Enhancement of Er luminescence from bridge-type photonic crystal nanocavities with Er,O-codoped GaAs

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Quantum communication, storage, and computing show potential as the next-generation information technologies, and have been recently attracting scientific attention. Above all, controllable, stable, and repeatable single photon emitters (SPEs) have been of great significance as the important component of quantum information systems[1]. Er-2O luminescent center formed in Er,O-codoped GaAs (GaAs:Er,O) exhibits a sharp luminescence peak at 1.54 μm. Since the intra-4*f*-shell transition of Er^{3+} ions is screened by the outer $(5s)^2(5p)^6$ electron orbits, this material shows wavelength stability of light emission to the external environment, and hence should have excellent application prospects towards application in quantum information systems[2]. However, the long lifetime of the luminescent center hinders its application for SPEs. Photonic crystal (PhC) nanocavity is one of the effective solutions owing to its ultra-high quality(Q)-factor and extremely small mode volume, and has been so far proven to be effective to strongly enhance the emission rate of rare-earth ions via the Purcell effect[3,4]. We have so far demonstrated the observation of the enhanced Er luminescence induced by the Purcell effect in L3 PhC nanocavities[5]. In this contribution, we propose and demonstrate a bridge-type PhC to further improve the Q-factor, laying the foundation for the implementation of SPEs. Numerical simulations of the bridge-type PhC nanocavities are carried out using the finite-difference time-domain (FDTD) method to investigate the effect of the geometry of the PhC nanocavities on the cavity modes and Q-factor. Next, bridge-type PhC nanocavities with Er,O-doped GaAs as an active component are prepared, and finally their optical characterization is characterized.

In this research, the GaAs:Er,O active layer was grown by organometallic vapor phase epitaxy (OMVPE) on an AlGaAs sacrificial layer formed on a GaAs substrate under the detailed growth conditions described in our previous publication[5]. Numerical simulations of PhC nanocavities with different numbers of holes were carried out to investigate the effect of the number of holes in the bridge-type structure on the higher-order modes and Q-factor, and a maximum design Q-factor of 1.2×10^6 was obtained with 30 holes, as is shown in Fig. 1. Since higher-order modes are suppressed by reducing the number of circular holes, the proposed bridge-type PhC structure is able to achieve a high Q-factor while suppressing higher-order modes. As shown in Fig. 2, the fabrication of the bridge-type PhC does not collapse even after undergoing electron beam lithography to form the pattern, dry etching to form the circular holes, and wet etching with hydrofluoric acid to remove the sacrificial layer to form the hollow bridge-type structure. The optical characterization of the GaAs:Er,O bridge-type PhC nanocavities was carried out using a conventional micro-photoluminescence (μ-PL) setup with excitation by a He-Ne laser. Figure 3 shows PL spectra of the bulk sample and the fabricated bridge-type PhC nanocavity at room temperature. The PhC nanocavities couple to the luminescence due to the Er-2O centers from GaAs:Er,O at 1538 nm, and the peak intensity of Er-2O luminescence is enhanced by a factor of 7.3 at a pump power of 40 nW. The linewidth based on the cavity mode of the luminescence spectrum is ~0.128 nm, which corresponds almost to the resolution limit of the μ-PL setup. The experimental Q-factor is estimated to be greater than 1.2×10^4, which is much larger than our previous report on L3-type PhC nanocavities[5]. The observed enhancement is due to the Purcell effect, which could lead to a shorter lifetime of Er luminescence.

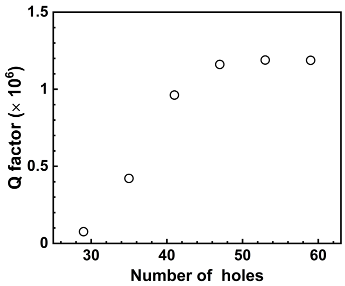

Fig. 1. Dependence of Q-factor on the number of holes.

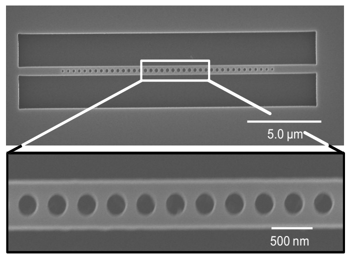

Fig. 2. SEM images of a GaAs:Er,O bridge-type PhC nanocavity.

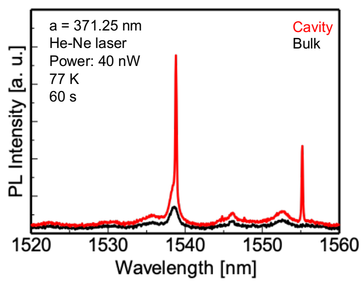

Fig. 3. Room-temperature PL spectra of the bulk sample and the fabricated PhC nanocavity.

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Reference: [1] I. Aharonovich *et al.*, Nat. Photonics **10,** 631 (2016). [2] K. Takahei *et al.*, J. Appl. Phys. **76,** 4332 (1994). [3] T. Zhong and P. Goldner, Nanophotonics **8,** 2003 (2019). [4] T. Zhong *et al.*, Science **357,** 1392 (2017). [5] M. Ogawa, Y. Fujiwara *et al.*, Appl. Phys. Lett. **116** (2020).