

Manipulation of Photons by Photonic Crystals — Recent Progress and New Trends —

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Abstract- Photonic crystals, in which the refractive index changes periodically, provide an exciting tool for the manipulation of photons and have made substantial progresses in recent years. In this presentation, I will discuss recent progresses in photonic-crystal researches including (i) two-dimensional photonic-crystal cavities and waveguides, (ii) three-dimensional photonic crystals, and (iii) two-dimensional photonic-crystal lasers.

(i) Two-dimensional photonic-crystal nanocavities and waveguides:

Remarkable progresses in nanocavities and waveguides based on two-dimensional (2D) photonic-crystals have been achieved recently. For example, nanocavity- Q over two million has been successfully achieved while maintaining ultrasmall modal volume based on the concept of Gaussian confinement. The combination of nanocavities and waveguides leads to the realization of photonic nano-devices. Here, if the properties of such photonic-crystal nanocavities and waveguides could be changed or controlled dynamically during their operations, the resulting functionalities would be greatly expanded. In the present talk, I at first discuss the dynamic control of photonic crystals [7,8], where the characteristics of nanocavities and waveguides are dynamically controlled within picosecond time scales, which will contribute to future applications including the stopping/slowing of light, quantum information systems, and next generation ultra-high capacity communications. Then, I will discuss the recent progress of photonic-crystal nanocavities combined with quantum dots, where the stress is on the importance of quantum anti-Zeno effects [9-11] as a third emission mechanism in addition to Purcell effect and vacuum Rabi-oscillation.

(ii) Three-dimensional photonic crystals:

3D photonic crystals with 3D periodic refractive-index distributions are expected to possess the capability of ultimate control of photons, and the manipulation of photons by 3D photonic crystals has so far been carried out by embedding artificial defects and light emitters 'inside' crystals, using 3D directional bandgap effects. In the present talk, I will describe that photons can be manipulated even at the 'surface' of 3D photonic crystals, where 3D periodicity is terminated. This phenomenon is of interest because of its relevance to the surface plasmon-polariton effect of metals and the related surface photon physics. We first show that 3D photonic crystals possess surface states and that photons can be confined and propagate through them. Then I will demonstrate that 3D localization of photons at desired surface points is possible by forming a surface-mode gap and introducing artificial surface-defect structures. Surprisingly, the obtained Q factors of the surface-defect mode are the largest reported for 3D photonic crystal nanocavities (up to $\sim 9,000$). This represents an important step towards realizing a new route for photon manipulation by 3D photonic crystals, and establishing the surface science of photonic crystals. Furthermore, the absorption-free nature of the 3D photonic-crystal surface could make possible new sensing applications and light-matter interactions. Finally, I will discuss about a new top-down fabrication method of 3D photonic crystals.

(iii) Two-dimensional Photonic-Crystal Lasers:

Photonic-crystal surface-emitting lasers have recently attracted much attention because of their perfect, broad-area single-mode surface-emitting operation, their narrow beam divergence angles of $< 1^\circ$, and the possibility of producing tailored beam patterns by controlling the electric field distribution inside the photonic crystal. These fascinating features arise from the photonic band-edge effect, where the group velocity of light becomes zero and a 2D cavity mode is formed. We will describe the recent progresses in such unique photonic-crystal lasers including the recent achievement in producing tailored beam patterns and lasing oscillation in blue-violet wavelengths.