Fabrication of High-Brightness Light-Emitting Diodes by Wafer Bonding Technology

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ABSTRACT

High-efficiency light-emitting diodes (LEDs) are desired for many applications such as brake lights, traffic lamps, and outdoor displays. It is well known that the AlGaInP LEDs lattice-matched GaAs substrates have the highest luminous efficiency in the yellow-to-red spectral region. However, the absorbing GaAs substrate significantly limits the light extracting performance. The inferior thermal conductivity (GaAs versus Si) also yields the joule-heating problem, which limits the luminous efficiency at high injection currents. In this thesis, a 2-inch-diameter Si wafer coated with a Au/AuBe reflector was fused to an AlGaInP LED epilayers grown on GaAs. After the wafer bonding process, the GaAs substrate was chemically removed. Here the Au/AuBe mirror can not only be used as an adhesive layer, but also as ohmic contacts to the p-AlGaInP in the LED structure. The optimum fusion process can be controlled below 450 ° C for the wafer-bonded AlGaInP LEDs. From the crack-opening method, the bonding surface energy of the fusion interface was determined to be 1.2155×106 erg/cm2, which is greater than that of the Si-Si wafer bonding at 1400 ° C (2200 erg/cm2). The present adhesion property can afford the LED backend process including chip dicing and wire bonding. The effect of SiO2 film in the wafer-bonded AlGaInP/Si LED structure was investigated. It is found that the Si substrate with a 500-nm-thick SiO2 film can reduce the residual stress of the epilayer. From x-ray diffraction and cantilevel beam methods, the wafer-bonded epilayer with a SiO2 interlayer showed compressive stress from 17.6 to 39.2 MPa. For the sample without a SiO2 interlayer, the AlGaInP epilayer suffers a tensile stress of 97.21 MPa as measured by the cantilevel beam method. The results obtained were compared with the data measured by photoluminescence and the discrepancy was discussed. The wafer-bonded AlGaInP LEDs with mirror substrates show that the flux can reach to 7500 mlm and 25 mW at 100mA, resulting in the highest lumen efficiency of 84 lm/W. The light intensity is 8 times over than the conventional AlGaInP LED without the distributed Bragg reflector. By stressing 50mA at 80 ° C after 2000 hours, the voltage and light intensity variations of the wafer-bonded AlGaInP/Si LEDs were within ±10 % for an applied current of 20 mA. Furthermore, under an aging test condition 20 mA, 400 ° C, the wafer-bonded LED with a SiO2 interlayer can withstand 9.5 hours, which is better than that without a SiO2 interlayer (5.5 hours). Based on the results of this thesis, it can be concluded that the wafer-bonded AlGaInP epilayers with mirror substrates have high potential in high-brightness, high-power and large-area LED applications.

Keywords : AlGaInP ; wafer bonding ; LED ; Reliability ; mirror substrates

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