Numerical Analysis of Optical Feedback Noise and Its Reduction in Semiconductor Lasers

Dissertation Abstract

Numerical Analysis of Optical Feedback Noise and Its Reduction in Semiconductor Lasers

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Abstract

This dissertation shows numerical simulations on the phenomena of the optical feedback (OFB) noise in semiconductor lasers, its suppression by the superposition of high frequency (HF) current and conditions at which the HF current is unable to suppress the noise. A set of multimode rate equations are formulated, in which the self and mutual gain saturation effects among lasing modes, re-injection of delayed feedback light reflected at surface of connecting optical device and Langevin noise sources for the intensity, phase and carrier number fluctuations are taken into account. Numerical simulations based on our theoretical model confirmed that the feedback noise is classified into two types based on profiles of the frequency spectrum, where one is the low frequency type and another is the flat type. Superposition of HF current is used as a technique to suppress the OFB noise. However, this is not effective when frequency of the HF current coincides with a rational number of the round trip time for the OFB. Generating mechanism of the OFB noise and its suppression are explained with approximated but analytical equations. The evidence of agreement between experimental results and numerical simulations based on our model supports the accuracy of the model.

Semiconductor lasers play a central role in the growing world of optoelectronic technologies. A measure of the importance of this emerging optoelectronic technology is provided by the optical disc players, laser printers and the optical fiber communication system. But semiconductor lasers tend to be suffered by the optical feedback (OFB) noise caused by reflection of the output light at surface of the optical disc or the optical fiber. Hence, it is required to reveal the lower noise for the higher performance. This dissertation shows numerical simulations on the phenomena of the OFB noise, its suppression by the superposition of high frequency (HF) current and the condition at which the HF current is unable to suppress the noise.

In this dissertation, we present an improved theoretical model to analyze dynamics and operation of semiconductor lasers under optical feedback. The model is based on a set of multimode rate equations in which the self and mutual gain saturation effects among lasing modes, re-injection of delayed feedback light reflected at surface of connecting optical device and Langevin noise sources for the intensity, phase and carrier fluctuations are taken into account. The proposed model is applied to 850nm GaAs lasers operating under optical feedback. Temporal variations of photon numbers, optical phases and electron density are traced by numerical calculation, and frequency spectra of intensity noise are determined by help of the fast Fourier transformation. Characteristics of the OFB noise are expressed in terms of the relative intensity noise (RIN).

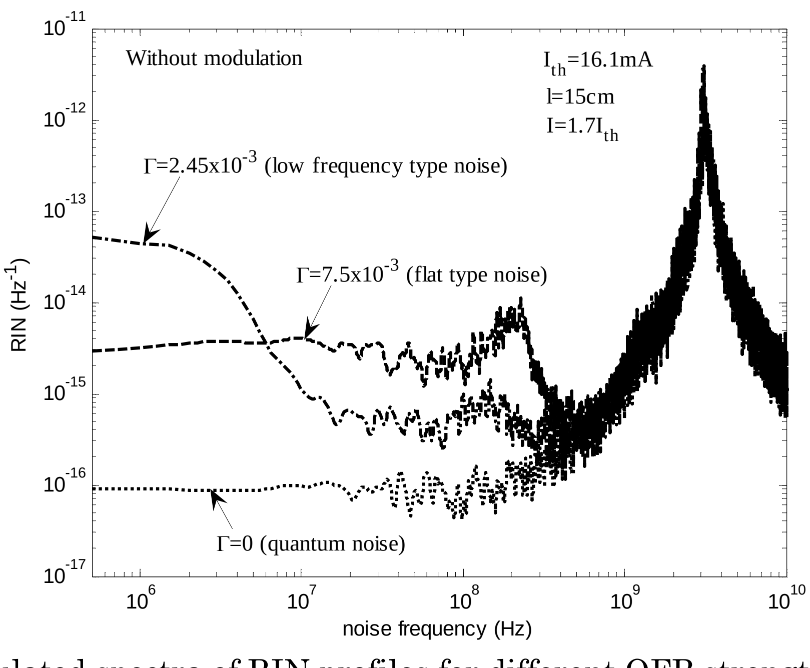

Fig. 1. Simulated spectra of RIN profiles for different OFB strengths. OFB noise is classified into low frequency type and flat type based on noise freq. profile.

The intensity noise of the semiconductor lasers consists of the quantum noise and the optical feedback noise. The quantum noise is generated by intrinsic property of the quantum mechanical fluctuation of the laser and very difficult to control in principle. On the other hand, numerical simulations based on our theoretical model confirmed that the OFB noise is classified into two types based on profiles of the frequency spectrum, where one is the low frequency type and another is the flat type. The low frequency type noise must be caused by the mode competition among the lasing modes in the solitary laser, and the flat type noise by the phase distortion between the internal reflected light and the external feedbacked light [1].

The output noise level of the laser is increased by 20dB or more as a result of the optical feedback and this excess noise degrades performance of the system. Superposition of high frequency current is used in this dissertation as a technique to suppress the OFB noise. The OFB noise is well suppressed by suitable selections of frequency and amplitude of the superposed current. The HF current modulates both electron number and photon number which works to change the operating state of the lasers from bi-stable to monostable, and stop mode hopping resulting in suppression of the OFB noise.

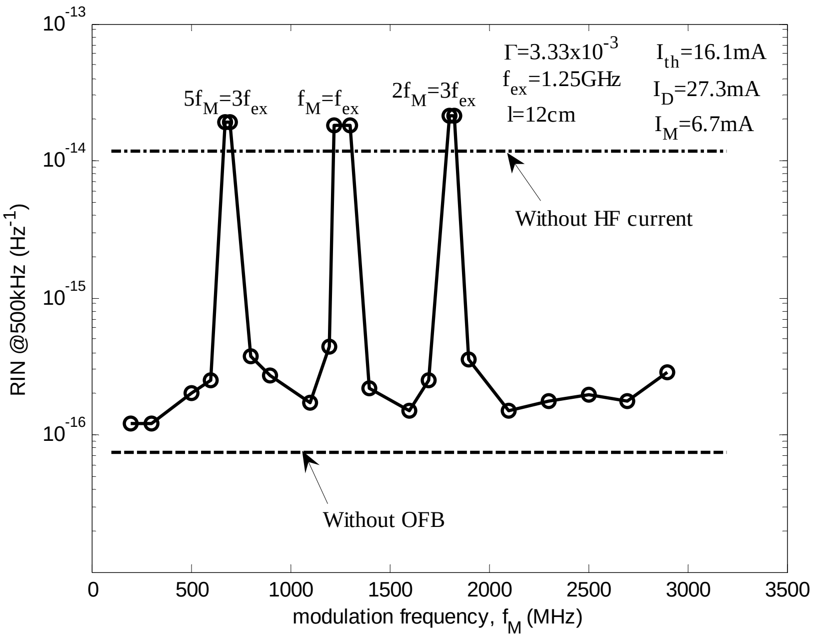

Fig. 2. Calculated data showing dependence of the RIN on modulation frequency of the superposed HF current.

However, this technique is not effective when frequency of the HF current coincides with a rational number of the round trip time for the OFB. In that case, modulations of the electron number and the photon number are suppressed by the phase locking effect with undesirable phase relation and thus, the noise suppression effect does not work under this condition [2].

Generating mechanism of the optical feedback noise and its suppression by the superposition of high frequency current are explained in this dissertation with approximated but analytical equations. Excellent correspondence between previously obtained experimental data and simulation is also demonstrated.

References:

[1] S.M.S. Imran, M. Yamada and Y. Kuwamura, “A theoretical analysis of the optical feedback noise based on multimode model of semiconductor lasers”, IEEE J. Quantum Electron., vol. 48, no. 4, pp. 521-527, 2012.

[2] S.M.S. Imran and M. Yamada, “Numerical analysis of suppression effects on optical feedback noise by superposition of high frequency current in semiconductor lasers”, IEEE J. Quantum Electronics, vol. 49, no. 2, pp. 196-204, 2013.

学位論文審査結果の要旨

平成25年7月30日に第1回論文審査委員会を開催し、同年8月1日午後に口頭発表を行った。その直後に、第2回論文審査委員会を開催し慎重審議の結果、以下の通り判定した。なお、口頭発表における質疑を最終試験に代えるものとした。

半導体レーザは、光ファイバ通信や、光ディスクシステム、光計測技術に利用されているが、レーザから出射した光がレンズやディスク表面などで反射し、レーザに再入射すると「戻り光雑音」と呼ばれる過剰雑音を発生する。この過剰雑音の発生メカニズムとしては、レーザ内部モード間でのモード競合作用と、戻り光の位相遅延が原因とされている。しかし、これまでの理論解析は、一部のメカニズムだけを取り入れていたり、小振幅近似での解析しか存在しなかった。Imran氏は、レーザ内の多数モード、非線形利得、ランジュバン雑音源、および戻り光の位相遅延を含めた動作方程式を提案し、数値計算によって戻り光雑音の特性を解析し、戻り光雑音の発生メカニズムが2種存在することを、理論的にも解明した。また、「戻り光雑音」を低減化する方法として「高周波重畳法」が利用されているが、その低減化特性も数値解析を行い、低減化が困難になってしまう条件などを示した。これらの結果は、半導体レーザの利用に対し大いに有用であり、本論文は博士(学術)に値するものと判定した。