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High Performance AlGaN Metal-Semiconductor-Metal Ultraviolet Photo Detectors

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Abstract

In this paper, we present Al0.25Ga0.75N ultraviolet Schottky barrier photodetectors on Al2O3, that was modeled using The two-dimensional device simulator Silvaco and ATLAS. It was found that the device has very low dark current, with the applied bias below 1 V, the dark current was below 16 pA and the peak responsivity of 0.07A/W was achieved at 308nm. We have performed a comparison between our modeling and the experimental results.

Keywords: Photodetector, MSM, ultraviolet Schottky barrier photodetectors

Introduction

Nitride-based materials are recognized as very promising candidates for the fabrication of semiconductor photodetectors PDs in the UV spectral [1, 2]. The bandgap energy of AlxGa1−xN can be adjusted by changing Al content to match up requisite detector cut off wavelength. Various types of AlGaN based detectors have been proposed such as p–n junctions, PIN diodes, Schottky barrier detectors and photoconductors [3]. The wide direct bandgap provides an intrinsic visible blindness, which is a critical advantage for a number of applications [1] and can operate under severe conditions (high temperature and energy levels) [3]. Among these structures, MSM photodetectors has a special place. It is a planar photodiode based on simple technology, it is easy to integrate [2], it has fast response, small capacitance and dark current, as well as large active device area [2]. It consists of two Schottky electrodes, often interlinked in the form of a comb structure, leaving a free semiconductor surface between the two contacts which forms the active region in which light will be absorbed [2, 4].

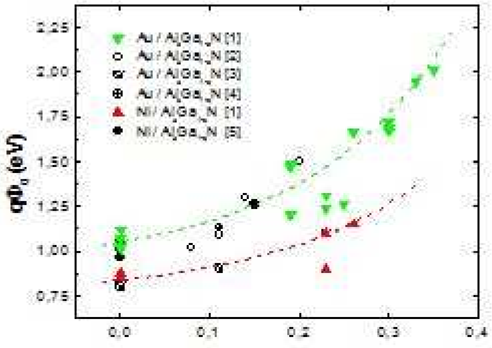
The substrate choice is one of the key issues in nitride semiconductor. Aluminum nitride (AlN), with ultra-low dislocation density are very promising for use in III-nitride epitaxial growth required for ultraviolet (UV), gallium nitride (GaN) and sapphire (Al_2O_3) are potential candidates which are all under investigation [5].

The active detector was a 3 µm thick unintentionally doped AlGaN layer which was gown on top of a 10 nm thick AlN buffer layer and the AlN buffer layer was on a 1 µm thick GaN. The electrode fingers are 5 µm wide, and with a 5 µm spacing gap. A 200 nm thick Au was deposited [6]

Modeling Software

In comparison with an exclusive experimental procedure for this optimization the TCAD (Technology Computer Aided Design) methodology exhibits the advantages of reduced development costs and development time [7]. ATLAS is a physically-based two and three dimensional device simulator. It predicts the electrical characteristics of physical structures by simulating the transport of carriers through a two-dimensional grid. [3]. ATLAS was used also to extract the optical characteristics such external quantum efficiency, responsivity, and frequency response characteristics when the photodetector is illuminated [7].

To obtain an accurate structure and mesh description for device simulation, the following procedure is used. The Mesh is basically a two dimensional grid that covers the domain of physical simulation [8]. An important step in achieving accurate performance simulations for the device is incorporation of well documented material parameters and their dependences, like that of mobility on the doping level.



Molar fraction x of Al

Figure 1. Variation of the height of the Schottky barrier as a function of the molar fraction of Al [2]
(1)=[9], (2)=[10], [3]=[11], (4)=[12], (5)=[13]

The nature of the metal used to fabricate the Schottky diode and the excitation wavelength, for values situated both above and below the bandgap energy of the semiconductor. The decrease in the response coefficient observed when the fraction x of aluminum increases Fig. 1.

The schematic illustration about the structure was shown in Figure 2.

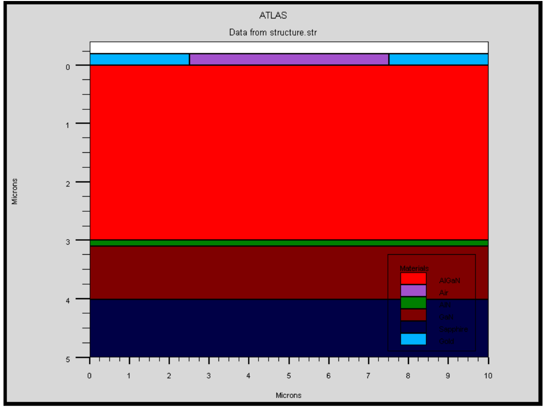


Figure 2. : MSM photodetector struture

Results and Discussion

ATLAS was used to obtain the electrical characteristics of the simulated device. Figure 3 shows the I–V curve of the photodetector. The dark current was lower than 16 pA at 1 V bias. The current transport in metal-semiconductor contacts is due mainly to majority carriers, in contrast to p-n junctions where the minority carriers are responsible. The five processes are (1) emission of electrons from the semiconductor over the potential barrier into the metal, (2) quantum mechanical tunneling of electrons through the barrier (3) recombination in the space-charge region (4) diffusion of electrons in the depletion region, and (5) holes injected from the metal that diffuse into the semiconductor [4].

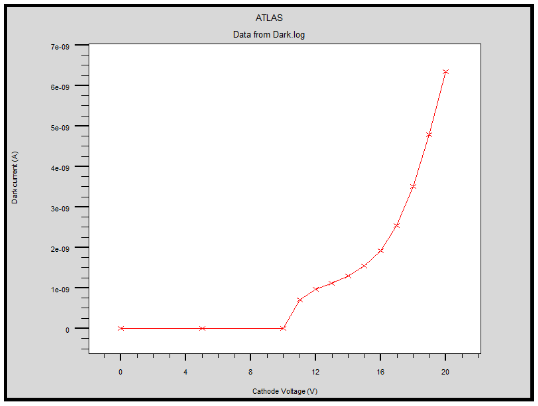


Figure 3. The I–V curve of the $Al_{0.25}Ga_{0.75}N$ MSM photodetector in dark

The low dark current show the high quality $Al_{0.25}Ga_{0.75}N$ layer and good Schottky contacts.. This current will improve and make a significant contribution to the signal-to-noise ratio, the different sources of noise in MSMs, as in other photodetectors, are thermal noise, $1/f^{\alpha}$ noise and shot noise.

Fig. 3 shows the simulated distribution of the electric field of the photodetector in obscurity. If the bias voltage is sufficiently high, the region between the electrodes is completely depleted and this produces an electric field.

The peak electric field of the is $7.81*10^4$V/cm.

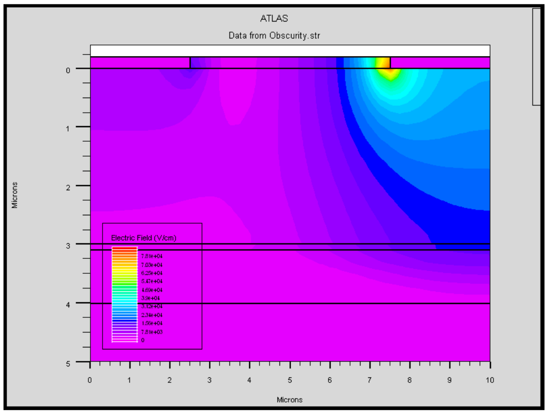


Figure 4. Electric Field distribution in Dark

We illuminate the device at 300 nm, Fig 5, 6. Present the I–V curve and the distribution of electrical field respectively.

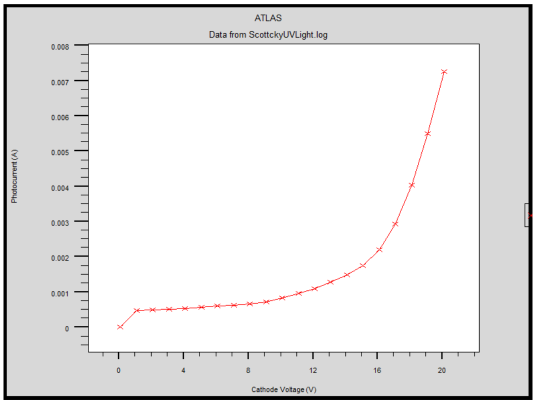


Figure 5. The I–V curve of the Al0.25Ga0.75N MSM photodetector under illumination

The absorption of light near the reverse-biased junction creates electron-hole pairs which are separated under the effects of the electric field. The photocurrent/dark current rejection is more than five orders of magnitude.

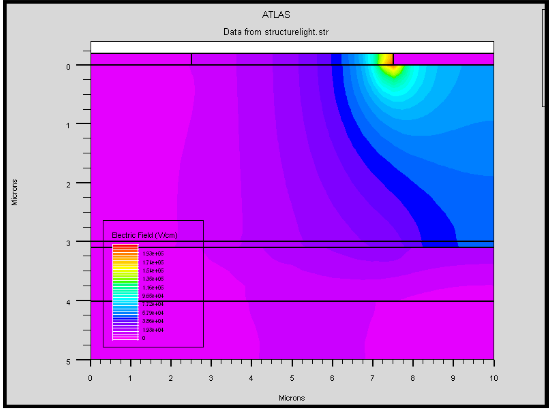


Figure 6. Electric Field distribution under illumination

Figure 7 shows the spectral responsivity of a $Al_{0.25}Ga_{0.75}N$ UV photodetector under 1 V bias, the peak responsivity is found at 308nm, and it achieved about 0.07 A/W.

We calculated also the the responsivity under 1, 2, 4 and 6 bias V. There is a good linear relationship between the peak responsivity and bias voltage Figure. 8.

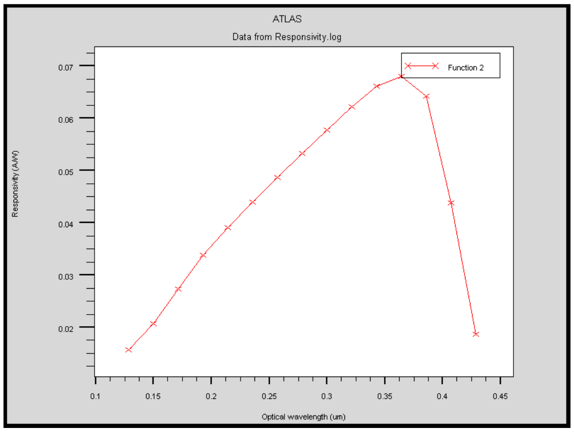


Figure 7. Spectral responsivity of a $Al_{0.25}Ga_{0.75}N$ UV photodetector under 1 V bias.

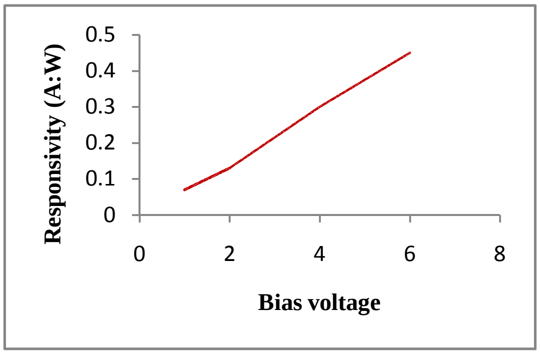


Figure 8. The peak responsivity as a function of bias voltage.

The NEP is defined as the incident optical power for which the signal-to-noise ratio is 1, and hence the photocurrent I_{ph} is equal to the noise current I_b. In other words, it is the smallest optical power which can be measured. It follows that the NEP parameter is given by the equation: NEP= Ib/R, where R is the measured responsivity, and we calculated I_b as [6]:

$$< I_b^2 >= (4k_bT/R_{dark} + 2qI_{dark})\Delta f \ \ldots\ldots (1)$$

We can use NEP to define the detectivity [2, 6]:

$$D=(A\Delta f)^{1/2}/NEP \ldots\ldots.(2)$$

where A is device area. With a 1V applied bias it was found a maximum D of $4.43*10^{11}$cm.Hz$^{1/2}$/W at 307nm . The detectivity of the device was higher than those ($7\sim50*10^{9}$ cm.Hz$^{1/2}$/W) observed from GaN-based MSM photodetectors with a similar structure [6].

Conclusions

High performance visible-blind AlGaN-based MSM photodetectors are attractive because of their low dark current about 16 pA under 1V bias. The photocurrent/dark current rejection is more than five orders of magnitude. That can reduce noise level, and enhance the detectivity of the PDs. The experimental results [6] are in agreement with our simulations.

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