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Wafer-Bonded AlGaInP/Au/AuBe/SiO2/Si Light-Emitting Diodes

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1. Introduction

High-efficiency light-emitting diodes (LEDs) operating in the wavelength region from red to green light have been recently realized employing the AlGaInP alloy system grown on GaAs substrate. However, the absorbing GaAs substrate significantly limits the performance of the device. This problem can be minimized by growing a distributed Bragg reflector (DBR) between the LED epitaxial layers and the absorbing substrate [1,2]. Another approach was performed by replacing GaAs substrate with a GaP transparent substrate via wafer bonding after epitaxial growth [3,4]. An increase in luminous efficiency can be achieved by the first method, since the DBR will reflect light that is emitted or internally reflected in the direction of the absorbing substrate. However, the improvement is limited, because the DBR only reflects light that is of near normal incidence. On the other hand, the AlGaInP LEDs with wafer-bonded GaP substrates have been demonstrated with highly reliable and performance. It is worthy to mentioned that the AlGaInP/ GaP bonding process needs high temperature (>600°C) and long thermal-anneal duration (≥1h). This might result in additional disadvantage of redistributing the doping profile. Moreover, an important step in this wafer bonding process is the matching of the crystallographic orientations of the bonded wafers. This crystallographic alignment makes the LED operate at low voltage and high efficiency [5]. In this work, the development of a new family of reflective mirror deposited on Si substrate instead of DBR structure is proposed. A new AlGaInP/Au/AuBe/SiO2/Si LED was fabricated by wafer bonding technique.

2. Experimental

The LED structure employed in this work is p-AlGaInP/undoped AlGaInP active layer/n-AlGaInP/10-pair (GaAs/AlGaAs) DBR/n^+GaAs substrate. Fig. 1 shows the wafer bonding process. The Au/AuBe/SiO_2/Si is bonded to the LED structure at elevated temperature (300 °C for 20 min) and under applied uniaxial pressure to form robust chemical bonds. Notably, it is not necessary to care the crystallographic alignment between the bonded wafers. For comparison, the absorbing substrate LEDs fabricated from the same as the AlGaInP/DBR/GaAs epitaxial material were also prepared.

3. Result and Discussion

A successful sample of a 2 cm × 2 cm AlGaInP LED wafer bonded on a Au/AuBe/SiO2/Si substrate can be obtained and it is expected that even larger areas can be obtained using this fusion process. No visible artifacts are present in the mirror-like surface. Instead, only a uniform dark red color is observed, indicating the excellent wafer-bonded uniformity. The revealed dark red color is attributed to the convolution of the eye response with the wavelengths reflected from the $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P$ LED active region.

In order to demonstrate the metal being mirror after wafer fusion and ohmic process, the bonded epilayer will be etched away. The bottom metal still presents mirror surface. This point can be confirmed by the reflectivity measurement after removing the bonded LED epilayers, as shown in Fig. 2. The reflectivity of the processed mirror is over 90% as the incident wavelength variation from 600 to 900 nm. It suggests that the metal still is a high reflective mirror for the LED emission wavelength. Moreover, the mechanical strength of the bonded interface exceeds that required withstand the chemical etching, ohmic contact processing and chip dicing.

Fig. 3 (a) and (b) show the photomicrographs of the unencapulates AlGaInP LED chips with a DBR structure grown on a absorbing GaAs substrate and a bonded mirror substrate. Obviously, the extraction efficiency of the AlGaInP LED grown on GaAs with DBR structure is limited, since the DBR will reflects light that is of near normal incidence. Thus, only 1 mcd luminous intensity can be obtained under 20-mA injection current. On the contrary, the light intensity in Fig. 3(b) is more uniform than that in Fig. 3(a). The light appears to radiate evenly from the top surface of the mirror-substrate (MS) chip (b). It can be due to the fact that the metal mirror can reflect the light that is emitted or internally reflected downwardly toward the mirror. The reflected light is then emitted from the top of the chip to substantially improve the efficiency of the LED. So, the MS chip emits 90 mcd under 20 mA injection and 205 mcd at 50 mA. A MS device offers significant advantages over such DBR structure.

Fig. 4 show the peak spectral wavelength as a function of DC drive current for the LEDs of Fig. 3. For the LED with absorbing GaAs substrate, the emission peak wavelength shifts towards longer wavelengths with increasing injection current. This phenomenon is caused by joule heating. For the LED bonded to metal/Si substrate, the emission peak wavelength is almost the same. It may be due to the fact that Si has a relatively high thermal conductivity, and it provides a good heat sink.

4. Summary

High-brightness MS AlGaInP/Au/AuBe/SiO2/ Si LEDs have been fabricated by wafer fused technology at low-temperature and short duration time. Measurements of the device performance of these MS AlGaInP LED are superiors to that of the conventional LED with DBR structure. The metals not only act as adhesion layers, but also act as mirror. Experimental results indicated that the mirror effectively solves the DBR problem of only reflecting near normal incidence light. Moreover, the Si substrate provides a good heat sink and the joule heating inhering in conventional LED problem can be solved.

ACKNOLEDGMENT

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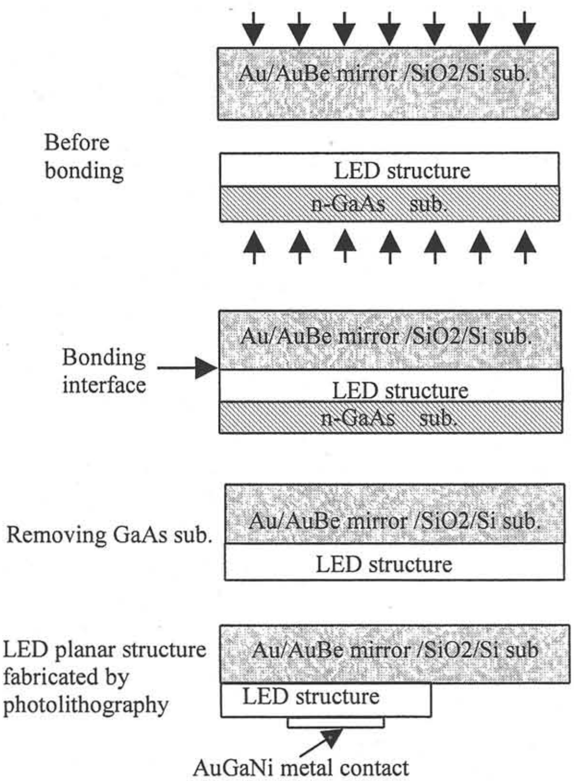

Fig. 1 Wafer bonding process

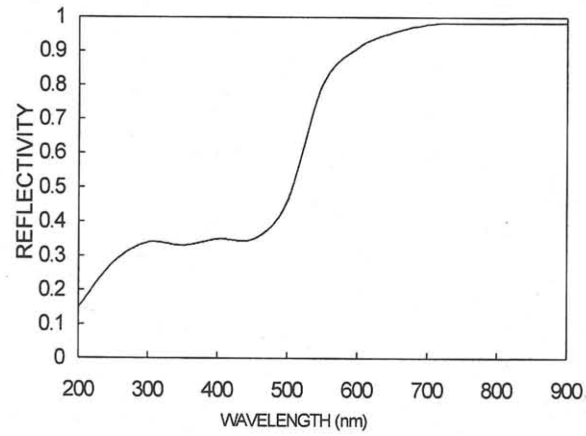

Fig. 2 Reflectance spectrum of the processed Au/AuBe /SiO2/Si mirror.

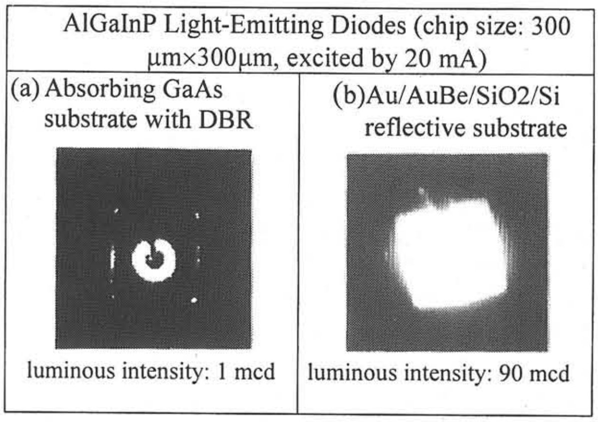

Fig. 3 Photomicrographs of AlGaInP LEDs with (a) a DBR structure on an absorbing GaAs substrate and (b) a bonded substrate under a forward 20-mA injection.

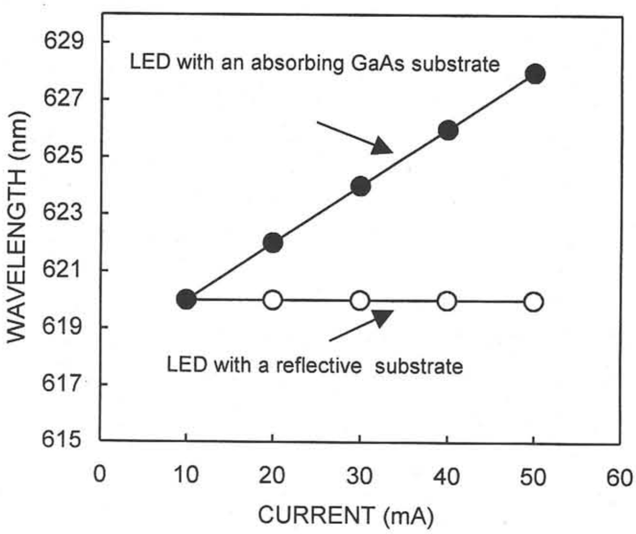

Fig. 4 Peak spectral wavelength as a function of DC drive current for the LEDs with an absorbing GaAs substrate and a reflective substrate.