERENCES

[1] Y. T. Gau, L. K. Dai, S. P. Yang, P. K. Weng, K. S. Huang, Y. N. Liu, C. D. Chiang, F. W. Jih, Y. T. Cherng and H. Chang, "256 x 256 InSb focal plane arrays", *Proc. SPIE*, vol. 4078, pp.467, 2003.

[2] A. Rogalski, "Infrared detectors: an overview", *Infrared Physics & Technology*, 43, pp. 195-196. 2002.

[3] K. M. Chang, J. J. Luo, C. D. Chang and K. C. Liu, "Wet Etching Characterization of InSb for Thermal Imaging Applications", *Japanese Journal of Applied Physics*, 45, pp. 1477 2006.

[4] I. Kanno, S. Hishiki, O. Sugiura, R. Xiang, T. Nakamura, and M. Katagiri, "InSb cryogenic radiation detectors", *Nuclear Instruments and Methods in Physics Research A*, 568, pp. 416, 2006.

[5] I. Kimukin, N. Biyikli, and E. Ozbay, "InSb high-speed photodetectors grown on GaAs substrate", *Journal of Applied Physics*, 94, pp. 5414, 2003.

[6] I. Kimukin and N. Biyikli, "High-Speed InSb Photodetectors on GaAs for Mid-IR Applications", *IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS*, 10, pp. 766, 2004.

[7] H. T. Pham, S. F. Yoon, D. Boning, and S. Wicaksono, "Molecular beam epitaxial growth of indium antimonide and its characterization", *J. Vac. Sci. Technol. B*, 25(1), pp. 11, 2007.

[8] W. J. Parrish, J. D. Blackwell, G. T. Kincaid and R. C. Paulson, "Low-cost high-performance InSb 256 x 256 infrared camera", *Proc. SPIE*, vol. 1540, pp. 274, 1991.

[9] N. Guo, W. D. Hu, X. S. Chen, C. Meng, Y. Q. Lv and W. Lu, "Optimization of Microlenses for InSb Infrared Focal-Plane Arrays", *Journal of Electronic Materials*, 40, pp. 1647-1650, 2011.

[10] 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", *Applied Physics Letters*, 99, pp. 091101, 2011.

[11] W. D. Hu, X. S. Chen, Z. H.Ye, C. Meng, Y. Q. Lv, W. Lu, "Effects of absorption layer characteristic on spectral photoresponse of mid-wavelength InSb photodiodes", *Optical and Quantum Electronics*, 42, pp. 801-808, 2011.

[12] W. D. Hu, X. S. Chen, F. Yin, Z. H. Ye, C. Lin, X. N. Hu, Z. J. Quan, Z. F. Li and W. Lu, "Simulation and design consideration of photoresponse for HgCdTe infrared photodiodes", *Optical and Quantum Electronics*, 40, pp. 1255, 2008.

[13] W. D. Hu, X. S. Chen, F. Yin, Z. H. Ye, C. Lin, X. N. Hu, Z. F. Li, W. Lu, "Numerical analysis of two-color HgCdTe infrared photovoltaic heterostructure detector", *Optical and Quantum Electronics*, Volume 41, pp. 699-704, 2009.

[14] M. Davis, M. Greiner, J. Sanders and J. Wimmers, "Resolution issues in InSb focal plane array system design", *Proc. SPIE*, vol. 3379, pp. 289, 1998.

[15] M. Davis and M. Greiner, "Indium antimonide large-format detector arrays", *Optical Engineering*, 50, pp. 061016, 2011.

[16] H. A. Timlin and C. J. Martin,"Electro-optical detector array", U.S.Patent No. 5,227,656, 1993.