Semiconductor Nanorods for Micro–LED Down Conversion with Alleviated Temperature Effect

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Keywords: Quantum Rod, micro-LED, temperature effect, stability

ABSTRACT

The development prospect of high-resolution displays is very broad, especially micro-LED has attracted much attention. However, due to size effects and high temperature, the development has been bottlenecked in achieving full-color display. Compared with traditional quantum dots, thermal stable quantum rods with anisotropic shapes can effectively solve the problems of Light efficiency and long-term stability. In this paper, we attempt to study the thermal stability of micro-LEDs by testing the luminous intensity changes of red and green quantum rods at different temperatures. The results show that the luminous intensity attenuation of QR can be guaranteed to be about 10% within 130 ° C.

1 Introduction

The Light-Emitting Diode (LED) field in the 21st century is booming. Micro-LEDs technology is a possible replacement due to its excellent contrast ratio, response time, and energy efficiency[1]. However, the efficiency problem of micro-LEDs is being urgently discussed. The shrinking of the chip size leads to the passivation of the sidewalls of the device, the increase of non-radiative losses, and the decrease of external quantum efficiency (EQE)[2][9]. In addition, the red-light micro-LED based on AlGaInP also reduces its EQE due to the leakage of carriers caused by the temperature change [2]. On the other hand, due to the differences in Light extraction efficiency (LEE) and internal quantum efficiency (IQE) of green LEDs, the "green gap" problem also limits the development of solid-state lighting[4]. Down-conversion semiconductor quantum dots (QDs) and quantum rods (QRs) are possible solutions.

Relative intensity	Blue	Green	Red	QR@620nm CdSe/CdS/ZnS
90%	80℃	30℃	30℃	130℃
50%	80℃	-	60℃	180℃
Refs	[3]	[3]	[3]	This work

Table 1: Comparison of temperature stability of RGB micro-LED display reported in the commercial product and QR result[3]

As a new type of display material, QRs have greatly improved the efficiency and performance of backlight display technology due to their high coupling efficiency, color gamut, color purity, and unique polarized emission. Based on these advantages, previously, we have demonstrated photo-alignment nanorod enhancement film (NREF) for down-conversion of LCD backlight [5] and full-color photoluminescence color filters for flexible displays combined with perovskite nanoparticles [6]. We also showed QR on chip LEDs with efficacy up to 150 lm/W for LCD backlight [7 8]. However, the application of these technologies is challenged in terms of temperature stability. On the one hand, the backlight chip has temperature dependence on luminous efficiency, emission wavelength, and forward voltage.

On the other hand, thermal quenching can also increase the non-radiative relaxation process of quantum rods to affect the photoluminescence intensity due to changes in surface defects [8][9]. The actual temperature stability of the QR micro-LEDs after curing and encapsulation needs to be further studied. This article intends to study the effect of temperature on QRLEDs.

2 Experiment

We varied the temperature through a heating table and a temperature probe. The collected excitation light was integrated to obtain the luminescence intensity. And use a DC power supply to control the current and collect voltage data. To prevent multivariate influence, we first measure the PL intensity of QR at 30~200°C and peak wavelength. Then, the temperature dependence of the bare blue LED was verified under different currents of 0~10mA.

3 Results

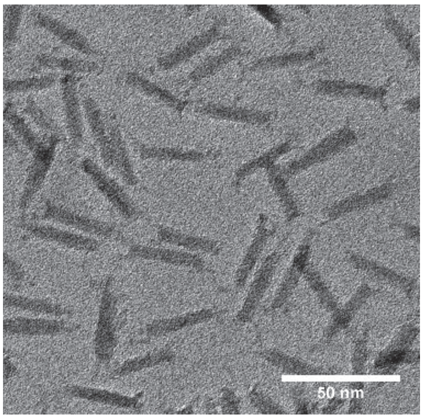

Fig. 1 Morphology of the CdSe/CdS/ZnS quantum rods

The red QR (CdSe/CdS/ZnS) in **Figure 1** was excited with a blue laser at 450 nm, and the relative results are shown in **Figure 2**.

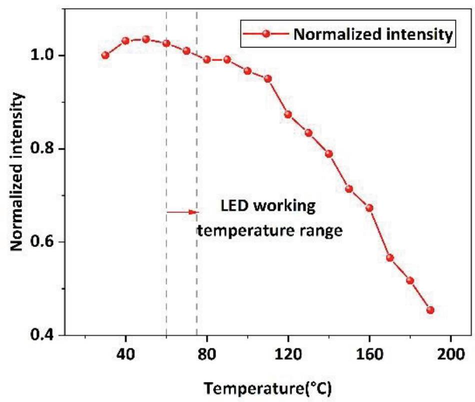

Fig. 2 Intensity ratio attenuation by temperature for the Red QR (led working temperature for 5000nits) [11]

The normalized intensity is applied here by calculating the ratio between real-time power and initial intensity. The intensity shows a bit increasing around 30 degrees due to the anti-quenching of the Quantum rod surface defect. And as the temperature keeps rising, the surface non-radiative relaxation centers are passivated. So, the intensity drop is slow. Until it reaches about 110 degrees, the suppression of the shell is no longer effective, and the material exhibits rapid thermal quenching[10]. It is worth mentioning that, for the micro-LED operating temperature (60~75°C) on the market today, our material can guarantee a luminous intensity ratio of more than 95%[11].

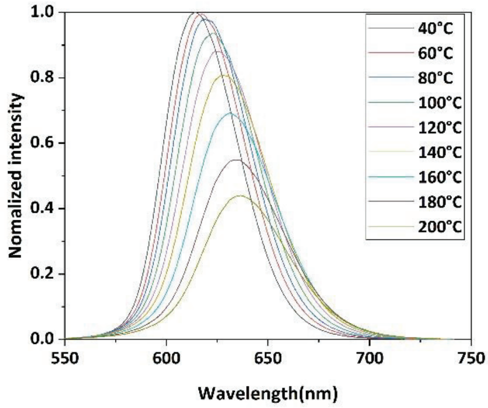

Fig. 3 Spectrum of the QR emission under different temperature conditions

As the spectrum is shown in **Figure 3**, the peak wavelength of PL is red-shifted due to the shrinkage of the semiconductor band gap during heating. And follow the Varshni empirical relationship:

$$E_g(T) = E_{g_0} - \alpha\frac{T^2}{T+\beta}$$

Where Eg_0 is the energy bandgap at 0K, α is the temperature coefficient, and β is the fitting parameter close to the Debye temperature[10].

When heating the energized blue LED, we analyzed the detected PL Intensity, and we found that the blue LED had about 20% attenuation at 40~50°C. Furthermore, by analyzing the switch-on voltage of blue LEDs, we get a linear relationship between voltage and temperature, which is shown in **Figure 4**

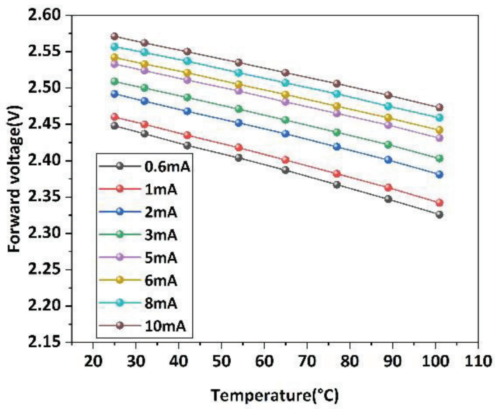

Fig. 4 Forward voltage for the Blue LED

The forward voltage V_f is in line with the conclusion of previous work:

$$\mathbf{V_f} = \frac{\mathbf{nkT}}{\mathbf{q}}\mathbf{ln}\left(\frac{\mathbf{I_f}}{\mathbf{I_0}}\right) + \mathbf{R_s I_f}$$

Where kT/q is the thermal voltage, I_f is the forward current, I_0 is the reverse saturation current, R_s is the series resistance, and n is the perfection parameter of the junction [12].

4 Conclusions

This paper aims to solve the present problems of the temperature stability of red micro-LEDs and the efficiency of green LEDs in the LED industry. Using quantum rods as color conversion materials to improve the temperature stability of LEDs, more than 90% relative light intensity can be guaranteed within 130°C. It is demonstrated that this material can be applied to high-resolution display technologies such as micro-LED displays.

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