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Comparative analysis of spontaneous emission factor and its stability of QD laser using Group-III nitrides above room temperature

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This paper presents a comparative analysis of spontaneous emission factor and its stability above room temperature of quantum dot laser using Group-III nitrides. Effect of different parameters has been analyzed on the spontaneous emission factor of quantum dot laser using InN, GaN and AlN quantum dot in the active layer of the device structure. To investigate the stability of spontaneous emission factor, rate of change of it has been analyzed with respect to the different parameters. Parameters considered in this research are: wavelength, energy band-gap and carrier concentration at conduction band. Numerical analysis has been carried out through mathematical modeling and using MATLAB. It was ascertained by comparative analysis that AlN based quantum dot laser possess the lowest value of spontaneous emission factor with respect to wavelength and band-gap energy and the rate of change of spontaneous emission factor with respect to these two parameters has also been the lowest. Besides, AlN quantum dot laser possess the highest value of spontaneous emission factor with respect to carrier concentration at conduction band and the rate of change of spontaneous emission factor with respect to spontaneous emission factor is also the highest. GaN quantum dot laser possess the highest value of spontaneous emission factor with respect to wavelength and band-gap energy and the rate of change of spontaneous emission factor with respect to these two parameters has also been the highest. GaN quantum dot laser possess very high value of spontaneous emission factor with respect to carrier concentration at conduction band and the rate of change of spontaneous emission factor with respect to spontaneous emission factor is moderate, which lies between the highest and the lowest value. InN quantum dot laser possess moderate value of spontaneous emission factor with respect to wavelength and band-gap energy and the rate of change of spontaneous emission factor with respect to these two parameters has also been moderate. InN quantum dot laser possess the lowest value of spontaneous emission factor with respect to carrier concentration at conduction band and the rate of change of spontaneous emission factor with respect to spontaneous emission factor is also the lowest.

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Keywords: Laser, Wavelength, Band-gap, Spontaneous emission factor

1. Introduction

Spontaneous emission plays an important role in determining the performance of many optoelectronic devices, including lasers and optical amplifiers. The rate of spontaneous emission has been the topic of interest for researchers to be an inherent, unchangeable property of an emitter [1]. With the development of science and technology, Nano scale materials are experiencing ever increasing demand, due to their unique optical, electronic, and mechanical properties. When the size of a material is reduced to be comparable to the de-Broglie wavelength of electrons, significant effects has been observed [2]. Therefore, enhanced device characteristics are expected for lasers having lower dimensionality in the active region, such as quantum well (QW), quantum wire (QWR), and especially quantum dot (QD). Self-organized QDs have become one of the most important subjects for the researchers in the field of semiconductor optoelectronic device design [3]. Laser characteristics depend on many factors such as: properties of the material, QD parameters and the structural parameters of the device itself. The material properties include: band-gap energy, carrier life time, and the other non-uniform characteristics of the material used in the active layer like carrier density [4, 5]. Consequently, in the last decade researchers have paid particular attention to the ultimate reduction of the cavity length with maintaining a high quality factor. It has been acknowledged that ultra-small cavity is expected to provide the threshold less operation [6,7].

Laser characteristics vary in a complex way on many QD parameters like size, shape, dimensions, strain, and composition. The composition of optical confinement layer, residual strain along with ground quantized energy levels of carriers are also important parameters related to QD. These parameters also have evidential impacts on the laser characteristics. Among the parameters related to the design of the device structure, the length of the cavity is the most important parameter that affects the device performance significantly [7, 8].

Cavity length has a radical effect on output characteristics such as output power, emission wavelength, and quantum efficiency and so on [9-11]. Therefore, very recently researchers have achieved reduction of cavity length dependence of revolutionary QD lasers (QDLs) characteristics using InN [7]. Significant improvements in the characteristics of the semiconductor laser using InN based QD in the active layer has also been achieved. These improvements have been demonstrated in terms of higher performances such as ultralow threshold current density, high gain, high efficiency, and improved photon lifetime, ultra-high temperature stability of threshold current, narrow chirp characteristics, higher modulation speed and broad small-signal modulation bandwidth. Therefore, potential device applications range from high power semiconductor lasers to high speed light sources for fiber optic data transmission systems [12, 13]. Hence lasers have been greatly miniaturized over the past few decades, from meter scale to micrometer scale [7,14], providing a range of improvements including reduction in lasing threshold, photonic integration, and cavity quantum electrodynamics effects such as spontaneous emission control and threshold less operation [15, 16]. Previously it was reported that threshold current of GaInAsP–InP base laser has been reduced and spontaneous emission factor has been estimated to be 0.2 [17]. QDLs have achieved ultralow threshold current due to the small volume of the active region and due to the small length of the cavity [7]. The emission rate is directly proportional to the local density of optical states (DOS) the effect of which requires further investigation [18]. Therefore, this research is devoted to the analysis of spontaneous emission factor of QDL and its stability with respect to different parameters such as: operating wavelength of the laser, energy band-gap of the active layer material, carrier concentration at conduction band of the Group-III nitride trios.

2. Methodology

This section represents the detailed description of the device structure: structure of InGaN QD, which is used in the active layer of the device structure as well as its energy band structure. For proper explanation, this section has been divided into four subsections, which describes device structure, formation of InGaN QD and energy-band structure of proposed QD. Finally, the numerical model was developed to analyze the device characteristics.

2.1. Device structure

Laser structure composed of InN based QD in the active layer has been considered for investigating the effect of wavelength, energy band-gap and carrier concentration at conduction band on spontaneous emission factor of laser. The laser structure with InN based QDs is shown in Fig. 1. Considering the domain of InN emission wavelength raises the possibility to tune the wavelength by controlling the dots size [19]. Hence InN QD possess greater interest for the possible applications in the wide range of optoelectronic devices.

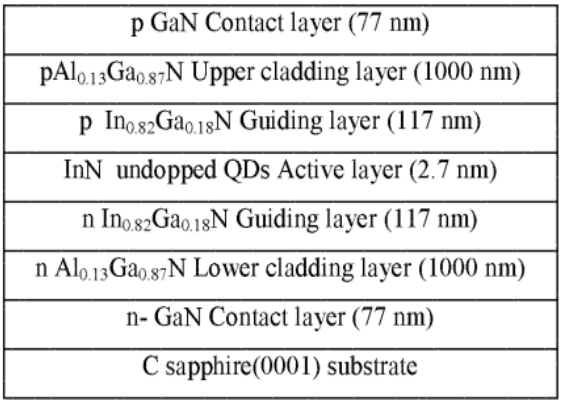

Fig. 1. Schematic diagram of layer structure of InN QDL

For the optimization of the band-gap energy of InN QD to operate exactly at 1.55μm the mean height of the QD is reported as 2.7nm [6, 20]. Hence the active layer thickness has been considered as 2.7 nm, which is equal to the QD heights. Formation of InGaN QD has been presented in Section 2.2.

Schematic structure of InN based QDL consists of InN-plane sapphire (oriented along 0001 direction) wafer as the substrate along with 77 nm-thick n+ GaN contact layer, a 1000 nm thick n $Al_{0.13}Ga_{0.87}N$ lower cladding layer, a 117nm-thick n- $In_{0.82}Ga_{0.18}N$ guiding layer, a 2.7 nm–thick InN active region with single layer undoped QDs, a 117 nm-thick p $In_{0.82}Ga_{0.18}N$ guiding layer, a 1000 nm thick p Al0.13Ga0.87N upper cladding layer; 77 nm-thick p+ GaN contact layer. The optical confinement layer thickness is 236.7 nm. To form Fabry-Perot cavity mirrors by etching facets FIB etching technique is proposed which provides high quality etched facets. Fabry-Perot resonator is composed of two highly reflective mirrors which allow small portions of light to pass through, while reflecting the most of the light back through the active region, where it can be further replicated through stimulated emission. A pair of parallel planes (or facets) is etched. Under appropriate biasing condition laser light will be emitted from these planes. The two remaining sides are roughened to eliminate lasing in any direction other than main one.

2.2. Formation of InGaN QD

The use of InN QDs raises the possibility to tune the wavelength by controlling the dot size [19]. It is of great interest for possible applications. As a new material system, group-III nitride-based devices are of particular interest due to their wide range of emission frequencies from red to ultraviolet and their potential for high-power electronic applications.

The lattice mismatch between InN and GaN leads to the occurrence of a strain field in the hetero structure. This field modifies the conduction- and valence band edges of the InN QD. For InN, the isotropic electron effective mass $m_e = 0.069m_0$ [21]. The embedded QD-WL system is schematically shown in Fig. 2.

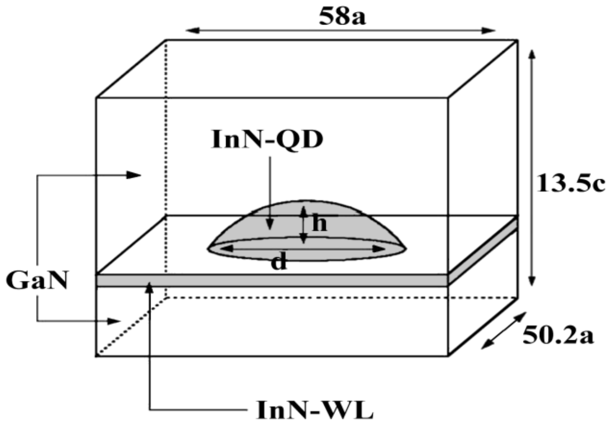

Fig. 2. Illustration of the finite-size super cell in which the QD geometry is modeled. The investigated lens-shaped InN QDs are sitting atop an InN wetting layer (WL) and have circular symmetry around the z axis. The InN QD-WL system is embedded in a GaN matrix

Being a technologically promising system, self-assembled lens-shaped InN/GaN QDs with mean diameter d = 6 nm and mean height h = 2.7 nm are used here, which are typically grown by molecular beam epitaxy in the Stranski–Krastanov growth mode [22]. This lens-shaped QD confines three bound electron states. Lens-shaped quartzite InN QDs, grown in the (0001) direction on top of an InN wetting layer and embedded in a GaN matrix, are considered here. A super cell with dimension 58 a×50.2 a×13.5 c (188,181 atoms) is employed to reach good convergence for the localized QD states. For the WL, a thickness of one lattice constant c is assumed.

2.3. Energy-band diagram of the proposed QDL

Optical-confinement layer (OCL) of the p–n double hetero structure QDL (Fig. 1) is formed in the field region. The active layer is composed of QD-array, which is formed through the center of OCL along the longitudinal direction of wave propagation and lateral directions in the slab-dielectric waveguide.

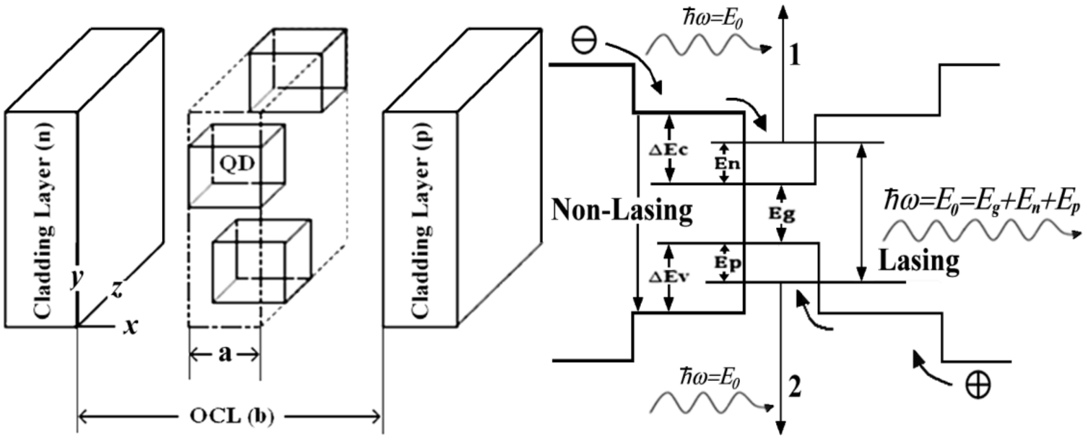

Fig. 3. Schematic view and energy band diagram of the QD-laser structure. The QDs are not drawn to scale. Arrows 1 and 2 show the transitions of carriers from the quantized energy levels to the continuous spectrum states in the process of light absorption [20]

The carrier injection from the cladding layers, occurs in the transverse direction. The photon energy is expressed as

$$E_0 = E_g + E_n + E_p$$

where E_g is the band-gap energy of QD material, and E_n are the ground quantized energy levels of an electron in conduction band measured from the band edges, and E_p is the ground quantized energy levels of a hole in the valence band measured from the band edge.

In Fig. 3, a is the thickness of the OCL of the QD and b is the thickness of the OCL of the upper cladding and the lower cladding layers. In this research we have assumed single electron-level QDs; i.e., the QD sizes and/or the conduction-band offset at the QD–OCL hetero boundary are not large enough for the second level to exist. Such limitations on the QD sizes and/or the compositions of QDs and OCL are reasonable and desired for improvement of the laser characteristics. The point is that the presence of the higher energy levels of holes in rectangular boxlike QDs does not significantly affect the threshold current. The reason is that the radiative transitions from the lowest electron level to the higher hole levels are (at least partly) forbidden in such QDs. Because of the descending behaviour of the light-intensity distribution across the transverse direction, Thus, one is inclined to think that the best (aiming at minimizing jth) plan of QD sitting is to arrange them within a single layer in the OCL centre (Fig. 3).

2.4. Numerical model

Spontaneous emission is the process in which a quantum mechanical system such as a molecule, an atom or a subatomic particle, transits from an excited energy state to a lower energy state e.g., its ground state and emits a quantized amount of energy in the form of a photon [23].

The spontaneous emission factor is then defined as the fraction of spontaneous emission radiated into a specific optical mode, here denoted as the cavity or lasing mode. It involves a summation or integration of the atom-field coupling over all optical modes and thereby touches the heart of quantum electrodynamics [24]. The spontaneous emission factor indicates the relative strengths of the spontaneous and stimulated emission process [25].

The spontaneous emission factor is defined as the coupling efficiency of the spontaneous emission into a lasing mode and is expressed as [26]:

$$C=\frac{p\Gamma_r\lambda_{sp}^4F_{sp}}{8\ \pi\ n_{eq}^3\ V_m} \tag{1}$$

where, p is the coefficient denoting the polarization anisotropy of the spontaneous emission, F_{sp} is the normalized spontaneous emission spectrum, V_m is the mode of volume, Γ_r is the relative confinement factor, $\lambda_{sp}=\lambda$ is the wavelength of spontaneous emission, n_{eq} =n is Effective density of states,

Taking derivative of both side of equation (1) with respect to wavelength, we get

$$\frac{dC}{d\lambda}=\frac{p\Gamma_rF_{sp}}{8\ \pi\ n_{eq}^3\ V_m}\times 4\lambda^3 \tag{2}$$

We know that the wavelength is given by:

$$\lambda=\frac{hC}{E_g} \tag{3}$$

From equation (1)

$$C=\frac{p\Gamma_rF_{sp}}{8\ \pi\ n_{eq}^3\ V_m}\times\left[\frac{hc}{Eg}\right]^4 \tag{4}$$

where, Eg is the Band-gap energy; c is the velocity of light; h is the Planck's constant.

$$\mathrm{Eg(T)}=\mathrm{Eg(0)}\ -\frac{\gamma T^2}{T+\beta} \tag{5}$$

Now to analyze the effect of temperature on spontaneous emission factor putting the value of Eg in Equation (4) from Equation (5) we obtained as follows:

$$C=\frac{p\Gamma_rF_{sp}}{8\ \pi\ n_{eq}^3\ V_m}\times\left[\frac{hc}{\mathrm{Eg(0)}\ -\frac{\gamma T^2}{T+\beta}}\right]^4 \tag{6}$$

Derivative the both side of equation (4) with respect to energy band-gap the following equation is obtained:

$$\frac{dC}{dEg}=-\frac{p\Gamma_r\ F_{sp}h^4c^4Eg^{-5}}{2\ \pi\ n_{eq}^3\ V_m} \tag{7}$$

Here the (-ve) sign indicates that the rate of change of spontaneous emission factor of QDL decreases with the increase in energy band-gap or vice versa. Now considering only the magnitude of the rate of change of spontaneous emission factor with respect to temperature using the Equation (8) from Equation (6) and (7) become as follows:

$$\left|\frac{dC}{dEg}\right|=\frac{p\Gamma_r\ F_{sp}h^4c^4Eg^{-5}}{2\ \pi\ n_{eq}^3\ V_m} \tag{8}$$

To simplify putting the value of the value of Eg(T) in Equation (6) the following equation is obtained:

$$\left|\frac{dC}{dEg}\right|=\frac{p\Gamma_r\ F_{sp}h^4c^4(\mathrm{Eg(0)}-\frac{\gamma T^2}{T+\beta})^{-5}}{2\ \pi\ n_{eq}^3\ V_m} \tag{9}$$

3. Results and discussion

This section represents the detailed description of the obtained results throughout the comparative analysis of the effect of wavelength, energy band-gap, carrier concentration at conduction band on spontaneous emission factor and its rate of change using InN, GaN and AlN semiconductor based QD in the active layer of the laser structure. The rate of change of spontaneous emission factor has been investigated numerically with respect to wavelength, energy band-gap, carrier concentration at conduction band for three different types of semiconductor materials based QD, in the active layer of the laser structure. These are – Indium Nitride, Gallium Nitride, and Aluminum Nitride.

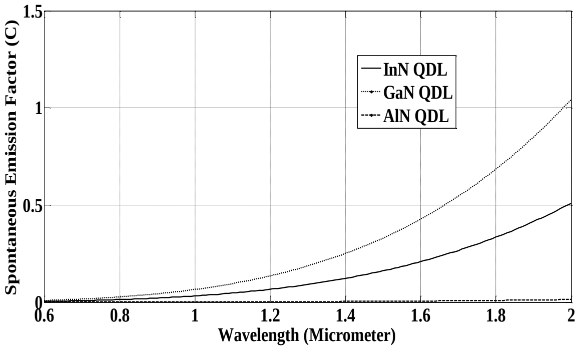

Fig. 4. Wavelength dependence of spontaneous emission factor using AlN (Dashed line), InN (Solid line), and GaN (Dotted line) based QD as the active layer material of the QDL layer structure

Fig. 4 presents the effect of wavelength on spontaneous emission factor using AlN, InN, and GaN based QD in the active layer of the laser structure. The dashed line, solid line and dotted line represents the effect of wavelength on the spontaneous emission factor using AlN, InN and GaN based QD as the active layer material. It is clear from the figure that spontaneous emission factor increases exponentially using AlN, InN and GaN based QD in the active layer of the laser structure. From Figure 4 it is ascertained that AlN based QDL has the lowest spontaneous emission factor and for GaN based QDL the highest spontaneous emission factor has been achieved. However, for InN QDL moderate spontaneous emission factor has been achieved in between the other two material based QDL. As 1.55μm is the most promising wavelength in the field of Optical Fiber Communication (OFC) system, it is found that the spontaneous emission factor at 1.55 μm are approximately 0.1, 0.75 and 1.4 using AlN, InN and GaN based QD as the active layer material. Now the effect of wavelength on the rate of change of spontaneous emission factor will be analyzed to ensure the stability of the laser characteristics.

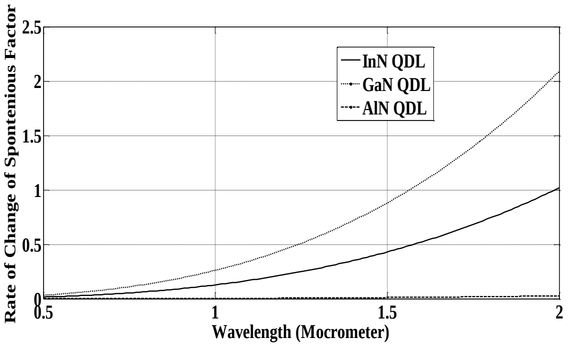

Fig. 5. Wavelength dependence of the rate of change of spontaneous emission factor using Alan (Dashed line), InN (Solid line), and GaN (Dotted line) based QD as the active layer material of the QDL layer structure

Fig. 5 presents the effect of wavelength on the rate of change of spontaneous emission factor with respect to wavelength using AlN, InN and GaN based QD in the active layer of the laser structure. The dashed line, solid line and dotted line represents the effect of wavelength on the rate of change of spontaneous emission factor with respect to wavelength using AlN, InN and GaN based QD as the active layer material of the laser structure. It is clearly seen from figure that the rate of change of spontaneous emission factor is increases exponentially for three different types of QD in the active layer of the laser structure with the increase of wavelength. From Fig. 5 it is also ascertained that for AlN the lowest rate of change of spontaneous emission factor has been achieved and for GaN the highest rate of change of spontaneous emission factor has been achieved. However, for InN QD a moderate rate of change of spontaneous emission factor has been achieved in between the QDLs based on AlN and GaN. Fig. 5 also shows that the rate of change of spontaneous emission factor at 1.55 μm is approximately 0.01, 0.75, and 1.5 using AlN, InN and GaN based QD as the active layer material respectively.

Hence we can say from Fig. 4 and Fig. 5 that for AlN QDL, spontaneous emission factor is the lowest and the rate of change of spontaneous emission factor is also the lowest, for GaN QDL, spontaneous emission factor is the highest and the rate of change of spontaneous emission factor is also the highest. Conversely, for InN based QD the spontaneous emission factor and the rate of change of spontaneous emission factor has been found in between the highest and the lowest. Finally, to get an ample output with better stability InN QD is preferred to design QDL.

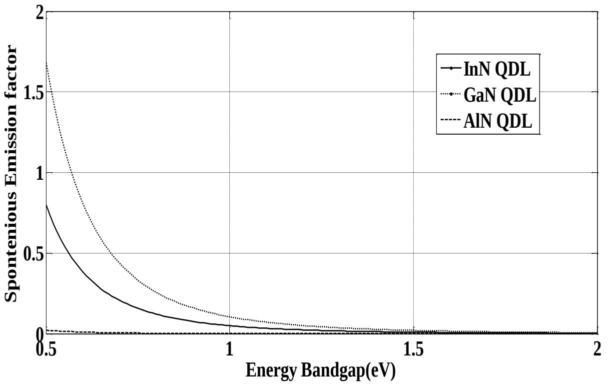

Fig. 6. Energy band-gap dependence of spontaneous emission factor of QDL using AlN (Dashed line), InN (Solid line), and GaN (Dotted line) based QD as the active layer material of the QDL layer structure

Fig. 6 presents the effect of energy band-gap on the spontaneous emission factor of laser using AlN, InN, and GaN based QD in the active layer of the laser structure. The dashed line, solid line and dotted line represents the effect of energy band-gap on the spontaneous emission factor using AlN, InN, and GaN based QD as the active layer material. Fig. 6 clearly indicate that the spontaneous emission factor reduces nonlinearly with the uniform increase of energy band-gap. As shown in Fig. 6 the slope of the line curve is the minimum and after the energy band-gap of 1.5 eV it is almost flat. It is ascertained that for AlN QDL the highest spontaneous emission factor has been achieved. For GaN the lowest spontaneous emission factor has been achieved. However, for InN QD in the active layer of the laser structure a moderate spontaneous emission factor has been achieved in between highest and lowest. As energy band-gap of 0.8 eV is required for the laser to operate at 1.55μm wavelength, which is the most promising window of OFC, therefore 0.8 eV has been selected for comparison point. From Fig. 6 it is found that the spontaneous emission factor at 0.8 eV energy band-gap are approximately 0.05, 0.25 and 0.5 using AlN, InN and GaN based QD as the active layer material.

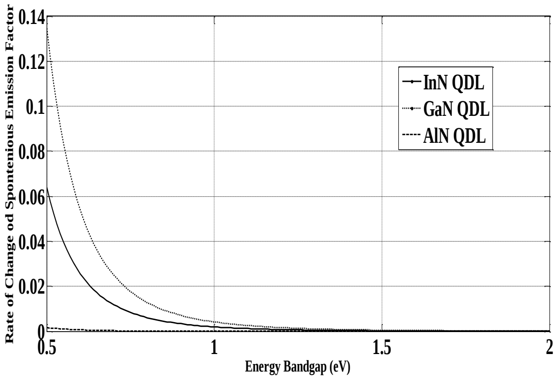

Fig. 7. Energy band-gap dependence of rate of change of spontaneous emission factor of QDL using AlN, InN and GaN based QD as the active layer material of the QDL layer structure

We can see from Fig. 7, the effect of energy band-gap on the rate of change of spontaneous emission factor using AlN, InN, and GaN based QD in the active layer of the laser structure. The dashed line, solid line and dotted line represents the effect of energy band-gap on the rate of change of spontaneous emission factor using AlN, InN, and GaN based QD as the active layer material of the laser structure. It is clearly indicating in Fig. 7 that the rate of change of spontaneous emission factor reduces nonlinearly with the uniform increase of energy band-gap. As shown in Fig. 7 the slope of the line curve is the minimum and after the energy band-gap of 1.25 eV it is almost flat. From this results, we can claim that AlN has the highest rate of change of spontaneous emission factor and for GaN the lowest rate of change of spontaneous emission factor. Whereas, using InN QD in the active layer of the laser structure, we get moderate rate of change of spontaneous emission factor, which is in between highest and lowest. We found from Fig. 7 that the spontaneous emission factor at 0.5 eV energy band-gap are approximately 0.001, 0.06 and 0.12 using AlN, InN and GaN based QD as the active layer material.

It has also been observed that although the highest spontaneous emission factor has been achieved using GaN QD, analyzing the slope of the curves presented in Fig. 7, highest rate of change of spontaneous emission factor has also been acknowledged for GaN QD based laser. For AlN based laser, spontaneous emission factor is the lowest and the rate of change of spontaneous emission factor is also the lowest. However, InN based laser offers a reasonable spontaneous emission factor and the rate of change of spontaneous emission factor is in between highest and lowest. Therefore, to get output with good stability InN can be the most promising material for designing the QDL.

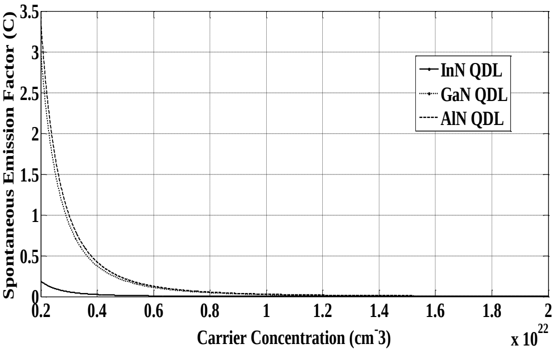

Fig. 8. Carrier concentration at conduction band dependence the spontaneous emission factor of QDL using AlN (Dashed line), InN (Solid line), and GaN (Doted line) based QD as the active layer material of the QDL layer structure

Fig. 8 presents the effect of carrier concentration at conduction band on spontaneous emission factor of QDL using AlN, InN, and GaN based QD in the active layer of the laser structure. The dashed line, solid line and the dotted line represents the effect of carrier concentration at conduction band on the spontaneous emission factor using AlN, InN, and GaN based QD as the active layer material of the laser structure. It is clear from Fig. 8 that spontaneous emission factor reduces nonlinearly with the uniform increase of carrier concentration at conduction band. As shown in Fig. 8 the slope of all the line curves i.e. dashed, solid and dotted reaches to the minima afterwards the carrier concentration at conduction band of 1.6× 10^{22} cm^{-3} it is almost flat. It is ascertained that for AlN QD based laser, the highest spontaneous emission factor has been achieved and for InN QD based laser, the lowest spontaneous emission factor has been achieved. However for GaN based laser, spontaneous emission factor has been achieved very close to that of GaN based QDL.

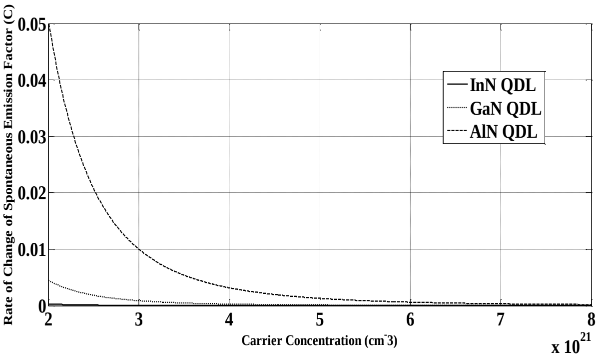

Fig. 9. Carrier concentration dependence of rate of change of spontaneous emission factor of QDL using AlN (Dashed line), InN (Solid line), and GaN (Dotted line) based QD as the active layer material of the QDL layer structure

Fig. 9 demonstrate the effect of carrier concentration of conduction band on the rate of change of spontaneous emission factor using AlN, InN, and GaN based QD in the active layer of the laser structure. The dashed line, solid line and dotted line represents the effect of carrier concentration at conduction band on the rate of change of spontaneous emission factor of QDL using AlN, InN, and GaN based QD as the active layer material of the laser structure. Fig. 9 shows the rate of change of spontaneous emission factor reduces nonlinearly with the uniform increase of carrier concentration at conduction band. As shown in Fig. 9, the slope of the line curve is the minimum and after the carrier concentration at conduction band of 7× 10^{22} cm^{-3} it is almost flat. From the results in Fig. 9, we can state that AlN has the highest rate of change of spontaneous emission factor and InN has the lowest rate of change of spontaneous emission factor. On the other hand, GaN offers the rate of change of spontaneous emission factor, which is in between highest and lowest. It was found that the spontaneous emission factor at 2×10^{22} cm^{-3} are approximately 0.05, 0.0001 and 0.06 using AlN, InN and GaN based QD as the active layer material.

Hence from Fig. 8, it is clear that the highest spontaneous emission factor has been achieved for AlN QD based laser. It has been observed that although the highest spontaneous emission factor has been achieved for AlN based QDL the highest rate of change of spontaneous emission factor has also been acknowledged using AlN QD. For InN QDL, spontaneous emission factor is the lowest and the rate of change of spontaneous emission factor found is also the lowest. However, GaN based laser offers a reasonable spontaneous emission factor close to AlN based QDL and the rate of change of spontaneous emission factor is in between highest and lowest. Therefore, finally to get the output with good stability InN can be the most promising one to design QDL with lowest rate of change of spontaneous emission factor of QDL

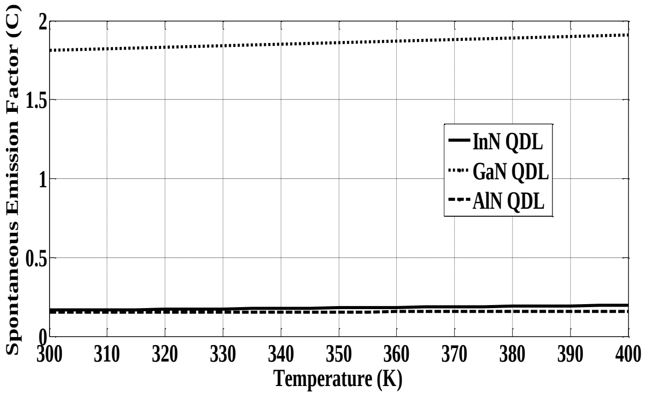

Fig. 10. Temperature dependence of spontaneous emission factor of QDL using AlN (Dashed line), InN (Solid line), and GaN (Dotted line) based QD as the active layer material of the QDL layer structure

Finally, the effect of temperature on spontaneous emission factor of laser has been determined using AlN, InN, and GaN based QD in the active layer of the laser structure, as shown in Fig. 10. The dashed line, solid line and dotted line represents the effect of temperature on the spontaneous emission factor of QDL using AlN, InN, and GaN based QD. Here we observed that the spontaneous emission factor increases in a very small amount with the increase of temperature. As seen from Fig. 10, the line curve is almost flat over the temperature of 400 K above room temperature. We can then conclude from Fig. 10 that for AlN the highest spontaneous emission factor has been obtained, and for GaN the lowest spontaneous emission factor has been achieved. However, for InN the spontaneous emission factor has been achieved in between highest and lowest. We found the spontaneous emission factor is approximately 1.9, 0.2 and 0.19 using AlN, InN and GaN based QD at 300 K. From the flatness of the line curve it is revealed that the lowest rate of change of spontaneous emission factor of QDL has been achieved using InN QD in the active layer of the laser structure, which ensures the temperature insensitive operation of QDL using InN QD.

4. Conclusion

This paper reports that the application of InN QD offers an acceptable limit of fluctuation of spontaneous emission factor to increase the efficiency and ensure better performance of laser using InN QD in the active layer of the device structure. The effect of operating wavelength, energy band-gap of active layer material and effective DOS of carriers on spontaneous emission factor has been investigated. From the comparative analysis obtained through numerical simulation it was found that the spontaneous emission factor increases exponentially with respect to wavelength and reduces nonlinearly with the uniform increase of energy band-gap using InN, GaN and AlN based QD in the active layer of the laser structure. Although highest spontaneous emission factor has been achieved using AlN based QD at any wavelength, the rate of change of spontaneous emission factor is also highest. For GaN based laser, spontaneous emission factor is the lowest and the rate of change of spontaneous emission factor is also the lowest. However, InN QD in the active layer of laser offers moderated spontaneous emission factor and moderated rate of change of spontaneous emission factor as it lays between AlN and GaN based QDL. In addition, the spontaneous emission factor reduces nonlinearly with the uniform increase of effective DOS using the same semiconductor materials based QD in the active layer of the laser structure. It is ascertained, for GaN based laser, the highest spontaneous emission factor has been achieved, for AlN based laser, the lowest spontaneous emission factor has been achieved. However moderate spontaneous emission factor has been achieved using InN. Finally, we can draw a conclusion that there is no effect on spontaneous emission factor with respect to temperature on in QDL.

Acknowledgments

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