Numerical analysis of Mid-wavelength InSb Infrared Focal Plane Arrays

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Abstract

The spectral photoresponse and crosstalk characteristic for mid-wavelength InSb infrared focal plane arrays have been numerically studied. Effects of mesa depth, substrate thickness, pixel dimension and channel length on the photoresponse and crosstalk have been investigated. Our work shows that the spectral photoresponse and crosstalk are largely dependent on the geometric design of device.

I. INTRODUCTION

InSb, which is a III-V semiconductor, has a 0.227eV band gap at 77K and a cut-off wavelength of 5.5μm. Due to its excellent absorption ability in the spectral range of 3-5μm[1,2] and superior fundamental properties, InSb has been widely used in military and civil fields. So fully understanding the inner physics mechanism of crosstalk and optimizing the device structure to improve the photoresponse is particularly important.

In this paper, effects of the pixel crosstalk on the photoresponse are numerically investigated. The photoresponse is limited by the position and size of depletion region, which is related to mesa depth, substrate thickness, pixel dimension and channel length.

II. SIMULATION MODELS

For plain drift-diffusion simulation the well known Poisson equation and continuity equations are used. The carrier generation-recombination process consists of SRH, 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[3].

The InSb mesa-type structure discussed in this study is composed of three pixels, as shown in Figure 1. The n-region with the doping density of 10^{15} cm^{-3}, consists of one part of mesa and the substrate, which is the absorption layer. The p-region with the doping density of 10^{17} cm^{-3}, has a thickness 0.8μm, which is the capping layer. In addition, the device surface and sidewall of the mesa is covered by SiO_2 passivation layer. The separation between two adjacent mesas is defined as the channel length, *d*. *L* used in this configuration, is the dimension of pixel. And then the pixel pitch is equal to *L* + *d*, see figure 1. *H* and *h* represent the mesa depth and substrate thickness, respectively. During the simulation, only the center pixel is backside illuminated using a 5.5μm incident light under 77K background. It should be noted that the illumination area is the pixel pitch. Finally the photoresponse curve from pixel 2 is obtained. At the same time, the crosstalk, which is defined as a percentage corresponding to the pixel 1 response divided by pixel 2 response[4], can be evaluated by computing the photocurrent at the contacts.

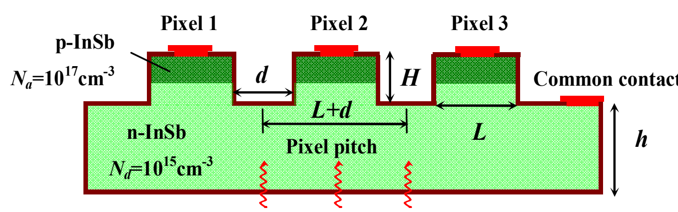

Figure 1. Schematic of mesa-type linear InSb infrared focal plane array.

III. RESULT AND DISCUSSION

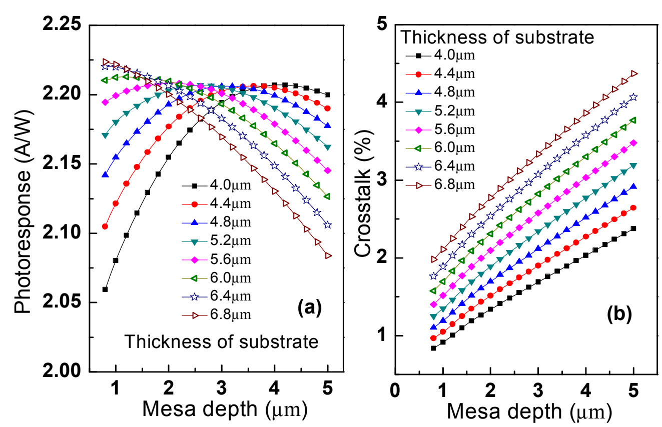

Figure 2 (a) Photoresponse vs. mesa depth with substrate thickness changing from 4.0 to 6.8μm. (b) Crosstalk vs. mesa depth with substrate thickness changing from 4.0 to 6.8μm.

Figure 2 (a) shows that the calculated photoresponse as a function of the mesa depth (*H*) with the thickness of substrate

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(h) changing from 4.0 to 6.8μm, L=40μm, and d=10μm. At the short H range, the photoresponse monotonously increases with the increase of h. Under backside illumination, the incident lights are almost absorbed in n-region. With the increase of absorption layer, more and more photons are absorbed with lots of electron and hole pairs being generated. So a further increase of the response can be obtained. At the long H range, the photoresponse monotonously decreases with the increase of h. This is because that the increase of H and h results in enlarging the distance from photogeneration region to the junction. So the recombination mechanism dominates in the carrier transportation leading to the decrease of response.

Figure 2 (b) shows the crosstalk as a function of the mesa depth (H) with the thickness of substrate (h) changing from 4.0 to 6.8μm. The spectral crosstalk monotonously increases with h and H, respectively. This is because that with the increase of H and h, the junction is moving away from the place where the electron and hole pairs are generated. Therefore the photo-generated minority carriers are collected by center pixel weakly, and diffuse to other pixels easily.

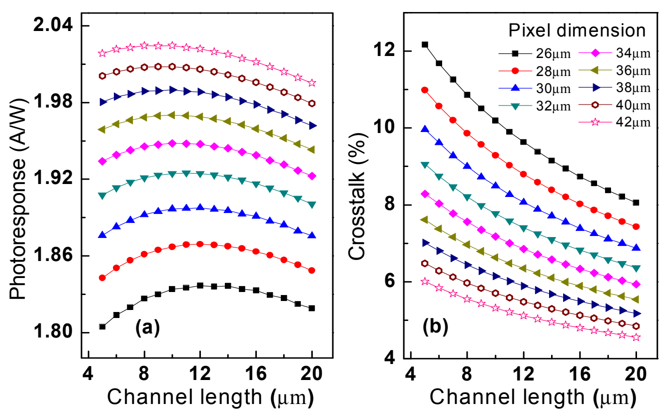

Figure 3 (a) Photoresponse vs. channel length with pixel dimension changing from 26 to 42μm. (b) Crosstalk vs. channel length with pixel dimension changing from 26 to 42μm.

Figure 3 (a) is the calculated photoresponse as a function of the channel length (d) with the pixel dimension (L) changing from 26 to 42μm, h=10μm, and H=3.0μm. It can be seen from this figure that response increases monotonically with the increase of pixel dimension. Due to L increase, the scope of depletion region is larger than before. This change enhances the collection efficiency of the junction. It's obvious that response increases first, and then decreases as the d increases. The increased channel length reduces the pulling effect of the adjacent pixels on the photo-generated minority carriers. Therefore, most of carriers, which would possibly be attracted to the other pixels, are collected by the center junction. But, continuous increase of d makes a considerable part of light incident on the interval between the two pixels. And then the photo-generated carriers need to diffuse a long distance to be collected. So the recombination mechanism dominates in the carrier transportation leading to the decrease of response.

The crosstalk as a function of channel length (d) with pixel dimension (L) changing from 26 to 42μm is presented in figure 3 (b). The spectral crosstalk monotonically decreases with L increase. This is because that the larger pixel dimension makes the bigger junction area. This change enhances the collection efficiency of the junction and reduces the carrier diffusion to other pixels. It also can be found that crosstalk monotonically decreases with d increase. There are two mechanisms for this. The first is the increase of channel length results in the junction of pixel 1 away from the photogeneration region. So the carriers are attracted by pixel 1 not easily. The second is the carriers, which contribute to crosstalk, are recombined during a long lateral diffusion distance.

IV. CONCLUSION

The spectral photoresponse and crosstalk of mid-wavelength InSb infrared focal plane arrays have been numerically simulated with a two-dimensional simulator. The simulation results show that the position and size of junction have an important effect on both spectral photoresponse and crosstalk. The thicker absorption layer can absorb lots of photons to generate more electron and hole pairs which result in a high photoresponse. But the increase of the layer thickness can also enlarge the distance, which is from photogeneration region to the junction, to make the recombination dominated in the diffusion process. So the maximum photoresponse is the consequence of competing effects of the absorption and recombination. With the junction away from the photogeneration region, the photo-generated minority carriers feel the effect of built-in electric field more and more weakly and diffuse laterally to other pixels easily to increase the crosstalk. The lager junction size, which enhances the collection efficiency of the junction and reduces the carrier diffusion to other pixels, can lead to the higher photoresponse and lower crosstalk.

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