Development of 230 nm Wavelength Far-Ultraviolet C Light-Emitting Diodes

波長 230nm far-UVC LED の開発

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Abstract

Although deep ultraviolet (UV) light with a wavelength of 265 to 280 nm has a high virus inactivation effect, there are concerns about its effect on the human body. UV light with a wavelength of 220 to 230 nm (far-UV C (UVC) light) is considered to be harmless to the human body, but it has not been put into practical use because its luminous efficiency is extremely inferior to that of light with a wavelength of 265 to 280 nm. In this research, we developed a 230 nm far-UVC light-emitting diode (LED) through joint research with RIKEN. In the fabricated 230 nm far-UVC LED, a single chip achieved a maximum light output power of 2.7 mW in pulse operation, a maximum light output power of 1.1 mW in continuous operation, and a maximum external quantum efficiency of 0.25%. We also created a panel equipped with 25 LEDs and confirmed that there were no problems with its operation.

波長 265nm～280nm の深紫外光は高いウイルス不活化効果がある反面，人体への影響が懸念される．波長 220nm～230nm の紫外光(far-UVC)は人体に無害とされているが，発光効率が波長 265nm～280nm の LED に比べて極端に劣ることから，実用化には至っていない．本研究では，理化学研究所との共同研究により，230nm far-UVC LED の開発を行った．作製した 230nm far-UVC LED において，チップ単体でパルス動作では最大 2.7mW，連続動作では最大 1.1mW，最高 EQE0.25%を達成した．また，LED を 25 個搭載したパネルを作製し，動作に問題が無い事が確認できた．

1. Introduction

Ultraviolet (UV) light is used for air purification and water purification because of its virus inactivation effect. However, the wavelength of the deep UV light that is generally used is 265 to 280 nm, which is considered harmful to the human body, and its use is limited to spaces in which no humans are present. Therefore, in recent years, UV light of 220 to 230 nm (far-UV C (UVC) light), which is considered harmless to the human body, has attracted attention.

The reason why UV light of 265 to 280 nm is considered harmful to the human body is that light of this wavelength is close to the absorption spectrum of DNA and can penetrate the skin and cornea. Conversely, 230 nm far-UVC light is mostly absorbed at the surface of the skin and cornea, so it is less likely to damage human cells. Additionally, because viruses are much smaller than human cells, 230 nm far-UVC light has an inactivating effect on viruses.

The excimer lamp produced by Ushio Inc., which takes advantage of the characteristics of these wavelengths, uses 222 nm far-UVC light. It is considered to be harmless to the human body and effective in inactivating viruses, has a track record of being used in public institutions, and is widely accepted around the world.

We wondered if it would be possible to develop a light source device that is even more compact and durable than excimer lamps by using light-emitting diodes (LEDs) as the light source. However, UVC LEDs have the problem that the luminous efficiency decreases as the wavelength decreases [1].

In this study, we developed a 230 nm LED in collaboration with the Hirayama Quantum Light Device Laboratory of RIKEN. LEDs with this wavelength were fabricated and their performance was investigated. In addition, we developed a device that can mount multiple LEDs to achieve high output power.

2. Experimental

2.1 Chip and panel fabrication

LED wafers were fabricated by forming AlGaN-based LED layers on sapphire substrates using the metal organic chemical vapor deposition method. Sapphire was chosen as the substrate because it is inexpensive and has better light out-coupling efficiency than AlN.

After forming p- and n-electrodes on the fabricated wafers, the wafers were stealth diced into 1.2 mm × 1.3 mm pieces. The p-electrodes were composed of Ni/Au, and the n-electrodes were composed of V/Al/Ti/Au. The individualized chips were mounted on a circuit board (3.45 mm × 3.45 mm pieces) with Cu electrodes and then sealed with microlenses (NGK).

Twenty-five LEDs (single LEDs) sealed with microlenses were mounted on a copper base and fixed on a heat sink with a cooling fan. The panel consisted of five LEDs connected in series and five rows of LEDs in parallel.

2.2 Performance check

The light output, spectrum, and radiation pattern of the single LED were measured, and the operation of the panel was verified. The light output was measured in pulsed (1 ms, 5% duty ratio) and continuous (CW) operation, and the light emitted from the LEDs was measured using a measuring instrument equipped with an integrating sphere. Both the instruments and power supplies were provided by RIKEN.

3. Results and Discussion

The measured optical output of the fabricated chip versus the current is shown in **Fig. 1**. The maximum external quantum efficiency (EQE) was 2.7 mW in pulsed operation (1 ms, 5% duty ratio) and 1.1 mW in continuous operation, and the highest EQE was 0.25%. There are few reports of LEDs that emit 230 nm light using inexpensive sapphire as the substrate, and this can be considered to be one of the leading-edge research results in this field.

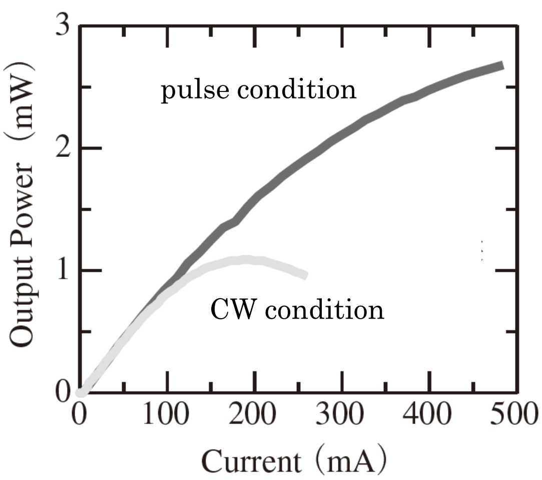

Fig. 1 Light output power versus current of the LED

The emission spectrum of the LED is shown in **Fig. 2**. Although the peak position varied depending on the current value, the main peak was at 232–234 nm, which was as expected. Although there was a sub-peak near 270 nm, the intensity was approximately 1/100 to 1/200 of that of the main peak. In addition, the main peak had a tail at approximately 260 nm. To suppress light on the long wavelength side (wavelengths of 240 to 280 nm), future challenges include shortening the wavelength, suppressing the half-value (steepening the peak), and developing filters that cut specific wavelengths.

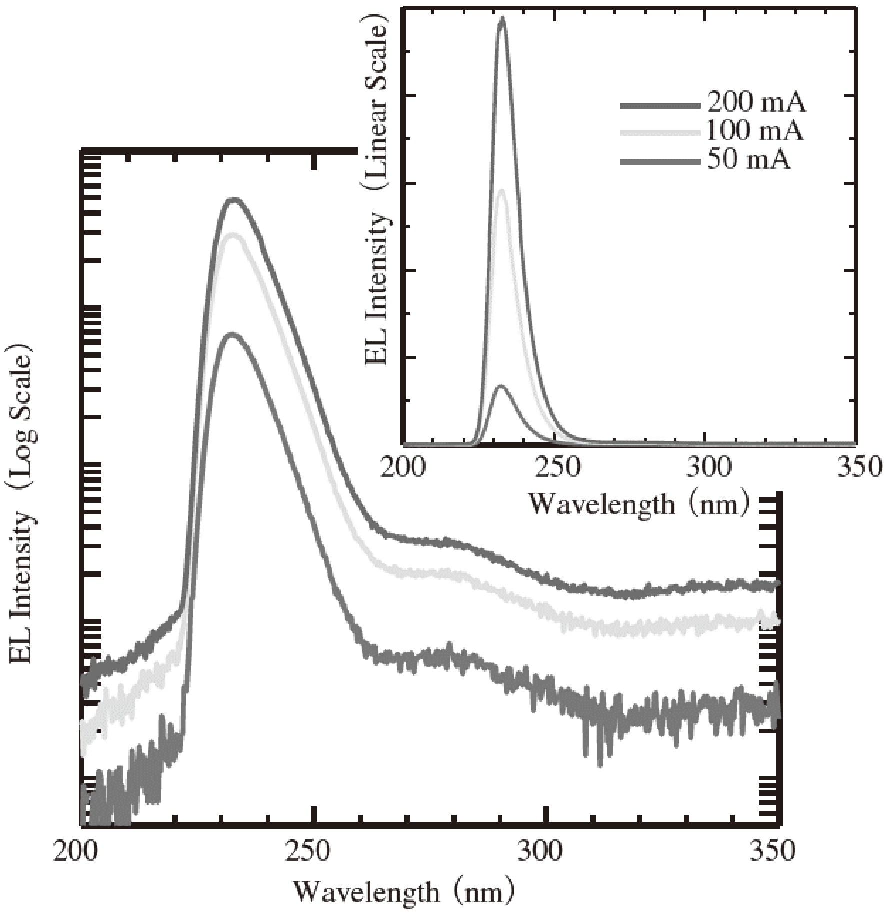

Fig. 2 Emission spectra of the LED at different currents

The radiation patterns of the chip with and without a lens are shown in **Fig. 3**. Without a lens, the directivity angle was approximately 140° to 160°. However, with a lens attached, the light was focused in front of the chip.

It was confirmed that the electrode pattern of the fabricated LED chip caused a tilt of the optical axis (although it is not shown in **Fig. 3**), and the issue is to improve the electrode pattern to improve the luminous efficiency.

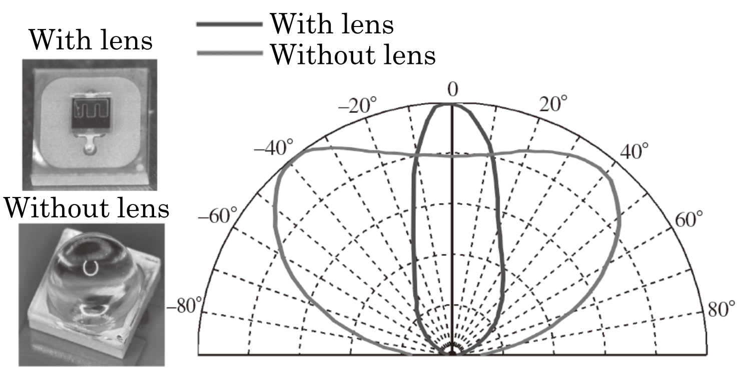

Fig. 3 Radiation patterns of the LED with and without a lens

Photographs of the panel equipped with 25 LEDs and the light-emitting condition are shown in **Fig.4**. By installing 25 LEDs in this panel, a maximum output of 2.7 mW × 25p = 68mW during pulse operation and 1.1 mW × 25p = 28 mW during CW operation can be expected. Although the accurate light output cannot be measured at present, it was confirmed that all of the installed LEDs emitted light, indicating that the device worked without any problems.

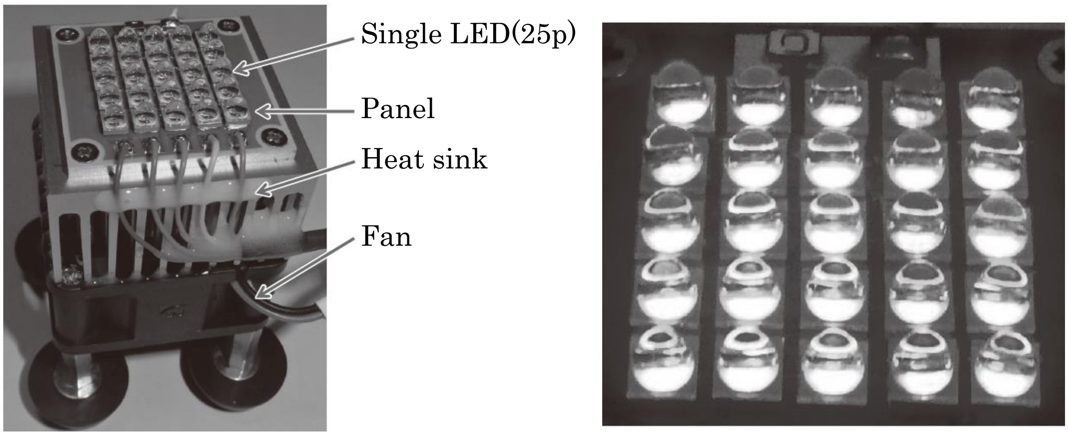

Fig. 4 Photographs of the panel (left) and light-emitting condition (right)

There are many issues to overcome before the reported 230 nm LED can be put into practical use. Among these issues, improving the external quantum efficiency is an important issue. It is thought that the decrease in the p-type and n-type concentration as the Al composition of the AlGaN light-emitting layer improves affects the deterioration of the characteristics.

To improve the hole conductivity on the p-side, we introduced a polarization-doped structure and attempted to improve the efficiency of the 230 nm LEDs. The polarization-doping effect generates a high concentration of holes simply by tilting the Al mixed crystal of AlGaN from a larger direction to a smaller direction. This feature means that by using an undoped compositionally graded layer, the same carrier generation as that in the case of impurity doping can be obtained.

By fabricating 230nm LEDs using this polarization-doping method and comparing the results obtained, it was confirmed that the EQE can be improved by approximately 10 times. We filed a patent application for these results, and the patent number 7291357 is registered in Japan [2].

4. Conclusions

In this study, we developed a LED that produces 230 nm far-UVC light, which has less effect on the human body than higher wavelength light. We fabricated a LED and evaluated its performance. The conclusions are as follows.

(1) The maximum optical output of the fabricated chip was 2.7 mW in pulsed operation and 1.1mW in continuous operation.

(2) The main peak of the fabricated LED was at 232–234 nm.

(3) A good light focusing effect was obtained by implementing microlenses.

(4) We created a panel equipped with 25 LEDs and confirmed that there were no problems with its operation.

References

[1] Hideki Hirayama et al. (2023). "Recent Progress of 230 nm AlGaN far-UVC LED on sapphire substrate" *OPTRONICS* , No.5, 1-8

[2] Hideki Hirayama et al. Ultraviolet light emitting device and electrical equipment with the ultraviolet light emitting device. JP patent 7291357. 2023-6-15.