Relative intensity noise of silicon-based quantum dot lasers

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***Abstract*—This work experimentally investigates the relative intensity noise (RIN) of semiconductor quantum dot (QD) lasers epitaxially grown on silicon. Owing to the low threading dislocations density and the p-modulation doped GaAs barrier layer in the active region, a RIN level as low as -150 dB/Hz at 9 GHz is demonstrated. The results show that the p-doping decreases the high-frequency RIN and the damping factor. In the latter, a damping factor up to 30 GHz at three times the threshold is extracted from the RIN spectrum along with a K-factor of 1.7 ns. These results pave the way for high speed and low noise QD devices for future integrated photonics technologies.**

Keywords—Quantum dot lasers, Relative intensity noise.

Quantum dot (QD) lasers epitaxially grown on silicon are regarded as an excellent candidate to achieve energy and cost-efficient optical sources in order to enhance the performance of future photonics integrated circuits (PICs) [1]. Owing to the atom-like discrete energy levels, QD lasers exhibit outstanding properties such as high temperature stability, low threshold lasing operation, long device lifetime and low alpha factor [1,2]. Furthermore, optical sources with low intensity noise are highly desired to carry broadband data with low bit error rate as well as for some radar applications [3,4]. This paper aims at investigating the RIN of QD lasers epitaxially grown on silicon. The InAs/GaAs Fabry-Perot (FP) lasers studied are directly grown on an on-axis (001) Si wafer in a Veeco Gen-II molecular beam epitaxy chamber. A schematic diagram of the p-modulation doped QD laser structure is displayed in Fig. 1(a). The QD laser consists of 5 QD layers spaced by 37.5 nm thick GaAs barrier layers, where the first 10 nm GaAs layer was undoped, followed by a 10 nm p-GaAs layer at a target hole concentration of 5×10^{17} using Be, and the final 17.5nm GaAs layer was undoped again to complete the GaAs barrier. Moreover, both undoped and p-doped QD lasers are compared. The undoped (p-doped, respectively) QD laser has a 1.1 mm (1.35 mm, respectively) long cavity and both lasers have the same ridge waveguide of 4 μm. Fig. 1(b) depicts the light current characteristics of the undoped and p-doped QD lasers. The threshold current at room temperature (293K) for the undoped laser is found at 14 mA while that of the p-doped laser is found a bit larger at 24 mA. In order to measure the RIN of QD lasers, the laser output is coupled into a lensed fiber and then the optical signal is converted into the electrical domain through a low-noise photodiode with a bandwidth of 10 GHz. The DC voltage is measured by a voltage meter through the DC monitor port of the photodiode, while the AC signal is amplified by a broadband amplifier with a typical small-signal gain of 30 dB. In the end, the amplified noise spectrum is measured on an electrical spectrum analyzer. Fig. 2 shows the measured RIN of the undoped (a) and p-doped (b) QD lasers. For the undoped QD laser, a low RIN level of -140 dB/Hz between 1 GHz and 9 GHz is demonstrated. However, the undoped laser is overdamped due to the absence of resonance peak whatever the pump current. In contrast, as shown in Fig. 2 (b), the p-doped QD laser exhibits a strong resonance peak at around 2 GHz due to a smaller damping factor, while at higher pump currents, the peak shifts towards a higher frequency along with a reduced amplitude. At high frequency, the RIN level is further reduced from -140 dB/Hz to -150 dB/Hz at 9 GHz. Fig. 3 displays the damping factor extracted from the RIN spectrum as a function of the squared relaxation oscillation frequency for the p-doped laser. A damping factor of 30 GHz at 3 times the threshold is extracted along with a K-factor of 1.7 ns. By comparison, the damping factor of the undoped laser is estimated to be more than two times larger at 3 times the threshold current (not shown). To sum, these experimental results show that the p-doping decreases the damping factor and the intensity noise. Further improvements can be envisioned by reducing the carrier noise originating from the ground and excited states or by increasing the energy interval between the quantum confined levels which are even more suitable for low-intensity noise operation [4]. Overall, these results are of first importance for designing future high speed and low noise QD devices to be integrated in future PICs. Last but not least, the high damping factor is also an important feature for isolator-free applications [5].

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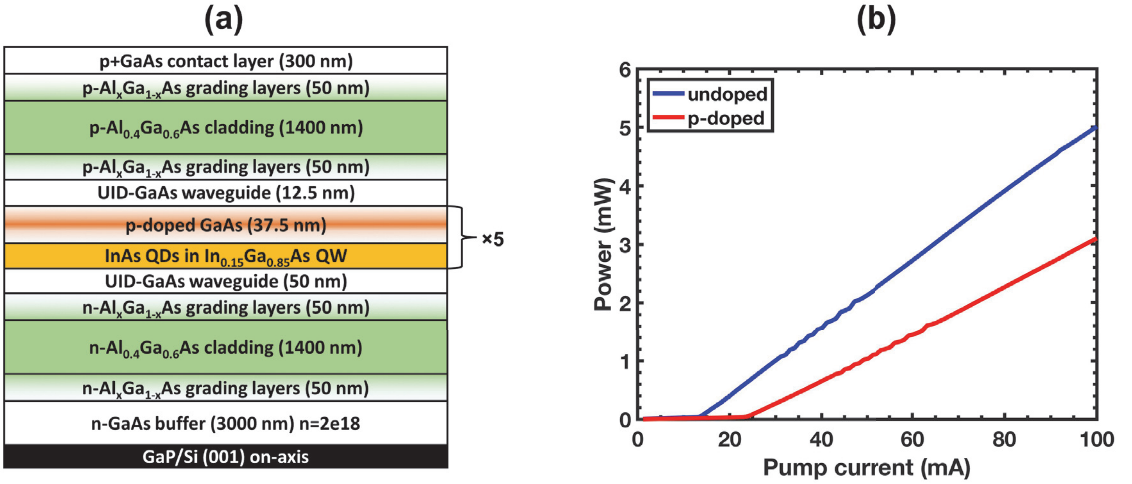

Fig. 1. (a) Epi-structure of the p-doped silicon-based InAs/GaAs QD laser. (b) Light-current characteristics of undoped (blue) and p-doped (red) QD lasers at room temperature.

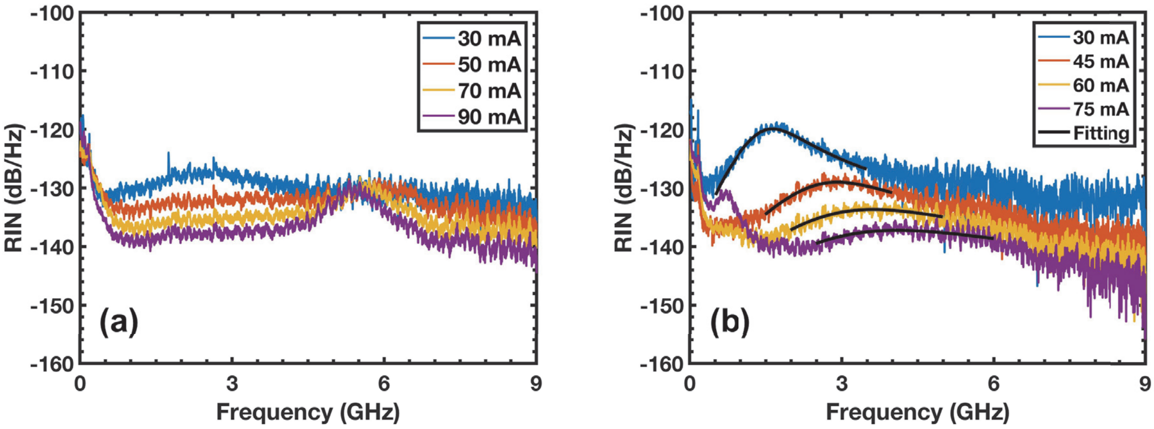

Fig. 2. Measured RIN spectra of (a) undoped and (b) p-doped QD lasers at various pump currents. The black lines in (b) indicate the fitting.

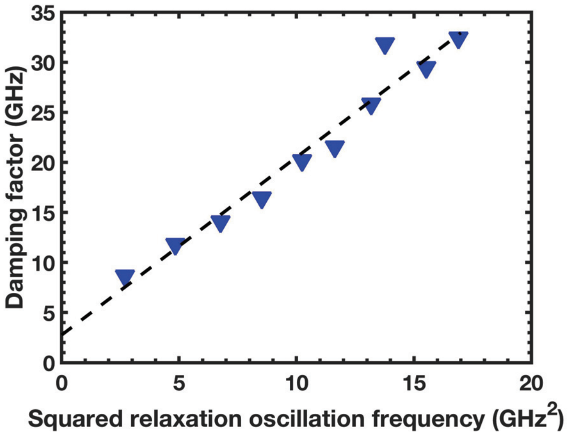

Fig. 3. Damping factor versus squared relaxation oscillation frequency for p-doped QD laser.

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