Polarization controlled quantum dashes VCSELs

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***Abstract*— Polarization controlled quantum dashes (QDHs) VCSEL grown on InP are investigated. Using optimized growth conditions, QDHs are obtained, presenting a polarized photoluminescence at 1.55 µm at room temperature, following the [1-10] direction according to QDH length. VCSEL polarized output laser emission is demonstrated at room temperature. Output VCSEL polarization is oriented following the [1-10] direction, the extinction ratio is as high as 30 dB. Confrontation between QDH and QW VCSEL show improved performances for QDH VCSEL, in terms of polarization stability (static and dynamic) and polarization extinction ratio.**

Keywords- polarization, VCSEL, quantum dashes

I. Introduction

Vertical cavity surface emission lasers (VCSEL) operating at 1.55 µm present important interests for the telecommunication network. They present the opportunity to benefit from lasers characterized with a circular beam, a spectral purity, and a low cost of fabrication. Nevertheless, one of the most known drawbacks of such laser sources is related to the instability of the optical polarization, leading to an increase of the data bit error rate [1]. By introducing an internal loss anisotropy, nearly stabilized VCSEL have been demonstrated, using surface grating [2], birefringent mirror [3], elliptical cavity [4], and more recently high effective sub-wavelength grating [5]. Nevertheless, this approach requires complex processes. A technological process-free approach, based on the use of an anisotropic gain medium related to substrate orientation has shown polarization but unstable output VCSEL emission [6]. Recently, using InAs quantum dashes (QDHs), we have demonstrated their great interest in polarization controlled and stable output VCSEL emission [7]. In this paper, we present 1.55 µm emitting quantum dashes (QDHs) VCSELs. Polarization resolved measurements show the VCSEL output polarization control. Static and dynamic measurement will be shown.

II. QDHs growth and optcal characteristics

Samples have been grown on (001) nominally oriented InP substrate, using gas-source molecular beam epitaxy. The nanostructures have been obtained after the deposition at 480°C, of 2.1 InAs MLs on lattice matched $Ga_{0.2}In_{0.8}As_{0.435}P_{0.565}$ quaternary alloy. For capped samples, the double cap procedure has been used in order to control the wavelength emission [8]. A 0.3 sccm low arsenic overpressure has been used, in order to favor adatom migration, and get the QDHs formed. Inset of Figure1 is a 1*1 µm² AFM measurement. QDH appears to be formed along the [1-10] crystallographic orientation. The linear density, height, width and typical length has been estimated to be respectively 30 QDH/µm, 2.5 nm, 25 nm and 200-300 nm.

In VCSEL structures, an important aspect is the maximization of the modal gain, which consists in increasing the modal gain as optimizing the overlapping between this the gain medium and the internal electric field. A peculiar attention has been focused on that point, and simulation have shown that by decreasing the '*conventionnal'* 40 nm spacer layer between each QDH layer down to 15 nm, a nearly twofold increase in the optical confinement factor is expected. Thus, we have optimized the growth of of six QDH layers stacking, separated by a 15 nm spacer layer. AFM do not show any degradation, while optical efficiency at room temperature is still quite important.

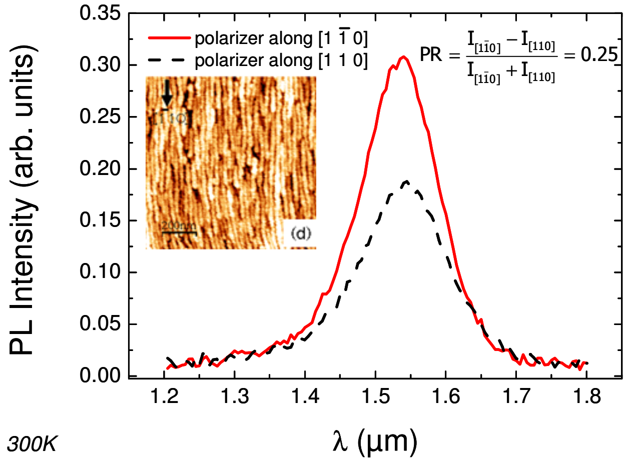

Figure 1 : RT PL of a six QDHs layers sample, separated with a GaInAsP spacer layer of 15nm, as function of the polarizer orientation (collinear with [110] or [1-10] direction). Inset is a 1*1 µm² AFM image of th sixth QDH layers

Figure 1 presents the room temperature photoluminescence (RT PL) spectrum of a six layers QDHs (15 nm spacer layer thickness) sample. The wavelength emission is well centered

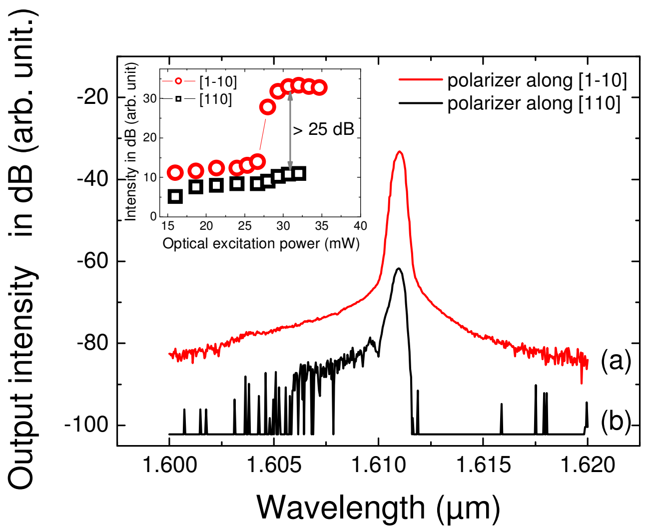

Figure 2 : RT CW laser emission spectra of a 3*6 QDHs VCSEL as function of the polarizer orientation ((a) along [1-10], (b) along [110]), at an excitation power of 30 mW. Inset represents the VCSEL light output integrated intensity versus the optical excitation power, depending on the direction axis of the polarizer, along [110] (squares) and along [1-10] (circles)

at 1.55 µm, the inhomogeneous broadening linewidth related to the size dispersion is 130 nm.

The photoluminescence spectrum appears to be strongly polarized along the [1-10] direction, in relation with the important morphology anisotropy of the QDHs structures. A polarization rate (PR) of 0.25 can be extracted from the measurement. This PR appears to be quite important compared to the value of 0.11 we have measured on a seven lattice matched InGaAs/InP quantum wells (QWs).

III. VCSEL PROCESSING

VCSEL devices containing QDHs have been realized. The active region consists in three groups of 6 QDH layers (or InGaAs QWs lattice matched on InP), each group being located at a stationary electric field maximum intensity position of the microcavity. The microcavity has been designed with two dielectric Bragg mirrors, in order to benefit from a better reflectivity and thermal conductivity in comparison with epitaxial Bragg mirrors available on InP substrate [8]. The dielectric materials used are amorphous silicon and amorphous silicon nitride deposited with a magnetron sputtering system. The lower Bragg mirror of 6 periods is deposited directly on the sample. An Au-In eutectic bonding is employed to transfer the sample on a silicon substrate. The InP substrate is removed by mechanical polishing and chemical etching. The process ends up with the deposition of an upper Bragg mirror of 6 periods.

IV. VCSEL CHARACTERIZATIONS

QDHs VCSEL are optically excited, using a 1.064 µm emitting continuous wave (CW) YAG laser, on a 10 µm diameter spot.

From L(I) curve (see figure 2 inset), laser emission is clearly demonstrated for incident excitation power above 27 mW. Sidemode suppression ratio (not shown) is over 50 dB. For incident power larger than 32mW, the output intensity saturates and even starts to decrease, mainly because of thermal effects.

Polarization resolved measurements have been carried out, to test the QDH VCSEL polarization and stability. A 30 dB extinction ratio optical polarizer has been settled between the VCSEL and the spectrum analyser. Figure 2 represents the output laser spectra of the QDHs VCSEL, depending on the polarizer orientation. Above laser threshold, the QDH VCSEL emission is strongly polarized along the [1-10] direction. The OPSR, defined as the ratio of the laser intensity polarized along [1-10] and the intensity polarized along [110], reaches a maximum value of 30 dB (mainly limited by the polarizer).

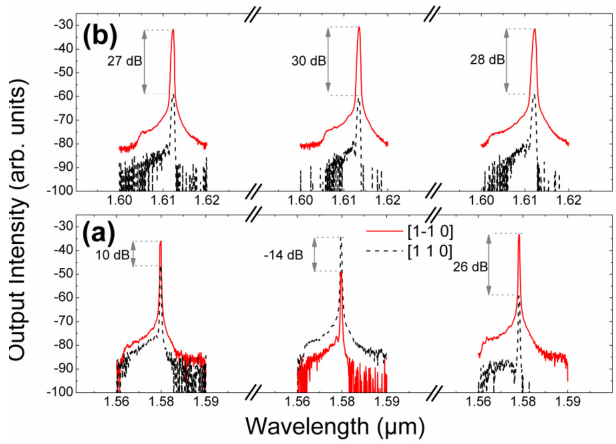

Figure 3 : Typical polarization resolved room temperature spectra from 3*3 QW VCSELs (a) and 3*6 QDH VCSELs (b), measured above threshold (in CW) at different location on samples (average spacing between VCSELs of 4 mm) Continuous line corresponds to the polarizer orientation along [1-10] direction, dashed lines along the [110]. Close to each spectra, the OPSR is indicated.

In order to confront QW VCSEL versus QDH VCSEL, we have made similar polarization resolved experiments, on both QDH and an conventional 1.55 emitting QW VCSELs. Figure 3 presents the output spectra of both VCSELs, depending on the location on a 1 cm² sample. For QDH VCSEL, the output polarization spectrum remains always oriented following the [1-10] direction, and the OPSR is rather constant at 28-30 dB. Regarding the QWs VCSEL performances, the optical polarization orientation changes from a VCSEL location to an another, and the OPSR presents important variations from 25 down to -14 dB. This QW VCSEL polarization instability has been already observed on most VCSELs in CW and modulated devices. Experiments have been investigated, in order test the dynamic stability of

VCSEL output polarization. The set-up consists in modulating the incident optical excitation, using a 1 MHz electro-acoustical modulator. Preliminary results (not shown) have shown that as expected, the QW VCSEL output polarization switches at starting, from a dominant polarization to an another at the end of the pulse. In case of QDH, stable and constant polarization is observed along the whole optical pulse.

CONCLUSION

We have successfully grown QDH nanostructures and realized a QDH VCSEL emitting at the telecommunication wavelength. QDHs exhibit a strong polarized luminescence along the [1-10], corresponding to a polarization rate of 26%. A VCSEL device based on QDHs has been realised. CW lasing is demonstrated at RT. This VCSEL exhibits a stable polarized laser emission on the whole sample without any switching, an OPSR as high as 30 dB is measured. Those QDH VCSELs have been confronted to QW VCSELs. Measurements show that QDH VCSEL output polarization is stable, oriented following the [1-10] direction, in CW and modulated mode; in opposition with QW VCSEL, for which polarization has been observed to switch.

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