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Spatial hole burning degradation of AlGaAs/GaAs laser diodes

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The degradation of AlGaAs/GaAs laser diodes is studied in detail using laser scanning confocal microscopy, cathodoluminescence images, and x-ray diffraction (XRD) techniques. Our analysis has identified a degradation mechanism that results from the periodic distribution of the carrier density and the near-field intensity originating from periodic spatial hole burning. Based on the XRD measurements, we find that the epitaxial layer enters a polycrystalline phase during degradation due to the dark line defects, and the out-of-plane strain and in-plane compressive stress are induced by degradation. © 2011 American Institute of Physics. [doi:10.1063/1.3634051]

Rapid progress has been made in the development of high power AlGaAs/GaAs laser diodes (LDs) for different applications, such as solid state laser pumping, materials processing, optical communications, and printing machines. However, the degradation behavior of LDs is still a subject of discussion, with reliability being a critical issue for laser commercialization. Recent efforts have improved the performance and analysis of the degradation of LDs.1–5 The interplay between stress and defects within the active region has been analyzed, and a model for the degradation of LDs has been derived.6,7 Although these are remarkable achievements, the reliability of LDs is still a critical issue for improving performance. In this letter, we report on the degradation behavior and identify a degradation mechanism of AlGaAs/GaAs LDs. We observed periodic melting spots on the output facet, together with some dark line defects (DLDs) in the cavity, which are all caused by the periodic spatial hole burning (SHB). We further showed that out-of-plane strain and in-plane compressive stress can be induced by degradation.

The investigated devices are AlGaAs/GaAs single quantum well structures emitting at 808 nm with a 1-W output power operating at a power density of $1.45 \times 10^7$ W/cm². The devices are 100-μm thick, 500-μm wide, and have a cavity length of 1000 μm. The active region has a width of 100 μm which is made up of AlInGaAs. The LDs are grown on a (100) GaAs substrate using metalorganic chemical vapor deposition (MOCVD). The output and reverse facets are asymmetrically coated with Al₂O₃ and Al₂O₃/Si. The devices are mounted p-side-up on a Cu heat sink with Indium solder.

We applied a bias stress with a constant current of 1 A to the devices for 106 h at a fixed case temperature of 35 °C. Laser scanning confocal microscopy (LSCM) is an appropriate tool for the characterization of the morphology of the output facet of LDs. This method utilizes coherent light (semiconductor laser, 408 nm) and collects light exclusively from the focal plane while rejecting light outside of the focal plane. Figure 1 presents the LSCM images of the output facet. As shown in Fig. 1(b), equally spaced melting spots were discovered in the output facet after degradation. The melting spots were caused by the rise of the local temperature at the output facet. Conventionally, there are two explanations for the occurrence of melting spots. The first attributes it to the reabsorption of light generated in the LDs that results in an extra enhancement of the facet heating.8 The second suggests that the facet heating is caused by the nonradiative recombination of carriers at the surface and is mainly determined by the injected current density.9 Both processes depend on the carrier density and near-field intensity at the output facet, which are distributed periodically as a result of the periodic SHB at the output facet as well as within the cavity.10,11 From Figs. 1(b) and 2, we find the period of SHB is about 9 μm and is in good agreement with the results presented in Ref. 11.

FIG. 1. (Color online) LSCM imaging of the output facet (a) before degradation, (b) after degradation, and (c) after the coating materials Al₂O₃/Si were removed. The inset of (b) shows the profile of melting spots B, C, and D, and the inset of (c) shows the profile of melting spots C and D in color after the coating materials were removed.

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In addition to the investigation of the periodic SHB effect on the output facet, we also studied it in the cavity using the cathodoluminescence (CL) technology. CL measurements (parameters: 30 kV, 15 nA) were performed at 25 °C after removing the p metallization and electrode by grinding and wet chemical etching. The top-view panchromatic CL images in Fig. 2 show that some DLDs appeared along the cavity with their positions corresponding to the melting spots at the output facet. Likewise, the DLDs can be attributed to the SHB effect as same as the melting spots on the output facet. Because the SHB can occur uniformly along the cavity, each DLD has almost the same intensity within the cavity.

The structural properties of the epitaxial layer were also investigated using the x-ray diffraction (XRD) technique. The XRD measurements were performed using a D8-Discover diffractometer with a CuKα x-ray beam (λ = 1.5406 Å), and a particular region of the epitaxial layer including the active region was selected as the scattering plane with a diameter of 300 μm. Two x-ray scanning experiments, one for the non-degraded sample and the other for the degraded sample, were carried out, as shown in Fig. 3. Before degradation, the epitaxial layer was in the cubic phase with a dominant orientation of (400). However, the intensity of (400) decreased, and the intensity of (220) and (222) increased after degradation. The results indicate that there is a transition of the epitaxial layer from the initial single phase to the polycrystalline phase as well as the out-of-plane strain, the crystal interplanar spacing of the epitaxial layer, the in-plane stress, Young’s modulus, and Poisson’s ratio, respectively. ε⊥ and σ∥ are calculated to be 0.00063 and −85.3 MPa, respectively, meaning a compressive stress existed in the epitaxial layer after degradation, which was induced by the DLDs as a result of the polycrystalline phase of the epitaxial layer.

In summary, we employed LSCM mapping, CL imaging, and XRD techniques to investigate periodic SHB degradation in AlGaAs/GaAs LDs and identified a degradation mechanism of AlGaAs/GaAs LDs. We find that there are periodic melting spots present on the output facet and some uniform DLDs in the cavity as a result of the periodic SHB. We also observed a transition of the epitaxial layer from the initial single phase to the polycrystalline phase as well as the out-of-plane strain and in-plane compressive stress induced by degradation.

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