Sensitivity Analysis of GaN/AlGaN Quantum Dot Based Led

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SENSITIVITY ANALYSIS OF GaN/AlGa_N QUANTUM DOT BASED LED

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Abstract The impact of various geometrical parameters and doping parameters on the performance of GaN/AlGa_N quantum dot-based light-emitting diode using 3D numerical simulations have been studied in this work. The parameters are ranked based on their sensitivity coefficients. Four important performance metrics, (i) internal quantum efficiency, (ii) responsivity, (iii) optical gain, and (iv) input power are used for this study. The bottom radius of the quantum dot is found to be the most significant parameter with respect to the internal quantum efficiency and optical gain. Nanocolumn radius is the most significant parameter with respect to Responsivity and input power. The overall ranking suggests that the Nanocolumn radius is the most sensitive parameter.

Keywords LED, Nanocolumn, Quantum dot, TCAD, III-V materials

1 INTRODUCTION

A quantum-confined structure is one in which the motion of the charge carriers is confined in one or more directions by potential barriers [1]. It has been classified into three categories as quantum wire, quantum well, and quantum dots are based on the confinement direction. Charge carriers are confined to move in a plane and are free to move in a two-dimensional quantum well. when two dimensions of the system are confined in quantum wires. A motion of charge carrier is confined in all three spatial directions is a quantum dot. A

quantum dot is a semiconductor nanostructure having electronic and optical properties that are sensitive to the size, shape, and composition of the material. Quantum dot light-emitting diodes (QLEDs) are having due to their properties highly desirable for the display units, mobile phones, and lighting industries, and most recently in the photomedicine field and quantum computing. By changing the dot size of the quantum dot (QD) can emit any color of light from the same material. It consists of bright colors coupled with their high efficiencies, longer lifetimes, and high extinction coefficient. The major impacted markets include digital information, instrumentation, communications, security, healthcare, and biotechnology. Owing to their lucid fluorescence, narrow emission, broad UV excitation, and photostability. QDs have been adopted in biological coding, cancer signature, bioengineering, and therapeutics. QD in III-V material system has been used in many different optoelectronic applications including LED, diode lasers [2,3], semiconductor optical amplifiers, infrared detectors [4], and mid-IR lasers. In recent days InAsSb/AsSb, InGaAs/GaAs [5], InGa_N/Ga_N [6], and AlGa_N/Ga_N are some of the materials largely used in the construction of quantum dot. Among these materials, AlGa_N/Ga_N QDs offer several promising features, such as size-dependent emission wavelength, narrow emission spectrum, and high luminescence efficiency [7,8].

GaN has a large bandgap and exhibits very strong internal piezoelectric and pyroelectric fields. GaN/AlGa_N QDs consists of a variation of the QD size a large (interband) photon emission tunability ranging from 2.6 to 4.5 eV is obtained [9,10]. A high potential as high-quality light emitters in the visible to the ultraviolet spectral range is mainly due to Ga_N QD. A conical/truncated Ga_N QD structure contains high crystalline

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quality, self-organized growth process, and compatibility with Si(111) substrates [11]. Yang et.al [12] reported a hexagonal truncated pyramid quantum dot fabricated using GaN/AlN for deep UV LED, which emits very efficiently at 308 nm with an estimated IQE as high as 62% showing high-temperature stability in both emission wavelength and line width. Analyzing the optical gain and threshold performances of the GaN/Al_{0.2}Ga_{0.8}N quantum dot lasers, based on the effect of doping varying the side lengths of the box in the structure. They reported that the gain is efficient in p-doping when compared to the n-doping region and undoped region [13]. Inzamam Ul Islam Chowdhury, [14] reported the structure of $In_xGa_{1-x}N$ /GaN quantum dot (QD) intermediate band solar cell (IBSC) manifests larger power conversion efficiency be controlled by tuning the position of Fermi energy bands as well as changing the certain QD size, interdot distance, Indium content, and doping concentration.

At these nano dimensions for quantum dots discussed in the literature, process variations are inevitable, even when stringent methods are used for fabrication. Due to the process variations, the actual geometries of the fabricated quantum dot-based LED may differ from the desirable geometries considerably, resulting in variation of the device (QLED) performance. The effect of variation in a particular device parameter is different for different performance metrics (IQE, Responsivity, optical gain, input power) of the LED. Hence, it is important to predict a LED performance for device and process parameters before the actual fabrication of LED.

These process variations lead to variation in the device geometrical parameters such as bottom radius, top radius, quantum dot height, wetting layer thickness, nanocolumn radius, doping concentration, p-region thickness, etc., and doping, which in turn will affect the device performance. Process variations in quantum dots have not been explored in greater detail in the literature. A systematic sensitivity study of the GaN quantum dot-based LED is yet to be explored. In this context, this paper discusses the impact of process variations on performance metrics like internal quantum efficiency, responsivity, optical gain, and input power in GaN quantum dot-based LED. The TiberCAD simulator and simulation methodology has been discussed in the next section. Simulation results are discussed in sections 3, 4, and 5. The ranking of structural and doping parameters based on sensitivity analysis is discussed in section 6. Finally, section 7 gives the conclusion.

2 SIMULATION METHODOLOGY

2.1 SIMULATOR

The truncated conical GaN quantum dot was modeled with a bottom diameter of 10 nm and a top diameter of 6nm. TiberCAD multiscale simulation is used to perform all the simulations. The following modules are used in this study even though it has many modules.

- GMSH: To create the device structure, to define doping, to define contacts, and to generate mesh for device simulation.
- TiberCAD solver: To perform all descriptions of the input file structure, device section, Modules, simulation section, output description, and material database.
- Paraview and Aptplot: To view the results.

2.2 DEVICE STRUCTURE AND CALIBRATION

The structure generated from TiberCAD is shown in Fig.1. Doping and mesh information can be observed in Fig.1. It is a 15 nm diameter $Al_{0.3}Ga_{0.7}N$ nanocolumn of 100 nm height, a diameter of 5 nm, and a height of 5 nm [15]. It is grown on a thin wetting layer of 4 nm. As can be observed from Fig. 1, WL is much thinner than QD height and the growth direction of the structure is z. The device is doped with a pin profile, where the dopant density for both donors and acceptors is $10^{19}cm^{-3}$. The undoped regions of a model are $10^{15}cm^{-3}$ donor residual concentration. Both GaN and AlGaIn have wurtzite crystal structures [16]. Therefore (0001) substrate index is assumed in the simulation. Geometrical parameters of various dimensions are used in device creation are shown in Fig.1. The physics section of TiberCAD includes the appropriate models for Shockley-Read-Hall recombination, doping dependency of mobility, strain model, k.p model for effective masses, and optical recombination. In this simulation set up, various models such as strain, drift-diffusion, and envelope function approximation multiband K.P are incorporated. The simulated structure is calibrated against the published results [17]. The V-I characteristics and the optical power spectral density are used for the calibration purpose and are shown in Fig. 2(a) and (b) respectively.

The thickness of the active layer (GaN) plays a critical role in achieving higher efficiency due to spontaneous and piezoelectric polarization, potential well, and recombination rate. Strain calculation is mainly done due to the lattice-mismatched heterostructure between GaN and AlGaIn within elasticity theory[18]. Transport of hole and electrons is based on the drift-diffusion model is applied to calculate current in the pin diode.

Figure 1: Structure generated from TiberCAD

Fig. 1 Structure generated from TiberCAD

Fig. 2 (a) IV characteristic of the nanocolumn growth in (0001) direction

2(b) Spontaneous emission of the LED spectrum as a function of Energy

When a bias is applied between the two contacts. Quantum calculations are performed only in the intrinsic region, to calculate confined state and optical spectrum. Simulations are performed at the 3D level.

2.3 PARAMETER SPACE FOR SENSITIVITY STUDY

Sensitivity analysis is done by varying one parameter at a time, keeping all other parameters as a constant quan-

tity, and observing the output quantity of interest [19, 20]. The process parameters considered here are bottom radius, top radius, quantum dot height, wetting layer thickness, nanocolumn radius, doping concentration, p-region, and n-region thickness, etc. These ten parameters are varied over a range of values to capture their sensitivity on internal quantum efficiency, responsivity, optical gain, and input power. Table 1 gives the dimensions of the nominal device and also gives the range for the various parameters studied. The parameters are grouped, and the group names are given in the last column of Table 1.

Table 1 Dimensions of the nominal device and their range of values in GaN quantum dot used in LED

Device parameters	Nominal values	Range of values
Bottom Radius (a)	5 nm	3 nm to 7.4 nm
Top Radius (a_1)	3 nm	2 nm to 5 nm
Nanocolumn Radius (a_2)	7.5 nm	6 nm to 9 nm
Quantum dot height (h)	5 nm	2 nm to 8 nm
Wetting layer thickness (h_1)	4 nm	2.5 nm to 5.5 nm
Height of p-region (h_4)	43.5 nm	35.5 nm to 51.5nm
Height of n-region (h_3)	39.5 nm	30.5 nm to 48.5 nm
Doping density for p-region (N_p)	$10^{17}/cm^3$	$10^{15}/cm^3$ to $10^{18}/cm^3$
Doping density for n-region (N_a)	$10^{17}/cm^3$	$10^{15}/cm^3$ to $10^{18}/cm^3$
Doping density for Intrinsic region (N_i)	$10^{15}/cm^3$	$5*10^{15}/cm^3$ to $5*10^{18}/cm^3$

3 EFFECT OF QUANTUM DOT PARAMETERS ON OUTPUT CHARACTERISTICS

The structural parameters of GaN quantum dot- LED such as QD height, QD top radius, QD bottom radius, and QD wetting layer are varied over a range and the values are given in table 1. Using sensitivity analysis, these above structural parameters impact on Internal Quantum Efficiency (IQE), responsivity, optical gain, and input power are studied.

3.1 Effect of quantum dot height

It can be observed from Fig. 3 that IQE decreases with the height of QD. The internal quantum efficiency for

Fig. 3 Effect of variations in QD height on IQE and responsivity

the radiative processes has been defined as [21, 22]

$$\eta_{int} = \frac{\text{No photons emitted from the active region/s}}{\text{No electrons injected into the LED/s}} \quad (1)$$

$$\eta_{int} = \frac{\frac{\Phi_{active}}{h\nu}}{\frac{I_F}{q}} \quad (2)$$

The total photon flux is obtained by [23]

$$\Phi_{active} = \frac{V_l}{\sqrt{2}} * \left(\frac{m_r}{\pi}\right)^{3/2} * \frac{1}{\hbar^2 * \tau_r} * (K_B * T)^{3/2} * e^{\frac{\epsilon_f n - \epsilon_f p - \epsilon_g}{K_b * T}} \quad (3)$$

Where V_l - active volume region, τ_r - radiative recombination lifetime, Φ_{active} - radiant power emitted from the active region, I_F - Forward current injected into active region, h - reduced Planck constant. The expressions (2) and (3), show that the total photon flux in the active region and hence the IQE is inversely proportional to the total recombination lifetime. It can also be observed from Fig. 3, that the responsivity is reduced significantly as QD height increases [24]. As QD height increases, optical power decreases up to 7 nm and then increases. The responsivity R , of an LED, is defined as the ratio of the emitted optical power P_{opt} to the injection current I .

$$R = \frac{P_{opt}}{I} (W/A) \quad (4)$$

Where P_{opt} is the emitted optical power in watts and I is the injected current in amperes. Both the P_{opt} decreases and injected current decreases with QD height up to 7 nm, but P_{opt} dominates and hence the responsivity decreases up to 7nm. After 7 nm, P_{opt} increases which in turn increases the responsivity for 8 nm.

Fig. 4 Effect of variations in QD height on optical gain and input power

The optical gain is given by the following expression

$$\gamma = \frac{\left(\frac{c}{n}\right)^2}{8\pi\vartheta^2} * \frac{1}{\tau_r} * \rho(\gamma)f_g(\gamma) \quad (5)$$

where c is the velocity of light, ϑ is the frequency of light, n is the refractive index, τ_r is the recombination lifetime, $\rho(\gamma)$ is the reduced density of states, $f_g(\gamma)$ is Fermi inversion function. Figure 4 shows that, when the QD height decreases from the nominal value, a significant increase in gain is observed whereas, the change in optical gain is insignificant when the QD height increases from the nominal value. As per expression (5), the optical gain coefficient is inversely proportional to recombination lifetime, and hence optical gain decreases as the QD height increases up to nominal value and above the nominal value, there is no significant change is observed. Figure 4 also shows that the input power is reduced significantly as the height of QD increases. Mobility depends on the effective mass of the carriers in the semiconductor. It has been observed that the device's effective bandgap increases with the increase in the QD height [25]. The conduction band effective mass increases rapidly with increasing bandgap as per equation (6). So, as E_g increases, the injected current decreases, and hence the input power decreases.

$$\left[\frac{1}{m^*}\right] = \left[\frac{1}{m_0} + \frac{2P_{cv}^2}{m_0^2 * E_g}\right] \quad (6)$$

where p_{cv} - the momentum or dipole matrix element between the conduction and valence bands, m_0 - is the free electron mass.

3.2 Effect of quantum dot top radius

As shown in Figure 5, IQE increases with the top radius. Increasing the top radius of the quantum dot re-

Fig. 5 Effect of variations in QD top radius on IQE and responsivity

sults in an increase in the volume of the active region and hence IQE increases. It can also be observed from figure 5, the responsivity is reduced significantly as the QD top radius increases and has been justified in section 3.1. As shown in Figure 6, the overall optical gain

Fig. 6 Effect of variations in QD top radius on optical gain and input power

is reduced as the QD top radius increases. This trend can be attributed to the increase in recombination lifetime with QD top radius. When the QD top radius decreases from the nominal value, a significant increase in gain is observed, whereas the change in gain is insignificant when the top radius increases from the nominal value. It can be observed from Figure 6 that the input power increases with the QD top radius. The increase in the top radius of QD increases current electron mobility and hence current and therefore the input power to the LED increases.

3.3 Effect of quantum dot bottom radius

Fig. 7 Effect of variations in QD bottom radius on IQE and responsivity

As shown in Figure 7, IQE increases when the QD bottom radius increases from the nominal value, which can be ascribed to the decrease in total recombination lifetime. It can also be seen from Figure 7, that responsivity decreases with the bottom radius from 3 nm to 7 nm. The injected current of LED increases with QD bottom radius, emitted output power increases, which in turn decreases responsivity. Popt decreases rapidly with bottom radius up to 7.4 nm and then increases and so the Responsivity increases.

Fig. 8 Effect of variations in QD bottom radius on optical Gain and input power

As shown in Figure 8, the optical gain is decreased as the QD bottom radius increases. When the bottom radius of QD increases, the energy gap reduces which leads to an increase in electron mobility, which is due to

the decrease in the effective mass of charge carriers. The device's effective band gap decreases with the increase of the QD bottom radius and hence reduces conduction band effective mass. The effective density of states in equation 5 is given by

$$\rho(\gamma) = \frac{2m_r}{\pi * \hbar * L_Z} \quad (7)$$

Where L_Z - thickness of quantum well and m_r -reduced density of mass of electron As shown in Figure 8, the input power increases with the bottom radius of QD. As discussed in section 3.2, the increase in the bottom radius of QD increases electron mobility, therefore the power increases.

3.4 Effect of quantum dot wetting layer

Fig. 9 Effect of variations in QD wetting layer on IQE and responsivity

As shown in Figure 9, IQE increases with wetting layer thickness. Increasing the wetting layer thickness of QD [26-28] increases the volume of the active region and hence the quantum efficiency increases as per expressions (2) and (3). As shown in Figure 9, the responsivity is decreasing significantly as the wetting layer thickness of QD increases. The injection current of LED increases with wetting layer thickness, so the responsivity decreases, as wetting layer thickness increases. As shown in Figure 10, the overall optical gain is reduced significantly as the wetting layer thickness of QD increases. When the quantum dot wetting layer thickness increases from the nominal value, the thickness (L_z) increases and so the effective density of states as per expression (7) decreases, and hence the gain decreases. As shown in Figure 10, the power is increased significantly as the wetting layer thickness

Fig. 10 Effect of variations in QD wetting layer on optical Gain and input power

of QD increases. The device's effective band gap decreases with the increase of the wetting layer thickness of QD. The conduction band effective mass decreases with decreasing bandgap as per equation (6). So the conductivity increases and also power increases.

4 EFFECT OF COLUMN PARAMETERS ON OUTPUT CHARACTERISTICS

4.1 Effect of quantum dot Nano column Radius

Fig. 11 Effect of variations in QD Nanocolumn radius on IQE and responsivity

As can be observed from Figure 11, when the quantum dot Nanocolumn radius decreases from the nominal value, a significant decrease in IQE is observed. The overall change in IQE is insignificant when the quantum dot Nanocolumn radius increases from the nominal value, which can be attributed to the change in total

recombination lifetime with nanocolumn radius. It can also be observed from Figure 11, responsivity is reduced significantly as the nanocolumn radius increases. The injection current of LED increases with quantum dot nanocolumn radius, Popt decreases, and so the responsivity decreases rapidly with a nanocolumn radius. As

Fig. 12 Effect of variations in QD nanocolumn radius on optical Gain and input power

shown in Figure 12, the overall change in optical gain is less when the quantum dot Nanocolumn radius increases from the nominal value. When the quantum dot Nanocolumn radius decreases from the nominal value, a significant increase in gain is observed. This behavior of gain for quantum dot Nanocolumn radius can be attributed to a change in recombination lifetime. As per equation (5), the optical gain coefficient is inversely proportional to the recombination lifetime. It can be observed from Figure 12, that the power is increased significantly as the nanocolumn radius of QD increases and can be reasoned out similar to section 3.4 as the device's effective band gap decreases with the increase in the nanocolumn radius of QD.

4.2 Effect of the height of n-region

Figure 13 shows that IQE increases with the height of the n-region of the QD. As the height of the n-region increases, the energy bandgap increases which in turn increases the conduction band effective mass, so injection current decreases, and hence IQE increases as per equation (6). It can also be observed from Figure 13, that the responsivity is increased as the height of the n-region increases. As the height of the n-region increases, optical power decreases the injected current decreases and so responsivity increases. As shown in Figure 14, the opti-

Fig. 13 Effect of variations in the height of n-region on IQE and responsivity

Fig. 14 Effect of variations in the height of n-region on optical gain and input power

cal gain is increased significantly as the height of the n-region variation of QD increases. The increase in height of n-region of QD increases the effective bandgap, so effective mass of the electron as per Equation (6) and hence the effective density of states as per Equation (7) and therefore increases the gain of the quantum dot. As shown in Figure 14, the input power decreases with the height of the n-region. Mobility depends on the effective mass of the carriers in the semiconductor. The conduction band effective mass increases with increasing bandgap as per equation (6), which decreases the current with the height of the n-region, and hence the power.

4.3 Effect of the height of p-region

Figure 15 shows that IQE increases with the height of the p-region and responsivity increases as the height of

the p-region increases. This can be explained similarly to n-region.

Fig. 15 Effect of variations in height of p-region on IQE and responsivity

Fig. 16 Effect of variations in height of p-region on optical gain and input power

As shown in Figure 16, the optical gain increases significantly as the height of the p-region increases. This can be attributed to an increase of the effective mass of the electron as per Equation (6) and hence the effective density of states as per Equation (7). As can be observed from Figure 16, the input power reduces significantly as the height of the p-region increases which can be explained in a way similar to the height of n-region variation in section 4.2.

5 EFFECT OF DOPING PARAMETERS ON OUTPUT CHARACTERISTICS

The various doping parameters mentioned in Table 1 are varied to study their impact on IQE, responsivity, optical gain, and input power of quantum dot LED.

5.1 Effect of doping density of QD on IQE

Fig. 17 Effect of doping parameters on output characteristics

Figure 17 shows that IQE decreases with the increase of doping of the intrinsic region. As doping increases, τ_r decreases initially until doping reaches nominal value and then τ_r increases, whereas injection current increases continuously. Since IQE is inversely proportional to injection current and τ_r , there is a small reduction in IQE until the value of doping reaches nominal value and then IQE decreases rapidly. Figure 17 also shows that IQE increases with doping of p-region and n-region. As the doping density of n-region increases, τ_r decreases a little, and hence IQE increases slightly, whereas for p-region τ_r decreases by an order of magnitude which in turn increases IQE rapidly, as per equations (2) and (3).

5.2 Effect of doping density of QD on Responsivity

As shown in Figure 18, increasing the doping concentration of the intrinsic region of the quantum dot results in decreasing responsivity. As shown in Figure 18, responsivity is reduced significantly as the doping of the p-region and n-region increases. As discussed in section 3.1, the injection current of LED increases with a doping concentration of intrinsic region, n-region, and

p-region in a different manner and so the responsivity decreases. At higher doping densities, the responsivity shows a flat behavior.

Fig. 18 Effect of variations in Quantum dot doping density on Responsivity

5.3 Effect of doping density of QD on optical gain

As shown in Figure 19, the change in the optical gain is not significant as the doping concentration of the intrinsic region and n-region increases, whereas optical gain increases significantly with the doping of the p-region. As per equation (5), the optical gain coefficient is inversely proportional to the recombination lifetime. This behavior of gain for the doping concentration can be attributed to the corresponding change in recombination lifetime.

Fig. 19 Effect of variations of doping density of QD on optical Gain

5.4 Effect of doping density of QD on the input power

As can be observed from Figure 20, the change in input power is not as significant as the doping concentration of the QD intrinsic region increases. The input power increases as the doping concentration of the n-region increases and it increases rapidly with p-region doping. This can be ascribed to the corresponding changes in the current.

Fig. 20 Effect of variations of doping density of QD on optical Gain

6 RANKING BASED ON SENSITIVITY ANALYSIS

The sensitivity coefficient of different output parameters for the variation in structural and doping parameters was calculated using the expression [29],

$$X(i, w) = \frac{(\delta y_i)/y_i}{(\delta a_w)/a_w} \quad (8)$$

where δy is the change in the performance metrics, IQE, optical gain, Responsivity, and input power, and δa is the change in the structural and doping factors, quantum dot height (QH), top radius (TR), bottom radius (BR), wetting layer thickness (WL), nanocolumn radius (NCR), the height of n-region (HNR), the height of p-region (HPR), doping density of intrinsic region (DIR), n-region (DNR) and p-region (DPR). The sensitivity coefficients for four performance metrics, internal quantum efficiency, responsivity, optical gain, and input power are calculated and ranking is given in table 2.

It can be observed from table 2 that for IQE, the most significant parameters are bottom radius, doping density of the intrinsic region, and nanocolumn radius, whereas the doping concentration of n-region and

Table 2 Ranking of parameters based on the sensitivity study

Device parameters	Ranking Based on Sensitivity (%)				
	IQE	Responsivity	Optical Gain	Input Power	Overall Ranking
QH	8	8	4	9	4
TR	6	4	5	5	5
BR	1	6	1	4	2
WL	4	5	3	2	3
NCR	3	1	2	1	1
HNR	10	9	7	8	8
HPR	7	3	6	3	6
DPR	5	2	8	6	7
DNR	9	7	9	7	9
DIR	2	10	10	10	10

height of n-region, is the least significant parameters. Similarly, for responsivity, the most significant parameters are nanocolumn radius, doping density of p-region, and height of p-region, whereas the doping concentration of intrinsic region and height of n-region is the least significant parameters. It was found that the bottom radius, nanocolumn radius, and wetting layer are the most significant parameters whereas the doping concentration of p-region, intrinsic region, and n-region is the least significant parameters for optical gain. It can also be observed from table 2 that input power, nanocolumn radius, wetting layer, and the height of p-region are the most significant parameters whereas the doping concentration of intrinsic region, height of n-region, and n-region are the least significant parameters. The overall sensitivity of structural and doping parameters is calculated by adding all the coefficients values and arranging them in descending order, the overall ranking is evaluated and is given in table 2. It can be observed from Table 2 that the Nanocolumn radius is the most sensitive parameter and the doping density of the intrinsic region is the least sensitive parameter. Table 2 depicts that the NCR and BR occupy the top ranks. The last two ranks are occupied by DNR and DIR.

7 CONCLUSION

In this paper, we had considered ten different parameters, Quantum dot height, QD top radius, QD bottom radius, wetting layer thickness, Nanocolumn radius, the height of p-region, the height of n-region, and doping concentrations of p-region, n-region, and intrinsic region of GaN quantum dot LED. The impact of the above parameters on the performance metrics, internal quantum efficiency, optical gain, responsivity, and input power has been studied using 3D numerical simulations. The study has two parts. (i) all the ten parameters are varied over a wide range, (ii) around the nominal val-

ues, the sensitivities of all the ten parameters to the four output parameters have been extracted. Based on the sensitivity values, the parameters were ranked individually for the four output parameters. It was found that the bottom radius is the most significant parameter for internal quantum efficiency and optical gain whereas the Nanocolumn radius is the most significant parameter for Responsivity and input power. The result in the overall ranking shows the Nanocolumn radius is the most sensitive parameter whereas the doping density of the intrinsic region is the least sensitive parameter.

References

1. D.A.B.Miller, D.S.Chemla, Band-edge electroabsorption in quantum well structures, *Physical Review Letters* 19, 2173 (1984).
2. P.G.Eliseev, A.Ukhanov, A.Stintz, *Quantum Electronics* 39 , 6 (2009).
3. S.Ghosh, S.Pradhan, P.Bhattacharya, *Applied Physics Letters* 81 , 2173 (2003).
4. A.Asgari, S.Razi, *Optics Express* 18 ,14604-15 (2010).
5. D.L.Huaker,D.G.Deppe, *Applied Physics Letters* 73, 520 (1998).
6. D. Barrett, M. A. der Maur, A. di Carlo, *Nanotechnology* 28, 520 (2017).
7. Calleja, et al., *Physical Review Letters* 62, 16826-16834 (2000).
8. Vurgaftman, J. R. Meyer, *Journal of Applied Physics* 94,3675 (2003).
9. A. D. Andreev, E. P. O'Reilly, *Physical Review B* 73, 520 (2000).
10. D.Bimberg, M.Grundmann, N.N.Ledentsov, *Quantum dot heterostructures* (1999).
11. G. Sanusi, et al, *Physics Review B* 75, 75306 (2007).
12. W. Yang, J. Li, Y. Zhang, *scientific reports* (2014).
13. Bouchenafa, B. Benichoub, *Revista Mexicana de Fisica* 65,38-42 (2019).
14. I. U. I. Chowdhury, J. Sarker, *Results in Physics* 9,432-439 (2018).
15. G. Perazzi, et al, *Journal of Computational Electronics* , 69-72 (2009) .
16. S.L.Chuang, C. Chang, *Physical Review B* 54, 2491-2504 (1996).
17. G. Perazzi, A. Pecchia, *Physical Review B* 47, 123-128 (2010).
18. V. A. Fonoberov, A. A. Balandin, *Journal of Physics* 94, 7178 (2004).
19. D.M.Hamby, *Environmental monitoring and assessment* 32, 135-154 (1994).
20. K.K.Nagarajan, R. Srinivasan, *European Journal of Scientific Research* 97,263-271 (2013).
21. M. A. der Maur, A. Pecchia, *Physics Review Letters* 116,027401 (2016).
22. J.-I. Shim, D.-S. shin, *Nanophotonics* 7 (2018).
23. P. Bhattacharya, *Semiconductor optoelectronic devices* (1997).
24. Martyniuk, A.Rogalski, *Bulletin of the Polish Academy of Sciences* 5, 1 (2009).
25. S. Baskoutas, *Journal of Applied Physics* 99,013708 (2006).
26. M. Shahzadeh, M. Sabaeen, *Journal of Applied Physics* 4, 067113 (2014).
27. S. Lee, O. L, *Physical Review B* 70,125307 (2004).
28. S. Huang, A. V.Semichaevsky, *Journal of Applied Physics* 110, 073105 (2011).
29. G. Goh, K. Noborio, *International Scholarly Research* 824721, 7 (2015).

Figures

Figure 1: Structure generated from TiberCAD

Figure 1

please see the manuscript file for the full caption

Figure 2

(a) IV characteristic of the nanocolumn growth in (0001) direction (b) Spontaneous emission of the LED spectrum as a function of Energy

Figure 3

Effect of variations in QD height on IQE and responsivity

Figure 4

Effect of variations in QD height on optical gain and input power

Figure 5

Effect of variations in QD top radius on IQE and responsivity

Figure 6

Effect of variations in QD top radius on optical gain and input power

Figure 7

Effect of variations in QD bottom radius on IQE and responsivity

Figure 8

Effect of variations in QD bottom radius on optical Gain and input power

Figure 9

Effect of variations in QD wetting layer on IQE and responsivity

Figure 10

Effect of variations in QD wetting layer on optical Gain and input power

Figure 11

Effect of variations in QD Nanocolumn radius on IQE and responsivity

Figure 12

Effect of variations in QD nanocolumn radius on optical Gain and input power

Figure 13

Effect of variations in the height of n-region on IQE and responsivity

Figure 14

Effect of variations in the height of n-region on optical gain and input power

Figure 15

Effect of variations in height of p-region on IQE and responsivity

Figure 16

Effect of variations in height of p-region on optical gain and input power

Figure 17

Effect of doping parameters on output characteristics

Figure 18

Effect of variations in Quantum dot doping density on Responsivity

Figure 19

Effect of variations of doping density of QD on optical Gain

Figure 20

Effect of variations of doping density of QD on optical Gain