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1.55μm 波長帯単一光子源用サブミクロン直径 Si/SiO$_2$-InP 微小共振器

Hybrid SiO$_2$/Si-InP micropillar cavity with submicrometer diameter for single-photon sources in 1.55-μm-wavelength telecommunication band

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Solid state microcavities are powerful in producing high efficiency light-emitting diodes, low-threshold lasers and single-photon sources. Quantum key distribution over 50 km has been successful with 1.55-μm InAs/InP quantum dot (QD) single photon sources (SPSs) [1]. Its further development for higher speed, photon-indistinguishability demands for implementing QD-SPSs in microcavities. Recently, we have proposed an effective micropillar cavity with the Purcell factor over 20 consisting of Si/SiO$_2$ distributed Bragg reflectors (DBRs) and an InP spacer [2]. However, this cavity has a diameter as large as ~2 μm so that resonance with a single QD imposes the strict requirement for the dot density. For the wavelength below 1 μm, recent studies show that the design of tapered DBRs can obtain high Q factors (>10^4) in GaAs/AlAs and TiO$_2$/SiO$_2$ micropillar cavities with sub-micrometer diameters [3]. We herewith apply the tapered DBRs to our hybrid micropillar cavity for 1.55-μm wavelength and numerically study its optical performance in sub-micrometer region.

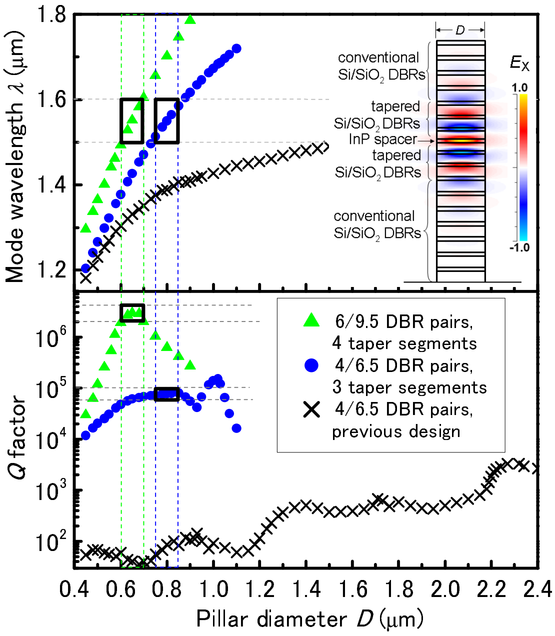

Fig.1. The mode wavelength and Q factor of the tapered and previous cavities as functions of pillar diameter. The inset shows the schematic cross section of the tapered cavity, together with a representative mode profile.

As shown schematically in the inset of Fig. 1, there inserted tapered Si/SiO$_2$ DBRs in between the conventional Si/SiO$_2$ DBRs (each layer $\lambda/4$ thick) and an InP spacer, both of which also existed in our previous design. In the tapered DBRs, the Si and SiO$_2$ layers adiabatically get thinner as they come close to the spacer. Using finite-difference-time-domain analysis, the fundamental mode of such a cavity is resolved. The mode profile is found, as expected, well confined horizontally within the pillar and vertically within the tapered DBRs. The Q factor for wavelength around 1.55 μm is found greatly improved with respect to our previous cavities while the pillar diameter D is decreased to be less than 1 μm, as shown in Fig. 1. Focusing on the mostly interested wavelength range λ=1.55±0.05 μm, a structure with 4/6.5 DBRs and 3 taper segments gives Q~8×10^4 as D=075-0.85 μm, and a structure with 6/9.5 DBR pairs and 4 taper segments gives Q~3×10^6 as D=0.60-0.70 μm. The obtained Q factors are at least two orders of magnitude higher than the previous (*i.e.* non-tapered) micropillar cavity [2] comparing at the same pillar diameters. Moreover, the Q factors also exceed the highest performance (Q~3×10^3) reported in the previous result for the optimum diameter (D~2.3 μm).

Taking into account the typical parameters of InAs/InP QDs [1,2] and the mode volume of V~0.8$(\lambda/n)^3$, we can conclude that our hybrid cavity with tapered DBRs has a potential to realize a gigahertz-clock SPS at 1.55 μm for well isolated single QD by enhancing the spontaneous emission rate with a Purcell factor of over 100. The tapered hybrid Si/SiO$_2$-InP micropillar cavity is thus promising for realizing high-speed quantum communication network based on QD-SPSs.

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