

Photonic crystal lasers grown on CMOS-compatible on-axis Si(001)

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Abstract: Semiconductor photonic crystal (PC) lasers are regarded as promising ultra-compact light sources with ultra-low energy consumption. Here, we demonstrate PC lasers monolithically grown on CMOS-compatible on-axis Si (001) substrate with an ultra-low threshold of $\sim 0.6 \mu\text{W}$. © 2020 The Author(s)

1. Introduction

The recent exponential growth in data traffic requires a more efficient on-chip optical interconnection method with lower energy consumption and higher density of processing unit [1, 2]. In this regard, nanoscale PC cavity with ultra-small mode volume and low energy consumption is one of the most promising architectures for integrated nanoscale devices. Monolithic integration of efficient III-V light-emitting sources on planar on-axis Si (001) has been recognized as an enabling technology for realizing Si-based photonic integrated circuits (PICs) [3, 4]. In addition, zero-dimensional quantum dots (QDs) monolithically grown on Si platform as gain materials provides various advantages, including low lasing threshold, reduced temperature sensitivity, and hence have been widely investigated in last few years.

Here, we present the ultra-small InAs/GaAs QD PC membrane lasers monolithically grown on CMOS-compatible Si substrate. The PC laser with a small mode volume of $0.88 (\lambda/n)^3$ was continuous-wave optically pumped under room temperature, and exhibits an ultra-low lasing threshold of $\sim 0.6 \mu\text{W}$. The demonstrated Si-based PC lasers with a small footprint as well as low power consumption are expected to play an important role in the next-generation nanoscale Si photonics.

2. Results and Discussion

The InAs/GaAs QD PC membrane lasers were grown on planar on-axis Si (001) substrates. The active region with 4 layers of InAs/GaAs QDs has been grown between the upper and lower 40 nm $\text{Al}_{0.4}\text{Ga}_{0.6}\text{As}$ cladding layer, which are grown on the top of 1 μm $\text{Al}_{0.6}\text{Ga}_{0.4}\text{As}$ sacrificial layer. The QDs within active region present a dot density of $\sim 4 \times 10^{10} \text{ cm}^{-2}$ with a typical size of 25 nm in diameter and 8 nm in height. Figure. 1(a) present the schematic diagram of the fabricated InAs/GaAs QD PC laser epitaxially grown on on-axis Si (001) substrate. The top-view (Fig. 1(b)) and tilted cross-section view (Fig. 1(c)) scanning electron microscope (SEM) images of the fabricated PC cavity show smooth etching profiles.

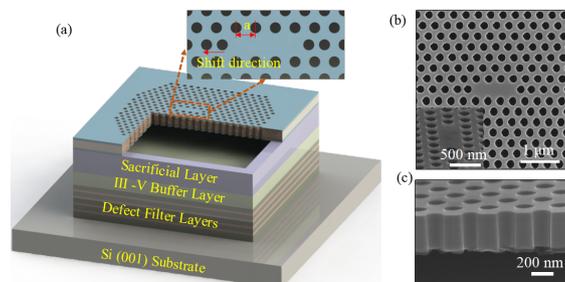


Fig. 1. (a) Schematic diagram of the fabricated InAs/GaAs QD PC (L3 cavity) laser epitaxially grown on on-axis Si (001) substrate. The lattice constant, radius and shift of L3 photonic cavity are a , r and $0.15a$, respectively. (b) Top-view and (c) tilted cross-section view SEM images of the fabricated PC cavity.

The fabricated PC lasers were continuous-wave (CW) optically pumped at room-temperature using a 632.8 nm He-Ne laser as the excitation source. The measured spectra under various pumping powers of a single mode PC laser with $a = 310$ nm and $r/a = 0.27$ is shown in Fig. 2(a). The collected intensity (L-L) and the linewidth of the lasing peak at ~ 1306 nm under various pumping powers are shown in Fig. 2(b), which exhibit the evidence of the lasing with a clear kink of L-L curve and the spectral linewidth narrowing effect. The lasing threshold is estimated to be around $0.6 \mu\text{W}$ from the L-L curve. The inset in Fig. 2(b) shows the calculated E_y field profile of the fundamental mode. In addition, the normalised spectra of various PC lasers above threshold with slightly different radius of air-holes and lattice constant are shown in Fig. 2(c), of which a wide tunable range near 70 nm is achieved by changing the structural parameters.

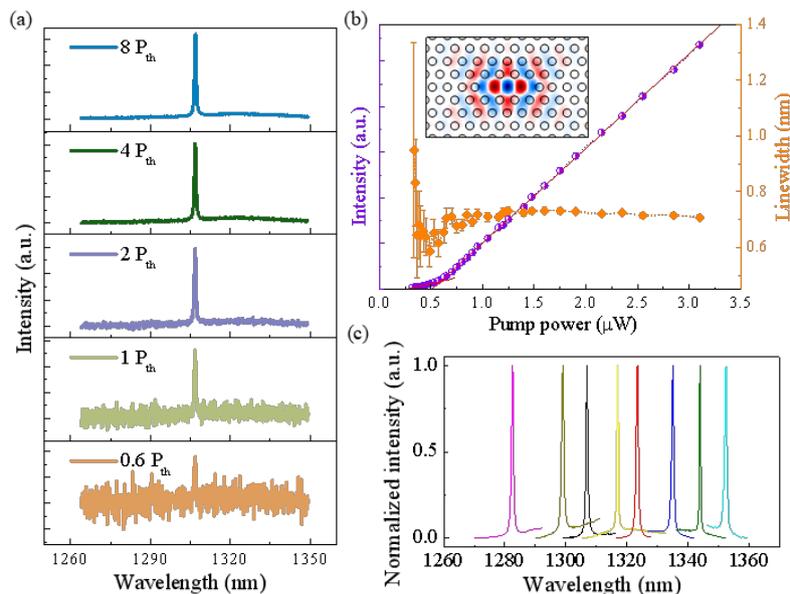


Fig. 2. (a) Measured spectra under various input pumping powers of the PC laser with $a = 310$ nm and $r/a=0.27$. (b) Collected L-L curve and linewidth of the lasing peak at 1306 nm. The inset shows the calculated E_y field profile of the fundamental mode. (c) Normalized PL spectra from representative PC lasers above lasing threshold.

3. Conclusion

In conclusion, we report the ultra-small InAs/GaAs QD PC membrane lasers monolithically grown on CMOS-compatible Si substrate. The PC lasers were CW optically pumped at room temperature, exhibiting an ultra-low lasing threshold of $\sim 0.6 \mu\text{W}$. The lasing wavelengths were finely tuned by manipulating the geometrical parameters. The Si-based PC lasers presented in this paper, providing great advantages in terms of a small footprint as well as low power consumption, can be a promising light source in the next-generation nanoscale Si photonics.

References

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