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An improved method and experimental results of noise used as reliability estimation for semiconductor lasers

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Abstract

The low-frequency noise is a sensitive non-destructive indicator of semiconductor devices reliability. In this paper, the noises in InGaAsP/InGaAs/GaAlAs double quantum well semiconductor laser diodes (LDs) are measured, and the correlation between the noise and device reliability is studied. The insults indicate that the noise level in the LDs operating in low bias current is very important for estimating device reliability. So when noise is used as reliability indicator, the noise levels in LDs operating in both low and higher bias current should be considered, which improves the validity of reliability estimation.

Keywords: Semiconductor lasers; Reliability; Noise

1. Introduction

Semiconductor laser diodes (LDs) are widely used in optical fiber communication, optical sensor, medicine treatment and pumping solid lasers. Their reliability is of great concern in practical applications. So one of the most important technological challenges in the manufacture of semiconductor lasers is to determine device quality and reliability without damaging the device itself. The low-frequency electrical noise has shown potential as a sensitive non-destructive indicator of device quality and reliability [1–3]. The factors contribute to noise are either non-radiative recombination centers drawn in by impurities and defects in active region generating the *g-r* noise or the bad state in the facet and large leakage generating $1/f$ noise. All these factors affect devices reliability. The defects and impurities in the active region are associated with the noise level (S_{v1}) of the devices operating in low bias current [4,5]. The series resistance and contacts contribute to the noise level (S_{v2}) of the devices operating in higher bias current [5]. So when the noise is used to estimate device reliability, both S_{v1} and S_{v2} should be measured and considered. However, in early study only S_{v2} was measured [1–3]. In our report, the S_{v1} is also used for reliability estimation together with the S_{v2}. The validity before and after S_{v1} being considered is discussed, respectively.

2. Experimental results

The noise measuring system is shown in Fig. 1.

To eliminate the fluctuation from the power supply, we use battery as the power supply for the amplifier and the laser. When the noise level is higher, the switch K is open; when the noise level is lower than 1 $nV/Hz^{1/2}$, the cross-spectrum estimator is used to reduce the background noise [6], then K is shut.

At room temperature (20°C), the low-frequency voltage noises in 40 InGaAsP/InGaAs/GaAlAs double quantum well (DQW) semiconductor laser diodes were measured with the operating current (I) of 20 μA and 5 mA. Then, the devices were aged at 400 mA and at 70°C for 200 h. The devices are determined to have failed when the output power decrease to 70% of original power.

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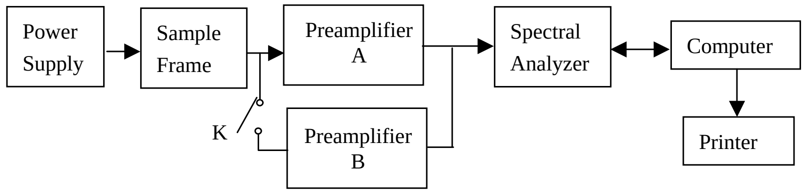

Fig. 1. Noise measuring system.

Table 1
Noise measuring and aging results of first group devices (40 LDs)

Device no.	S_{v1}	S_{v2}	After aging
2515	1650	111.6	
2516	15700	821	Failure
2517	2320	563	
2518	96.4	51	
2519	3980	1510	
2520	24300	2720	Failure
A41	17700	320	Failure
A51	10800	412	Failure
A91	771	92.6	
A101	691	230	
A111	978	60.2	
A221	169	98.2	
A131	2100	226	
A141	42300	852	Failure
A151	34400	329	Failure
A161	8410	586	
A171	621	72.3	
A181	647	64.3	
A191	1240	131.6	
A201	2560	116.7	
2521	178	87.4	
B21	17500	916	Failure
B41	2610	578	
B51	1860	480	
B61	4210	1360	
B71	27200	819	Failure
B101	1550	110.3	
B111	2870	1970	Failure
B121	405	134	
B151	1210	89	
B201	1870	3370	Failure
B211	2500	130	
B221	2140	121.5	
B231	4650	1483	Failure
B261	2160	84.3	
B271	2910	1210	
B281	1100	89.1	
A11	891	126.8	
A21	1301	81.6	
A31	13200	2658	Failure

The noise measuring and aging results are shown in Table 1. In Table 1, S_{v1} (nV/Hz$^{1/2}$) and S_{v2} (nV/Hz$^{1/2}$) are the voltage noise at 2.5 Hz in the device operating in the bias current of 20 μA and 5 mA, respectively.

3. The discussion on validity of noise used for reliability estimation

A key problem is to draw a threshold value to screen poor quality devices. Konczakowska [7] suggested a classification algorithm which has been verified by reliability experiments. On the basis of noise measurement results, the border values for quality groups are:

$$S'_v = \overline{S_v} - \alpha\sigma,$$

$$S''_v = \overline{S_v} + \alpha\sigma,$$

where $\overline{S_v}$ denotes the mean value of S_v, σ denotes the variance of S_v, α equals 0.67 [7]. The ruler of classifying devices into three classes according to noise level is as follows:

First class—$S_v \leqslant S'_v$—high quality is expected,
Second class—$S'_v < S_v < S''_v$—good quality is expected,
Third class—$S_v \geqslant S''_v$—poor quality is expected.

So S''_v is defined as the threshold of noise criterion, i.e., the device with higher noise than S''_v is unreliable and should be screened out. In our experiment, S''_{v1} (when $I = 20$ μA) and S''_{v2} (when $I = 5$ mA) are 13229.69 and 1175.41 nV/$\sqrt{\text{Hz}}$, respectively. That is to say, if the noise (S_{v1}) of device operating with the bias current of 20 μA is higher than 13229.69 nV/Hz$^{1/2}$ or the noise (S_{v2}) of device operating with the bias current of 5 mA is higher than 1175.41 nV/Hz$^{1/2}$, the device will be rejected.

For a large number of devices, a correlation should exist between failure rate and noise level, i.e., devices with higher noise must have a large failure rate λ_1 (λ_1 is the number of failure devices with higher noise than threshold level of noise criterion divided by the sum total of devices with higher noise than threshold level). Devices with lower noise must have small failure rate λ_2 (λ_2 is the number of failure devices with lower noise than threshold level of noise criterion divided by the sum total of devices with lower noise than threshold level) [8]. Otherwise, the ratio of the failure is defined as

$$\lambda = \frac{\lambda_1}{\lambda_2}.$$

Then the optimal threshold levels of noise criterion based on statistical analysis for number of devices must assume that λ has a maximum [8].

Table 2
Failure rate and statistical experimental results of 40 LDs

Condition	Devices with higher noise than threshold	Failed devices with higher noise than threshold	Failed devices with lower noise than threshold	λ
Before S_{v1} being considered	7	5	7	3.4
After S_{v1} being considered	13	11	1	23

Table 3
Noise measuring and aging results of second group devices (30 LDs)

Device no.	S_{v1}	S_{v2}	After aging
6	1255	197.15	Failure
3	11200	3290	Failure
B14	1532	276	
13	1458	141	
B161	100	86.27	
2491	16763	52.7	
B392	89.2	69	
2495	337	127.8	
B311	78	46.32	
B291	11200	1000	
B33	1828	196	
B41	170	81.39	
B39	1070	147.9	
2505	2450	13200	Failure
2508	990	152.23	
2498	8070	1700	
2509	39960	233	Failure
B411	56.5	50.1	
B38	1358	142.59	
4	1532	272	
2512	1288	169.8	
2511	3980	102.3	
2499	30150	213.2	Failure
2504	19950	676.1	Failure
B271	28780	1623.6	Failure
2497	12590	1412.5	
2514	398	41.69	
2507	645	28.84	
B411	367	20.89	
B221	101200	1995.2	Failure

From Table 1, after aging, 12 devices have failed. The ratios of the failure before and after S_{v1} being considered are shown in Table 2. The results indicate that the validity of reliability estimation improves after S_{v1} is considered together with S_{v2}.

In order to confirm the above conclusion, another 30 LDs were selected to repeat the same process for noise measuring and aging. The results are shown in Table 3. The λ values are 4.76 and 16.95 before and after S_{v1} being considered. The results make sure that S_{v1} acts as an important role of noise used for reliability estimation of semiconductor lasers.

4. Conclusion

In different bias current range, the noise mechanisms in LDs are different. The factors contribute to S_{v1} level (when $I = 20$ μA) may be bad state in the facet or the defects and impurities in the active region. The series resistance and contacts are associated with S_{v2} level (when $I = 5$ mA). Both S_{v1} and S_{v2} levels are closely correlated with device quality and reliability. If one of them is higher, the device is usually unreliable. So when the noise is used to estimate device reliability, both S_{v1} and S_{v2} should be measured and considered, which improves the validity of reliability estimation.

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