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Nitride-based flip-chip LEDs with transparent ohmic contacts and reflective mirrors

W. S. Chen[1], S. J. Chang[1], Y. K. Su[1], Y. C. Lin[1], C. S. Chang[1], T. K. Ke[1], C. F. Shen[1], and S. C. Shei[2]
[1]Institute of Microelectronics & Department of Electrical Engineering
National Cheng Kung University, Tainan, 70101, TAIWAN
Phone: +886-6-275-7575 ext.62391 Fax: +886-6-2761854 E-mail: q1892101@mail.ncku.edu.tw
[2] South Epitaxy Corporation, Hsin-Shi 744, TAIWAN

1. Introduction

In recent years, the research about III-V nitride-based materials has been done much more extensively and impressively. At RT, the band gap energy of AlInGaN, which varies from 0.8 to 6.2 eV, depends on element composition. Therefore, III–V nitride semiconductors are successfully developed for light-emitting diodes or laser diodes in shorter wavelength region [1]-[2]. There are some studies and literatures reported to improve the output intensity of nitride-based LED chips. Although the light emission efficiency is enlarged more and more, the chips have light loss problem all along. LEDs with flip-chip geometry provide an option to the conventional fabrication on the LEDs. The lights are emitted through the sapphire substrate rather than the epitaxial semiconductor layer. In other words, more photons should be able to escape from substrate for the flip-chip designs, as compared to conventional top-emitting LED chips.

2. Experiments

In this study, we select various metal materials with high work function to deposit onto p-GaN. Then flip-chip process is applied on the nitride based LED fabrication combined with large reflectance metal materials as the reflective mirror, such as Ag, Al, and Pt (LED-I, II, and III). The optical and electronic characteristics of these chips are researched and compared with conventional top-emitting LED chips with ITO and Ni/Au transparent contact layers (LED-IV and V).

3. Results And Discussion

The InGaN/GaN epitaxial layers used in this investigation are all grown by metalorganic chemical vapor deposition (MOCVD) on c-face 2” sapphire (Al_2O_3) (0001) substrates. Figure 1 shows the optical transparency as a function of wavelength for Ni, Pd, and Pt ohmic layer materials. We could see obviously the transparency of Ni (i.e. 92% at 470 nm) is much larger than those of Pd and Pt. In figure 2, it is shown that the electrical properties of Ni, Pd, and Pt on p-GaN. The specific contact resistances of Ni, Pd, and Pt on p-GaN are individually 7.9×10^{-4} Ωcm^2, 1.56×10^{-3} Ωcm^2, and 6×10^{-4} Ωcm^2. From the electrical and optical characteristics, Ni is the most suitable to serve as the transparent ohmic layer. Figure 3 shows the schematic diagram of nitride-based flip-chip designed LEDs with reflective mirror and transparent ohmic contact layer. Figure 4 (a) shows the photo of the entire flip-chip device with electroplating bumps. The picture in the figure 4 (b) overlooks the light-emitting side of the flip-chip device. In figure 5, it is shown that the reflection spectra of the reflective mirrors. It can be seen that Ag is the most highly reflective mirror material (i.e. about 92% reflectance at 465nm wavelength). Figure 6 depicts the measured I-V characteristics of these three reflective mirrors with Ni contact layer on p-GaN. It is found that we obtain the less current with Al reflective mirror. The reason is that there is Al metal permeating into Ni film to affect the ohmic contact properties. Figure 7 shows the I-V characteristics of the five chips measured. The 20mA forward voltages measured from LED-I, II, III, IV, and V are 3.15, 3.29, 3.18, 3.22, and 3.03 V, respectively. Figure 8 shows intensity-current (L-I) characteristics of these five different kinds of LED chips. The output powers of LED-I, II, and III can reach 16mW, 13.3mW, and 11.6mW. Significantly the flip chip with Ag reflective mirror possesses the highest output intensity and the wall-plug efficiency is about 25%. In figure 9, it is shown that intensity-current (L-I) characteristics is measured from 0 to 120 mA. We can observe there exist the better linear tendency with larger current injection (i.e. larger than 90 mA) for LED-I, II, and III. It is because the chips with flip-chip design own the better mechanism to flow heat. Figure 10 shows life tests of relative luminous intensity measured from the three chips (i.e. LED-I, IV, and V), normalized to their respective initial reading. After 1000 hours, it is found that the luminous intensity only decreases by 4.5% for LED-I. It is because most heat generated in the MQW active region can flow easily to Si sub-mount for the flip-chip LEDs.

4. Conclusions

These excellent opto-electrical properties of flip-chip LEDs allow the chip size scale down for the future package and substitute for the conventional light sources.

References

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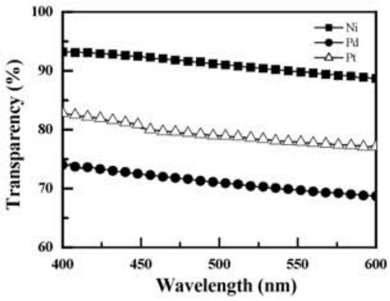

Fig. 1

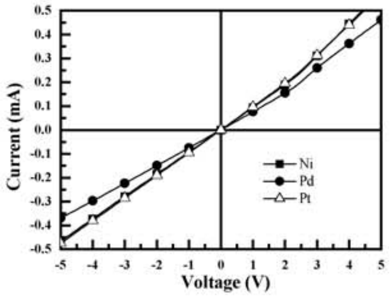

Fig. 2

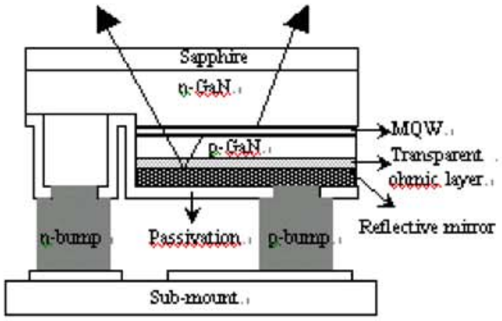

Fig. 3

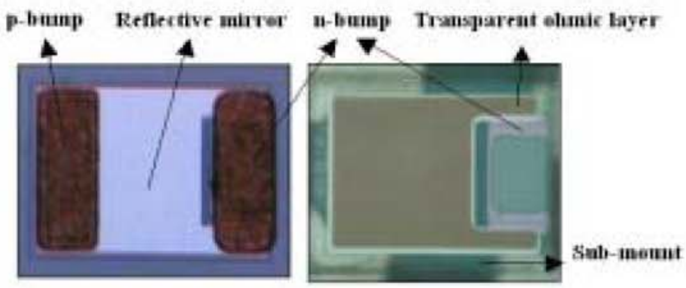

Fig. 4

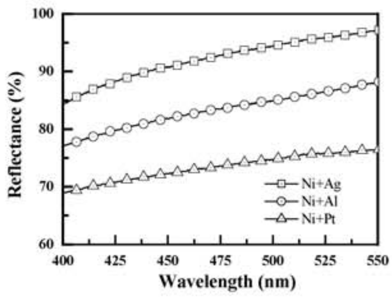

Fig. 5

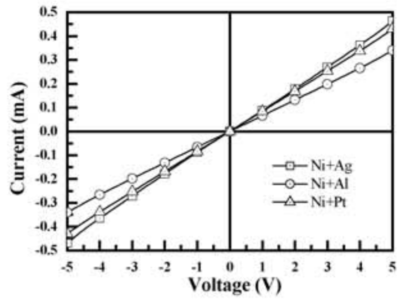

Fig. 6

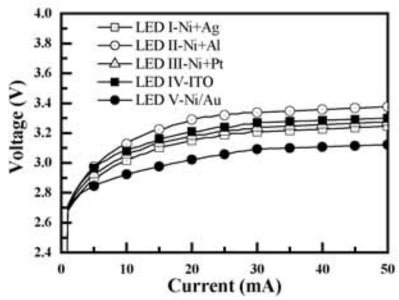

Fig. 7

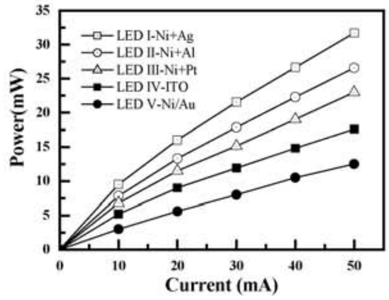

Fig. 8

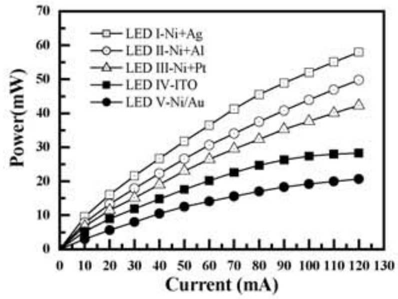

Fig. 9

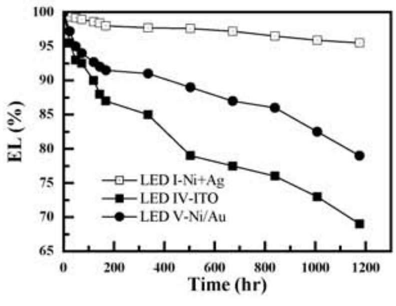

Fig. 10