AlGaInP–Si glue bonded high performance light emitting diodes*

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We propose a new method of using conductive glue to agglutinate GaAs based AlGaInP light emitting diodes (LEDs) onto silicon substrate, and the absorbing GaAs layer is subsequently removed by grinding and selective wet etching. It was found that AlGaInP–Si glue agglutinated LEDs have larger saturation current and luminous intensity than the conventional LEDs working at the same injected current. The luminous intensity of the new device is as much as 1007.4 mcd at a saturation current of 125 mA without being encapsulated, while the conventional LEDs only have 266.2 mcd at a saturation current of 105 mA. The luminescence intensity is also found to increase by about 3.2% after working at 50 mA for 768 h. This means that the new structured LEDs have good reliability performance.

Keywords: glue agglutinated, AlGaInP LEDs, Si substrate, luminous intensity

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1. Introduction

The $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ quaternary material has a direct bandgap in the visible light range between the red and yellow/green spectra regions. Furthermore, AlGaInP can be precisely lattice matched to GaAs substrate without generating much misfit dislocation. For these reasons, AlGaInP has become the most promising material for high brightness red, yellow, and yellow/green light emitting diodes (LEDs), which can be used for indoor or outdoor multicolour displays, traffic light lamps, LCD back light sources, and general illumination.[1,2] However, the refractive index of AlGaInP is different from the air, thus the light that emits from AlGaInP to air would be restricted by Snell law, as GaP, only the light beams with the incidence angle smaller than 17° can escape to the outside; other beams are reflected to the GaAs substrate. Photons emitted downward in AlGaInP LEDs will be absorbed by the GaAs substrate underneath, since the bandgap energy of GaAs is much smaller than that of AlGaInP. As a result, the emission efficiency of the conventional AlGaInP–GaAs LEDs (AS-LEDs) will be significantly reduced.[3] Although such a problem can be solved partially by inserting a distributed Bragg reflector (DBR) between the GaAs substrate and the active region to reflect light emitting toward the absorbing GaAs substrate, the improvement is limited since DBR can only efficiently reflect normal incident light.[4] The other possible way to solve this problem is to bond an AlGaInP LED with a GaP transparent substrate (TS-LEDs). In order to achieve such TS AlGaInP–GaP LEDs, one needs to grow a thick p-type GaP window layer on top of the AS-LEDs, selectively remove n–GaAs substrate, and then wafer bond the exposed n–AlGaInP to an n–GaP substrate. It has been shown that such a TS AlGaInP–GaP LEDs exhibits a twofold improvement in light output compared with absorbing substrate AlGaInP–GaAs LEDs. However, in order to match the crystallographic orientations of n–AlGaInP and n–GaP, it is necessary to perform high-temperature (600 °C wafer bonding for a long time (usually longer than 1 h). Such a high thermal budget process could result in an impurity redistribution and an interfacial mixing in the multi-quantum well (MQW) region of the AlGaInP LED structure, and in addition the processing is extremely complex.[5,6] Some people used 2-μm Au or AuSn alloy layer as the bonding material to bond the AlGaInP LED structure onto an Au–AuBe–Si mirror substrate (MS-LEDs) at low temperature (300 °C for a short time (about 20 min). However, it

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was found that to grow 2-μm Au or AuSn is expensive for productivity.[7−9] In this paper, we present a new method to glue AlGaInP–GaAs LEDs onto silicon substrates to form the AlGaInP–Si conductive glue agglutinated LEDs (SGA-LEDs). The optical, electrical, and thermal properties of such SGA-LEDs will be presented.

2. Experiment

AlGaInP MQW LEDs were first grown on GaAs substrate by the low pressure metal organic chemical vapour deposition (MOCVD) technique. The epitaxial structure obtained was as follows: GaAs substrate with 15° deflection from (100) to (110); 0.2-μm GaAs buffer layer used to reduce the lattice mismatch during growth; a 60-nm thick n–GaInP etching stop layer prepared for removing the GaAs substrate, the p-type and n-type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ upper and lower cladding layers doped with Mg and Si respectively, MQW active region made of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ without doping on purpose; and a 5-μm GaP current spreading layer grown above the upper cladding layer with the carrier concentration of about 10^{-19} cm^{-3}.

The transparent conductive glue was prepared to agglutinate AlGaInP epitaxial wafer and Si substrate, which was formed mainly by ITO (Indioumtin–oxide) powder, the bulk resistance being about 1×10^{-4} Ω/cm, and the agglutinate intensity larger than 10 MPa. This material is suitable for wafer bonding instead of 2-μm Au bonding layer. The process is as follows. First, cover the silicon substrate with a 300-nm Au layer as the mirror surface to reflect the light upside. In this experiment, we use the sputter method because it can produce a compact Au structure. And cover the GaP surface with an ITO current spreading and light transparency layer of about 300 nm in thickness. Secondly, we use the spin-on-glass (SOG) method to obtain the transparent conductive glue layer ready on top of a silicon substrate with a Au layer mirror for agglutination. The rotation speed of the spinner is kept at 5000 rpm so that we can achieve a uniform 800-nm coating layer. These two wafers are then agglutinated together by applying a uniform uniaxial pressure. The glue agglutinating process is performed at 200 °C for 5 h in the oven. Thirdly, the absorbing GaAs substrates are removed by grinding, the thickness removed being 200 μm. Then the samples are dipped in $2NH_4OH{:}15H_2O_2$ for 1 h. We use the selective etching method to put the stop layer in the solution $1HCl{:}2H_2O$ for about 5 s, thus the pink surface is exposed, which is the highly doped GaInP layer. Lastly, we start to fabricate the devices. A 300-nm ITO current spreading and anti-reflecting layer is coated on the n-GaInP side, the silicon substrate is subsequently lapped down to about 200 nm and the backside is polished for evaporation, then the Ohmic contact layer is subsequently evaporated separately onto the ITO layer and silicon substrate to serve as the n-type and p-type electrodes. For the n-type contact, we use AuGeNi as the electrode material, and for the p-type contact, we use AuZnAu as the electrode material. The annealing process is needed for Ohmic contacts to complete the fabrication of AlGaInP–Si LEDs (SGA-LEDs). The structure is shown in Fig. 1. Figure 2 shows the superfacial image of the SGA-LEDs. For comparison, conventional AlGaInP–GaAs LEDs (AS-LEDs) are also fabricated. The electroluminescent (EL) characteristics of these LEDs are then evaluated by injecting dc current. Room temperature current–voltage (I–V) measurements are performed by the LED620 semiconductor parameter analyser. Life tests of these LEDs are also performed.

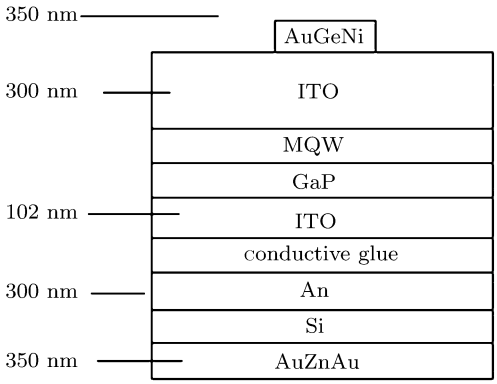


Fig. 1. Schematics of AlGaInP–Si glue agglutinated LEDs.

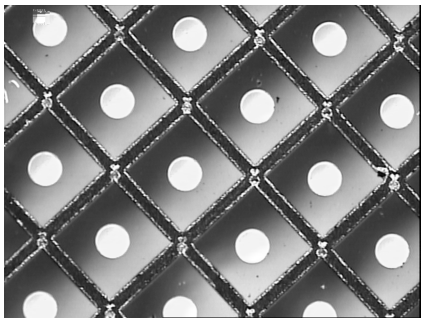


Fig. 2. An n-side image of SGA-LEDs chips.

3. Results and discussion

All the testing results of the 300 μm × 300 μm AlGaInP–silicon SGA-LEDs and AlGaInP–GaAs AS-LEDs are obtained under 20-mA injection current conditions. The peak wavelength of the two samples is located at about 635 nm. Figure 3 shows the I–V characteristics, in which it is found that both the turn-on voltage and the dynamic resistance of SGA-LEDs are larger than that of AS-LEDs. The operation voltages measured at 20 mA and 100 mA are 2.02 V and 2.60 V for the AS-LEDs, and 2.10 V and 2.7 V, respectively, for the SGA-LEDs. Compared with the AS-LEDs, the large turn-on voltage, dynamic resistance, and operation voltage of the SGA-LEDs are attributed to the dislocation and defect induced during the glue bonding process; and the exposed stop etching layer without high doping intensity could also increase the series resistance during the process of removing the absorbing GaAs substrate.

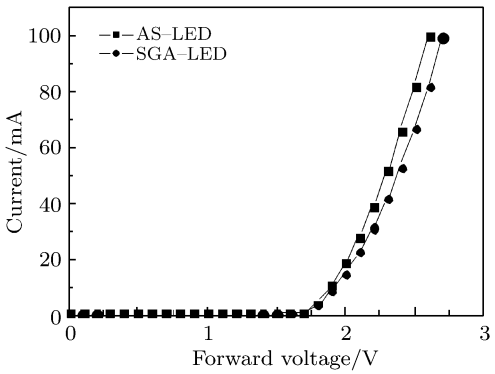


Fig. 3. The I–V characteristics of 635 nm SGA-LEDs and AS-LEDs.

Figure 4 shows the luminous intensity–current (L–I) characteristics of the two kinds of LEDs. The EL intensity will saturate at high current injection for both samples, i.e., 125 mA for SGA-LEDs and 105 mA for AS-LEDs. The main reason for this kind of phenomenon is that the Au-mirror reflector in the SGA-LEDs has high reflectivity, which would reflect the light emitting to the absorbing GaAs substrate, thus the light absorption is decreased and less heat is generated inside. It is found that the EL intensity is about the same for these two LEDs under low current injection, as shown in Fig. 4. However, the output intensity of the SGA-LEDs becomes larger than that of the AS-LEDs when the injected current is larger than 40 mA. It is also found that the output intensity will increase to a maximum, and then start to decrease with increasing injected current for both LEDs. Furthermore, the maximum output intensity occurred at the injected current of 125 mA and 105 mA for the SGA-LEDs and AS-LEDs, respectively. Accordingly, the output intensities are 1007.4 mcd and 266.2 mcd, respectively. The maximum output intensity of the SGA-LEDs is found to be about 3.78 times that of the AS-LEDs. These results indicate that the optical properties of AlGaInP–Si SGA-LEDs are good.

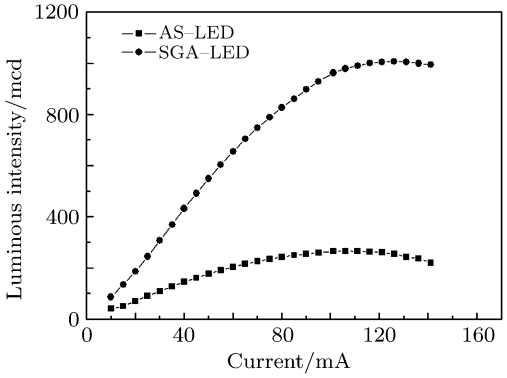


Fig. 4. The L–I characteristics of 635-nm SGA-LEDs and AS-LEDs.

The life test of the SGA-LEDs was also performed. During life testing, we injected 50-mA current into the SGA-LED at room temperature. The luminescence-output intensity variation as a function of time was then recorded, as shown in Fig. 5. The luminescence-output intensity variation is also found to have increased within 8% after 768 h, so we could achieve highly reliable AlGaInP–Si SGA-LEDs. The Au mirror reflector could increase the light efficiency effectively, with less heat generated inside at the same time, which can improve the LEDs' thermal properties.

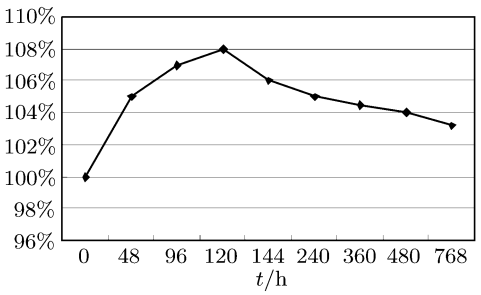


Fig. 5. Luminesence-output intensity variation as a function of time t.

As a result, we are able to achieve an even more significant improvement in AlGaInP–Si SGA-LED light-output intensity by combining glue bonding technology with flip-chip technology. Transparency and conductive glue bonding is a simpler method compared with that using a Au layer of about 2 μm in

thickness as the bonding material. Such SGA flip-chip AlGaInP LEDs are particularly suitable for high-power applications, which would work reliably under high injected current.

4. Summary

In summary, a new method is proposed to use transparency conductive glue instead of a 2-μm Au layer as the bonding material to bond GaAs based AlGaInP-LEDs onto silicon substrate. The experimental results have shown that AlGaInP–Si glue bonded LED devices have greater luminous intensity and saturation current than conventional LED devices at the same injected current. It is found that the luminescence output intensity of SGA-LEDs is increased by about 3.2% after working at 50 mA for 768 h, which is highly reliabe.

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