Degradation analysis in asymmetric sampled grating distributed feedback laser diodes

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Abstract

This paper presents the experimental observation of the degradation in asymmetric sampled grating DFB lasers by the accelerated life tests. Two degradation phenomena related to the electrical characteristics of LDs are observed during the tests. The first degradation phenomenon by increasing the reverse current is considered as a formation of leakage current path enough to prevent lasing operation in lateral blocking layer near active region of lasers. The second degradation phenomenon by decreasing the forward current is considered as activation of non-radiative Auger recombination process by thermal energy. It is also experimentally observed that the second degradation phenomenon is recovered after remained in room temperature with no electrical stress. Therefore, the criteria for LD reliability can be determined by observing the degradation of the reverse current–voltage characteristics.

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1. Introduction

As wavelength division multiplexing (WDM) technology has been required in broadband fiber optic communication systems, the lasers with multiple wavelength have been researched up to now. Generally, the multiple-wavelength lasers have been presented as laser array and the studies for the monolithic integration of lasers with multiple-wavelength laser array have been reported, because it can reduce the cost per wavelength by sharing the package and the module.

As approach into the multiple-wavelength laser array, several methods containing the sample grating method have proposed in the fabrication of multiple-wavelength laser array. The sample grating method is versatile tool for tailoring the optical characteristics of lasers because it is simple to control wavelength by adjusting sampling periods [1]. However, the device reliability must be ensured in advance to be sufficiently usable for practical applications in broadband fiber optic communication systems. Several studies have been performed for the reliability and the degradation of DFB lasers proposed in order to apply to optical communication systems. Hwang et al. [2] presented for the empirical degradation model of multiple-quantum-well DFB lasers by using a power law model. Wakabayashi et al. [3] performed reliability testing of quarter wavelength shifted DFB lasers fabricated by mass-production basis.

In this paper, the structure, fabrication, and two observed degradation behaviors of the sample grating distributed feedback laser diodes (DFB-LDs) are presented. The test of the devices is performed in monitoring the electrical and the optical characteristics of the devices. The analysis of degradation behaviors is also investigated in view of the electrical to optical conversion characteristics.
2. Device structure and fabrication processes

The schematic diagram of the device structure is shown in Fig. 1(a). The laser consists of two sections A and B along the laser cavity that are electrically pumped together. Each section is embedded with a sampled grating of its own period. The asymmetric sampled gratings induce two sets of reflection combs of different peak separations ($\Delta \lambda$). The extra index layer is now placed and it makes the effective index at the section B increased so that the Bragg wavelength of the section B ($\lambda_{oB}$) becomes different from that of the section A ($\lambda_{oA}$). The inclusion of an index shifter is crucial for obtaining the laser operation not at the Bragg wavelength, but at the first-order reflection of the sampled gratings. Fig. 1(b) shows a schematic of reflection spectra for both sampled grating mirrors. Aside from the main Bragg peaks, there are several reflection peaks originated from the periodicity of sampled grating. By adjusting the sampling period of each section, both reflection peaks of the two mirrors could be coincided at the first-order reflection wavelength. This overlap would lower the threshold gain at first-order reflection wavelength, so lasing takes place at that wavelength rather than at the Bragg wavelength [1]. An operating wavelength was determined by adjusting the sampling periods ($Z$) of both sections based on

$$\Delta \lambda = \frac{\lambda_{oA}^2}{(2n_{eff}Z)},$$

where $\Delta \lambda$ is the separation between adjacent reflections, $\lambda_{o}$ is the Bragg wavelength of the base grating and $n_{eff}$ is the effective refractive index of the waveguide. The effective refractive index at the section A was assigned to be 3.225 that corresponded to $\lambda_{oA}$ of 1570 nm. The index difference ($\Delta n$) between sections A and B was 0.010 that changed $\lambda_{oB}$ by 5 nm.

The asymmetric sampled grating laser was fabricated by conventional laser fabrication process at the Electronics and Telecommunication Research Institute in Korea. It was processed into planar-buried heterostructure laser [1]. After the formation of sampled grating, the active layers and the index shifter were overgrown by low-pressure metal-organic vapor phase epitaxy. The active structure contained compressively strained ($\varepsilon = 0.8\%$) four quantum wells. The index shifter was a 76-nm-thick InGaAsP ($\lambda_g = 1.24 \mu m$) which let the Bragg wavelength move by 5 nm. The layer structure was experimentally optimized.
until $\Delta n$ agreed to the desired value. The index shifter was, then, selectively removed from the section A. Conventional mesa etching and p–n–p regrowth were used and followed by p-InP clad layer overgrowth. Each section of the laser was 400 $\mu$m long. Both facets of the device were antireflection coated with TiO$_2$/SiO$_2$ layers. In addition, the p-type and n-type electrodes were deposited using Ti/Pt/Au alloy followed by the post-annealing process at 400 $^\circ$C for 30 s.

3. Experiment conditions

The accelerated life tests for asymmetric sampled grating DFB-LDs were performed in constant forward current of 30 mA at two different temperature levels of 100 and 150 $^\circ$C. In order to maintain a constant operating current, Keithley 236 source measure unit was used in these tests. During these tests, the current–voltage ($I–V$) characteristics of the DFB-LDs and the monitoring photodiodes (mPDs) were measured. In addition, the light–current ($L–I$) characteristics of DFB-LDs were measured at room temperature (300 K) after the life testing. Especially, the $L–I$ characteristics of devices were compared with the monitoring light current of the reliable photodiodes.

The initial threshold currents of devices were in the range of between 5 and 10 mA. The driving currents at the 4 mW optical power were in the range of between 20 and 35 mA and the optical powers of devices at the driving current of 30 mA were in the range of between 3 and 6 mW.

4. Results and discussion

In order to monitor optical power of laser diodes during the accelerating tests, the highly reliable mPDs was used in high-temperature testing and room-temperature testing. In the accelerated life tests, the two kinds of degradation tendency were observed. Assuming the electrical characteristics presented by $I–V$ curves of devices are related to the optical characteristics presented by $L–I$ curves of devices, the test results can be categorized by the changes of the $I–V$ characteristics.

The first group shows severe degradation of the reverse current in $I–V$ curve. Fig. 2 shows changes of the optical and electrical characteristics of the devices of the first group after the accelerating test. It can be considered that the leakage current path enough to preventing lasing operation of lasers is formed in the lateral p–n blocking layer near active region. It was previously reported that the
optical output power of laser diodes at high-temperature operation is affected by the leakage currents in blocking layer near active region of LDs [4]. After the rapid increase of the reverse current for DFB-LDs, the decrease in the optical power of lasers is also observed in tests.

The second group shows degradation of the forward current in the $I-V$ characteristics. They have also degradation behavior of the optical characteristics. Fig. 3 shows the accelerating test results for DFB-LDs in optical and electrical characteristics. However, the recovery of their degradation was then observed after the tested devices remained in room temperature and no electrical stress. As shown in Fig. 4, the recovery effect is observed in both $I-V$ and $L-I$ characteristics. It is shown that the observed degradation of the forward $I-V$ characteristic cannot affect to the reliability of the devices because of recoverability. The similar recovery effect was previously explained by drift of mobile defects from bulk region to near active region in test periods and redistribution of defects to the bulk region in the off-test periods [5]. However, the results observed in the tests show the different characteristic from the previous work, since the drift of mobile defects from bulk region cannot describe the decrease in the forward current for $I-V$ characteristics of devices.

As the possible cause for the results of the tests, thermal dependency of non-radiative Auger recombination rate, indicating the impermanent degradation of electrical and optical characteristics, in multiple-quantum-well layer is considered. It can be concluded that the optical characteristics of DFB-LDs are affected by temperature dependence of the non-radiative Auger recombination in sufficiently high temperatures, which is classified to the threshold-free, the quasi-threshold, and the threshold Auger process and three processes have the different properties for the temperatures [6]. These Auger processes also have the different threshold energy levels to activate each Auger process: the threshold energy levels of the threshold-free, the quasi-threshold, and the threshold Auger process is −0.01, 0.05, and 0.28 eV, respectively. They are activated by thermal energy such as temperature and lead to the increment of the total non-radiative Auger recombination rate, which is sum of three Auger processes. Especially, the quasi-threshold Auger process in the increment of the total Auger recombination rate by high temperature is dominant [6]. The temperature dependence of the forward current for the DFB-LD is presented in Fig. 5. The temperature activation energy of the DFB-LDs is calculated at 0.07 eV and it is considered that this is sufficient for activating the

![Fig. 3. $L-I-V$ room-temperature measurement of the sample device in second group: (a) forward current, (b) reverse current, and (c) optical power.](image-url)
quasi-threshold Auger process. The non-radiative Auger recombination process activated by high temperature can increase the threshold-driving current for lasing and it can finally lead to decrease the optical output power of DFB-LDs, which can lead to the reduction in forward current of the $I-V$ characteristics due to disappearance of injected carriers. Therefore, these processes can be recovered by removing thermal energy.

5. Conclusion

This paper has presented the observation of the $I-V$ and $L-I$ characteristics degradation in asymmetric sampled grating DFB lasers. From the accelerated life tests, the two degradation models, which are the reverse current degradation and the forward current degradation, are observed. The degradation by the increase of the reverse current can be induced from the formation of leakage current path in the lateral blocking layer near the active region of DFB-LDs. The degradation and the recovery of the forward current can be considered as the activation of the non-radiative Auger recombination process by the thermal energy. Therefore, the reverse current degradation can be regarded as the important factor for the reliability estimation of DFB-LDs whereas the forward
current degradation, which is the recoverable degradation, cannot be considered as the main factor for the reliability estimation.

References


