Photoresponse simulation of visible blind GaN/AlGaN p-i-n photodiode

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Abstract

The spectral photoresponse characteristics for visible blind GaN/AlGaN p-i-n photodiode have been numerically studied. Effects of the absorption layer thickness and the n-layer thickness on the photoresponse spectra have been investigated. Our work shows that the absorption layer thickness and n-layer thickness have important impact on the peak value of photoresponse spectra and rejection ratio of short-wavelength side, respectively.

I. INTRODUCTION

Visible-blind ultraviolet photodetectors are critical components in many applications including UV astronomy, flame sensors, missile warning, and space-to-space communications [1-2]. Although recent advances in GaN-based ultraviolet detectors have opened the way for their practical applications, most of them have been made experimentally[3-4], only a limited amount of theoretical works have been performed to study dependence of the device characteristics on device geometry. Numerical simulations, which can contain structural details such as layer thicknesses, doping profiles and trap concentrations, provide key insights into device design and the degradation mechanisms of the reliability. In order to obtain the comprehensive understanding of photoresponse mechanism of photodetector and improve the performance of the device, the two dimensional numerical simulation is carried out for visible blind GaN/AlGaN p-i-n photodiode.

In this paper, the effects of the absorption layer thickness and n-layer thickness on the performance of visible blind GaN/AlGaN p-i-n photodiode are theoretically investigated in detail.

II. SIMULATION MODELS AND DEVICE STRUCTURE

Steady-state numerical simulations are performed using Sentaurus Device [5]. Physical models consist of drift-diffusion model for carrier transport, high field saturation model for carrier mobility, Shockley-Read-Hall, Auger, and Radiative recombination model for carrier generation-recombination rate, and Raytrace model for optical generation. Additionally, barrier tunneling models both for electron and hole are included in the interface of GaN and AlGaN to obtain more precise simulation results.

The structure of visible blind GaN/AlGaN p-i-n diode consists of a 0.6μm n+-doped AlGaN layer with the doping density of $3\times10^{18}cm^{-3}$, a 0.1μm unintentionally doped GaN absorption layer with the electron density of $5\times10^{15}cm^{-3}$, and a 0.15μm p+-doped GaN layer with doping density of $3\times10^{17}cm^{-3}$. Figure 1 shows the cross-section of simulated visible blind $GaN/Al_xGa_{(1-x)}N$ p-i-n diode with Al mole fraction (x) of 0.3. The thickness of the absorption layer and n-layer are defined as d_{abs} and d_n, respectively.

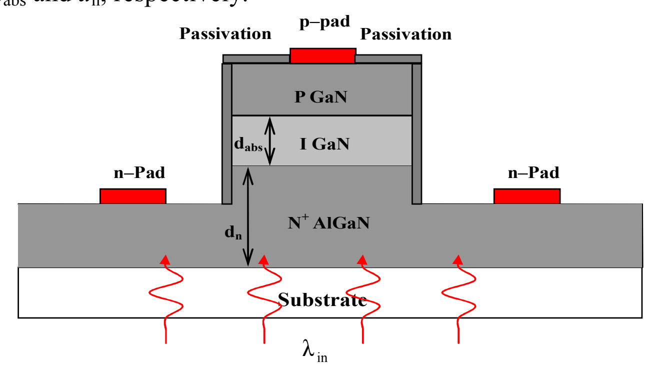

Figure 1. Schematic cross section of GaN/AlGaN p-i-n photodiode.

III. RESULT AND DISCUSSION

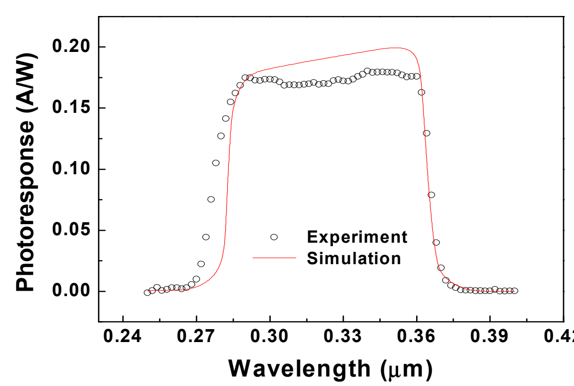

Figure 2 Comparison of experimental and simulated photoresponse spectra.

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agreement with the experiment, which confirm the right selection of the simulation models. As shown in the figure 2, an obvious response window is observed at the wavelength range between 0.28μm and 0.36μm. As the wavelength is below 0.28μm or above 0.36μm, photoresponse decreases sharply. The latter is because the absorption coefficient at long wavelength range is relatively small, and the light is scarcely absorbed over the entire absorption layer. The former can be attributed to the additional absorption of AlGaN n-layer.

Figure 2 (a) presents the photoresponse as a function of d_{abs} with the different incident light wavelength. The photoresponse increases with the increase of d_{abs} first, and then decreases. The maximum photoresponse is achieved at d_{abs}=0.5μm, which is the consequence of competing effects of the density of photo-generated carriers and electric filed intensity in the absorption layer. Specifically, as d_{abs} increases, more light will be absorbed, thus photo-generated carriers accordingly increase. Meanwhile, as shown in the figure 2 (b), the electric filed intensity in the absorption layer is overall decreased. According to the well known formula [6]:

$$J = J_n + J_p = (q\Delta n\mu_n + q\Delta p\mu_p)\varepsilon \qquad (1)$$

Variation relation of photoresponse with the increased d_{abs} is dominated by increased photo-generated carriers density and decreased electric field intensity in the absorption layer.

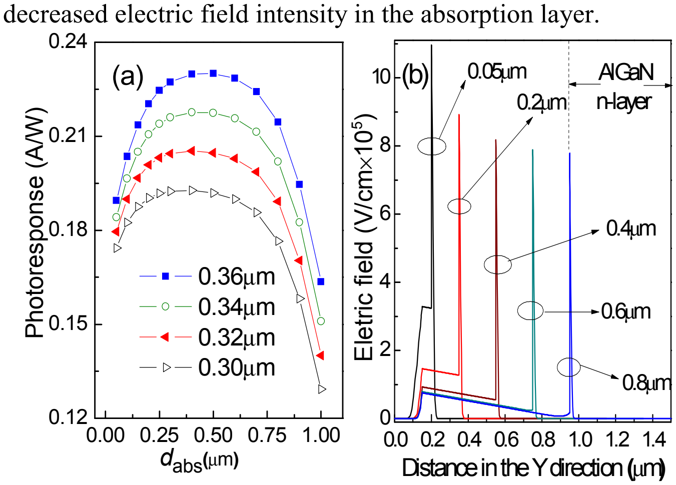

Figure 3 (a) Photoresponse vs. d_{abs} with incident light wavelength of 0.30, 0.32, 0.34, 0.36μm, respectively; (b) Electric field vs. distance in the Y direction with d_{abs} changing from 0.05μm to 0.8μm.

Figure 4 (a) compares the photoresponse for different carrier lifetimes at λ_{in}=0.36μm. It is found that photoresponse increases with the increase of the carrier lifetime, and the optimal absorption layer thickness increases as well. This is because that the larger the carrier lifetime is, the longer the diffusion length is, thus the less the loss of carriers because of recombination in the absorption layer will be. The figure 4 (a) casts light on how to obtain the optimal absorption layer thickness on the condition that the carrier lifetime is known, which provides a basis for the device optimization. The rejection ration is defined as the ratio of the maximum value of response window to the minimum value at the long-wavelength side or the short-wavelength side, which is an important parameter for estimation of device quality. Figure 4 (b) shows the rejection ratio as a function of d_n with the different doping density of the absorption layer. The rejection ratio for short-wavelength side increases with the increase of the doping density of the absorption layer, and when the doping density of the absorption layer remains constant, the rejection ratio increases monotonously with the increasing of d_n, and finally saturates. Generally, out of consideration of fabrication costs, d_n should not be too thick, so according to figure 4 (b), the optimal d_n can be obtained taking both high rejection ratio and low fabrication costs into consideration.

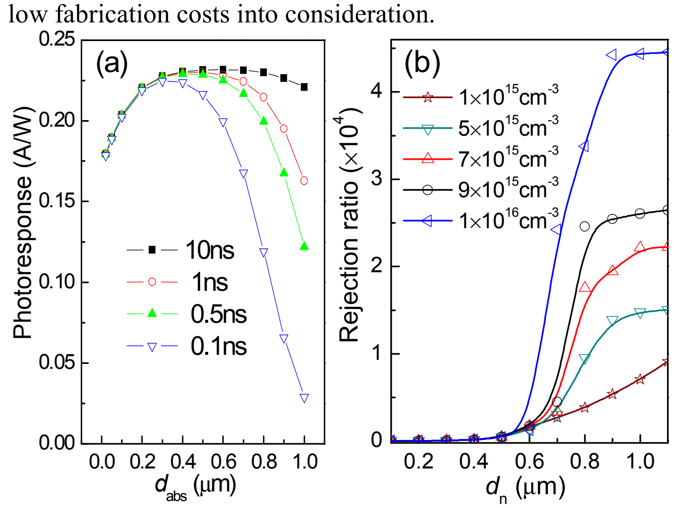

Figure 4 (a) Photoresponse vs. d_{abs} with τ=10, 1, 0.5, and 0.1ns respectively; (b) Rejection ratio for short-wavelength side vs. d_n with different doping density of the absorption layer.

IV. CONCLUSION

The spectral photoresponse characteristics for visible blind GaN/AlGaN p-i-n photodiode have been numerically simulated. The simulation results is in good agreement with the experiment, the optimal d_{abs} can be extracted as consequence of competing effects of the density of photo-generated carriers and electric field intensity in the absorption layer.

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