High-Efficiency InGaAlP Green Light-Emitting Diodes

H.Sugawara, K.Itaya, *H.Nozaki, and G.Hatakoshi
Research and Development Center, Toshiba Corporation
1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki 210, Japan

*Semiconductor Division, Toshiba Corporation
72, Horikawa-cho, Saiwai-ku, Kawasaki 210, Japan

A high external-quantum-efficiency of 0.7% in the green region was obtained with InGaAlP light-emitting diodes (LEDs). InGaAlP LEDs offer candela-class light emission from the red to green regions, a performance which can not be obtained with other materials such as GaAlAs and GaAsP.

InGaAlP quaternary alloy compounds have been investigated extensively for optical device applications in the visible light region. One problem in shortening the emission wavelength of InGaAlP LED is that the high Al composition required for the active layer causes a reduction in radiative efficiency. In this letter, we report high-efficiency InGaAlP green LEDs which employ a new device structure and are grown on an off-angle substrate.

The wafer was grown on a 15°-off (100) toward [011] oriented GaAs substrate by low-pressure metalorganic chemical vapor deposition (MOCVD). We investigated the effect of the off-angle substrate on the emission properties by estimating the diffusion length through cathodoluminescence (CL) measurements.

Figure 1 shows the dependence of CL intensity on the electron beam position, distance between electron beam and probe point. The ambipolar diffusion length is given by the reciprocal of the slope. A longer diffusion length of 2.7 μm was obtained for the wafer grown on an off-angle substrate. This can be explained as a reduction in non-radiative recombination centers.

The wavelength dependence of external quantum efficiency for the InGaAlP LEDs is shown in Fig.2. The Al composition ratios of the active layer were 0.2, 0.3, and 0.4. An improvement in external quantum efficiency by using the off-angle substrate was obtained, as predicted from the diffusion length measurements. Even in this case, however, efficiency falls in the shorter wavelength region. We designed a new InGaAlP LED structure with a current blocking layer and a Bragg reflector, as a way to obtain further improvements in efficiency. Figure 3 shows a schematic cross-sectional view of this structure. A current injected from the p-electrode effectively spreads through the low-resistivity current-spreading layer, and does not enter the undesired region under the electrode because of the blocking layer. The Bragg reflector acts to prevent absorption by the GaAs substrate. Light extraction efficiency was drastically improved by these methods. The improvement in external quantum efficiency is shown in Fig.2. An efficiency of 0.7% was obtained even for the high Al composition ratio of 0.4, corresponding to green (573 nm). Thus highly efficient light emission in the region between red and green was achieved by InGaAlP LEDs, which are based on a new device structure grown on an off-angle substrate.

References
Fig. 1. Dependence of cathodoluminescence intensity on beam position

Fig. 2. The wavelength dependence of external quantum efficiency for InGaAlP LEDs

Fig. 3. Schematic cross-sectional view of the InGaAlP LED structure