Upping the efficiency of ultraviolet LEDs

Substrate thinning, device encapsulation and the introduction of gold interconnects takes single-chip ultraviolet LED performance to a new level

A PARTNERSHIP between engineers at Crystal IS and the US Army Research Laboratory claims that it has set a new benchmark for the performance of LEDs operating in the UVC range, which spans 100 nm to 280 nm.

"67 milliwatts at 300 milliamps and a wall-plug efficiency of 2.5 percent is the best-reported value for a single-chip LED shorter than 280 nm operated in continuous-wave," explains corresponding author James Grandusky from Crystal IS.

This advance in LED performance, which stems from improved extraction efficiency and better thermal management, will help to increase the success of this solid-state device in the ultraviolet lamp market. These chips are already being used in niche applications that do not require high output powers, and thanks to the work of the US team, they will soon be able to start competing with more powerful mercury lamps used for many different tasks.

Recent improvements to the extraction efficiency of the team's ultraviolet LEDs resulted from a combination of a substantial thinning of the substrate and the encapsulation of the device in a transparent, robust material. These modifications are claimed to propel extraction efficiency to about 15 percent – the on-wafer value is less than 3 percent.

The team fabricated its 271 nm LEDs on AlN substrates. These are often assumed to be transparent, due to their bandgap of 6.1 eV, which equates to 205 nm. However, AlN substrates feature point defects that cause absorption in the mid-ultraviolet – for a typical Crystal IS substrate the absorption coefficient is 35 cm^{-1}. This means that if an ultraviolet LED emitting at around 270 nm were fabricated on AlN that is 200 μm-thick, about half the light generated by this device would be absorbed before it reaches the substrate's surface.

One way to reduce these losses is to reduce the densities of the point defects. According to Grandusky, this should be possible, but he admits that completely removing them is probably impossible.

So the team has instead thinned its substrates, reducing them from 425 μm to just 20 μm, a step that cuts the single-pass absorption loss to less than 10 percent.

"The thinning process is straightforward, and uses similar processes to those that are used when preparing AlN substrates from boules," says Grandusky.

Encapsulated 271 nm LEDs with a chips size of 0.82 mm by 0.82 mm can lead to a continuous-wave output in excess of 60 mW

Encapsulating the device in a transparent material that has a refractive index of 1.4 also boosts light extraction, due to a reduction in refractive index contrast.

Preliminary accelerated reliability testing of the encapsulant, which is shaped as a hemisphere to aid efficient light extraction, suggests that if it were used in a 100 mW device for 5000 hours, it would show just a negligible change in transmission characteristics.

The team has enhanced the thermal management of its ultraviolet LEDs by switching from a Au/Sn eutectic alloy to a gold-to-gold interconnect process.

Devices can span the 250-280 nm range, thanks to the use of pseudomorphic growth. The 271 nm LED, which has a chip size of 0.82 mm by 0.82 mm, produced 5.3 mW, 26.2 mW and 66.8 mW at drive currents and forward voltages of 20 mA and 6.7 V, 100 mA and 8.0 V and 300 mA and 9.0 V, respectively.

External quantum efficiency of the LED is relatively constant, falling from 5.8 percent at 60 mA to 4.9 percent at 300 mA, the maximum operating current. This behaviour is very similar to previous results from pulse-driven ultraviolet LEDs, indicating that thermal droop is not a major contributing factor to the decline in efficiency with increasing drive current.

The team claims that another attribute of its UV LED is its low thermal derating – this means that it produces a small reduction in output power and efficiency with increasing junction temperature.

"A lower thermal derating allows for operation at higher temperatures without significantly lowering the output power from the device," explains Grandusky. "This also allows for operation at high input powers without significantly decreasing the efficiency of the device."

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