Photonic Crystal Defect Microcavities with Indium Arsenide Quantum Dots

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Strong atom-photon interaction in a small cavity was predicted by Purcell to enhance spontaneous emission [1]. The radiation process can be more efficient than that in free space because of the confinement provided by high reflection mirrors of the cavity. Contemporary nanofabrication technology allows us to construct solid state microcavities such as micropillars [2,3], microdisks [4], or AlO_x-apertured microcavities [5]. Such cavities have very high quality factor Q, but the modal volume V is still big relative to $(\lambda/n)^3$ where λ and n are the resonance wavelength and refractive index. Therefore Purcell's factor, the cavity-related parameter, which is proportional to $Q(\lambda/n)^3/V$ is limited by the large modal volume coefficient $V/(\lambda/n)^3$. In order to clearly see the cavity QED effects, it is, therefore, crucial to obtain small relative modal volume coefficient, too. For the above solid state microcavities, quantum dots as well as single quantum dot are often used as emission sources due to the narrow linewidth emission which can fit well to the cavity resonance.

We have recently demonstrated lasing from photonic crystal defect cavity in the 1.5 μm telecommunication wavelength range [6]. The 2-D photonic crystal defect cavity is expected to combine moderately high quality factor with relatively small modal volumes, and thus provides significant advantage over the above microcavities[7]. The defect cavity in which an air hole is removed from two dimensional haxagonally arrayed photonic crystal has a C_{6v} symmetry. Even if we shrink the defect size until the higher modes are cut off, some modes are allowed to exist in the photonic bandgap. However, by reducing the symmetry to C_{2v}, the modes can be detuned and only one mode could survive in a forbidden bandgap as a defect mode. In this report, we describe the emission from two dimensional photonic crystals that contain an InAs QDs active layer.

The epitaxial layers were grown on (001) GaAs by molecular beam epitaxy. The InAs QDs layer is clad by $Al_{0.15}Ga_{0.85}As$ layers on a top of 0.4μm $AlAs/Al_yGa_{1-y}As$ superlattice where y is close to 1. The GaAs/AlGaAs cap layers are added on the top at last. The cavity thickness is designed to be around 0.2μm. The patterns of hexagonal arrayed photonic crystal defect cavity was precisely transferred into PMMA resist by EB lithography system with field emission electron microscope. The photonic crystal has ten layers with a single defect on the center. To reduce the symmetry to C_{2v} and lift the degeneracies of modes in addition to raising the Q, modification of holes around the defect was introduced. After the lithography, the patterns were transferred through the cavity by using Cl_2 assisted Ar ion beam etching. The etching depth was estimated to be approximately 0.4μm from the surface. Following this anisotropic etching, the $AlAs/Al_yGa_{1-y}As$ superlattice under cavities was oxidized in steam at 400°C to obtain a slab structure. Figure 1 shows the schematic of the photonic crystal microcavity used in this work. Light parallel to surface and normal to surface is confined by the photonic crystal in the plane and the slab structure vertically, respectively.

Optical pumping was conducted at room temperature by 830nm semiconductor laser diodes which was operated by the 2μsec width pulse in 3μsec period. The 830nm light can be absorbed only by

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QDs layer and wetting layer. The pumping light was focused on the defect and had 6μm diameter. The resonance was detected by optical spectrum analyzer as shown in figure 2. The pumping power is 1.5mW. The period and radius of photonic crystals are 345 nm and 205 nm, respectively. The emission but resonance is suppressed while unprocessed sample shows broad emission ranging from 1100nm to 1400nm. When the bandwidth of detector was 1nm, the resonance linewidth was 1nm.

In summary, the coupling of InAs QDs emission to the two dimensional photonic crystal defect cavity has been demonstrated for the first time and a narrow filtered emission linewidth could be observed.

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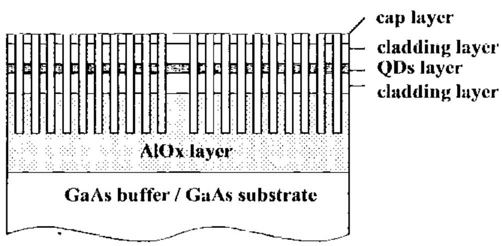

Fig. 1 schematic of photonic crystal defect cavity

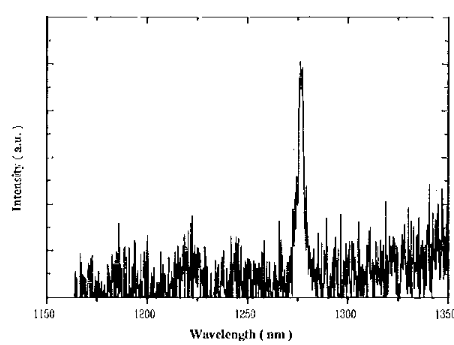

Fig. 2 photoluminescence from photonic crystal microcavity