Motivation

The goal of this work is to design and explore photonic crystals nanocavities, and study the advantages of minimum-volume photonic-crystal-slab nanocavities with quantum dots as the active medium for:

* Ultra-low power optical switching.
* Single-quantum-dot sources of single photons.
* Ultrafast, low-threshold many-quantum dot lasers.

These devices represent important building blocks for the next generation of photonic integrated circuit technology.

Introduction

Photonic crystals, in which the refractive index changes periodically, provide an exciting new tool for the manipulation of photons and have received keen interest from a variety of fields.

Photonic nanocavities figure(1), that strongly confine light are finding applications in many areas of physics and engineering, including coherent electron photon interactions, ultra-small filters, low-threshold lasers, photonic chips, nonlinear optics and quantum information processing.

Critical for these applications is the realization of a cavity with high quality factor, Q, and small modal volume, V. The ratio Q/V determines the strength of the various cavity interactions, and an ultra-small cavity enables large scale integration and single-mode operation for a broad range of wavelengths.

However, a high-Q cavity of optical wavelength size is difficult to fabricate, as radiation loss increases in inverse proportion to cavity size.

Background

Figure (1) shows a cross section through the middle of the photonic crystal nanocavity.

A defect is formed in the 2D photonic crystal by removing a single hole (or few holes), thus forming an energy well for photons similar to that for electrons in a quantum wire structure.

Photons are also localized vertically by TIR at the air-slab interface. The combination of Bragg reflection from the 2D photonic crystal and TIR from the low-index cladding (air) results in a three-dimensionally confined optical mode.

Simulation Results

Figure (3-c) shows the FT spectra corresponding to fig.(3-a), where the leaky region is inside the grey circle. The FT spectrum contains large components inside the leaky region, and this is due to the abrupt change at the cavity edges.

The strategy to obtain gentler confinement is to change the condition for Bragg reflection at the cavity edge. Such reflection is determined by a summation of partial reflections at a series of rods near the cavity edge.

When several rods near the cavity edge have been moved, the Bragg reflection condition should be modified. Because the phases of partial reflections at the moved rods are changed, the resultant phase-mismatch weakens the magnitude of Bragg reflection.

To compensate for the reduction of the reflection, light is considered to penetrate more inside the mirror and be reflected perfectly. It means that the electric field profile at the cavity edge becomes gentler.

Experimental Results

The resonant spectra of cavities with various air-rod shifts and the corresponding scanning electron microscope (SEM) pictures, are shown in fig.(4).

The width of the resonant peak changes drastically with shift of air rods. The spectral width becomes a minimum for the sample with shift 0.15a, from which a Q factor of 45,000 is achieved.

Future Scope

We will extend our investigations of the photonic nanocavities to explore new designs and device applications, such as interconnecting multiple cavities.

References
