Role of silicon wafer on performance of UV-LEDs

Yunfei Niu, Zhihua Xiong, Cong Chen, Juanli Zhao, Ting Wang and Ning Wu

Key Laboratory for Optoelectronics and Communication of Jiangxi Province, Jiangxi Science & Technology Normal University, Nanchang, 330013 China

Abstract. Increasing the performance of ultraviolet light-emitting diodes (UV-LEDs) is a challenging research in actual industrial applications. We propose a new method of package by adding a silicon wafer between the chip and ceramic substrate. Through a gold wire connection, the UV-LED chip is paralleled to a high resistance silicon wafer equated to the Zener diode, which improves the antistatic ability of device. Compared to the without silicon wafer, the light output power of UV-LEDs with silicon wafer make a maximal enhancement of 5.9%, which is due to enhancement of the reflection of light of Pt metal layer on the silicon wafer. Moreover, the degradation of light output power in UV-LEDs with silicon wafer is considerably smaller than that of no silicon wafer under 540 hours of aging. This work provides a favorable way for the packaging designs of UV-LEDs.

1. Introduction

Ultraviolet light-emitting diodes (UV-LEDs) are excellent candidates to replace the traditional UV light sources for various applications due to higher energy efficiency, longer lifetime and environmental friendly [1-4]. However, the LED chip is very sensitive to damage in terms of electrostatic discharge (ESD), high temperature, moisture, chemical oxidation, shocking, and so on [5-8]. The high transient voltages produced by the ESD cause physical damage to the metal contact layer, the active layer and the superficies of LED. Generally such damage can engender leakage current paths, leading to a deterioration in the optical and electrical properties of the LED [9, 10]. Thus, effective and reliable package techniques are critical for protecting the LED chip from damage. Most conventional UV-LEDs are directly mounted onto ceramic substrate without any processing, or paralleled with a Zener diode on the chip to improve the antistatic properties of the device. However, this technique to increase antistatic ability will block the output of light to some extent.

Some researchers reported the improvement of the performance parameter in different LED device structures. Chang et al. [11] designed the GaN Schottky diodes inside the GaN green LEDs to increase the antistatic properties. Bouangeune et al. [12] fabricated the transient voltage suppressor diode and connected in parallel with the chip, which effectively improved the ESD strength of LEDs. Liang et al. [13] proposed a new packaging structure by introducing a thin encapsulation layer doped with 0.4 wt% AlN nanoparticles and uniform quartz lens simultaneously, which enhanced optical and thermal performance of UV-LEDs. Effective and reliable packaging techniques are critical for the excellent performance of the power UV-LEDs. However, few experimental studies on the reliability and optical property of UV-LEDs have been investigated, especially, for adding the silicon wafer directly in packaging design.

In this paper, a packaging method of the UV-LED with silicon wafer is investigated, and the effects of silicon wafer on the optical properties and antistatic reliability of devices have been studied in detail.
2. Experiments

For developing a UV-LED package with high performance, we choose a high resistive silicon wafer with size of 1.53mm×1.25mm×0.24mm. The Pt metal with thickness of 300nm is coated on the surface of polished high resistance silicon, which acts as the conductive layer. A 395nm vertical structure chip with size of 1mm×1mm is chosen to package the power UV-LEDs, and the silicon wafer is used to fabricate connecting layer between the chip and Al₂O₃ ceramic substrate. Figure 1 shows the schematic structure of the packaged UV-LEDs with specific electrical connections. The p-electrode of chip is bonded by silver paste on the Pt metal layer of silicon wafer, and the n-electrode of chip is connected with the negative electrode region of ceramic substrate by gold wire. The top layer of silicon wafer is connected with the positive electrode region of ceramic substrate through the gold wire, and the bottom layer of silicon wafer is bonded by silver paste on the negative electrode region of ceramic substrate. And a hemispherical lens is covered on the ceramic substrate and nitrogen is filled in the middle. Then the ceramic substrate is mounted on a hexagonal aluminum plate by solder paste welding on the heating stage. Figure 2 shows the top view of UV-LEDs device with and without silicon wafer using electron microscope.

![Figure 1. Schematic structure of the packaged UV-LED with silicon wafer.](image1)

![Figure 2. Top view of UV-LED devices (a) with and (b) without silicon wafer.](image2)

In order to validate the relationship of silicon wafer with the optical performance of UV-LED, photoelectricity measurements are performed. Five samples with and without silicon wafer were selected for testing, respectively. The light output power of the UV-LEDs is measured using the HAAS-2000 Photoelectric Analysis System manufactured by the Everfine Corporation with a 50-cm-diameter integrating sphere. The degradation of light output power in UV-LEDs is tested using the LED Aging Tester DJ5000 by the Everfine Corporation under aging condition of 700mA and 540 hours. When the aging time was up, the testing samples are removed from the aging tester and placed for 30 minutes, and then carried on photoelectric testing under the current of 350mA [14].

3. Results and Discussion

The testing values of the light output power in UV-LEDs with and without silicon wafer are shown in table 1. The maximum optical power of the UV-LEDs with silicon wafer is 545.67mW and the minimum optical power of the UV-LEDs without silicon wafer is 515.13mW. We can see that the UV-LED with silicon wafer make a maximal enhancement of 5.9% of the light output power at the working current of 350mA. And the average value of light output power are 541.64mW and 517.30mW for samples with and without silicon wafer, respectively, corresponding to an enhancement of 4.7% in the light output power of these two samples. It is found that the light output power increases with the existence of silicon wafer. We think that the increase in light output power is mainly due to enhancement of the reflection of light of Pt metal layer on the silicon wafer, and the similar phenomenon has also been reported by Qiu et al. [15].
The high resistive silicon wafer is introduced between the chip and ceramic substrate, which plays a great role in the packaging circuit. Through the proper electrical connection, the UV-LED chip is paralleled to the high resistance silicon wafer equivalent to a Zener diode, which improves the antistatic ability of chip. When the positive bias passes through the UV-LED, the forward resistance of chip is much smaller than that of the silicon wafer, which makes the UV-LED glow normally. Once the reverse bias passes through the UV-LED, the resistance of the silicon wafer is much smaller than the reverse resistance of the chip, which makes the current flow through the silicon wafer to prevent the chip from electrostatic breakdown. Thus, the existence of silicon wafer improves the reliability of UV-LED.

In order to check the reliability of adding silicon wafer, we test the degradation of light output power in UV-LEDs with and without silicon wafer as shown in figure 3. It is found that the degradation of light output power in UV-LEDs with silicon wafer is considerably smaller than that of no silicon wafer, which may be attributed to the release of stress from the silicon wafer between the chip and the ceramic substrate during a long aging condition. Thus, the UV-LED with silicon wafer exhibits better reliability.

So, we think the introduction of silicon wafer in the UV-LED improves the optical performance as well as the reliability of the device, and we believe that the packaging technique can also be applied to visible LEDs.
4. Conclusions
In summary, we designed and packaged a high performance UV-LED with silicon wafer. Due to the addition of silicon wafers, the light output power of the UV-LEDs could be increased by 5.9% at the current of 350mA compared with the one without silicon wafer. The light output power of UV-LED with silicon wafer has the smaller degradation than that of no silicon wafer. Moreover, the silicon wafer equivalent to Zener diode is paralleled to the chip, which improves the antistatic ability of device. The introduction of silicon wafer contributes to packaging design and finally improve the performance of UV-LEDs. It can be believed that these results would be helpful to understand the work mechanism of UV-LEDs with silicon wafer.

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