LETTER

Quantum Noise and Feed-Back Noise in Blue-Violet InGaN Semiconductor Lasers

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SUMMARY Properties of the quantum noise and the optical feedback noise in blue-violet InGaN semiconductor lasers were measured in detail. We confirmed that the quantum noise in the blue-violet laser becomes higher than that in the near-infrared laser. This property is an intrinsic property basing on principle of the quantum mechanics, and is severe subject to apply the laser for optical disk with the small consuming power. The feedback noise was classified into two types of "low frequency type" and "flat type" basing on frequency spectrum of the noise. This classification was the same as that in the near infra-red lasers.

key words: *InGaN, blue laser, quantum noise, feedback noise, optical disk system*

1. Introduction

Semiconductor lasers are required to reveal the lower noise for the higher performance. Blue-violet InGaN semiconductor lasers have been developed to be light sources in the high density disk system [1]–[3].

The intensity noise of semiconductor lasers is classified into the quantum noise and the optical feedback noise. The quantum noise is generated by intrinsic property of the laser, which is too difficult to control. The optical feedback noise is caused by re-injection of the emitted light reflected at surface of the optical disk [4], [5].

In this letter, we report properties of these two types of noise in blue-violet lasers comparing with those in near-infrared lasers.

We found that properties of the noise in the blue-violet laser is not so differ qualitatively from those in the near-infrared lasers. However, the quantum noise in the blue-violet laser are eight times higher than that in the near-infrared laser in terms of RIN (Relative Intensity Noise) for identical output power.

2. Measuring Manor

We call here that the intensity noise without optical feedback is the quantum noise. The quantum noise was measured by directly detecting the output light from the laser without any reflection system.

The feedback noise was measured with experimental set up as illustrated in Fig. 1. ATT is an optical attenuator to control ratio of the optical feedback. PD is a photo diode. ℓ is distance between the laser and the reflecting mirror.

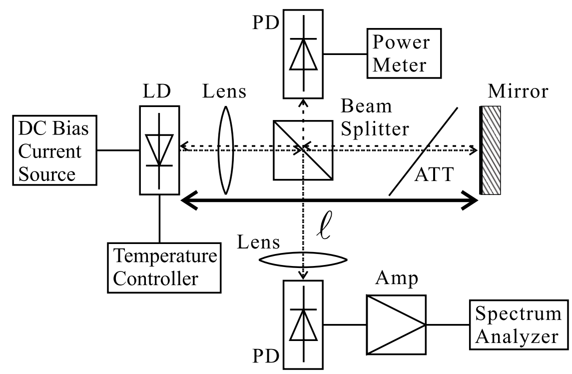

Fig. 1 Experimental set up.

Characteristics of InGaN blue-violet (410 nm) lasers and AlGaAs near-infrared lasers (780 nm and 830 nm) were examined in this work. Temperature of the laser was fixed at 25°C with a Peltie element.

3. Quantum Noise

Variations of the quantum noise with the injection current are shown in Fig. 2(a). Values and varying characteristics of the noise are almost identical among three types of lasers for variation of the normalized injection current I/I_{th}. This figure indicates that there is no remarkable difference such as the material defect or the inferior structure design between InGaN lasers and AlGaAs lasers.

Figure 2(b) show those characteristics for variation of the output powers from the lasers. We find the blue-violet laser of $\lambda = 410$ nm reveals almost 10 dB higher noise than those of the infrared laser $\lambda = 780$ and 830 nm for identical output power.

We understand this surprising result as follows: The output power P of the laser is proportional to the photon energy $S\hbar\omega = 2\pi S\hbar c/\lambda$ where S is the photon number and c is velocity of the light in free space. RIN of quantum noise is inversely proportional to third power of the photon number S for operation near the threshold as theoretically analyzed in [3]. Therefore RIN is related with wavelength λ and output power P as

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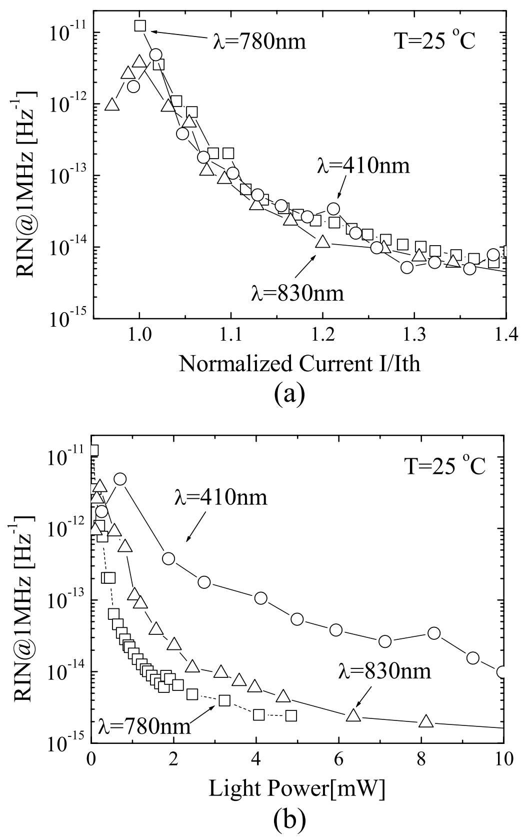

Fig. 2 Characteristics of quantum noise. (a) RIN vs. normalized current I/I_{th}. (b) RIN vs. output light power.

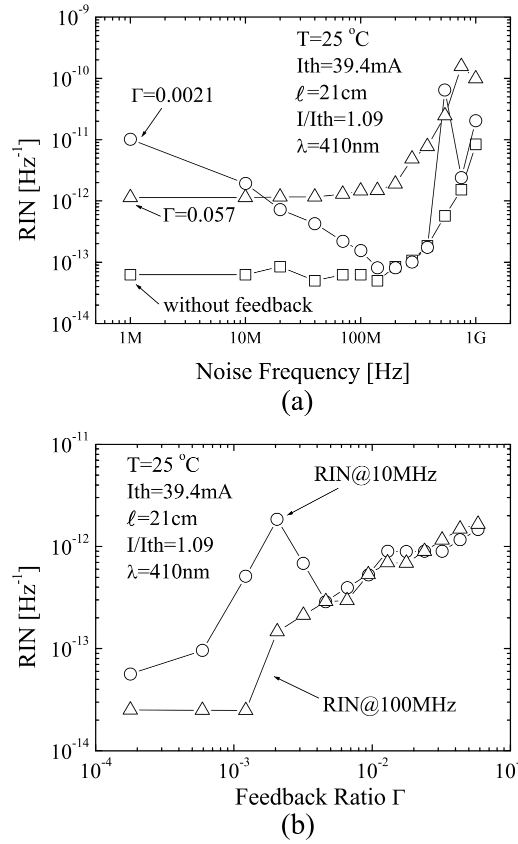

Fig. 3 Characteristics of the feed-back noise. (a) RIN vs. noise frequency. (b) RIN vs. feed-back ratio Γ.

$$RIN \propto \frac{1}{\lambda^3 P^3}. \tag{1}$$

Since wavelength of the blue-violet laser is almost half of the near-infrared laser, RIN value of the blul-violet laser is 8 times larger than those in the near-infrared lasers.

Real DVD system requires lower noise level than RIN = −125 dB/Hz for the reading operation with small output power such as 2 mW. Figure 2(b) tells us operating characteristic of blue-violet laser is very severe for real application.

The noise level of 830 nm laser is higher than that of 780 nm laser in Fig. 2(b). This relation seems to be contradicted to above explanation. This relation comes from that reflectivity of the front facet of 830 nm laser was lower than that of 780 nm laser. Then the photon number in 830 nm laser might be smaller than that in 780 nm.

4. Feed-Back Noise

We measured the optical feed back noise of three types lasers basing on the setup shown in Fig. 1. We could not find remarkable difference among the three types lasers for the feedback noise.

Examples of measured data of a blue-violet laser by setting $I/I_{th} = 1.09$ and feed back distance $\ell = 21$cm are given in Fig. 3. Noise frequency characteristics are shown in (a). The line of "without feedback" written with '□' corresponds the quantum noise.

Γ is the feedback ratio indicating power ratio of returned optical power to the output light. By increasing Γ from 0 to 0.0021, the RIN was increased in low frequency region. We call here this type of noise to be "low frequency type noise."

When feedback ratio Γ was increased more, the RIN profile became flat for wide frequency range over from 1 MHz to 100 MHz. We call here this type of noise to be "flat type noise."

The low frequency type noise must be caused by the mode competition among internal cavity modes. The flat type noise must be caused by the mode competition among external cavity modes, which is built by the space between the laser facet and the reflecting mirror [5].

Variations of the RIN with the feedback ratio Γ are shown in Fig. 3(b). Symbols '○' and '△' indicate RIN at 10 MHz and 100 MHz, respectively. The RIN at 100 MHz increased with the feedback ratio Γ, but the RIN at 10 MHz revealed a maximum value around Γ = 0.002. These characteristics were almost similar to those in the near-infrared lasers [5].

5. Conclusion

We measured the quantum noise and the optical feedback noise of blue-violet lasers. We confirmed that the shorter wavelength laser show the higher quantum noise for the operation with same lasing power.

Properties of the feedback noise were almost same as those in the infra-red lasers. The feedback noise can be suppressed by introduction of the superposition of the high frequency current [6] and of the self-pulsing lasers [7]. However, reduced noise level by help of these method must be higher than that of the quantum noise.

Reduction of the quantum noise is an important subject for application of the laser.

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References

[1] S. Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Yamada, T. Matsushita, H. Kiyoku, and Y. Sugimoto, "Characteristics of InGaN multi-quantum-well-structure laser diodes," Appl. Phys. Lett., vol.68, no.23, pp.3269–3271, June 1996.

[2] T. Asano, T. Tojyo, T. Mizuno, M. Takeya, S. Ikeda, K. Shibuya, T. Hino, S. Uchida, and M. Ikeda, "100-mW kink-free blue-violet laser diodes with low aspect ratio," IEEE J. Quantum Electron., vol.39, no.1, pp.135–140, Jan. 2003.

[3] M. Shono, Y. Nomura, and Y. Bessho, "High-power blue-violet laser diodes for next-generation optical disc systems," Proc. SPIE, vol.5380, pp.411–416, 2004.

[4] M. Yamada, "Variation of intensity noise and frequency noise with the spontaneous emission factor in semiconductor lasers," IEEE J. Quantum Electron., vol.30, no.7, pp.1511–1519, July 1994.

[5] M. Yamada, A. Kanamori, and S. Takayama, "Experimental evidence of mode competition phenomena on the feedback induced noise in semiconductor lasers," IEICE Trans. Elecrtron., vol.E79-C, no.12, pp.1766–1768, Dec. 1996.

[6] A. Ohishi, M. Chinone, M. Ojima, and A. Arimoto, "Noise characteristics of high-frequency superposed laser diodes for optical disc systems," Electron. Lett., vol.20, no.20, pp.821–822, Sept. 1984.

[7] S. Matsui, H. Takiguchi, H. Hayashi, S. Yamamoto, S. Yano, and T. Hijikata, "Suppression of feedback-induced noise in short-cavity V-channeled substrate inner stripe lasers with self-oscillation," Appl. Phys. Lett., vol.43, no.3, pp.219–221, Aug. 1983.