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Design and Characterize the GaN/AlGaN Asymmetrical Super-lattice Exotic pin Photo-Sensor in Visible Wavelength

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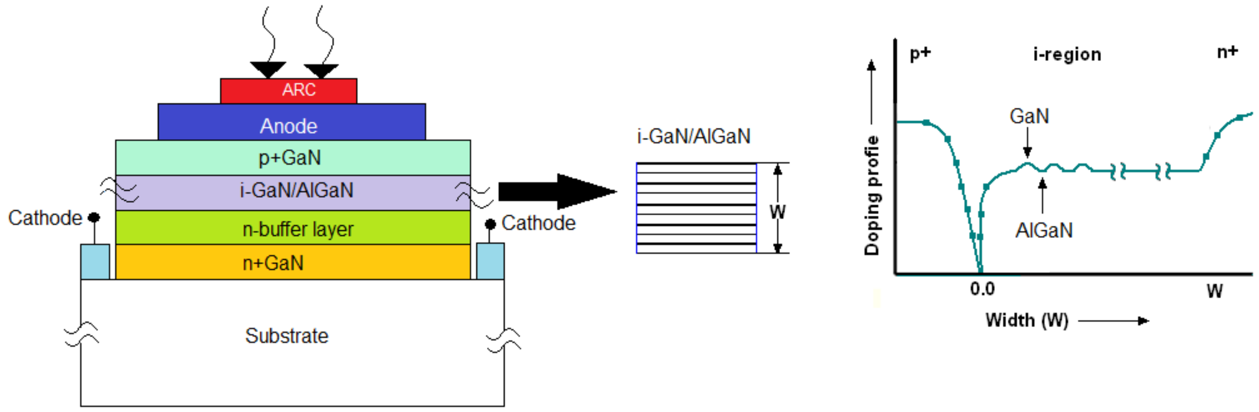
Abstract: In this paper, the super-lattice GaN/AlGaN single and array type photo sensor has been designed and simulated through the Quantum Modified Drift-Diffusion (QMDD) simulator in visible wavelength region (300nm-800nm). The photo sensor has been demonstrated with significant photo responsibility and quantum efficiency and the result of single photo sensor are compared with its array type photo sensor in between 300nm-800 nm wavelength region. To the best of author's knowledge, this is the first report on GaN/AlGaN super-lattice photo sensor in visible wavelength of optical illumination.

1. Introduction

The most of the research work have been done on the photo-electric characteristics (Photo-responsivity and Quantum efficiency) of Si, GaAs, GaN, SiC based single *pin* photo-sensors [1-6]. Owing to advantages of the shorter wavelength region, the photo-sensor *pin* device has got importance in recent years [7]. Therefore, the authors have designed and studied the GaN/AlGaN asymmetrical super-lattice exotic pin photo-sensor in visible wavelength region. Due to higher absorption co-efficient of GaN, a large amount of the photon-energy absorbs within the thin intrinsic-region of the GaN/AlGaN asymmetrical super-lattice exotic *pin* photo-sensor device. As a result, the free electron and hole-pairs generates in the active region of the designed device. Another excellent property of the super-lattice configuration, the width of the thin intrinsic region with a variation of doping density increases the spatial separation of the electron and hole-pair within the active region. Substantial Quantum Mechanical (QM) effects take place due to the addition of thin super-lattice structure in the intrinsic region of the designed exotic *pin* photo-sensor device. Thus, the authors have studied the photoelectric characteristics of the super-lattice exotic *pin* photo-structure in terms of photo-responsivity and quantum efficiency. The 2D-structure of the proposed exotic *pin* photo-sensor and corresponding doping profile are shown in Figure. 1 (a) & (b) respectively. At visible wavelength region, the simulation of the proposed device (single and array type) is carried out by incorporating the influence of Quantum effect.



(a) (b)

Figure 1: (a) 2D geometric structure of GaN/AlGaN super-lattice exotic pin-photo sensor. (b) Schematic of doping profile of exotic pin-photo sensor.

2. Methodology

In the paper, the authors describe the simulation methodology with the help of QMDD simulator which consists of the carrier transport phenomenon in semiconductor i.e. impurity scattering, hot carrier effect, field dependence of mobility, inter-band scattering of e-h pairs with photons, diffusivity, carrier generation and recombination, field dependent ionization rate, drift velocity overshoot effects in GaN/AlGaN 2-D vertical and asymmetrical doped super-lattice structure. Here the most important parameter for non-linear analysis of the *pin* sensor device is the electric field $(E(x,t))$ electron–hole drift velocity $(v_{p,n})$ and electron–hole saturation velocity ($v_{s_{p,n}}$), avalanche carrier generation-rate [7]. Here, the two important design parameters i.e. background doping concentration N_d and intrinsic region width (W). The total i-region width of super-lattice pin photo sensor is 80 nm which divided into asymmetrical width of 50 nm for GaN and 30 nm for AlGaN. The temperature and field dependent carrier drift velocities, saturation velocities, effective masses, mobility, intrinsic carrier concentration, ionization rates, diffusion constants, diffusion length and velocity overshoot effects are obtained from several experimental research works in selectively integrated in the model for quasi 2D simulation. In the photo–illumination arrangement, the radiation of the light ($h\lambda$) is incident on the designed pin photo sensor device through the optical window from a visible laser source. Due to mismatch of the refractive index small amount of incident power is reflected and remaining power are immersed by the thin i-region of the device. The photo current of the device can be expressed as a function of incident wavelength and it is given by- [3, 7] $I_{ph} = p_i(q\lambda / m_s m_{sc})(1-r)[1-e^{-(\alpha d)}]$. Where, r is reflectivity, p_i is the incident power, m_s is the refractive index between the medium and m_{sc} is the material. The photo-responsivity can be expressed as $R = (q\lambda / hc)\eta_i$, where, η_i is the quantum efficiency, R is the spectral response and the quantum efficiency can be determined by [7] - $\eta_i = |(I_{ph}/q)/(p_i = h\nu)|$.

3. Result and Discussion

In the visible optical illumination, the photo-responsivity analysis of single and array type of the GaN/AlGaN asymmetrical exotic *pin*-photo sensor device is shown in Figure 2. It is observed from Figure 2, that the value of photo-responsivity is ~ 0.72 A/W (single photo-sensor) and ~ 0.90 A/W (array of photo sensor) at 500nm wavelength respectively. Figure 3 show that the quantum efficiency of single and array type *pin* photo sensor. It is found from Figure 3, that the quantum efficiency is 67 % (single photo sensor) and 90 % (array type photo sensor) at 500nm wavelength. The results are tabulated in Table 1.

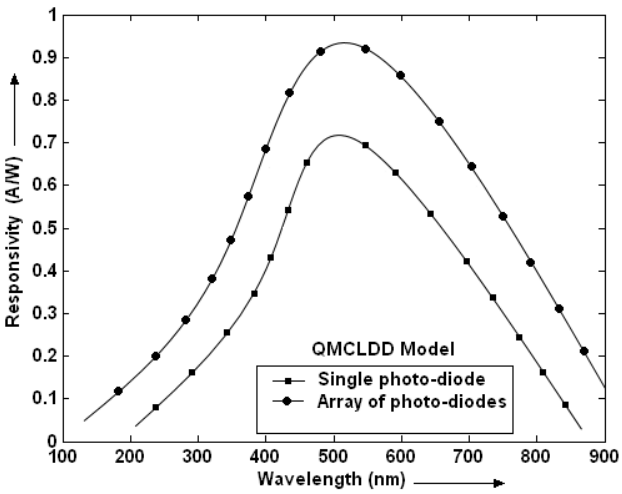


Figure.2 Simulation result of photo-responsivity of exotic pin photo sensor device (Based on QMCLDD model).

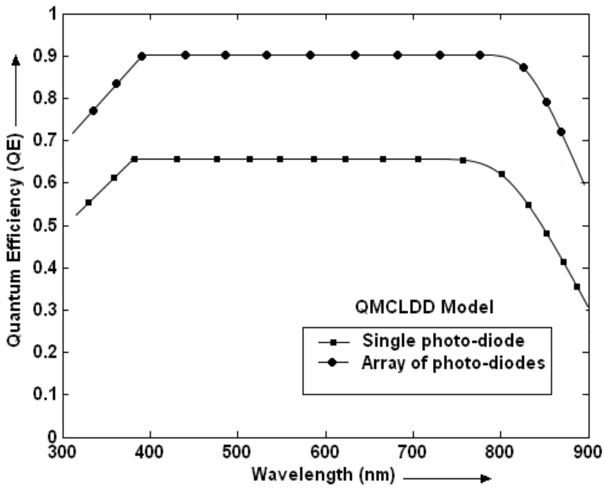


Figure.3 Simulation result of quantum efficiency based on pin type photo-sensors (Based on QMCLDD model).

Table 1: Observation Result for GaN/AlGaN single and array type *pin* photo-sensor at visible wavelength.

Base Material	Single *pin* photo-sensor			Array of *pin* photo-sensor		
	Wavelength (nm)	Responsivity (A/W)	QE	Wavelength (nm)	Responsivity (A/W)	QE
GaN/AlGaN	300	0.14	0.53	300	0.29	0.74
	400	0.35	0.63	400	0.64	0.87
	500	0.72	0.67	500	0.90	0.90
	600	0.65	0.65	600	0.88	0.90
	700	0.45	0.65	700	0.67	0.90
	800	0.19	0.64	800	0.41	0.90

4. Conclusions

The photo-responsivity and quantum efficiency of Single and array type *pin* photo-sensor have been studied through the QMDD Simulator at visible wavelength. The author has established the superiority of GaN/AlGaN array type exotic *pin* photo-sensor compared to its single *pin* photo-sensor.

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