Semiconductor Photonic Crystals

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Recently, much interest has been drawing in photonic crystals in which the refractive index changes periodically. A photonic bandgap is formed in the crystals, and the propagation of electromagnetic waves is prohibited for all wave vectors. Various important scientific and engineering applications such as control of spontaneous emission, zero-threshold lasing, very sharp bending of light, trapping of photons, and so on, are expected by utilizing the photonic bandgap and the artificially introduced defect states and/or light-emitters. It has been well recognized that a three-dimensional (3D) photonic crystal has great potential for ultimate control of photons, which leads to the realization of ultrasmall optical integrated circuits as shown schematically in Fig.1(a). On the other hand, a 2D photonic crystal has a merit of relatively easy fabrication and can control photons two-dimensionally, which leads to the realization of some important functional devices.

Thus far, we have reported that full 3D photonic bandgap crystals with stacked-stripes (or woodpile) structure were successfully developed by using single crystalline GaAs in optical communication wavelengths as shown in Fig.1(b) (1,2). The merits of this crystal are in i)having a complete 3D photonic bandgap, ii)easy introduction of defects and/or efficient light-emitters into the crystals, and iii)having a conductive crystal structure, compared with the other types of 3D photonic crystals. The optical rejection more than 40dB was observed with the crystal having eight stacked layers at 1.3-1.55μm region (1), which indicates that we have currently an ability to make a desired 3D crystals with III-V semiconductor which has a light-emitting capability. The next step is the introduction of a light-emitter and/or a defect into the crystals to realize the chip as shown in Fig.1(a). We already reported a design and fabrication of 3D sharp bend waveguide in 3D crystal (1,6). In this symposium, after brief review of the 3D crystal fabrication, we report on an experimental result on the introduction of the light-emitter into 3D crystal, which is an important step for the realization of zero-threshold laser.

On the 2D photonic crystals, we have proposed and investigated two unique devices: i)a surface-emitting-type single-defect channel-drop-filter (3), and ii)a photonic crystal laser (4, 5). In the former device, the single-defect traps the photons which propagate through a line-defect waveguide formed in 2D photonic crystal slab and emits them to free-space as shown in Fig.2(a). The phenomenon is very promising for the actual application to an ultra-small optical device with a function of dropping photons with various energies from optical communication traffic (fiber). In this symposium, we report on the characteristics of the device and also on the reverse function of channel-add-filtering as schematically illustrated in Fig.2(b), which has been successfully observed very recently. On the other hand, the latter device utilizes the multi-directional distributed feedback effect, and it is expected that the device can work as a high-output power surface-emitting laser, which can oscillate in a very large area with a single longitudinal and lateral mode. In this symposium, we also report on polarization mode control of the 2D photonic crystal laser by unit cell structure design as schematically illustrated in Fig.3.

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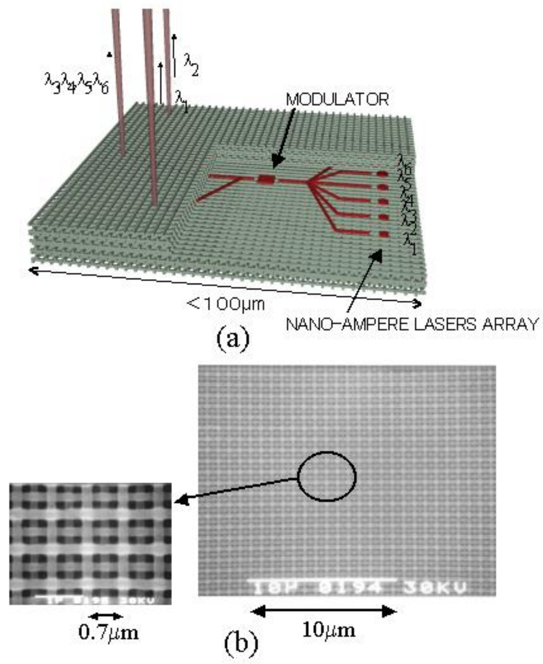

Fig.1: (a) Conceptual schematic drawing of an ultrasmall optical integrated circuit. (b) SEM picture of full 3D photonic bandgap crystals at 1.3-1.55μm wavelength region.

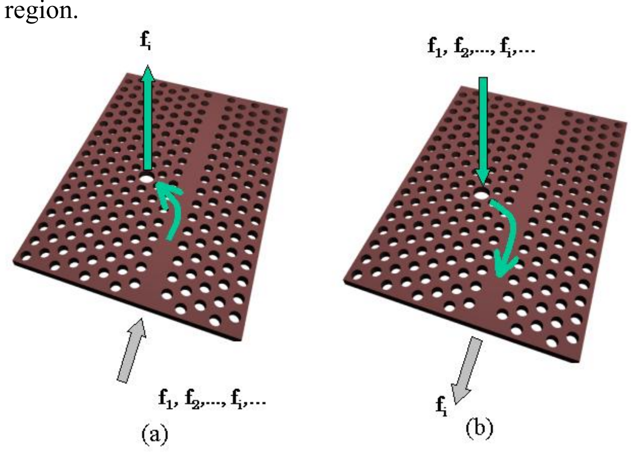

Fig.2: Schematic figures to show the (a) channel-drop-filtering function and (b) channel-add-filtering function using a single defect in the 2D photonic crystal slab.

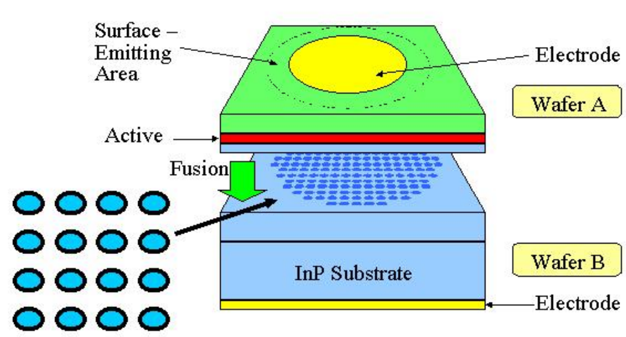

Fig.3: Schematic figure of 2D photonic crystal laser with elliptical unit cell structure developed by wafer fusion technique.