Electrically-driven photonic crystal nanocavity lasers using embedded active region

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Reduction of laser cavity volume has been attracted much attention of researchers in semiconductor laser because it can be reduced threshold current and, when employing direct modulation, also operating energy. To achieve the lasing in nanocavity laser, it is important to achieve Q-factor that is the same range of conventional edge-emitting laser, typically several thousands of Q-factor. Therefore, it becomes the challenge because this requires quite high-reflectivity. Vertical-cavity surface-emitting lasers (VCSELs) employs high-reflectivity semiconductor distributed Bragg reflector (DBR) and its operating energy is reduced to less than 100 fJ/bit [1]. Although cavity length of VCSEL is ~λ/2, where λ is lasing wavelength, diameter of VCSEL is a few micrometers range. For further reduction of cavity volume and operating energy, we have developed a λ-scale embedded active-region photonic crystal (PhC) laser, or LEAP laser, in which an ultra-compact active region is embedded with an InP-based PhC line-defect waveguide [2-4]. We fabricated cavity length of 6a, where a is lattice constant of PhC and 430 nm, and achieved 4.8-μA threshold current and 4.4-fJ direct modulation energy with 10-Gbit/s modulation [4]. In this presentation, we describe recent our developments for further reduction of cavity length until Ja. We carefully controlled the selective wet-chemical etching to fabricate extremely compact active regions and the thickness of regrowth InP layer to obtain flat top surfaces after embedding the active regions, which is important for achieving a high Q-factor. The LEAP lasers with cavity length of 2a and three quantum wells exhibited a 3.8-μA threshold current [5].

Cavity design and fabrication

In our previous works of the cavity length was 6a, there was no positional shift in the air holes in the PhC, because the required Q-factor could be obtained from the refractive index difference between the active region and InP. However, to reduce the cavity length, we shifted the positions of the nearest air holes for the active region. As a result, we achieved high Q-factors of more than 5 x 10^5 without an output waveguide. The fabrication procedure is the same as in ref. 3. Figure 1 shows a cross-sectional SEM image of the BH region. The active region was 250-nm wide and 150-nm thick including SCH layers.

Static characteristic

Figure 2 shows room-temperature continuous-wave (RT-CW) operated I-L characteristic of the LEAP laser with cavity length of 2a. Threshold current was 3.8 μA with clear threshold behavior. Lasing wavelength was 1553 nm and Q-factor at threshold was ~40,000. We also directly modulated the device and demonstrated 10-Gbit/s NRZ modulation with bias current of 10.6 μA, which results in operating energy of ~1 fJ/bit.

REFERENCES