COMD Behavior of Semiconductor Laser Diodes

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The lifetime of semiconductor laser diodes is reduced by facet degradation and catastrophic optical mirror damage (COMD). To increase the lifetime of such devices, a suitable facet coating combined with a suitable preparation before the coating process is necessary. The determination of the time-to-COMD behavior provides a measure for the quality of the facet coating.

1. Introduction

Edge-emitting semiconductor lasers are used for different applications in our daily work. When making a telephone call over long distance, an optical fiber transmission system is used with a semiconductor laser as transmitting source. Printing systems and data storage applications often use semiconductor lasers as light source. Considering all these applications, laser diodes have to work reliable without sudden failures and degradation effects. Especially the very high power densities at the facet of a semiconductor laser can destroy the device itself. So, a suitable protection to reduce chemical and thermal effects at the laser facet is necessary to increase the lifetime of the devices.

2. COMD Mechanisms

The mechanisms of facet-related degradation are illustrated in Fig. 1. The COMD-behavior can be schematically illustrated by a number of related loops and has been described by many researchers [1],[2]. A facet oxidation loop, a loop for dislocations at the facet, and some related phenomena are physically connected with the overall COMD loop. When light is absorbed at the facet, electron-hole pairs are generated and this pair generation enhances the bond breaking. The generated electrons and holes recombine nonradiatively and the temperature is increased at the facet. By this way, the band gap energy is reduced and the light absorption at the facet increases and more electron-hole pairs are generated. In the final stage, the temperature rise reaches the melting point of the laser material and COMD occurs. On the other hand facet oxidation is enhanced by the increase in bond breaking resulting in even more electron-hole pair generation. This photo-enhanced oxidation process can be understood as a defect injection process in the active area of the laser [1]. Fig. 2 shows the active area of a 4 μm ridge waveguide laser after COMD occurs. For lasers with facet coating, nonradiative recombination also occurs via the electronic states at the interface between the laser material and the coating.
Consequently, COMD also occurs in lasers with facet coating films although the COMD power level increases because of the lower density of the interfacial states compared to the density of the surface states and because of thermal conductivity of the films [3],[4],[5]. So a suitable design with respect to good thermal contactivity at the facet and good adhesion to the facet together with chemical and mechanical stability can shift the COMD level to high output power and increases the lifetime of the device.

Fig. 1. The mechanisms of facet-related degradation of edge-emitting lasers.

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Fig. 2. Active area of a 4-μm ridge waveguide laser after COMD occurs
3. Devices for Lifetime Tests

To measure the COMD behavior, single-mode ridge-waveguide lasers are used. Fig. 3 schematically shows the structure of such a ridge-waveguide laser.

The active region consists of an epitaxially grown graded-index separate confinement heterostructure (GRINSCH) with an InGaAs quantum well. The lateral emission region is defined by an etched laser ridge at the semiconductor surface which builds an optical waveguide because of the resulting index step. The device is contacted by a p-contact on top of the ridge and an n-type contact at back side of the substrate material. The output characteristic of such a device is shown in Fig. 4.

The device has a threshold current of about 12 mA and a differential efficiency of about 78%. The beam quality which is described by the $M^2$ value is nearly 1 if the output power is below 10 mW. Up to an output power of less than 55 mW, the $M^2$ value increases to 1.2. The picture
on the righthand side (Fig. 5) illustrates the lateral far-field behavior of this device at different output power levels. So the lateral full width at half maximum angle is less than 14°.

4. Time to COMD Measurement

The correlation between time to COMD and the aging condition has been studied for InGaAs/GaAs strained quantum well lasers by a group at IBM Zurich [6]. They have reported the following empirical relationship for InGaAs/GaAs strained QW lasers.

\[ 1/t_{\text{COMD}} = \nu e^{-\frac{E_a}{kT_D}}, \tag{1} \]

where \(1/t_{\text{COMD}}\) represents an Arrhenius like “COMD reaction rate”, \(k\) and \(c\) are the Boltzmann constant and the temperature proportionally term. \(PD\) is the optical power per unit \(\mu m\) ridge width. The pre-exponential factor (\(\nu\)) and the activation energy (\(E_a\)) are characteristic for the materials and for the procedure used to prepare the facet of the InGaAs/GaAs lasers, namely cleaving with air exposure. Before trying to influence these parameters with the aim to get a better COMD behaviour, we have measured an uncoated laser as reference device. A laser bar has been mounted on a copper heat sink. Each laser on the bar has been operated at a different output power and the time to COMD has been determined. An example for such a measurement at 75 mW output power is shown in Fig. 6.

![Fig. 6. Output power versus lifetime of a 4-\(\mu m\) ridge-waveguide laser.](image)

The resulting output power is constant over a long time until the COMD occurs and the device is destroyed. All the results of these measurement were plotted in Fig. 7. By fitting the measured values, the pre-exponential factor \(\nu\) and the activation energy \(E_a\) can be determined. To reduce the fit error of this plot, measurements for long time at low power levels are needed which will be done next. After this, different kinds of facet preparations will be done to get a better facet quality.
Fig. 7. Arrhenius plot of 4-µm ridge-waveguide lasers cleaved at air exposure without any coating.

References


