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Optical Polarization Properties of InAs/GaAs Quantum Dot Semiconductor Optical Amplifier

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1. Introduction

Semiconductor optical amplifiers (SOA) have received much interest for high speed optical communication windows of 1.3 and 1.55 micro-m [1,2]. The potential advantages of SOA are very compact, low-cost and wide gain bandwidth when compared to Erbium doped fiber amplifier. In particular, quantum dots (QD)- SOAs are more attractive owing to three dimensional quantum confinement effect and their atomic-like density of states [3]. QD-SOAs have been experimentally demonstrated for high-bit-rate optical amplification and wavelength conversion based on non-degenerate four wave mixing [4], in which enhancement of linear gain and nonlinear susceptibility properties lead to improvement in device performance. However, polarization sensitivity of such devices is being a problem for practical applications. Recently, we have reported that the optical polarization anisotropy of the dot can be controlled in the gain medium by changing Indium composition of $In_xGa_{1-x}As$ capping layer [5]. In this work, we have studied cleaved-edge photoluminescence (PL) polarization properties of InAs/GaAs QD-SOA devices and its temperature dependence of the optical polarization characteristics.

2. Experimental Details

The self-assembled InAs/GaAs QD structures investigated in this work were grown by Stranski -Krastanov mode using molecular beam epitaxy on n^+-GaAs (001) substrate. The InAs islands were grown over GaAs/AlGaAs buffer layer. After the growth of the island, a capping layer of $In_{0.17}Ga_{0.83}As$ was overgrown. The schematic diagram of the device structure is illustrated in Fig.1. Finally, AlGaAs/GaAs cover layers were grown. The samples had ridge waveguides of width 4 micro-m. SOA device structure was fabricated by a standard technology [3].

Linear PL polarization spectra of the samples were measured from the cleaved edge surface of the samples. Argon ion laser (λ = 488 nm) beam was focused on the cleaved surface of the QDs to a spot size of 16 micro-m by an objective lens. The excitation power was 74.28 kW/cm^2. PL signal was collected also by the same objective lens, and the signal passed through a 150 micro-m pin hole to acquire a high spatial resolution and dispersed by a TRIAX 320-mm single monochromator. The signal was detected by an InGaAs detector. TE- and TM-mode PL signals were measured by setting an analyzer along the in-plane and the growth direction, respectively.

3. Results and Discussion

Figure 2 shows the PL polarization spectra measured from the cleaved edge of the QD-SOA at 70 K. The solid and open circles indicate TE- and TM-mode PL polarization of the QDs, respectively. The ground state and excited state PL peaks of the QDs are observed due to band filling effects. Here, we focus ground state PL peak polarization of the QDs. The ground state emission is observed at 1.22 micro-m. The long wavelength emission is considered to be due to partial relaxation of compressive strain in the dot by the growth of $In_xGa_{1-x}As$ capping layer [6,7]. As can be seen from the fig.2, the TE-mode PL intensity is much stronger than the TM-mode intensity. The PL polarization depends on the carrier confinement direction within the quantum dot structure. The observed TE-mode dominant PL implies that the hole ground states of the quantum dots are heavy-hole (HH) like. It has been shown that the shape anisotropy (height-to-diameter ratio) of the dot is increased by the growth of $In_xGa_{1-x}As$ capping layer [8,9]. We considered that the major cause for the TE-mode dominant PL is due to the increase in the shape anisotropy and positive biaxial strain distribution in the dot. Although the quantitative contribution of the strain distribution in the post growth dot is not yet clear, we investigate the strain effect by changing the sample temperature that will be elaborated in the following discussion.

By defining the degree of polarization as $P = (I_{TE} - I_{TM})/(I_{TE} + I_{TM})$, the calculated ground state PL peak polarization is to be 0.58. In order to compare the degree of the polarization of the QD-SOA at device operating temperature, we carried out the PL polarization measurements at 300 K. Figure 3 shows the PL polarization spectra measured from the cleaved edge of the QD-SOA at 300 K. Similar to 70 K, the TE-mode dominant PL intensity is observed. The ground state emission is observed at 1.32 micro-m. The red-shift is about 100 nm, which is attributed to thermal strain induced bulk GaAs and

QD band gap shift. At 300 K, the degree of polarization of the ground state PL peak is calculated to be 0.45. It is clear that the contribution of the TM-mode component in this case is enhanced when compared to that at 70 K. The results suggest that the thermal strain could lift the LH in a pronounced way. Since the strain distribution depends on the QD shape [10,11], it is anticipated that the mixing and/or coupling of HH and LH states is also shape dependent. In order to calculate the thermal strain induced energy shift of the hole-states, we consider the standard elasticity equation reported elsewhere [12]. Taking into account that the thermal expansion coefficient of the GaAs substrate and the InAs QD, the calculated energy shift (ΔE_S) of the hole-states is to be 3.2 meV at 70 K whereas 2.2 meV at 300 K. Although the energy difference between HH and LH states is small, it is clear that a significant reduction of the thermal strain enhances the mixing and/or coupling of HH and LH states at 300 K. The observed results suggested that key parameters to control the optical polarization in QD-SOA devices are the QD shape, which can be controlled by capping layer In composition, and strain distribution in the QDs.

4. Conclusion

In summary, we have studied cleaved edge PL polarization spectra (TE- and TM-mode) of InAs/GaAs QD-SOA devices. It is observed that the TE-mode PL intensity is stronger than the TM-mode intensity. The result shows that the hole ground state is heavy-hole like. The temperature dependence PL polarization results show that the TM-mode component is enhanced at 300 K, which is attributed to thermal strain induced energy shift of the LH. By optimizing the capping layer In composition and strain, we can realize the polarization insensitive QD-SOA devices for future photonic networks.

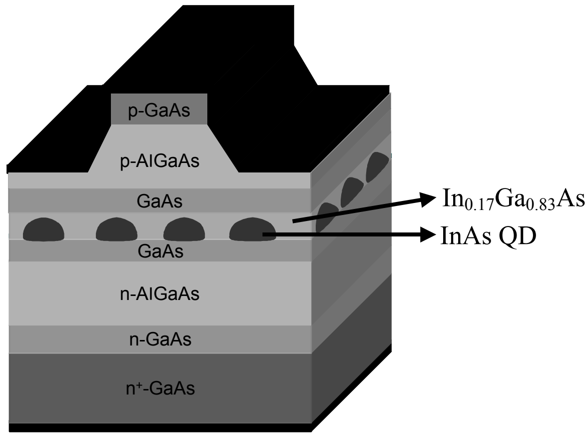

Fig.1 Schematic diagram of the InAs/GaAs QD-SOA device structure.

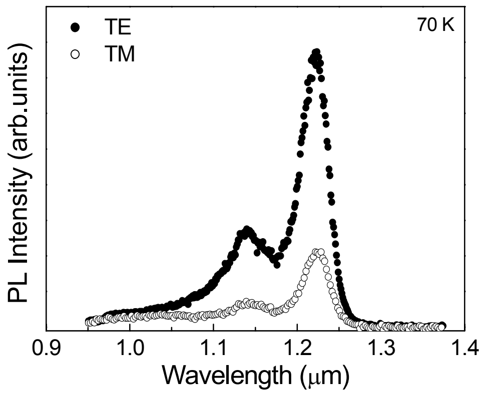

Fig.2. PL polarization spectra of InAs/GaAs QD-SOA measured at 70 K. Solid and open circles indicate TE- and TM-mode, respectively.

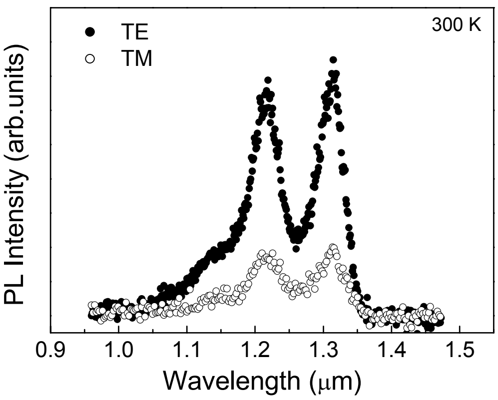

Fig. 3 PL polarization spectra of InAs/GaAs QD-SOA measured at 300 K. Solid and open circles indicate TE- and TM-mode, respectively.

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