Linear Modal Optical Gain in Quantum Dot Semiconductor Optical Amplifiers

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Abstract

Optical gain is calculated for Sb-based QD structures. The gain is reduced and shifted to longer wavelength with increasing Sb-mole fraction in the dot. Each curve has two peaks. The wavelength shift is small for the ES peak.

1. Introduction

quantum dots (QDs) have recently attracted great interest in various devices such as amplifiers, lasers, and detectors due to their unique advantages over the bulk and quantum-well (QW) devices such as low threshold current, lower temperature sensitivity, high differential gain, and high modulation bandwidth[1]. At the beginning of the 1990s universal self-organization effects were discovered, leading to the formation of self-similar nano-sized coherent clusters, quantum dots. Here a few atomic layers of one semiconductor material are deposited on the surface of another one, which is not lattice matched. The density of this novel class of QDs was observed to be easily tunable as well as their size and thus their optoelectronic properties. Other growth modes were subsequently discovered, such as submonolayer deposition of non-lattice-matched layers or spinodal decomposition leads to QDs with quite different optoelectronic properties. Detailed numerical modeling of the electronic properties of self-organized QDs using 8-band theory predicted that their eigenstates, showing only two–fold spin degeneracy, are tunable in energy across a large range as a function of size, shape and composition of the QDs [2]. The term quantum dot is usually used to describe a semiconductor nanocrystal. Quantum dots are confined, zero-dimensional semiconductor systems created at nanoscale [3].

Optical amplifiers can be thought of as a laser (gain medium) with a low feedback mechanism and whose excited carrier amplifies an incident signal but do not generate their own coherent signal. Similar to electronic amplifiers, optical amplifiers can be used to compensate for signal attenuation resulting from distribution, transmission, or component-insertion losses. Each amplifier requires some forms of external power to provide the energy for amplification. A voltage source is required for the electrical amplifier, and a current or optical source is required for the optical amplifier [4,5].

2. Theory

The material gain per QD layer of a self-assembled QD laser is expressed as[6]

$$\Gamma g^{(1)}(\hbar w) = \Gamma C_0 \sum_i \int_{-\infty}^{\infty} dE' \, |M_{env}|^2 \, |\hat{e} \cdot P_{cv}|^2 \, D(E') L(E', \hbar w) [f_c(E', F_c) - f_v(E', F_c)] \quad (1)$$

where the summation over i is carried out to account for all radiative transitions. The term $|M_{env}|^2$ is the envelope function between the QD electron and hole states. The term $|\hat{e}.P_{cv}|^2$ is the momentum matrix of QD depending on the polarization of light under the parabolic band model. $\hat{e}$ is a unit vector in the polarization direction. m_0 is the free electron mass [6,7]. $C_0 = e^2\pi / n_0 c \varepsilon_0 m_0 w$, where e is the elementary charge, ω is the optical angular frequency, n_b is the background refractive index of the material, c is the speed of light in free space, ε_0 is permittivity of free space. The terms f_c and f_v represent the respective quasi-Fermi level distribution functions for the conduction and valence bands. The Lorentzian line shape function for gain spectrum is given by [8]

$$L(E', \hbar w) = \frac{\hbar \gamma_{cv} / \pi}{(E' - \hbar w)^2 + \hbar^2 \gamma_{cv}^2} \quad (2)$$

3. Results & Conclusions

Optical gain is the fundamental property in understanding behavior of QD semiconductor devices. The structure used to study the modal linear optical gain in Sb-based QD structure is $Ga_{1-x}In_xAs_ySb_{1-y}/GaAs_{0.7}Sb_{0.3}/GaAs$, where $Ga_{1-x}In_xAs_ySb_{1-y}$ is the QD material, $GaAs_{0.7}Sb_{0.3}$ is the wetting layer (WL) and GaAs is the barrier layer. We studied effect of Sb-composition in the QD. Fig. (1) shows the modal linear gain for $Ga_{1-x}In_xAs_ySb_{1-y}/GaAs_{0.7}Sb_{0.3}/$ GaAs, for three Sb-mole fractions, 0.25, 0.45 and

0.55. The gain peak reduced and shifted to longer wavelength with increasing Sb-mole fraction in the dot. Each curve has two peaks depending on the transitions taken (ground- and excited-state transitions). The wavelength shift is small for the ES peak.

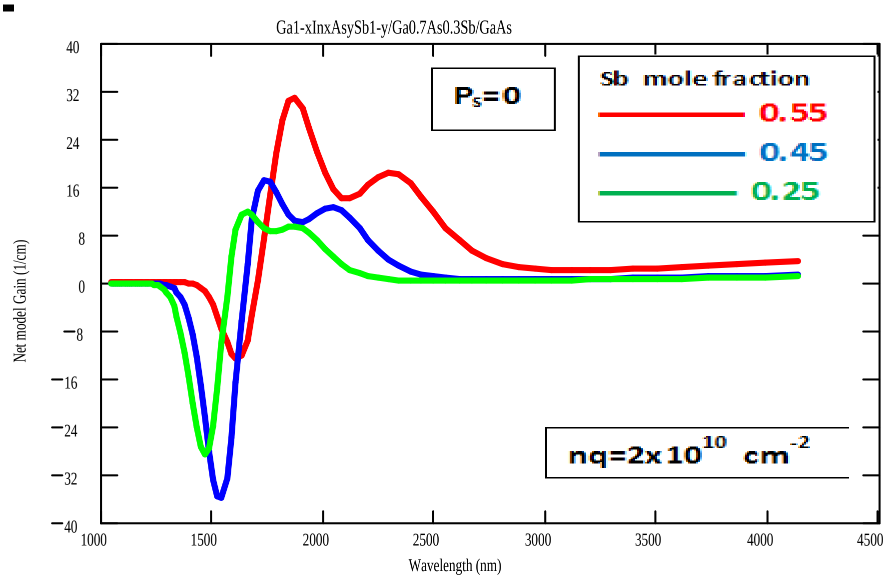

Figure 1: Calculated modal gain spectra for $Ga_{1-x}In_xAs_ySb_{1-y}/GaAs_{0.7}Sb_{0.3}/GaAs$ at three Sb-mole fractions.

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الخلاصة

تم حساب الربح البصري للتركيب الكمي النقطي ذي الأساس Sb . الربح البصري يقل ويزاح باتجاه الأطوال الموجيه الأكبر مع زيادة التركيز المولي من Sb في النموذج. كل منحني يحتوي قمتين, إزاحة الطول الموجي تكون صغيرة للقمة عند ES