フォトニック結晶工学の深化と新展開

Evolution of Photonic-Crystal Science and Engineering

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Photonic crystals, in which the refractive index changes periodically, provide an exciting new tool for the manipulation of photons and have received a keen interest from a variety of fields. In this presentation, I will review the recent progress of photonic-crystal science and engineering.

First of all, I will talk about ultrahigh-Q photonic nanocavities, which are very important for various scientific applications including nonlinear nano-optics, slow light/stopping light, nano-lasers, single-photon emitters, and electron-photon strong coupling for quantum computing. It will be shown that an important concept [1] to realize ultrahigh-Q nanocavities in 2D photonic crystal has been established, where the form of the cavity electric field distribution should vary slowly, ideally as described by a Gaussian function, in order to suppress vertical photon leakage. Tuning of air holes at the cavity edge [1] and/or the formation of a photonic double-heterostructure [2] have been found to be very effective to satisfy the concept and to realize an ultrahigh-Q nanocavity. Currently, the cavity Q exceeds 1,000,000 successfully [3,4].

Next, I will talk about light-emission control by the band-gap and artificial defects, where effects of 2D photonic crystals are described. 2D photonic crystals have a very unique feature on the control of spontaneous emission. It has been experimentally demonstrated that overall spontaneous emission rate is suppressed by 2D PBG effect, while emission efficiency for the vertical direction is significantly enhanced [4,5]. The effect of artificially introduced point defects, in which the carriers accumulated by 2D photonic band-gap effect can be effectively redistributed, is also described [6,7]. Then, I will touch on light-emission control by 3D photonic crystals [8], where it will been shown that spontaneous emission in complete 3D photonic crystal area can be suppressed while a strong emission can be observed at the artificial point defects [9].

Finally, I will describe the band-edge effect in photonic crystals. At the band-edge of photonic crystals, the group velocity of light becomes zero, which leads to a formation of stable 2D broad-area single-cavity mode [10,11]. The output beam can be emitted in the direction normal to the 2D crystal plane, using the crystal itself as a diffraction grating. It will be described that a high-power (>45mW), single-lobed, broad-area surface-emitting operation can be successfully achieved at room temperature, under continuous-wave condition, by optimizing photonic crystal structure. In addition, it will be described that a range of unique beam patterns can be produced by engineering of photonic crystals [12]. When we use a propagation band close to the band edge (or the mode edge of a waveguide mode), the group velocity of light becomes slowed down. The results of dynamic characterization of such slow light effect [13] will be also described.

References: [1] Y. Akahane, et al, *Nature*, 425 (2003) 944. [2] B. S. Song, et al. *Nature Materials*, 4 (2005) 207. [3] T. Asano, et al, *Optics Express*,14, (2006) 1996. [4] T. Asano, et al, *IEEE J. Sel. Top. on QE,* (Nov-Dec. 2006) (in press). [5] M. Fujita, et al. *Science*, 308 (2005) 1296. [6] K. Kounoike, et al, *Electron.Lett.*, 41 (2005) 1402. [7] S. Noda, *Science*, 314 (2006) 260. [8] S.Noda, et al. *Science*, 289 (2000) 608. [9] S. Ogawa, et al. *Science*, 305 (2004) 227. [10] M. Imada, et al, *Appl. Phys. Lett.*, 75 (1999) 316. [11] S. Noda, et al, *Science*, 293 (2001) 1123. [12] E. Miyai, et al. *Nature*, 441 (2006) 946. [13] T. Asano, et al. *Appl. Phys. Lett.* 84 (2004) 4690.