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Dielectric-band single-cell photonic crystal lasers

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We propose and demonstrate new types of dielectric-band photonic crystal (PhC) lasers in a two-dimensional modified single-cell cavity. In the properly designed cavity of Fig. 1, the air holes around the cavity are enlarged and thus the resonant modes, the hexapole and monopole dielectric-band modes, are pushed up from the dielectric band into the photonic band gap(1). For strong photon confinement, we set the radii of air holes in the first four subsequent layers to decrease linearly from the cavity center.

Figure 1 shows the field intensity distributions of the cavity modes computed in the real and Fourier spaces using three-dimensional (3D) finite-difference time-domain (FDTD) simulation. It demonstrates that the cavity modes whose electric fields are concentrated in the dielectric region originate from the first band-edge point in the dielectric band(1-3). The mode profiles in the Fourier space also show that the six dominant wavevector components in the cavity modes are localized at six K points as shown in Fig. 1 (bottom). In addition, the optical properties such as mode volume and quality factor (Q) are investigated by analyzing field distributions in both the real and Fourier space. In Fig. 1 (top), the electric fields of the monopole mode are more broadly distributed than those of the hexapole mode in real space. Thus, the monopole mode is expected to have larger mode volume than the hexapole mode. On the other hand, the hexapole mode has relatively negligible wavevector components inside light cone (dotted white circle in Fig. 1 (bottom)) compared with the monopole mode. Consequently, the hexapole mode is expected to have smaller vertical radiation loss than the monopole mode(4). FDTD simulations of mode volumes and quality (Q) factors in both cavity modes support these analyzes.

In experiment, photoluminescence (PL) spectroscopy is carried out to investigate the optical characteristics of the fabricated PhC cavity structures. The PhC cavities are optically pumped at room temperature by a 980-nm pulsed laser diode (10 ns pulses of 1% duty cycle). Then multi-lasing peaks are observed from the samples with various lattice parameters. Through the measurements of the spectral positions and the mode images in Fig. 2, these peaks are successfully identified as the hexapole and the monopole modes. Thresholds of these lasers are measured to ~340 μW and ~450 μW, respectively. In addition, using the simulation based on the actual fabricated structures(1), Q factors and mode volumes are computed to 4900 and 1.09 $(\lambda/n)^3$ for the hexapole mode, and 4300 and 2.27 $(\lambda/n)^3$ for the monopole mode, respectively. These realistic Qs and mode volumes are useful for comparison of the measured thresholds.

Threshold of the hexapole-mode laser with higher Q and smaller mode volume is lower than that of the monopole-mode laser.

The dielectric-band cavity modes can strongly interact with the gain medium positioned at the dielectric region, e. g. quantum dots. We believe that such a strong light-matter interaction will be of advantageous to the demonstration of low-threshold lasers and efficient nonlinear optical devices.

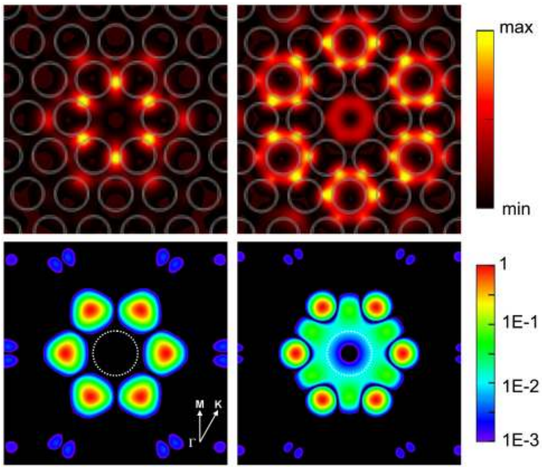

Fig. 1: FDTD simulation. (Top) electric field intensity profiles. (Bottom) corresponding Fourier space intensity profiles

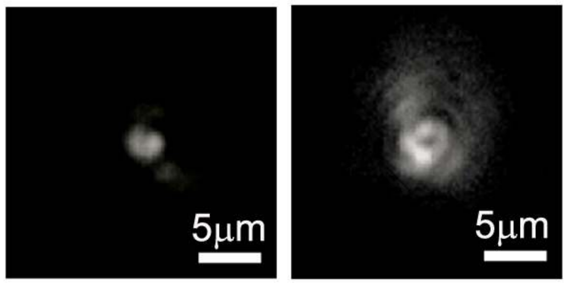

Fig. 2: Measured lasing mode images. (Left) hexapole mode. (Right) monopole mode.

References

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