Dot Density Effect by Quantity of Deposited Material in InP/AlGaInP Structures

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***Abstract*—Optical absorption spectra have been measured by the segmented contact method on InP quantum-dot (QD) laser structures for different quantities of deposited material, equivalent to 2, 2.5, and 3 mono-layers, and growth temperatures of 690 °C and 730 °C. The spectra suggest inhomogeneous distributions of “large” and “small” groups of dots and a group of “very large” dots in structures grown at 690 °C. The absorption peak energies do not change significantly with the amount of deposited material so we interpret changes in the magnitude of absorption as being due to changes in the density of dots. Using calculated values for the optical cross sections, we have estimated the variation of the number of dots in each group with monolayers of deposited material. The structures grown at 690 °C are unusual in that the density of small dots decreases with increasing material deposited whereas the density of very large dots increases superlinearly, suggesting the small dots agglomerate to form the “very large” dots, which may in fact be due to quantum mechanical coupling of closely spaced small dots.**

***Index Terms*—Optical gain, optical loss, quantum-dot (QD) devices, semiconductor lasers.**

I. INTRODUCTION

TO date, most studies of quantum dot (QD) laser performance have focused on InAs QD devices grown on GaAs substrates because they emit in the wavelength range between 1.3–1.6 μm, which is important for telecommunications technology [1], [2]. However self-assembled InP QD lasers grown on GaAs substrates with emitting wavelength range between 650–780 nm have also attracted some interest [3]–[5] because of potential applications in photodynamic therapies for cancer treatment, as dual or multiwavelength sources for data storage, biophotonic sensing and plastic optical fiber communications. We have reported InP QD lasers grown on GaAs substrates with lasing emission wavelengths range between 730–740 nm with threshold current densities at 300 K as low as 165 $\mathrm{A \cdot cm^{-2}}$ for 2000 μm long devices [6]. In that work it was observed that changing growth temperature between 690 and 750 °C changed the measured absorption spectra, due we supposed to a reduction in the number, and a change in the distribution in energy, of the dot states. To understand the effect of the growth conditions on the formation of dots in groups of different size, in this letter we report observations of optical absorption spectra as a function of quantity of deposited dot material at two growth temperatures of 690 and 730 °C. At a fixed growth temperature the strength of optical absorption is proportional to the number of dots within a group. For most laser applications it is desirable to use dot structures with minimum inhomogeneity in order to generate the maximum peak gain from a given amount of deposited material.

II. EXPERIMENTAL DETAILS

The InP QD laser structures were grown by metal organic vapor phase epitaxy (MOVPE) on n-GaAs (100) substrate oriented 10 ° off toward $\langle 111 \rangle$ and epitaxy was undertaken in a low-pressure (150 Torr) horizontal flow reactor using trimethyl and arsine AsH_3 and phosphine PH_3 precursors. Samples were grown at 690 °C and 730 °C in structures containing 5 dot layers, each formed from 2 or 2.5 or 3 monolayers (ML) of InP, per dot layer, as determined from calibrated gas flows, grown on $(Al_{0.3}Ga_{0.7})_{0.51}In_{0.49}P$ covered by 8 nm $Ga_{0.51}In_{0.49}P$ quantum wells (QW) and separated by 8 nm or 16 nm wide $(Al_{0.3}Ga_{0.7})_{0.51}In_{0.49}P$ barrier layers. The waveguide cores are clad with 1000 nm of $Al_{0.51}In_{0.49}P$.

The wafers were processed into 50 μm wide multisection structures with uncoated facets, angled at 10° to suppress optical feedback. Each of the 300 μm sections was pumped separately to measure the amplified spontaneous emission from which we determined the modal absorption spectra ($A_m(h\nu)$) as described in [7]. The devices were operated in pulsed mode (1 kHz, 1000 ns) to reduce self-heating.

III. RESULTS AND DISCUSSION

The optical modal absorption spectra, in Fig. 1, with three different quantities of deposited QD material for the two growth temperatures, show a variety of inhomogeneously broadened dot transitions. We hypothesize that the peaks labeled “large ground state” and “large first excited state” can be associated with the same set of dots since they coexist in all the spectra in similar proportion. These peaks are at higher energy for the higher growth temperature as has previously been reported for photoluminescence data taken on samples grown at 650 and 710 °C [8], where it was suggested that a greater interdiffusion with the aluminium-containing barrier at higher temperature produces the wavelength shift. Using the absorption data of Fig. 1 we also observe the peak labeled “small dots”, which we associate with a different set of dots since it diminishes with

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