# InAs/GaAs QDs and dilute nitride QWs VCSELs grown by molecular beam epitaxy

FATEN ADEL ISMAEL CHAQMAQCHEE*
*Koya University, Faculty of Science and Health, Department of Physics, Daniel Mitterrand Boulevard, Koya KOY45, Kurdistan Region - Iraq*

The quaternary of GaAsSbN capping layer (CL) and GaAsSb/GaAsN CL InAs/GaAs quantum dots (QDs) and the GaInNAs/GaAs quantum wells (QWs) VCSEL samples were grown by molecular beam epitaxy (MBE). Photoluminescence (PL) measurement was performed for InAs/GaAs QDs with two different CLs at low temperature, while PL was carried out for GaInNAs/GaAs QWs VCSELs at various temperatures. In addition, Integrated intensity of electroluminescence (EL) for the QWs VCSEL were measured under continuous-wave (CW) and pulsed conditions to reach emission wavelength at around wavelength of λ=1.28 μm for optoelectronics applications. Thus, a low temperature red shift was achieved using GaAsSbN CL and InAs/GaAs QD but in low intensity. In addition, amplification was observed by QWs devices at low temperature of T=77K.

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## 1. Introduction

Dilute nitride III-V semiconductor structures with thin layers include different compositions and properties have been grown by MBE technique [1]. An InAs/GaAs QDs have been used in the last decade due to their various optoelectronic devices applications such as GaSb/GaAs photodetector or solar cell [2,3], GaAsSb-capped CL of InAs/GaAs QD laser diodes LDs [4] and GaAsSb-capped CL InAs/GaAs QD infrared photodetectors. The use of a CLs QDs material has been widely studied to yield a high quality samples and low cost devices to reach long telecom wavelength [5].

The incorporation of small amount of nitrogen into Ga(In)As, the conduction band CB of GaAs or GaInAs reduced and theoretically expressed by band anti-crossing model (BAC) that was proposed by Wu and co-workers [6], and thus an increasing of refractive index values. Moreover, the inclusion of Antimony Sb to GaAs or into GaAsN, the valance band (VB) getting raised. Therefore, the quaternary GaAsSbN CL on InAs/GaAs QDs allows tuning separately the electron and hole confinement potentials [7].

The structure of QDs samples consists of monolayers (MLs), capped layers (CLs) and the active region. The active region for the samples consists of a single QD layer and always formed by MLs of InAs deposited at temperature around 487 $^{o}$C. A 250 nm of GaAsSb/GaAsN (or GaAsSbN) CLs were grown at about 500 $^{o}$C, and the samples were subsequently covered with 250 nm of GaAs layer grown at around 610 $^{o}$C on top of the CL. The structure all were grown on $n^+$ GaAs: Si substrate.

Furthermore, the VCSEL device consists of an active region embedded within a compositional p-n graded layers lying between top and bottom DBRs. The active region contains nine GaInNAs QWs that grouped in three sets of three wells each, positioned on the standing wave peaks 3/2 λ cavity. The top mirror consists of 21-pairs of undoped AlGaAs/GaAs DBR. The bottom mirrors have 24-pairs of n-doped AlGaAs/GaAs DBR with higher reflectivity, to get an emission from the top layers. The thickness of layers device can be found elsewhere [8].

In this work, we have studied InAs/GaAs QDs samples with GaAsSbN and GaAsN/ GaAsSb CLs and GaInNAs/GaAs QWs VCSEL device. Photoluminescence (PL) measurements were carried out by using the He-Ne laser for QDs samples at various temperatures and an Ar-ion laser as an excitation source plus a tunable laser as input signal were used for QWs VCSEL device. In addition, the electroluminescence (EL) spectra were achieved for VCSELs samples using CW conditions.

## 2. Experimental details

The QDs samples were grown by MBE techniques at Universidad Poletecnica de Madrid. In which, the He-Ne laser of λ= 632.8 nm was used as an excitation source on QDs samples of two different CLs. SR540 chopper which was used infront of laser set at frequency of f=37 Hz. An 850 Filter was used in front of monochrometor to cut unnecessary wavelengths that appear on the sample. PLs were measured using the liquid nitrogen-cooled Ge detector, where it cooled down to T=15 K using $N_2$ gas.

Applied Detector Corporation (0-1000 volt) was used to collect the light from the monochrometer (slits between 100 and 200 μm) and convert it to an electrical signal, which was enhanced using lock in amplifier. The wavelengths peak was changed according to the growth condition of QD.

In addition, dilute nitride QWs VCSEL device coded G0428 were also grown by MBE techniques. These devices are supplied by the optoelectronics research centre (ORC) Tampere University of Technology in Finland. Table 1 gives the typical growth parameters for the VCSEL samples, where the doping level, the layer compositions and the layer thickness are targeted according to the design.

*Table 1. Growth parameters used for the VCSEL samples*

| Elements | Growth temperature | As/III Beam equivalent pressures (BEP) ratio | Growth rate |
|---|---|---|---|
| n-AlGaAs/GaAs DBR and staircase grading layers | 600 °C | 40-60 | 0.248-1.348 μm/h |
| GaAs layers in the active region | 580 °C | 17-29 | 0.248 μm/h |
| $GaIn_{0.332}N_{0.022}As$ QWs | 340 °C | 16 | 0.371 μm/h |
| AlGaAs/GaAs top DBR and p-type staircase grading layers | 600 °C | 40-60 | 0.248-1.348 μm/h |

VCSELs samples were fabricated using etching steps to operate in reflection mode. The samples were excited using Ar-laser and the luminescence was measured using the monochromator and a cooled GaInAs detector. In addition, the NI PXI-1033 tunable laser is used as an input signal source, while 980 nm fibre pigtailed single mode diode laser (1999 PLM 980 nm pump module) is used for device excitation. The wavelengths of the tunable laser are varied from 1265 nm to 1345 nm and the optical output powers are ranged from 1 mW to 6 mW. The output signal from the laser is connected into the variable power. The optical coupler and optical circulator were used to separate the input and output signals, optical spectrum analyser is used to measure the amplitudes of output signals.

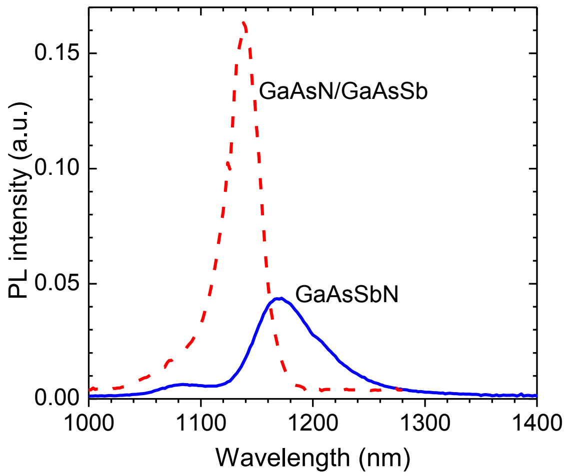


*Fig. 1. PL intensity against wavelength of InAs/GaAs QDs sample for GaAsSbN CL and GaAsN/GaAsSb CL measured at T=16 K*

## 3. Result and discussion

The PL spectra for the QDs samples were grown in different conditions using two different CLs. The PL spectrum can be enhanced by increasing the concentration of N and Sb during growth procedure. As shown in Fig. 1, the PL intensity versus wavelength was measured at temperature T=16 K. The emission peak of GaAsN/GaAsSb CL is around λ=1140 nm, while the emission peak of the quaternary GaAsSbN CL is about λ=1170 nm. The improvement was happened due to adding Sb to GaAsN in CL. However, low energy shoulder was observed at around λ=1080 nm probably fluctuation in the thickness of GaAsSbN layer during sample growing. Thus, the presence of Sb raised the valence band of GaAs [9] and it led to a red shift emission [10] but in weakened luminescence.

Fig. 2 shows the room temperature output characteristics of QWs VCSEL sample emitting at around λ=1.28 μm for an aperture diameter of 10 μm and the second mesa etch diameter is 60 μm. The emission occurred for a DC voltage and current as low as 2.7 V and 0.8 mA, respectively. In addition, the maximum single mode output power was 0.042 nW at 8 V. Series resistances were measured using digital multimeter high ranging from 50 Ω to 150 Ω, and this might be due to the thin p-doped layer. Therefore, no threshold current or no continuous-wave (CW) lasing was observed and thus the device is emitted spontaneously.

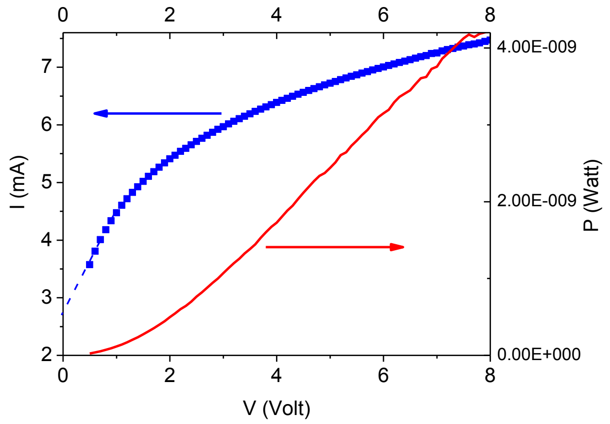


*Fig. 2. Current-voltage-power (I-V-P) characteristics of QW VCSEL under DC operation with aperture diameter of 10 µm at room temperature*

The voltage-current-luminescence (V-I-L) characteristics for the QWs VCSEL sample have been measured at temperature of T=14 °C. The pulse widths of the device was about 165 µs, 500 ns and 200 ns, where applied along the device of 70 µm diameter. Therefore, by reducing the pulse width into 200 ns, no indications of lasing were noticed as shown in Fig. 3.

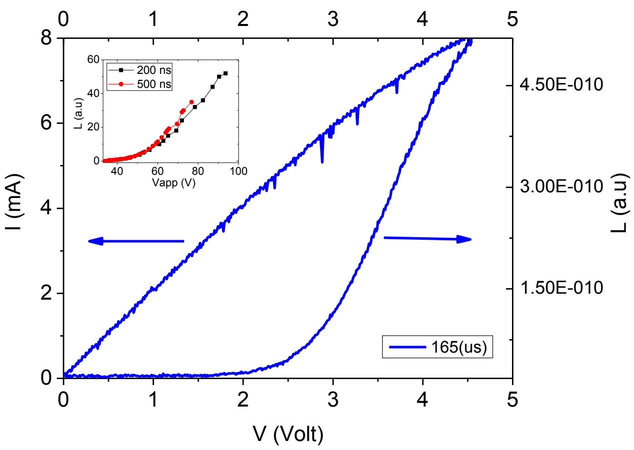


*Fig. 3. I-V-L characterization for QWs VCSEL sample using pulsed operation of 165 µs and their luminescence intensity of 200 and 500 ns pulsed width at T=15 °C*

Fig. 4 shows the spectra of QWs VCSEL sample at various applied currents using the pump laser of 980 nm pump laser at T= 288 K. Emission spectrum at lower applied current of I=100 mA was about -10 dB as a result in emission dominated by the low energy peak of the sample, while their emission amplitude at I=950 mA was around -20 dB. This was achieved without lasing even under high bias currents because the devices were designed for electrical pumping not for optical pumping. A significant problem that has been encountered with electrically pumped GaInNAs/GaAs VCSELs is that of free carrier absorption in p-type DBRs that varies with wavelength [11]. Furthermore, Fig. 5 shows the PL spectra for VCSEL sample using Ar-laser at room temperature and at liquid nitrogen temperature. At T=300 K, no stimulated emission was reported using incident laser power of P=140 mW. However, at T=77 K a stimulated emission was obtained using incident power of P=1200 mW.

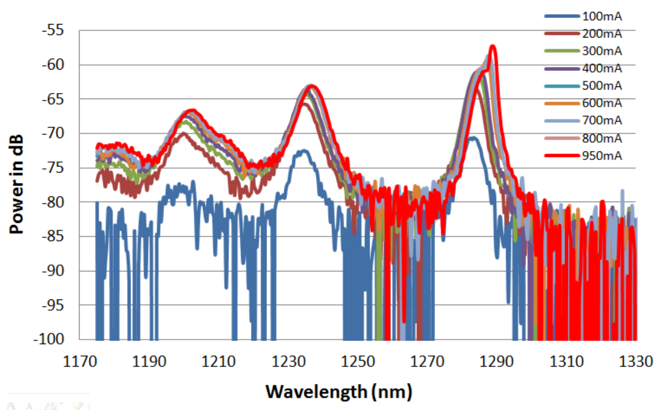


*Fig. 4. The spectra of QWs VCSEL sample plotted as a function of various applied currents of 980 nm pump diode laser at T=288 K*

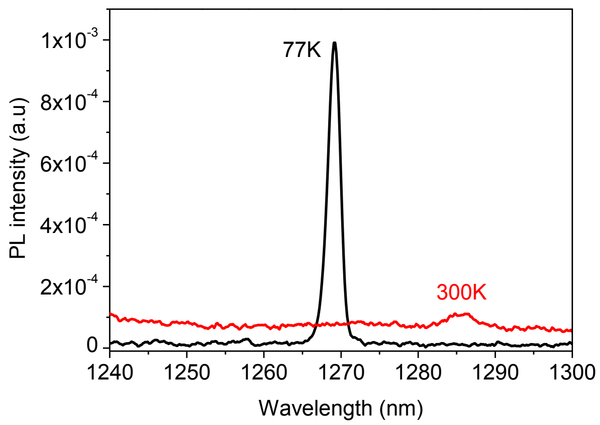


*Fig. 5. PL emission of VCSEL sample at temperatures and incident laser powers of T=77 and P=140 mW and T=300K and P=1200 mW, respectively*

## 4. Conclusions

In conclusion, a red shift emission of the PL peak for MBE grown InAs/GaAs QDs sample at temperature T=16 K is reported. This was completed by the incorporation of Sb contents on GaAsN capping layer but it reduces their intensity. This approach can be used in efficient photodetectors and LEDs applications.

A CW and pulsed operation were used to measure I-V-L characterization using an optical fiber. Room temperature PLs characterizations and integrated EL intensity began with the measurement of the losses incurred in the APC patchcord and circulator. Therefore, amplification was observed at low temperature using optical pumping by an Argon ion laser. Future improvements in performance can be achieved by further adapting the well-established 1.28 µm VCSEL technology.

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**Abbreviations**

VCSEL - Vertical-cavity surface-emitting laser
DBRs - Distributed Bragg reflectors
PL - Photoluminescence
EL - Electroluminescence
QDs - Quantum dots
QWs - Quantum wells

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*Corresponding author: faten.chaqmaqchee@koyauniversity.org