Numerical analysis of two-color HgCdTe infrared photovoltaic heterostructure detector

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Abstract

We report on 2D numerical simulations of spectral photoresponse characteristic for two-color HgCdTe infrared photovoltaic detector. Effects of thickness of absorption layer and doping profiles on the photoresponse, quantum efficiency and crosstalk have been investigated. Optimal thickness of absorption layers and doping profiles are numerically calculated.

I. Introduction

Over the past few years there has been exciting progress in developing two-color HgCdTe infrared photovoltaic detectors as growing demands both for civilian and military applications. Integrated two-color detectors can detect two spectral bands separately and independently in each pixel in a single focal plane with high temporal and spatial coherence [1-3]. The two-color HgCdTe photodetector provides an added dimension of contrast that is available for signal processing and serves as a visual aid in scene interpretation, and thus to determine both absolute temperature and unique signatures of the objects from the background [1]. For thin film two-color HgCdTe infrared detectors with epitaxial growth technology, the photoresponse, quantum efficiency and crosstalk of the two junctions are strongly affected by structure characteristics, such as thicknesses of absorption layer and doping profiles. To improve the device performance, detail analysis of mechanisms of structure-related characteristics for two-color HgCdTe infrared detector is needed. Numerical simulations, containing structural details such as layer thicknesses, doping profiles and trap concentrations, provide key insights into device design and the degradation mechanisms of the reliability [4].

In this paper, numerical simulations are used to investigate the spectral photoresponses of two-color HgCdTe infrared photovoltaic detectors. Effects of thicknesses of absorption layer and doping profiles on the performance of two-color HgCdTe photodetectors are theoretically studied.

II. Simulation Models

Steady-state numerical simulations are performed using Sentaurus Device, a commercial package by Synopsys. For plain drift-diffusion simulation the well known Poisson equation and continuity equations are used. The carrier generation-recombination process consists of Shockley-Read-Hall, Auger, and optical generation-recombination terms. Additionally, tunneling effects, such as band-to-band and trap-assisted tunneling models, are included in the continuity equations by representing them as additional generation-recombination processes.

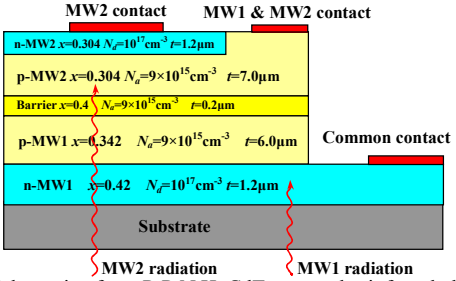

Fig.1. Schematic of n-p-P-P-N HgCdTe two-color infrared photovoltaic heterostructure detector

Figure 1 is the schematic of n-p-P-P-N two-color HgCdTe infrared photovoltaic heterostructure detector with an in-situ doped mesa mid-wavelength junction (MW1) and ion-implanted planar mid-wavelength junction (MW2).

III. Result And Discussion

Figure 2 compares the spectral photoresponse for different minority carrier lifetimes. The simulation results with the minority carrier lifetime larger than 10ns are in agreement with the reported experimental results with similar LETI structures [5, 6]. As shown in Fig. 2, the spectral photoresponse increases with an increase of the lifetimes. This is because that the bigger the minority carrier lifetime is, the larger the minority diffusion length is. The photo-generated electron-hole pairs are much easier to diffuse to the junction regions inducing the increased the photoresponse at the two p-n junctions.

Figure 3(a) shows the quantum efficiency and crosstalk as a function of the thickness of the MW1 absorption layer with the incident light wavelength of 3.8μm. It is found that the crosstalk of the MW1 from MW2 monotonously decreases with the increase of the thickness the MW1 absorption layer, and gradually approaches the saturation. Near the peak-photoresponse wavelength of 3.8μm, as shown in Fig. 3(a), the photoresponse increases with the increase of the thickness the MW1 absorption layer first, and then decreases. The maximum photoresponse, which is the consequence of competing effects of the absorption and diffusion, is at the thickness of 8~9μm.

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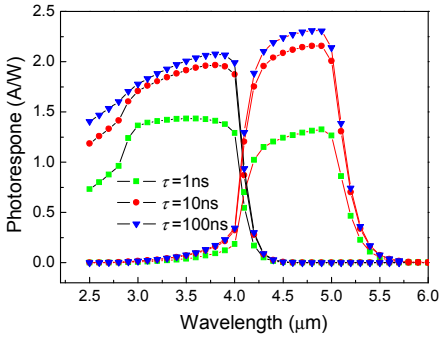

Fig. 2. Simulated spectral photoresponses with different carrier lifetimes.

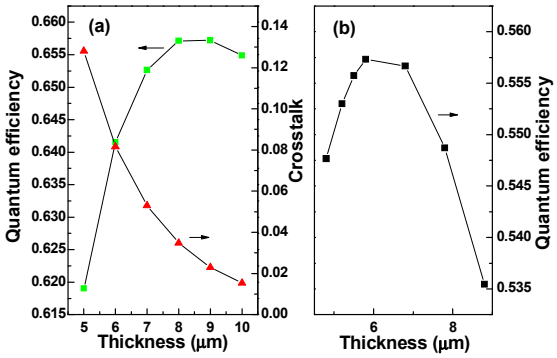

Fig. 3. (a) Quantum efficiency (left Y with green rectangles) and crosstalk (right Y with red triangles) vs. thickness of the MW1 absorption layer; (b) Quantum efficiency vs. thickness of the MW2 absorption layer.

Figure 3(b) presents the quantum efficiency as a function of the thickness of the MW2 absorption layer with the incident light wavelength of 4.8μm. Similar to MW1, there is an optimal photoresponse for the MW2 absorption layer. The corresponding maximum thickness of the MW2 absorption layer is about 6~7μm. From Figs. 4 and 5, it is found that a slight decrease of the thickness of the MW2 absorption layer does not cause the significant reduction of photoresponse, while a slight increase of the thickness of the MW1 absorption layer can significantly improve the photoresponse, meanwhile confine the crosstalk to a reasonable value. Therefore, the device photoresponse can be optimized by adjusting the absorption layers thicknesses between the MW1 and MW2 junctions while keeping a constant total thickness of the device.

Photoresponse as a function of p doping concentration is presented in Fig. 4(a). With the increase of the p doping density, the calculated photoresponses of both diodes decrease. According to the equation

$$\tau = \left(1/\tau_{SRH} + 1/\tau_{Aug} + 1/\tau_{Rad} \right)^{-1},$$

SRH lifetime dominates the total lifetime for the low doping densities, and effect of the Auger lifetime at the low doping density on the diffusion length is negligible. Therefore, the photoresponse decrease slowly with the increase of the doping density of the absorption layer. However, when the doping density larger than 3×10^{16}cm^{-3}, the photoresponses of the two junctions are significantly reduced due to Auger recombination which is related to the high doping density of the absorption layer.

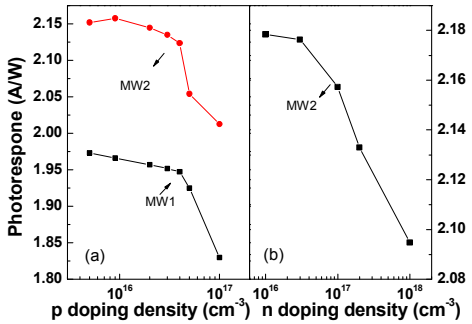

Fig. 4. Photoresponse as functions of (a) p and (b) n doping concentrations

Photoresponse as a function of n doping concentration is presented in Fig. 4(b). The calculated photoresponse of the MW2 diode decreases with the increase of the n doping density. The photoresponses, especially the MW1 diode (the results are not shown), are not very sensitive to the doping density of the non-absorption layers. However, for the n-p-P-P-N HgCdTe two-color infrared photovoltaic detector, the MW2 are a homojunction. Part of the incident light can also be absorbed in the n region of the MW2. Therefore, similar to the p absorption layer, the photoresponse of the MW2 as shown in Fig. 4(b) slightly decreases with the increase of the n doping density due to the Auger recombination.

IV. Conclusion

The spectral photoresponses of n-p-P-P-N HgCdTe two-color infrared photovoltaic heterostructure detector have been simulated with a 2-D numerical simulator. The simulation results show that the optimal thicknesses for the maximum quantum efficiency of the MW1 and MW2 taking into account the crosstalk of the two junctions are 8~9μm and 6~7μm, respectively. An increase of the doping profiles can induce a reduction of the photoresponse, especially for the high doping density of the absorption layer.

Acknowledgements

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