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Comparison on characteristics of InGaN-LEDs on sapphire substrates and (-2 0 1) β-Ga_2O_3 substrate

Yen-Chun Chen[1], Shun-Ming Hung[1], Yi-Yun Yeh[1], Kuan-Jan Chen[1], and Yu-Pin Lan[1]

[1] National Chiao Tung University
College of Photonics
No.301, Gaofa 3rd Rd., Guiren Dist.
Tainan City 71150, Taiwan (R.O.C.)
Phone: +886-6-303-2121 E-mail: yplan@nctu.edu.tw

Abstract

To systemically compare the characteristics of a InGaN-LEDs on sapphire substrate and (-2 0 1) β-Ga_2O_3 substrate, which include photoluminescence spectrum, electroluminescence spectrum, and Light-Current-Voltage (LIV) curves.

1. Introduction

To date, the research on Light-emitting diodes has been well developed and led the development of technology in the light field into the era of full-color. In which, violet, blue, and green LEDs commonly use GaN-based multiple quantum wells (MQWs) combined with other elements such as indium, phosphor, and aluminum. Similar structures also can apply in vertical external cavity surface/semiconductor emitting laser (VECSEL) to realize short wavelength, good beam quality, high power laser [1]. However, no matter LED or VECSEL with UV, blue, and green light are mainly based on GaN materials, which hetero-epitaxially grown on sapphire, Si, SiC or homoepitaxially grown on GaN wafers. While sapphire is cheaper, the lattice mismatch between GaN and sapphire is approximate 14% and the difference of thermal expansion coefficients about 19% [2], On the other hand, Si and SiC are invisible in the ultraviolet (UV) region, and then GaN is a cost issue [3].

In the decade, Ga_2O_3, one of the transparent semiconducting oxides (TSO) [3], with large energy bandgap of 4.8eV-4.9eV [4]. A Ga_2O_3 has five different polymorphs, namely, α-, β-, γ-, δ-, and ε-phase, only β-Ga_2O_3 is the stable under any temperature and conditions [5], therefore, widely studied and utilized on β-Ga_2O_3. Thanks to the growth method development, low-cost and large single crystal β-Ga_2O_3 wafer can be mass produced by floating zone (FZ) growth [6] and/or edge-defined film fed growth (EFG) method [7]. A single crystal gallium oxide wafers become a potential candidate as a substrate for GaN-based devices owing to the lattice mismatch between β-Ga_2O_3 and GaN was found to be about 2.6-4.7% [8].

In this paper, we use commercially available 2-inch (-2 0 1) β-Ga_2O_3 wafer fabricated by the edge-defined film-fed growth (EFG) method with intentional Sn doping and also commercial 2-inch sapphire, both been treated with acetone, methanol and isopropanol solvent clean. Sequentially deposited u-GaN nuclear layer, then fabricated a LED structure consisted of n-GaN, InGaN-MQWs, and p-GaN. The characteristics of the two LEDs on a sapphire substrate and β-Ga_2O_3 substrate by measuring the photoluminescence spectrum, electroluminescence spectrum, and Light-Current-Voltage (LIV) curves were observation and analyzation.

2. Experiment

Fig. 1 is the structure diagram of the samples. Firstly, a wafer cleaning, the procedure follows two steps, which one was organic solvent cleaning process that is alternately using acetone and methanol several times in an ultrasonic oven, then use a deionized water stream cleaner clean. Next was acid cleaning process, which uses sulfuric acid-hydrogen peroxide mixture (SPM) composed of one-fold deionized water mixed one-fold 30% H_2O_2 and four-fold 96% H_2SO_4 for 5 minutes, final clean by deionized water stream cleaner. After then, the wafers have been put into the APMOCVD. During an epitaxial process, trimethylgallium (TMGa) and ammonia (NH_3) were employed as the reactant source materials for Ga and N, respectively. With the temperature of wafer raised to the temperature of 500°C, a GaN buffer layer of 25nm-thick deposition on a sapphire substrate in a carrier gas of hydrogen. Since Ga_2O_3 wafer can be easily etched with hydrogen[9], the GaN nuclear layer growth on β-Ga_2O_3 substrate in a nitrogen ambient. After then, sequentially deposited undoped GaN layer with 2μm-thick at 950°C (LT) and 2μm-thick undoped GaN layer at 1180°C (HT) on the GaN buffer layer. Final follow by fabricating a LED structure consisted of n-GaN, InGaN/GaN-MQW, p-GaN.

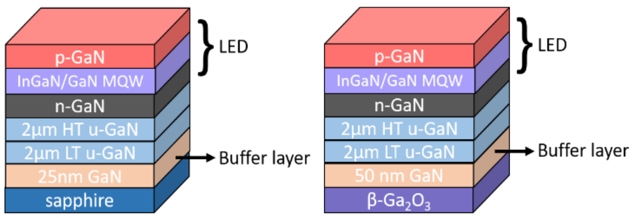

Fig. 1 The structure diagram of the samples, a GaN buffer layer, LT u-GaN layer, HT u-GaN layer, and LED structure sequentially deposited on a sapphire wafer (left) and β-Ga_2O_3 wafer (right).

3. Results and discussion

The photoluminescence (PL) measurement was carried out with a 355 nm Nd:YVO_4 pulse laser at a 1 kHz repetition rate and a pulse duration of 400ps, which could be regarded as a quasi-CW excitation for LED. The pumping laser spot size on the sample surface was about 60 μm in diameter at 60° incident angle. The light emission peaks of LEDs on sapphire substrate and β-Ga_2O_3 substrate were 390nm and 385nm, respectively, shown in Fig. 2(a). And Fig. 2(b) shows electroluminescence (EL) spectrum at an injection current of 20mA, the peak wavelength of LEDs on sapphire substrate and β-Ga_2O_3 substrate also revealed 390nm and 385nm, individually.

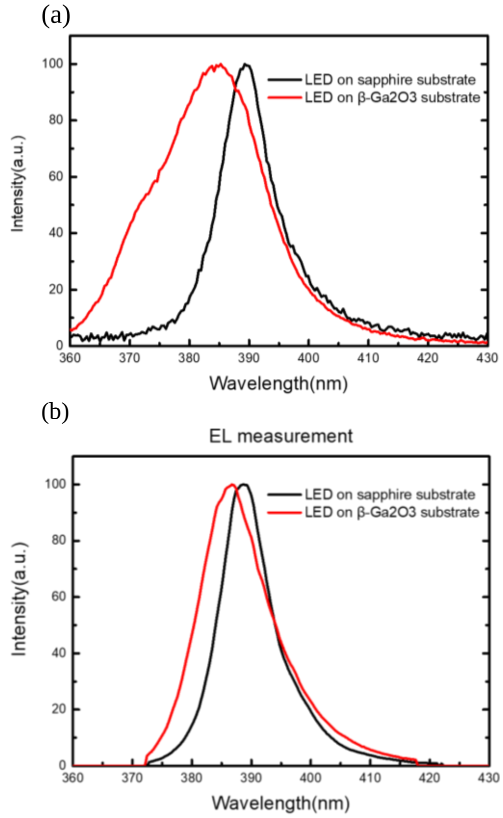

Fig. 2 (a) PL and (b) EL spectrum of LEDs on sapphire substrate and β-Ga2O3 substrate, respectively.

Figure 3 shows the characteristics of LEDs on the two wafers. I-V curve shows the turn on voltage of both samples was about 3V. With the injection current achieving 50mA, forward voltages were 6.8V and 4V for LED on sapphire substrate and β-Ga_2O_3 substrate, respectively. Competitive output power revealed between the two samples.

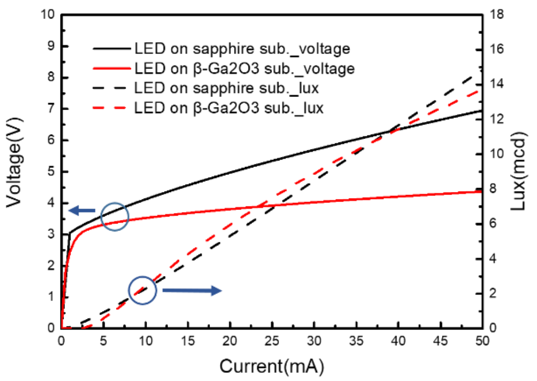

Fig. 3 L-I-V curve of the two LEDs, the black line is LED on sapphire substrate and the red line is one on β-Ga_2O_3 substrate. The solid line and dash line represent forward voltage and output intensity, respectively.

4. Conclusion

We have successfully fabricated InGaN-LED on a β-Ga_2O_3 substrate, in the meanwhile, a similar structure on a sapphire substrate to be as a reference. The results revealed the characteristics of LED deposited on the β-Ga_2O_3 substrates were competitive. Also, the I-V curve shows lower series resistance of LED on the β-Ga_2O_3 substrate than one on the sapphire. The β-Ga_2O_3 is not only for optical devices but also for high power devices. In the future, the studies of β-Ga_2O_3 definitely play an important role.

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