# Photonic Crystal Microlasers

Myung-Ki Kim, Min-Kyo Seo, Seo-Heon Kim and Yong-Hee Lee

*Department of Physics, Korea Advanced Institute of Science and Technology*
*yhlee@kaist.ac.kr*
*373-1 Kusung-dong, Yusung-gu, Taejon, Korea 305-70*

***Abstract.*** *Electrically-pumped single-cell photonic crystal lasers are reported. Two possible nondegenerate resonant modes are chosen and investigated in detail. In addition, our recent proposal and demonstration of 'reconfigurable' photonic crystal resonators will be discussed.*

The ability to localize photons into photonic bandgap semiconductor microcavities [1, 2] having wavelength-scale volumes and high quality factors enables us to study the cavity quantum electrodynamics in semiconductor material systems. Various optically-pumped, ultra-small, photonic crystal lasers and electrically-driven light emitting structures based on the concept of photonic crystal have been recently reported. However, the deployable microlasers should be built on the simple electrical pumping scheme. One of the realistic difficulties of the wavelength-scale electrically-driven photonic crystal laser is the electrical contact onto the sub-micron-size semiconductor slab resonator.

In our electrically-driven photonic crystal resonator structure [3, 4], a sub-micron-size semiconductor post is placed at the center of the single-cell photonic crystal resonator where the photon density is almost zero. This small central post functions simultaneously as an electrical wire, a mode selector and a heat sinker. Electrons are supplied laterally from the top *n*-electrode while holes are injected directly through the bottom *p*-post. A *nip* doping structure that is inverted from that of a typical semiconductor laser is used to exploit the high mobility of the electrons that has to travel a longer distance along the top surface. The central *InP* post was size-tuned by changing the temperature of dilute *HCl* solution from 10 degrees to room temperature. We observed single mode lasing operations from two nondegenerate modes, the monopole mode and the hexapole mode, respectively. For the monopole mode, the single modeness comes naturally since this resonance is spectrally well-isolated from the other modes. However, near the hexapole mode, the high-quality factor degenerate quadrupole modes always exist. We suppressed the quadrupole mode by controlling the size of the current post and hence the optical losses. Lasing operation in an intended mode is confirmed through contour finite difference time domain methods, where the structural input data is transferred directly from the digitized scanning electron microscope image of the fabricated sample. Threshold current and voltage are 100~300 A and 0.9~1.1 V, respectively, at room temperature, near 1,550 nm.

Semiconductor quantum dot combined with microcavities is the one of the attractive approaches for the single photon sources. Photons trained by a high *Q/V* resonant mode have a narrow spectral line and a well-defined polarization state. In addition, photon collection can be achieved more efficiently by controlling inner symmetries of the resonant mode of interest. The successful optical characterizations of PhC microcavities with quantum dots were performed recently. However, these trials employing PhC cavities exposed two critical problems clearly. The first issue is that of the spatial and spectral overlaps of two relevant resonances, the cavity resonance and the quantum dot resonance. In order to answer this question, one needs to control the emission wavelength of a quantum dot on the order of nanometer or better. At the same time, this right quantum dot should be placed at the anti-node of the resonant mode with precision on the order of nanometers. The second issue is that of the efficient collection and delivery of valuable photons to customers. This nontrivial issue requires good understanding of photon out-coupling out of a resonant cavity. Our microfiber-coupled 'reconfigurable' resonator allows the repeatable formation of the cavity's physical position until the quantum dot of 'right' emission spectrum is identified at the 'right' physical position. Efficient out-coupling into the tapered single mode optical fiber follows naturally and easily.

Free-standing 2-D slab *InP* triangular photonic crystals are employed as basic building blocks. The single-row photonic crystal slab waveguide is coupled with a highly-curved tapered fiber as shown in Fig. 2 [5]. Note that the whole real estate over the single-row PhC waveguide is where at least one 'right' quantum dot needs to be found. The beauty of this scheme is that of allowing a large margin of fabrication errors until one constructs the optimized resonant cavity supported by the 'spectrally-right' quantum dot. When a microfiber is placed on the PhC slab waveguide, the effective index near the point of contact increases relative to that of the bare waveguide as calculated in the dispersion curve shown in Fig. 3. With one step further along this logic, one is able to construct a photonic potential well by simply placing a tapered fiber on top of a PhC waveguide, in the proximity of a properly-selected spectral position in the PhC waveguide dispersion curve. As shown in Fig. 4, we confirmed the formation of a 'Gaussian' photonic potential well in the proximity of the contact point of the highly-curved-fiber. Considering that the electric field of the PhC guided mode penetrates into the silica in exponential fashion and the air-gap distance of the curved fiber from the slab has a quadratic dependence, the Gaussian dependence is physically understandable. In this scheme, the physical location and size of a PhC laser resonator can be defined (and redefined) repeatedly by simply relocating the microfiber along the PhC waveguide. Experimentally we confirmed the formation of reconfigurable resonators slightly below the all three available band edges in the form of lasing action.

## References

[1] E. Yablonovitch, *Phys. Rev. Lett.* **58,** 2059 (1987).
[2] O. Painter *et al.*, *Science* **284**, 1819 (1999).
[3] H. G. Park *et. al.*, *Science* **305**, 1444 (2004).
[4] M. K. Seo *et. al.*, *Appl. Phys. Lett.* **90**, 171122(2007)
[5] M. K. Kim *et. al.*, *Opt. Express* **15**, 17241 (2007).

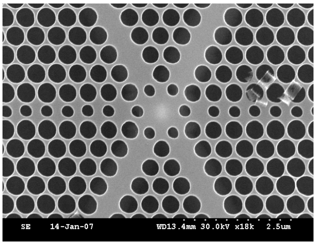

*Fig. 1 Hexapole mode resonator with six PhC waveguides.*

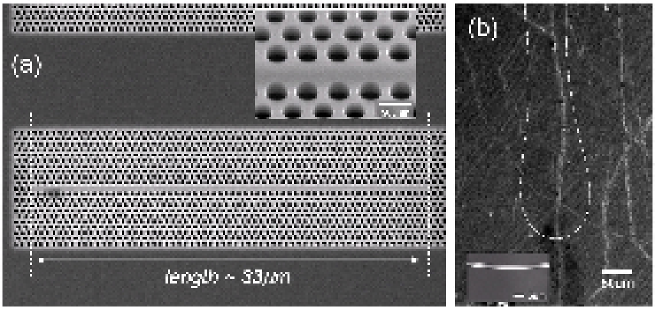

*Fig.2 Photonic crystal waveguide and tapered microfiber*

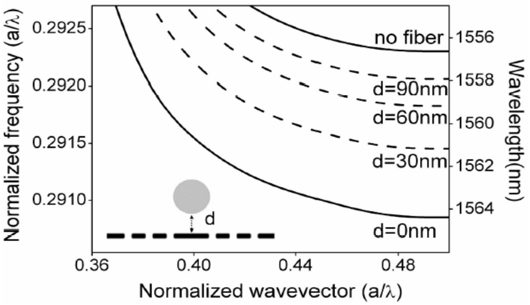

*Fig. 3 Dispersion curve of fiber-coupled PhC waveguide.*

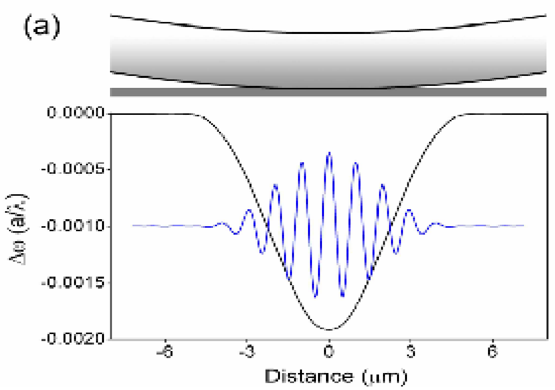

*Fig. 4 Photon localization by a reconfigurable Gaussian potential well.*