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Relative Intensity Noise Characteristics of Long-Wavelength Quantum Dot Vertical-Cavity Surface-Emitting Lasers

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In the study we experimentally investigated the relative intensity noise (RIN) characteristics of a quantum-dot vertical-cavity surface-emitting laser (QD VCSEL). The single-mode QD VCSEL grown on a GaAs substrate is a fully doped structure. Additionally, the resonance frequency of the QD VCSEL with external light injection is as high as 19.2 GHz.
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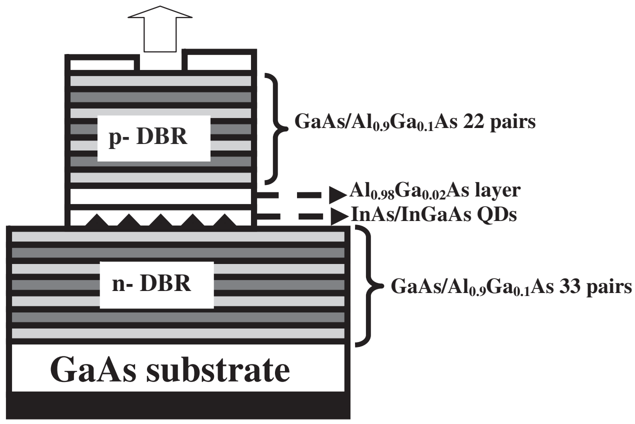
KEYWORDS: quantum dots, vertical-cavity surface-emitting laser, relative intensity noise

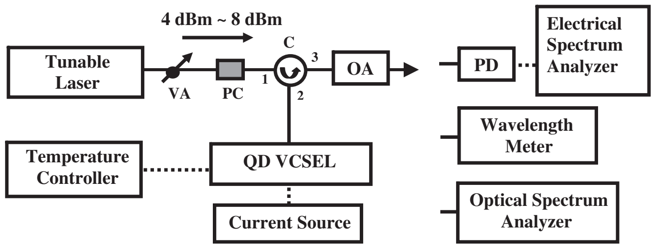
Quantum dots (QDs) are attractive quantum structures due to their superior characteristics and broad range of applications. In contrast with a quantum-well active region, a semiconductor laser with a quantum-dot active region exhibits excellent characteristics, such as low threshold current, temperature-insensitive threshold current, and high differential gain.[1,2] Vertical-cavity surface-emitting lasers (VCSELs) have been the focus of considerable research in recent years. The advantages of VCSELs, such as low power consumption, high beam quality, and low-cost production, have resulted in important applications in optical-fiber communications.[3] Recently, significant progress has been made in developing single-mode QD VCSELs.[4] However, the relative intensity noise (RIN) characteristics of single-mode QD VCSELs have not been reported. Furthermore, the intrinsic resonance frequency of the QD VCSEL with and without external light injection has not been determined.

The RIN peaks of a semiconductor laser with and without external light injection are the same as the resonance frequencies in the small-signal modulation response of the laser.[5,6] The resonance frequency determines the modulation bandwidth of the semiconductor laser. In this study we report the RIN spectra of a QD VCSEL with and without external light injection for the first time. Significant resonance frequency enhancement was observed. The resonance frequency of the QD VCSEL was 19.2 GHz with external light injection.

Figure 1(a) shows a schematic diagram of the QD VCSEL. The structure is grown on a GaAs(100) substrate using molecular-beam epitaxy (MBE). The wafer is then transformed into a VCSEL structure. The details of the QD VCSEL were described in our previous work.[4] The threshold current (I_{th}) of the InAs/InGaAs QD VCSEL is 1 mA at room temperature. The QD VCSEL is hermetically sealed using a standard TO-Can laser package with a built-in lens. Figure 1(b) shows the experimental setup for RIN measurement. The QD VCSEL is used as the slave laser, and a tunable laser is the master laser. Light injection power is controlled by a variable optical attenuator located at the tunable laser output. The polarization of the tunable laser is adjusted using a polarization controller before injecting it into the QD VCSEL. During the experiment, the polarization of the tunable laser is adjusted that the QD VCSEL receives the maximum enhancement of the resonance frequency. Figure 2 shows the RIN spectra of the QD VCSEL without light injection. The RIN spectrum as a function of bias current is measured at room temperature using an electrical spectrum analyzer. The inset in Fig. 2 shows the relationship between the resonance frequency and driving current of the QD VCSEL. The resonance frequency of the QD VCSEL biased at 2.2 mA is 1.83 GHz. Figure 3 shows the RIN



(a)



(b)

Fig. 1. (a) Schematic diagram of the QD VCSEL. (b) Experimental setup for relative intensity noise measurement (VA: variable optical attenuator, PC: polarization controller, C: optical circulator, PD: photodetector, OA: optical amplifier).

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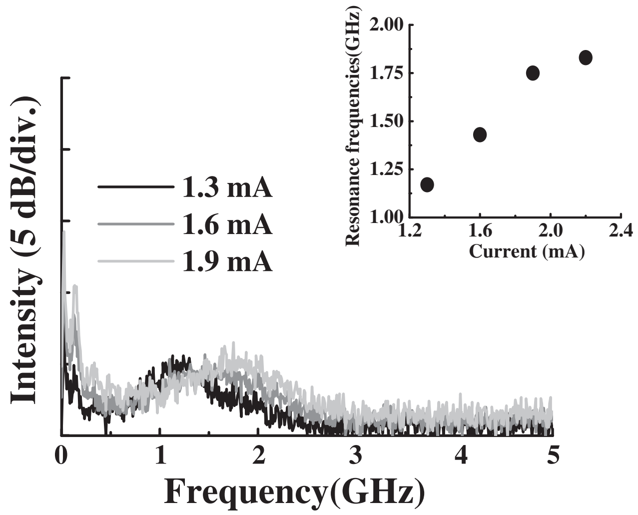

Fig. 2. Relative intensity noise spectra of QD VCSEL at different bias currents.

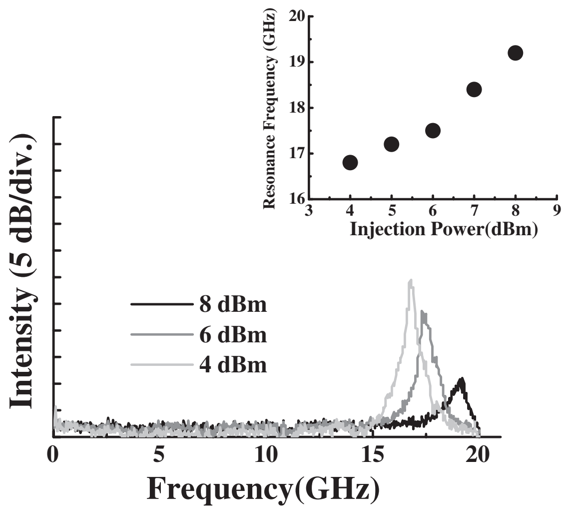

Fig. 3. Relative intensity noise spectra of QD VCSEL at different injection powers.

spectra of the QD VCSEL at different light injection powers. The wavelengths of the QD VCSEL and tunable laser are 1278.046 and 1277.964 nm, respectively. The difference in wavelengths is 0.082 nm. The RIN peak is shifted to a higher frequency with increasing light injection power. The inset in Fig. 3 shows the relationship between resonance frequency and injection power. Clearly, light injection significantly enhanced the resonance frequency. The maximum resonance frequency (19.2 GHz) was over 10 times that of the QD VCSEL without light injection.

In conclusion, the RIN characteristics of the QD VCSEL with and without external light injection are presented for the first time. The QD VCSEL is grown on a GaAs substrate. The resonance frequency of the QD VCSEL increased significantly under strong light injection. The resonance frequency was enhanced by a factor of over 10. For hybrid optical-access networks, a semiconductor laser with a high-frequency response is required. Hence, a long-wavelength QD VCSEL with external light injection used for hybrid optical access networks would support important applications.

Acknowledgments

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