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Tunnel Junction AlGaInP Light Emitting Diode

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Abstract: The n-type GaAs substrates are used and their conductive type is changed to p-type by tunnel junction for AlGaInP light emitting diodes(TJ-LED), then n-type GaP layer is used as current spreading layer. Because resistivity of the n-type GaP is lower than that of p-type, the effect of current spreading layer is enhanced and the light extraction efficiency is increased by the n-type GaP current spreading layer. For TJ-LED with 3μm n-type GaP current spreading layer, experimental results show that compared with conventional LED with p-type GaP current spreading layer, light output power is increased for 50% at 20mA and for 66.7% at 100mA.

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1 Introduction

High-brightness visible light emitting diodes (LEDs) are becoming increasingly important and have numerous applications, such as in the field of optical display, traffic signal and automobile lamp[1,2] with different aluminum composition. The quaternary AlGaInP alloys, which can be precisely lattice-matched to GaAs substrate, have a direct bandgap ranged from 1.88 to 2.30eV[3]. Mass production of AlGaInP high-brightness LEDs has been realized by using multi-wafers metal organic-chemical vapor deposition (MOCVD) system. One problem of the AlGaInP LEDs is the restriction of light extraction efficiency caused by light absorption of top anode because current injection concentrates under anode. Many methods were considered to reduce the current injection under anode, such as thick current spreading layer[3], transparent anode[4] and reverse biased pn junction current blocking layer or native oxide AlAs current blocking layer[5,6]. But these methods lead to higher cost or make fabrication process more difficult. Another way is using n-type GaP or AlGaAs as current spreading layer with p-type GaAs substrate because n-type GaP or AlGaAs current spreading layer's conductivity is better than that of p-type. But p-type GaAs substrate has several disadvantages listed below.

(1) Doping level of low resistivity substrate is very high, for example: $1\times10^{19}cm^{-3}$. Conventional dopant is Zn, then diffusion of Zn during the epitaxy will destroy the heterostructure interface, especially for quantum well structure. Reducing its doping level will increase the serial resistance of device.

(2) Quality of commercial p-type GaAs substrate is not as good as n-type GaAs substrate.

(3) Price is higher than n-type substrate.

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Semiconductor tunnel junctions have been widely researched[7] and used in semiconductor devices[8,9]. In this article n^{++}-GaAs/p^{++}-GaAs tunnel junction was grown on n-GaAs substrate. Then p-type $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ can be used on the p^{++} GaAs layer for lower current confinement layer. So the original n-type GaAs substrate worked as p-type substrate. In sequence n-GaP current spreading layer could be used on the top of the p-i-n double heterojunction active layer to enhance the effect of current spreading. The tunnel junction was reversely biased and worked as a resistance when the p-i-n double heterojunction active layer was forwardly biased.

2 Structure of device

For the sake of comparing the difference between the effect of n-type current spreading layer and p-type current spreading layer, we use simple double heterojunction (DH) active layer and GaP current spreading layer with same thickness for both TJ-LED and conventional LED.

The schematic cross sectional structure of TJ-LED is shown in Fig. 1. The epilayers were grown by MOCVD on n-GaAs substrate. In sequence the

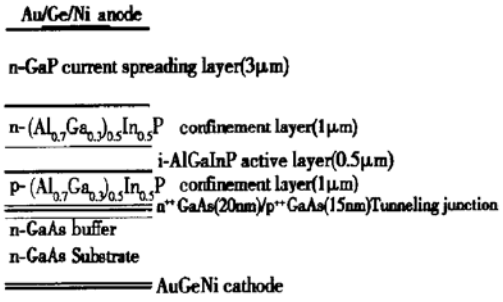

Fig. 1 Schematic structure of tunnel junction AlGaInP LED

device consists of 0.2μm n-GaAs buffer layer, n^{++} GaAs (20nm)/p^{++} GaAs (15nm) tunneling junction, DH structure with 1μm p-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ lower confinement layer, 0.5μm i-$(Al_xGa_{1-x})_{0.5}In_{0.5}P$ light emitting layer and 1μm n-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ upper confinement layer, and 3μm n-type GaP current spreading layer. The traditional LEDs were also fabricated with same DH structure and p-type GaP current spreading layer, but without tunnel junction.

3 Material growth and device fabrication

AlGaInP materials were grown on GaAs substrate with orientation (001) toward (111) A off 15° by AXITRON AIX 200 MOCVD system. TMGa, TMAl, and TMIn were used as group Ⅲ elements precursors. PH_3 and AsH_3 were used as group Ⅴ elements precursors. For AlGaInP material growth, the ratio of Ⅴ/Ⅲ was 100. DEZn and SiH_4 were used as dopants sources for p-type and n-type, respectively. The growth temperature of epilayer was 700~750℃. The total flow rate of hydrogen was 7 L/min.

For GaAs tunnel junction, Si was used as the n-type dopant with doping level reaching 5×10^{18} cm^{-3}, and C was used as p-type dopant with doping level of $1\times10^{20}cm^{-3}$. n-type GaP current spreading layers were doped with Si. The doping level reached $2\times10^{18}cm^{-3}$. p-type GaP current spreading layers were doped with Zn. The doping level reached $4\times10^{18}cm^{-3}$. The resistivities of GaP current spreading layers were 0.02Ω·cm and 0.05 Ω·cm for n-type and p-type respectively (Hall measurement results).

Au/Zn/Au was used as p-type contacts. Φ100μm round top anode was formed by lithography. AuGeNi was used as n-type contacts. The wafer was sawn to square dices of 300μm×300μm bounded on copper heat sinks for measurement.

4 Device properties and discussion

Light output power and operation voltage of the two kinds of LED were measured by HT semiconductor laser measurement system, which was calibrated at the visible light region. Figure 2 shows the results of measurement. The output

light power of TJ-LED reached 0.42mW at 20mA, which is increased for 50% more than that of LED without tunnel junction. And at 100mA the output light power of TJ-LED reached 2.0mW increased for 66.7%. It can be seen from Fig. 2 that the device saturation current with n-type GaP current spreading layer was increased. Because the injection current of LED with p-type current spreading layer will crowd under the top anode, the injection current will create more heat, and current crowding under anode increases the light emitting region carrier injection level which will cause more carriers leak from light emitting layer to confinement layer.

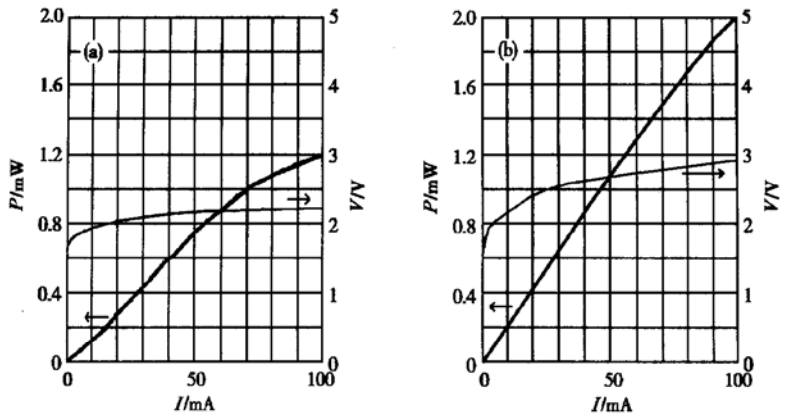

Fig. 2 Output power and operation voltage versus injection current of the AlGaInP 620nm LED without (a) and with tunnel junction(b)

Figure 2 also shows that the operating voltage of the TJ-LED is slightly higher than that of LED without tunnel junction at the same injection current. This is caused by two factors, the tunnel junction reverse operation voltage, and the n-type GaP ohmic contact resistance. Because n-type GaP doped with Si can not reach very high doping level, the top n-type ohmic contact resistance is larger than that of heavily doped p-type GaP ohmic contact. But the operating voltage of TJ-LED is around 2.4V at 20mA. This is acceptable for practical application.

5 Conclusion

Tunnel junction AlGaInP light emitting diodes (TJ-LED) with n-type GaAs substrate and n-type GaP current spreading layer were successfully fabricated. The effect of current spreading layer was enhanced and the light extraction efficiency was increased by n-type GaP current spreading layer. For TJ-LEDs with 3μm n-type GaP current spreading layer, experimental results show that the light output power was increased for 50% at 20mA and for 66.7% at 100mA of conventional LED with p-type GaP current spreading layer.

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隧道结 AlGaInP 发光二极管

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摘要: 报道了通过隧道结将衬底的导电类型从 n 型转变到 p 型, 从而可以利用 n 型 GaP 作为以 n 型 GaAs 为衬底的 AlGaInP 发光二极管的电流扩展层. n 型电流扩展层的电阻率低于 p 型电流扩展层的电阻率, 这种结构改善了电流扩展层的作用, 从而提高了发光二极管的光提取效率. 对 3μm GaP 电流扩展层的发光二极管, 实验结果表明, 隧道结发光二极管的发光功率与具有相同基本结构的传统发光二极管相比, 20mA 时发光功率提高了 50%, 100mA 时提高了 66.7%.

关键词: 隧道结; AlGaInP; 高亮度发光二极管; MOCVD

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