Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp240-241

Strudy on Structure Dependent Optical Characteristics of GaAs-related Photonic Crystal Cavities

Katsunari Nakano, Ryo Nakao, Hiroshi Nagatomo, Kentaro Kukita, Kenta Uwai, Fumitaro Ishikawa, Masato Morifuji and Masahiko Kondow
Graduate School of Engineering, Osaka University
Yamada-Oka 2-1, Suita, Osaka 565-0871, Japan
Phone: +81-6-6879-7767 E-mail: katsunari@e3.eei.eng.osaka-u.ac.jp

1. Introduction

Resonant modes formed in photonic crystal (PC) microcavity have been received keen attention due to their potential applications to integrated photonic devices and quantum optics.[1] A critical issue for these applications is the realization of a cavity with high quality factor (*Q*). To obtain high *Q*, a variety of cavity structures haves been studied up to now. Fabry-Pérot type cavity is one of the most standard structures.[2] Besides, circularly arranged hexagonal cavity using whispering gallery mode resonance is also a representative structure.[1] Further, the introduction of optical gain within the cavity is essential for the materialization of practical functional devices, since that shows prospect of future electrically driven lasers.[3,4] We thus proposed a PC cavity structure with a GaIn(N)As optical gain.[4] Then, the understanding on the optical characteristics of such cavity structures provides beneficial concept for the designing of the microcavity structure. In this report, we investigate the optical characteristics of PC microcavity structures having GaIn(N)As gain focusing on their dependence on the cavity structure.

2. Experimental

We prepared two series of samples based on triangular lattice air holes. One is rectangular cavity structure, and the other is a circular cavity structure.[2-4] Both the series of samples were fabricated with the multilayered structure having topmost 300 nm GaAs slab epitaxially grown on GaAs substrate. A 7 nm GaIn(N)As gain existed at the middle of the slab layer. The slab was formed on 500 nm AlO_x clad obtained by a selective wet oxidation of AlAs layer.[4] 2-dimentional PC cavity structures were fabricated by electron beam lithography and inductively coupled plasma etching. We prepared series of rectangular cavity varying its number of missing air holes, the detail of which will be described later. The rectangular cavity contains GaInAs gain having its emitting wavelength of 1.15 μm. We employed the PC's lattice constant a=300 nm and the radius of the air holes r=0.30a. On the other hand, we fabricated so-called modulated *H5* cavity for the circular cavity structure, containing GaInNAs having its emitting wavelength of 1.30 μm.[1,4] We employed the PC's lattice constant a=320 nm and the radius of the air holes r=0.30a. The fabricated cavities were characterized with a micro-photoluminescence (PL) setup at room temperature. The beam spot was focused to 2 μm diameter at the cavity surface by microscope objective. The PL was collected through the same objective lens. The observed feature was characterized by a plain analytical expression with the comparison of three-dimensional finite-difference time-domain (FDTD) simulations.

3. Result and Discussion

The structure of a rectangular cavity was shown in Fig. 1 (a). We define (V, H) cavity corresponding to the number of missing air holes. Fig. 1 (b) shows the spectra obtained from the cavities varying their V and H. The sharp peaks vary their wavelengths with respect to the cavity structure as indicated by the arrows in the figure. Note that when we vary H between 15 and 18, the wavelength of the sharp peaks do not change. Hence, the observed variation of the peak wavelengths in Fig. 1 (b) stems from the difference of V. That could be due to the parallel arrangement of the air holes adjacent to the cavity as indicated in Fig. 1 (a), providing an efficient Fabry-Pérot type resonance within the cavity.

For the characterization of the above observed resonance, we simulate the electromagnetic field distribution with FDTD simulation. Fig. 1 (c) shows a mode obtained by that, showing a Fabry-Pérot like distribution along the vetical direction. Further, we apply a plain analytical expression [2] described as

$$N \lambda_N = 2n\,(d+\alpha) \quad , \qquad (1)$$

where N is the number of waves, λ_N is the wavelength, n is the effective refractive index here we assumed that to be 3.4 of GaAs, d is the width of the cavity and α is the penetration length of the wave. Then, fitting for the experimentally observed mode peaks returns the penetration length α for each cavity structure. The results are plotted in Fig. 1 (d). As seen in the figure, the smaller the cavity structure, the shorter α becomes. This phenomenon is examined by FDTD simulation as also shown in Fig. 1 (d). The penetration of wave should be considered for the designing of devices, [5] thus the above finding can provide a concept for its control.

We also investigate the characteristics of circularly-arranged PC cavity (modified *H5* cavity) with the combination of analytical expression and FDTD simulation. The inset of Fig. 2 (a) shows the schematic structure of the cavity. The radius of the cavity was defined as seen in the figure, here we employ R = 4.50a. The PL obtained from the cavity associated with the spectra calculated by FDTD simulation are shown in Fig. 2 (a). We observe sharp peaks related to defect modes. We here focus on the peak observed at 1.3 μm indicated with arrows in the figure. Based on the design of the cavity with FDTD simulation, the mode should correspond to the one having whispering gallery mode adjusted at the telecommunication wavelengths.[1,4] The high Q factor can be achieved with this mode because of the resonance of the PC structure.[1,4,6] The simulated Hz distribution and the $|Hz|^2$ distribution along the indicated line is shown in Fig. 2 (b). We again try to investigate the feature of the mode with analytical expression,

$$N\lambda_N = 2 n_{\mathrm{eff}} \pi r_{\mathrm{FDTD}} \quad , \qquad (2)$$

where r_{FDTD} is the radius of electromagnetic field distribution for the mode defined as Fig. 2 (b), and n_{eff} is the effective refractive index. Then, we obtain r_{FDTD}/R = 0.833 and n_{eff}=2.66 from the results. Those parameterization should enable the estimation of the current injection area and the confinement efficiency of the system.[4]

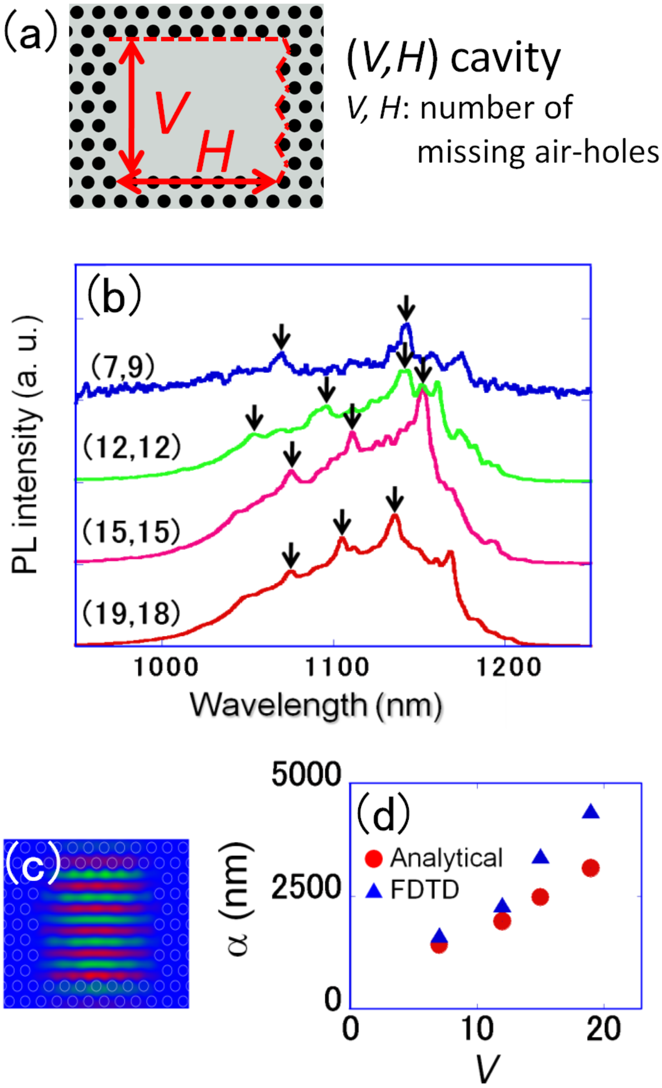

Fig. 1. (a) Schematic drawing of rectangular (V,H) cavity structure. (b) PL spectra from the cavities varying the V and H. (c) H_z distribution obtained by FDTD simulation. (d) Penetration length α obtained by analytical expression with eq. (1) and FDTD simulation.

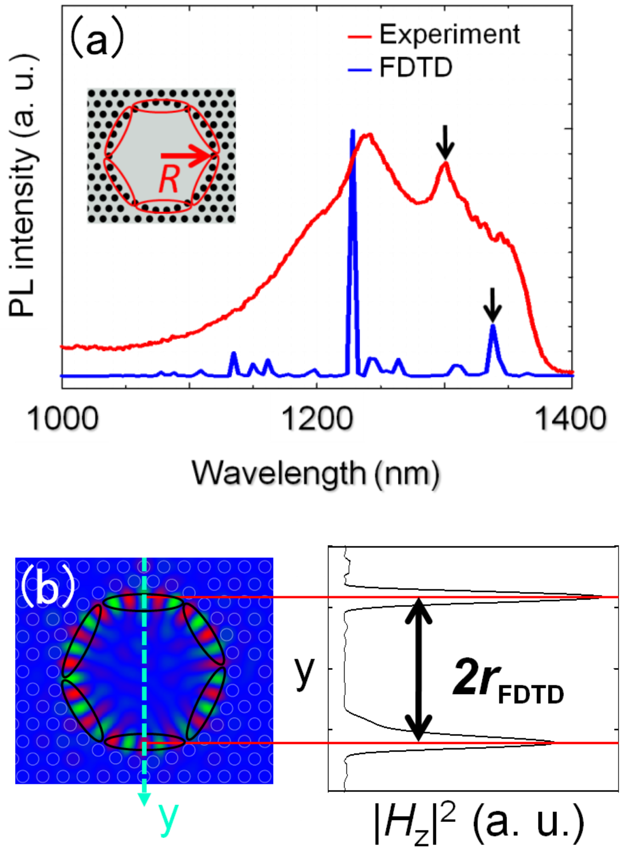

Fig. 2 (a) PL spectra from H5 cavity. The inset is the schematic of the cavity structure. (b) H_z distribution associated with $|H_z|^2$ along the indicated line obtained by FDTD simulation.

4. Summary

We have studied the characteristics of localized modes in GaAs-related PC cavity structures. Comparing the analytical expressions with FDTD simulation, we investigated the features of the cavity. For the Fabry-Pérot type resonance within the rectangular cavity, we found that the penetration of the wave into PC is longer for the larger cavity structure. The circular cavity shows whispering gallery mode resonance. The analysis enabled the estimation of the effective diameter and the refractive index of the modes, probably applicable to for the designing of device structure.

Acknowledgement

This work was partially supported by a Grant-in-Aid for Scientific Research from MEXT, Japan, and an Industrial Technology Research Grant Program in 2006 from NEDO, Japan.

References

[1] H.-Y. Ryu et. al, Opt. Express, 12, 1708 (2004).
[2] M. Rattier et. al, IEEE J. Quantum Electron., 37, 237 (2001).
[3] M. Nomura et. al, Opt. Express, 17, 15975 (2009).
[4] M. Morifuji et. al., IEEE Photon. Tech. Lett. 21, 513 (2009).
[5] H. H. J. E. Kicken et. al, J. Appl. Phys. 106, 083106 (2009).
[6] K. Nozaki et. al, IEEE J. Sel. Top. Quantum Electron., 9, 1355 (2003).