GaInAsP/InP 2-DIMENSIONAL PHOTONIC CRYSTALS

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1. Introduction

Photonic crystals are artificial nanostructures constructed by optical atoms arranged in a background medium with a period on the order of half the optical wavelength[1-4]. They are of great interest since those made of semiconductors have the possibility of spontaneous emission control, which realizes the thresholdless operation of laser diodes. A large refractive index contrast between semiconductor and air provides a wide photonic bandgap and hence provides an effective control of spontaneous emission.

Recently, 2-dimensional (2D) structures[5,6] are attracting attention owing to the fabrication much easier than for 3D[7,8] and the spontaneous emission control more effective than by 1D[9-13]. However, the evidence of spontaneous emission control has never been observed from so far fabricated GaAs/AlGaAs structures[14,15]. One of the serious problems is the surface recombination at the side wall of active region, which is damaged by the dry etching process but left uncovered by any low-index films to maintain the index contrast. To avoid this problem, we have employed GaInAsP/InP compounds in our experiments[16]. It has a surface recombination velocity nearly one order of magnitude slower than that of GaAs/AlGaAs. Another advantage of the compounds is their long emission wavelength. The designed structure becomes 1.4–1.8 times larger than that for GaAs/AlGaAs ones. This reduces the difficulty of etching process.

In this paper, we first discuss the spontaneous emission control in a photonic crystal of various dimensions and performance of lasers based on 2D photonic crystal. We also show how the surface recombination affects the performance. Next, we describe the fabrication process of GaInAsP/InP 2D structures by using reactive ion beam etching (RIBE) techniques. We evaluate the etching damage from the photoluminescence (PL) measurement. We also show polarization characteristics of the PL, which can be explained as an effect of spontaneous emission control by a photonic bandgap.

2. Spontaneous Emission Control in Photonic Crystals

Figure 1 illustrates the schematic of a photonic crystal of various dimensions and corresponding wavevector space of emission spectrum inhibited by each photonic bandgap. The 1D structure is a simple multilayer stack and its photonic bandgap is equivalent to the stopband of multilayer filters. Many experiments have been performed using such 1D structures[9-11] to avoid the complicated fabrication process of 2D and 3D. However, the inhibition of light is not perfect, since the light oriented in the lateral direction is permitted. The 2D structure consists of vertical holes or rods formed on a substrate. Although it permits the light to be oriented in near vertical directions, the total solid angle of inhibited orientation is much larger than that in 1D. The 3D structure is a complicated mosaic and all the orientations are inhibited in the ideal case.

Now we consider the condition that the center frequency of bandgap is tuned to that of the emission spectrum, as shown in Fig. 1. The spontaneous emission lifetime $\tau_s$ must be increased by the decrease of allowed optical modes. Figure 2 shows the relative change of spontaneous emission lifetime in photonic crystals, which is estimated from the ratio of allowed solid angle of light to the total solid angle $4\pi$. We have found that such a simple estimation unexpectedly gives a good approximation, when we compared the so obtained lifetime in a 1D microcavity with that accurately calculated by numerically integrating the density of modes[12, 13]. As seen in Fig. 2, the change of lifetime is more marked in 3D than in 1D and 2D, even with a small height of bandgap $\Delta \omega / \omega$.

On the other hand, we can expect a large coupling efficiency $\eta$ of spontaneous emission into a localized mode in the 2D structure. Figure 3 shows the rough estimation of $\eta$ in photonic crystals with a defect. Here, the polarization degeneracy is ignored. The

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*Figure 1*. Schematics of a photonic crystal of various dimensions.