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Development of 230-nm Wavelength Range UV-LEDs on Sputtered and Annealed AlN

Ultraviolet LEDs Enable Future "Sterilization and Disinfection Devices"

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Summary

- **Sputter-annealed aluminum nitride (AlN) enables low-cost, high-performance UV-LEDs with wavelengths from 260 nm to 280 nm that inactivate bacteria and viruses.**
- **UV-LEDs with wavelengths of 220–230 nm that do not cause damage to the human body have been realized.**
- **This fundamental technology is capable of becoming a future infrastructure for the sterilization and disinfection of society.**

A research group led by Kenjiro Uesugi of the Organization for Research Initiative and Promotion at Mie University have developed a UV-LED that generates far-UV light capable of inactivating bacteria and viruses. Employing a original method called "face-to-face annealed and sputter-deposited AlN (FFA Sp-AlN)," the group has realized a UV-LED with a wavelength of 260 nm to 280 nm that can inactivate bacteria and other viruses. In addition, a wavelength of 220–230 nm, which does not damage the human body, has been realized. This technology which operates on a power supply equivalent to that utilized in households is low-cost, enables non-contact sterilization and disinfection, and is truly the sterilization and disinfection device of the future.

Detail

Current Status and Issues of Glowing Sterilization and Disinfection

Since the pandemic of the COVID-19, a global crisis in public health, disinfection and sterilization have become a part of society's infrastructure worldwide. However, the existing disinfection methods rely significantly on liquid disinfectants. Liquid disinfectants have the disadvantages of being very large in volume, expensive to clean because disinfectants adhere to the area around the sprayer when used on the human body, and difficult to operate and manage from the standpoint of replacement costs.

A research group led by Kenjiro Uesugi of the Organization for Research Initiative and Promotion at Mie University has developed a UV-LED that generates far-UV light capable of inactivating bacteria and viruses. When ultraviolet light strikes bacterial DNA, a few DNA bonds are broken and the bacteria are unable to multiply. This is due to bacterial inactivation by ultraviolet light.

Mercury lamps have been utilized as UV light sources to inactivate bacteria and viruses. However, mercury lamps can only emit a fixed wavelength of 254 nm and the devices themselves are large (several centimeters to several tens of centimeters). In addition, they have the disadvantages of solely operating at high voltages, high costs, and high environmental impact.

LEDs that generate ultraviolet light with wavelengths in the 260–280 nm range have already been commercialized. However, commercially available UV-LEDs in this wavelength range have low output power and high device prices, which are barriers to their social implementation. Therefore, we developed a highly functional and inexpensive UV LED utilizing our proprietary thin-film crystal growth technology, stated Uesugi.

High temperature annealing at 1700 °C eliminates crystal defects

Uesugi and his research group focused on "threading dislocations," defects that exist in semiconductor crystals. Nitride semiconductors which make up LEDs have high output power and efficiency when there are few threading dislocations and the atoms are arranged neatly. Therefore, the fewer the number of threading dislocations, the more efficient the conversion of power into ultraviolet light.

In semiconductor manufacturing, thin films of crystals for n-type, light-emitting, and p-type layers are grown on a crystal substrate (wafer) using "thin-film crystal growth technology," and semiconductor chips are fabricated by cutting the substrate. In this process, an aluminum nitride (AlN) freestanding substrate with fewer defects is known to reduce threading dislocations, which are defects in semiconductors, and improve the performance. Utilizing freestanding aluminum nitride (AlN) substrates can achieve a high performance. However, a single 2-inch substrate alone costs several thousand dollars; thus, cost reduction cannot be achieved.

A way to reduce costs is to utilize inexpensive industrial sapphire substrates. The price of the substrate can be reduced to approximately one-hundredth that of a freestanding aluminum nitride (AlN) substrate. However, when sapphire substrates are used, aluminum nitride (AlN) templates have to be stacked on top of the sapphire substrate. The disadvantage of stacking materials with different crystal structures is that an extremely significant number of crystal defects are generated, which reduces the performance of the LEDs and makes it impossible to achieve high functionality.

The method proposed by Uesugi and his research group is “face-to-face annealed and sputter-deposited AlN (FFA Sp-AlN),” which offers both low cost and high performance. The research group employed the sputtering method as the deposition technology. Sputtering is a film deposition technology employed in the fabrication of large-area displays. However, semiconductor crystal fabricated by sputtering results in far more crystal defects than those prepared by common metalorganic vapor phase epitaxy method. We then annealed (heat-treated) the films at a high temperature of 1,700 °C after deposition. Consequently, the crystal defects that occurred during deposition by the sputtering method were eliminated, and a high-performance thin film was created."

Normally, exposure to temperatures as high as 1,700 °C would cause thermal decomposition and damage to the sapphire substrate and thin film of aluminum nitride (AlN); however, the research group has established a method that can eliminate only crystal defects without causing thermal decomposition using a unique “face-to-face” arrangement of two substrates facing each other. FFA Sp-AlN can reduce crystal defects even in thin films that are far thinner than those produced by the general metalorganic vapor phase epitaxy method. The advantage of using FFA Sp-AlN is that thin films with fewer crystal defects can be fabricated (Figure 1).

Toward the Disinfection Devices of the Future

The UV LEDs (Figure 2) realized by the research group using FFA Sp-AlN can be operated with a power supply equivalent to that utilized in households. They are hygienic because they enable non-contact sterilization and disinfection, far less expensive than conventional mercury lamps, and environmentally friendly.

Because of these characteristics, their application areas are wide. For example, irradiation of food can delay spoilage. This approach can provide a solution to the issue of food loss in several developed countries. It can also be employed to build water purification systems in developing countries that face challenges in procuring clean drinking water. A research group is currently focusing on UV LEDs to achieve a wavelength of 220–230 nm that does not cause damage to the human body. The advantage of being harmless even when directly irradiated on humans, further expands the range of applications. It is truly the disinfection and sterilization device of the future.

Compared with conventional aluminum nitride (AlN) freestanding substrates, sapphire substrates and FFA Sp-AlN can reduce costs by approximately one-tenth. In the future, we will expand our technologies to manufacturers that replace mercury lamps with UV LEDs and develop high-value-added sterilization and disinfection equipment.

Annotation

※ **Metalorganic vapor phase epitaxy (MOVPE)**: A commonly employed crystal growth method for fabricating compound semiconductors. It utilizes mixed gases containing organometallic materials as raw materials, and is a key technology for the mass production of optical devices.

Figures

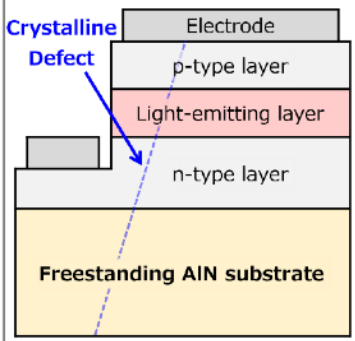
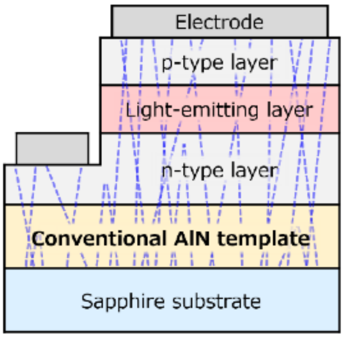
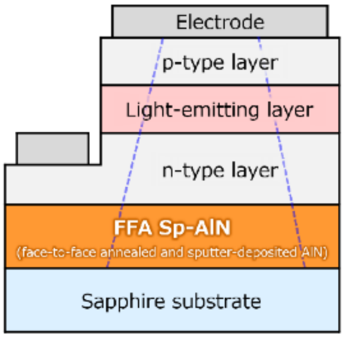
	Commercially available UV-LED (on freestanding AlN substrate)	Commercially available UV-LED (on sapphire substrate)	Original technology of Mie University
Cross-sectional schematics of UV-LEDs	 	 	
Performance	✓ High	✗ Low (High dislocation density)	✓ High
Price	✗ High (Expensive AlN substrate)	Neutral (Complicate fabrication process)	✓ Low

Figure 1 Comparison between existing UV-LEDs and this study

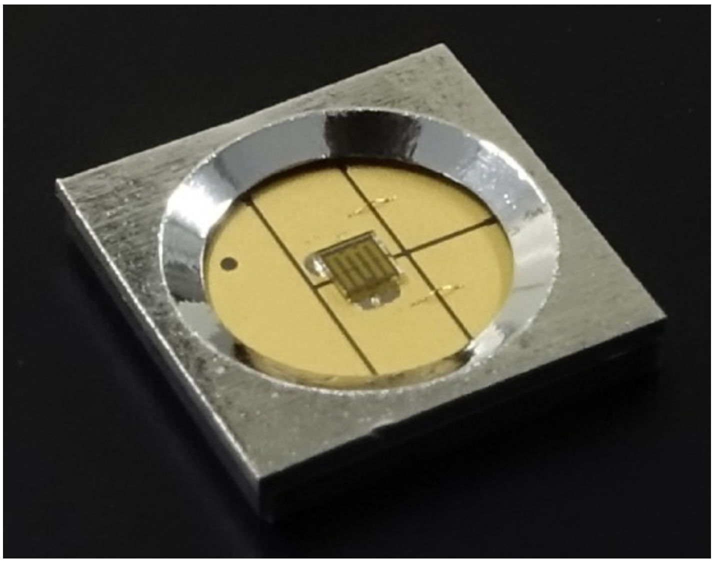


Figure 2 Prototype UV-LED