Submicron Size All-Semiconductor Vertical Cavities with High Q

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The miniaturization of lasers promises on-chip optical communications and data processing speeds that are beyond the capability of electronics and today's high-speed lasers [1]. Lasers with low-power consumption are one of the most important parts in creating a photonics integrated architecture. This requirement was the motivating force behind the development of small laser and nanolasers. Here, we propose a new method that could be utilized to fabricate such a laser. Oxide-VCSELs require strict control of the oxidation process with significantly reduced reliability for small size, and micropillars have degraded Q with fabrication artifacts for submicron diameter pillars [2]. We propose to use a phase-shifting current-blocking (PSCB) layer serving dual function for a nanocavity device (Fig. 1a) providing both optical- and electrical-confinement via lithographically defined and selectively-biased buried structures. Phase-shifting leads to optical-confinement tuning by layer thickness control and current-blocking provides electrical-confinement. By modifying the dimensions of these layers, the confinement can be tuned by lithographic means [3]. We studied the electromagnetic wave propagation and analyzed the quality factor (Q) of these cavities based on 3D finite difference time domain (FDTD) calculations.

For optical-confinement, our approach utilizes the effective index model by using thin epitaxial layers. The effective index depends only on the lateral changes in the cavity resonance and the cavity with a longer wavelength has a higher effective index ($\Delta\lambda/\lambda_0=\Delta n/n_0$) [4]. The schematic and key components of the studied cavity is shown in Fig. 1a. In our simulations, the structure consists of a λ-thick GaAs cavity spacer sandwiched between AlAs/GaAs quarter-wavelength distributed Bragg reflectors (DBR) with 35 pairs for the bottom and 5-35 pairs for the top mirror. Although the simulations in this study are realized for a cavity with a resonance at 980 nm, the design approach can be applied to different wavelengths and material systems. We performed a Q-factor comparison for the fundamental mode as a function of the diameter for different confinement strengths (see Fig. 1b for 15 pairs of top DBR). The maximum value of Q is less than 5000 for the studied region. For large confinement (Δn=0.087 and 0.053), the resonance wavelength of the fundamental mode (Fig. 1c) shifts to shorter wavelengths and Q-factor is also degraded, which is similar to the case in micropillars [2]. For lower confinement (Δn=0.022 and 0.011), there is an overall improvement of Q and the cavity supports modes with Q~4000 even for submicron diameters. To gain more insight about the Q-factor, we performed a side-by-side comparison of our approach and micropillar cavity. For a submicron diameter (D=0.9 µm), the saturation of Q-factor for the micropillar is reached at $\sim 10^4$. For the lithographic method, Q-factor increase to larger than 7×10^4 without saturation, which illustrates the improved photon confinement mechanism of the proposed method compared with the pillar design.

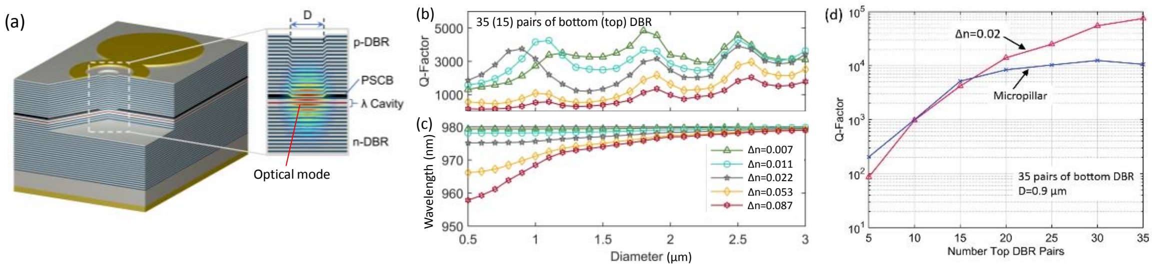

Fig. 1 (a) Lithographic all-semiconductor cavity geometry used in the study. (b) Cavity Q and (c) resonance wavelength of the fundamental mode as a function of the diameter. (d) Q-factor as a function of the number of top DBR pairs for lithographic (Δn=0.022) vs. micropillar cavity for D=0.9 µm.

We have proposed a novel method to enable photon confinement with high Q for submicron diameters. It is a promising approach to create a nanolaser. It can also be utilized to obtain large size, and hence high-power, single transverse mode light sources. This concept can also be extended to arrays of cavities for the implementation of novel nanophotonic devices.

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