

## LETTER

# Experimental Evidence of Mode Competition Phenomena on the Feedback Induced Noise in Semiconductor Lasers

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**SUMMARY** Mechanism of the noise generation caused by the optical feedback in semiconductor laser was experimentally determined. Two types of the mode competition phenomena were confirmed to be the generating mechanisms. Applicability of the self-sustained pulsation to be a noise reduction method was also discussed.

**key words:** semiconductor laser, feedback induced noise, self-sustained pulsation, mode competition

## 1. Introduction

Reduction of the feedback induced noise in a semiconductor laser is an important subject for application of this device to be an optical source in the optical disk systems. A generating mechanism of the feedback induced noise has been proposed by authors' group in terms of the mode competition phenomena [1]–[3]. While the self-sustained pulsation phenomena were found to be effective for reduction of the feedback induced noise and are applied in lasers for the optical disk systems [4], [5]. Conditions getting the self-sustained pulsation and mechanism for the noise reduction were theoretically analyzed by one of the authors [6], [7].

Two different types of mode competition phenomena were represented as the noise generating mechanisms with different shapes on the noise spectra [7]. One is with competition among the internal cavity modes (intrinsic modes of a solitary laser), where noise spectrum gives Lorentzian shape enhanced in lower frequency region than several MHz. Another is with competition among the external cavity modes which are built by the optical feedback, whose noise spectrum is flat on wide frequency region from DC to GHz. The theory indicated that former type of noise can be suppressed effectively by the self-sustained pulsation, but the latter type of noise is not always suppressed even by the pulsation.

This letter gives experimental evidence of two different types of the mode competition phenomena through characteristics on the noise spectrum.

## 2. Experimental Observation

The optical feedback and distribution of lasing modes are illustrated in Fig. 1, where length of the laser is  $L$ , length to the reflecting point is  $\ell$  and the feedback ratio is  $\Gamma$ . Wavelength separation and frequency separation of the internal cavity modes are  $\lambda^2/2n_rL$  and  $c/2n_rL$ , where  $\lambda$  is the lasing wavelength,  $n_r$  is the refractive index and  $c$  is velocity of the light. While those of the external cavity modes built by the feedback are  $\lambda^2/2\ell$  and  $c/2\ell$ .

Experimental set up is shown in Fig. 2. Temper-

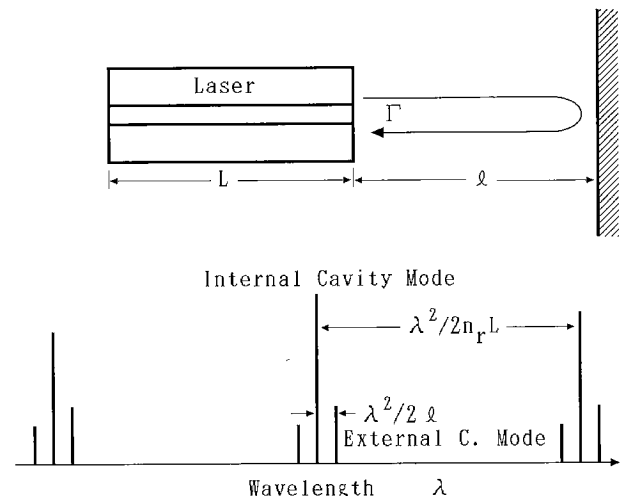


Fig. 1 Illustration of the optical feedback and lasing modes.

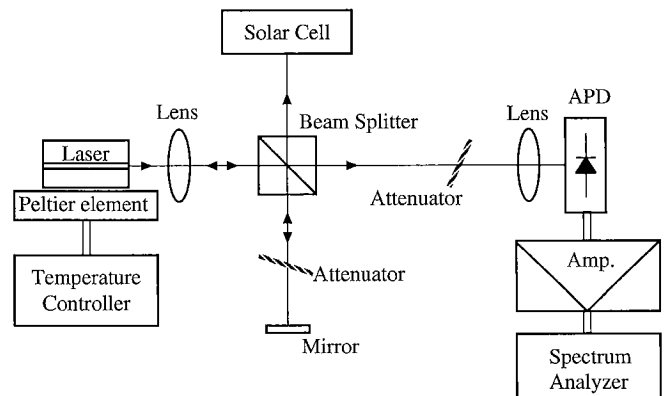
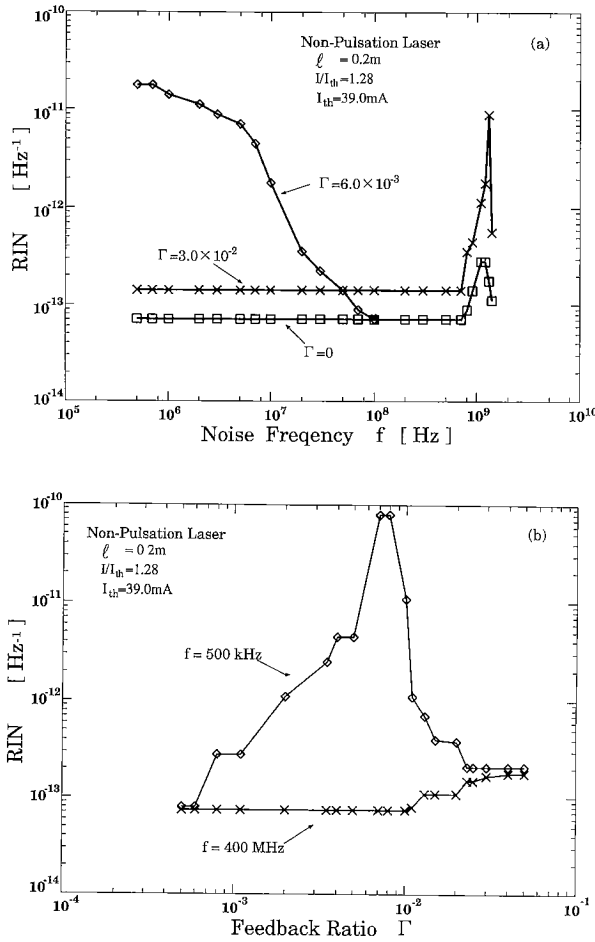


Fig. 2 Experimental set up to measure the feedback induced noise.

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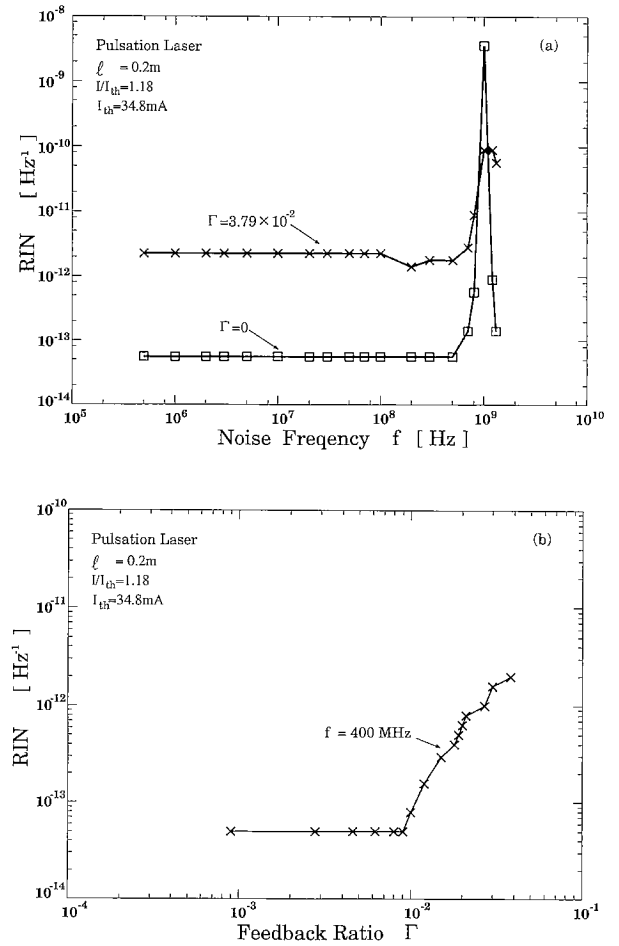
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**Fig. 3** Noise in a non-pulsation laser. (a) Frequency spectra where both the low frequency type and the flat type excess noises are observed by the optical feedback. (b) Variation of the noise with the feedback ratio.

ature of the laser sample was stabilized with a Peltier element to avoid additional mode hopping phenomena which are generated by changing the temperature even there are no optical feedback. The feedback ratio is monitored by a solar cell. Two types of laser samples were used for the measurement. One is a commercially sold AlGaAs laser labeled HL7801E with  $\lambda \approx 780$  nm, which is called in this letter be a non-pulsation laser. Another is an AlGaAs self-sustained pulsation laser with  $\lambda = 788.5$  nm, which is called here be a pulsation laser.

Typical noise spectra in the non-pulsation laser are shown in Fig. 3(a). The noise level was lower than  $10^{-13} \text{ Hz}^{-1}$  when there is no feedback, but raised up by the feedback of  $\Gamma = 6.0 \times 10^{-3}$  especially in lower frequency region than 10 MHz, which is called here be low frequency excess noise. The peak around at 1.1 GHz indicates the relaxation oscillation. The noise spectrum changed to a flat spectrum by increasing the feedback more. The shoulder around at 800 MHz for the feed-



**Fig. 4** Noise in a pulsation laser. The noise is suppressed in almost operation conditions, but raise up with some conditions as these figures. (a) Frequency spectra of the noise. The flat type excess noise was observed in this case. While the low frequency excess noise was never observed in the pulsation laser. (b) Variation of the flat type excess noise with feedback ratio.

back ratio of  $\Gamma = 3.0 \times 10^{-2}$  tells building up of the external modes whose original frequency separation is  $c/2\ell = 750$  MHz but seemed to be modified due to a nonlinear coupling effect in the laser.

Variations of the noise with the feedback ratio are shown in Fig. 3(b), for  $f = 500$  kHz representing the low frequency excess noise and for  $f = 400$  MHz as the flat type excess noise. As given by theoretical analysis in Ref. [2], the mode competition among the internal cavity modes starts with lower feedback ratio than that among the external cavity modes when  $\ell = 0.2$  m. Then we can say that the low frequency noise is caused by the mode competition among the internal cavity modes, while the flat type excess noise is caused by the mode competition among the external cavity modes.

The noise in the pulsation laser was neatly suppressed down to the level without feedback in almost operating conditions of the injection current  $I$  and the feedback distance  $\ell$ . However, the noise raised up under

some operating conditions. Typical examples of the increased noise is shown in Fig. 4, where increased noise is classified to be the flat type excess noise. The pulsation frequency was at the peak of spectrum around 1 GHz in Fig. 4(a). The pulsation was distorted by building up of the external modes whose original separation spectrum is  $c/2\ell = 750\text{ MHz}$  but was mixed into the distorted pulsation as found by the line of  $\Gamma = 3.79 \times 10^{-2}$ . Variation of the flat type excess noise with the feedback ratio is shown in Fig. 4(b). A remarkable fact was that the self-pulsation laser never reveals the low frequency excess noise.

### 3. Conclusions

These experimental data well support the theoretical results shown in Refs. [2] and [7] as the followings:

1. Mode competitions among the internal cavity modes reveal the low frequency excess noise.
2. Mode competitions among the external cavity modes reveal the flat type excess noise.
3. The low frequency excess noise can be well suppressed by the self-sustained pulsation.
4. The flat type excess noise remains under some operating conditions even in the pulsation laser.

Details of the operating conditions generating the flat type excess noise are still not clear. Further investigations on the feedback induced noise are expected.

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