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High Power Operation of Self-Sustained Pulsating AlGaAs Semiconductor Lasers with Multiquantum Well Active Layer

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Improvement of kink level in self-sustained pulsating AlGaAs multiquantum well (MQW) semiconductor lasers is examined by controlling the refractive index difference in the direction parallel to the junction. As a result, stable fundamental transverse-mode operation at output power over 30 mW is achieved in the samples without facet coatings. Relative intensity noise of less than $10^{-13}Hz^{-1}$ under optical feedback of 3~4 % is also attained in the output power range of 4 to 7mW. Furthermore, it is shown that kink level of self-sustained pulsating MQW lasers can be improved up to 65 mW with antireflective and reflective facet coatings.

1. Introduction

High-power low-noise characteristics have been demanded in semiconductor lasers used as light sources for optical disk systems. Self-sustained pulsating lasers are attractive as a low-noise light source because of thier short coherent length. However, kinks appear at low output power below 10 mW in conventional self-sustained pulsating lasers[1]. Self-sustained pulsation occurs in index-guided lasers having a small effective refractive index difference of $1{\sim}3\times10^{-3}$ parallel to the junction. Therefore, the transverse-mode is weakly guided by the small refractive index difference, and easily becomes unstable due to the refractive index change caused by carrier injection in such lasers. This suggests that it is important to reduce the carrier induced refractive index change in order to stabilize the transverse-mode up to the higher output power level. It has been shown that the refractive index change due to carrier injection in multiquantum well (MQW) lasers is smaller than that in double-heterostructure (DH) laers[2,3]. As previously reported, kink level of self-sustained pulsating lasers could be improved up to about 20 mW by introducing MQW structure into the active layer. The fundamental transverse-mode operation has been obtained over 50 mW with antireflective and reflective facet coatings[4].

In this paper, further improvement of kink level is examined by controlling the built-in effective refractive index difference parallel to the junction in self-sustained pulsating MQW lasers. The influence of the built-in refractive index difference on the output power range, where self-sustained pulsation appears, is also investigated.

2. Experiments and results

The device investigated in this study has a planar-buried ridge stripe structure, as shown in Fig. 1. The structure was fabricated by three-step growth of the metalorganic chemical vapor deposi-

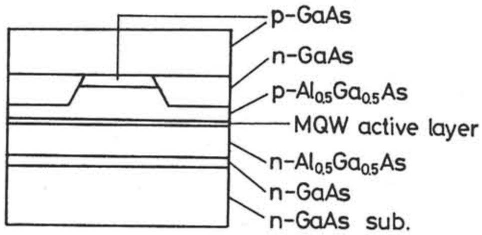

Fig. 1 Schematic cross section of planar-buried ridge stripe structure

tion technique. The current injection width was made about 1~2 μm narrower than that of an optical waveguide with a mesa ridge stripe. The MQW active layer consists of four 10 nm thick quantum wells ($Al_{0.06}Ga_{0.94}As$) and five 4 nm thick quantum barriers ($Al_{0.27}Ga_{0.73}As$), and the total thickness of the active layer is about 60 nm. Conventional DH lasers, with almost the same active layer thickness as that of the MQW lasers, were also fabricated for comparison. The thickness of the p-cladding layer was changed to control the effective refractive index difference parallel to the junction. The lasers having a stripe width of about 5 μm and a cavity length of 250 μm were fabricated.

Fig. 2 shows light output power versus injected current characteristics in MQW and DH lasers with the p-cladding layer

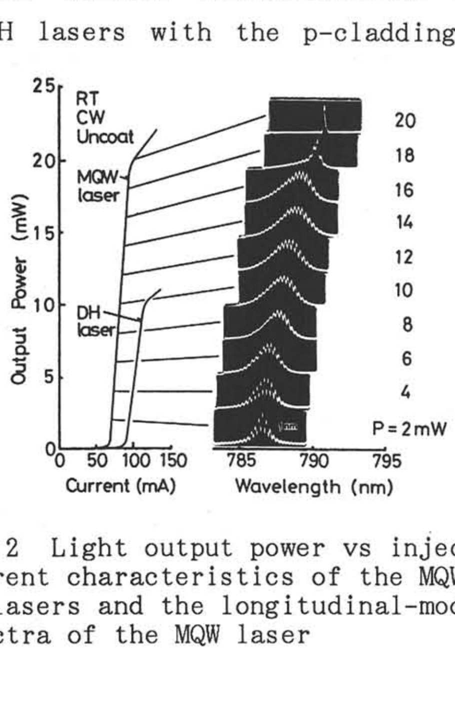

Fig. 2 Light output power vs injected current characteristics of the MQW and DH lasers and the longitudinal-mode spectra of the MQW laser

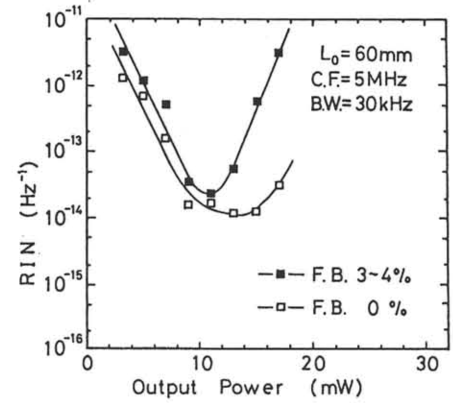

Fig. 3 Relative intensity noise vs. light output power

thickness of 0.5 μm. The longitudinal-mode spectra of the MQW laser, as a function of the output power, are also shown in the figure. The kink level is two times larger than that in the DH laser. This result shows that the transverse-mode is stabilized up to the higher current injection due to the small carrier-induced refractive index change in MQW lasers. The broad multiple longitudinal-mode peculiar to self-sustained pulsation continued up to output power near kink level. Modulated pulse signals of self-sustained pulsation up to near kink level were observed by the frequency spectra.

Fig. 3 shows RIN versus light output power in the MQW laser without coatings. The RIN level was measured at the center frequency of 5 MHz, band width of 30 kHz, optical path length of 60 mm and temperature range of 20~50 ℃. A low RIN level of less than 10^{-13} Hz^{-1} was obtained in an output power range from 8 to 14 mW under optical feedback of 3~4 %. It was found that RIN levels depend on the modulation depth of pulsated signals, and became the lowest at an output power of around 10 mW where the modulation depth was largest.

In order to improve kink level of self-sustained pulsating MQW lasers, increase of the effective refractive index

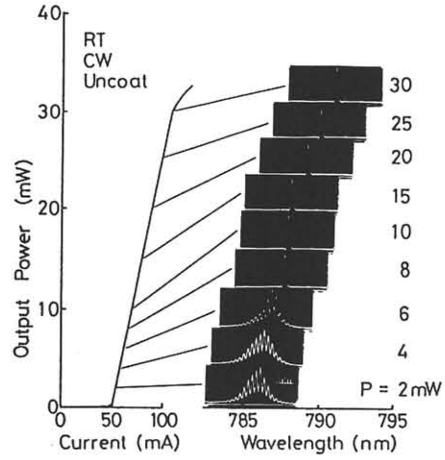

Fig. 4 Light output power vs injected current characteristics and the longitudinal-mode spectra of the MQW laser

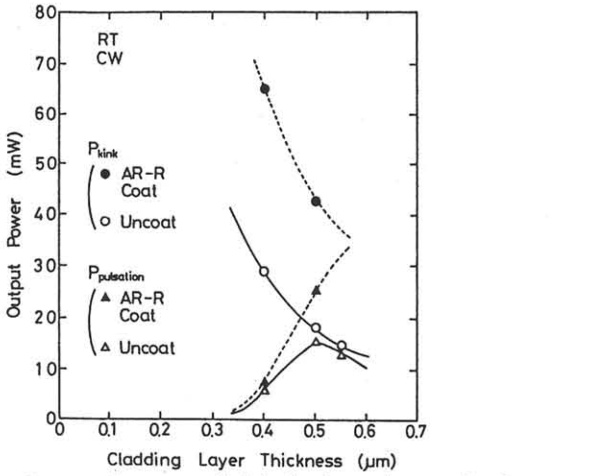

Fig. 6 Dependence of kink levels and the maximum powers where self-sustained pulsation are observed on the cladding layer thickness

difference parallel to the junction was examined. This was done by making the cladding layer thickness thinner. Light output power versus injected current characteristics of a MQW laser having a thinner cladding layer of 0.4 μm is shown in Fig. 4. It is seen that kink level was improved up to 30 mW. The spectra showed broad multiple longitudinal-mode peculiar to self-sustained pulsation at lower output power. The longitudinal-modes become single at higher levels of current injection. Fig. 5 shows RIN versus light output power characteristics in the sample of Fig. 4. RIN of less than 10^{-13} Hz^{-1} was obtained in the output power range of 4 to 7 mW under optical feedback of 3~4 %. This output power range is about a half

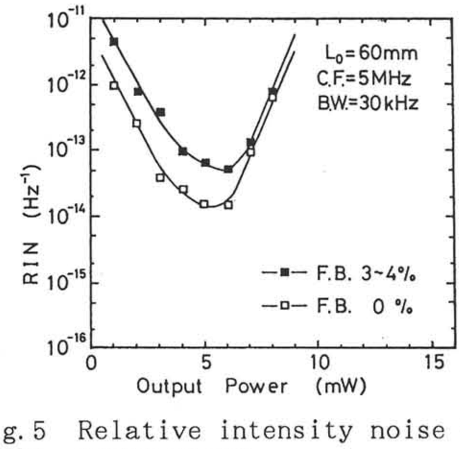

Fig. 5 Relative intensity noise vs. light output power

of the output power range of the sample shown in Fig. 3. These results show that the optical power range where self-sustained pulsation appears can be controlled by the cladding layer thickness, i. e. the built-in effective refractive index difference.

Dependence of kink levels and the maximum powers where self-sustained pulsation was observed on the cladding layer thickness are shown in Fig. 6. As the cladding layer thickness becomes thinner, kink level increases and the maximum power where self-sustained pulsating is observed decreases. The larger the effective refractive index difference, the higher the transverse-mode stabilized output power. On the other hand, the maximum power when self-sustained pulsation appears decreases as the cladding layer becomes thinner. Finally, self-sustained pulsation disappears and the single longitudinal-mode operation begins at lower output power. These results show that it is possible to improve kink level and change output power range where self-sustained pulsation appears by controlling the built-in effective refractive index difference properly.

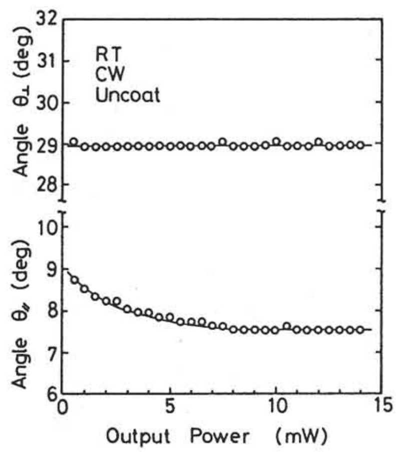

Fig. 7 Dependence of FWHM perpendicular and parallel to the junction on the output power

Fig. 7 shows the dependence of the full width at a half maximum (FWHM) perpendicular and parallel to the junction on the output power in the sample of Fig. 4. Although the FWHM perpendicular to the junction was constant, the FWHM parallel to the junction gradually decreased down to about 7.5° and became constant at an output power of more than 7 mW. This output power corresponds to that when the longitudinal-mode became single, as shown in Fig. 4. The behavior of the FWHM parallel to the junction and the longitudinal-mode may be understood by the following explanation.

At lower output power levels, the width of the beam distribution parallel to the junction is narrower than that of the optical waveguide, and the transverse-mode is weakly guided by the small effective refractive index difference at lower output power levels. Therefore, self-sustained pulsation appears at these output power levels. At higher output power levels, the beam extends to the width of the built-in optical waveguide parallel to the junction due to carrier diffusion and the transverse-mode is stabilized by the larger effective refractive index difference. Therefore, the lasers tend to operate in a single longitudinal-mode.

With antireflection of 10 % and reflection of 90 % facet coatings, kink level could be further improved over 65 mW, as shown in Fig. 6. Moreover, a low RIN level of 10^{-13} Hz^{-1} could be obtained at output power of around 5 mW in the samples. The life tests were performed under a heat block temperature of 50 ℃ and the automatically controlled output power of 30 mW. No remarkable deterioration has been observed in the lasers with antireflective and reflective facet coatings, with over 1200 hours operation.

3. Summary

Kink level in self-sustained pulsating lasers was remarkably improved by introducing the MQW structure in the active layer. Furthermore, self-sustained pulsating optical power range could be controlled by the thickness of the cladding layer. As a result, kink level up to over 65 mW and low RIN level of 10^{-13} Hz^{-1} at around 5 mW were obtained in the samples with antireflective and reflective facet coatings. These results suggest that self-sustained pulsating MQW lasers are promising high-power low-noise light sources for optical information systems.

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