

Light-emitting diodes reach the far ultraviolet

In November 1962, Robert Hall and his team from General Electric reported an infrared-emitting diode made from gallium arsenide. One month later, Nick Holonyak and Sam Bevacqua, also of GE, reported a red light-emitting diode made from GaAs alloyed with phosphorus. And so began the quest to widen the application of LEDs by shortening their wavelengths.

The record now stands at 210 nm. Yoshitaka Taniyasu of NTT in Atsugi, Japan, has made the first LED that emits in the far UV. Based on aluminum nitride, the NTT LED is about a million times dimmer than its commercial, longer-wavelength counterparts. But if its output could be improved, the device could serve as a compact germicide or photolyser of harmful chemicals.

LEDs are simple devices. In essence, two slabs of semiconductor, one p-doped, the other n-doped, abut each other. Applying voltage across the slabs, from p to n, drives the extra electrons from the conduction band of the n-doped slab to fill holes in the p-doped slab. If the electrons can cross the bandgap without having to gain or shed momentum—that is, if the conduction band's minimum and the valence band's maximum line up in momentum space—each recombination yields a photon whose energy matches the bandgap.

Such "direct" bandgaps make for efficient LEDs, but they are the exception rather than the rule among semiconductors. Indeed, nearly all LEDs—from GE's IR archetype, through Shuji Nakamura's pioneering blue LED of 1994, to NTT's new UV device—are based on compounds of elements from groups III and V of the periodic table.

Short wavelengths come from wide bandgaps; wide bandgaps come from tight binding; tight binding comes from small atoms. Unfortunately, the wider the bandgap, the more insulating the material. Aluminum nitride barely conducts. Doping, which is necessary for an LED to work, boosts conductivity, but becomes less effective as the bandgap widens: The donated electrons or holes tend to lie inside the gap not outside it. Offsetting that effect by raising the doping ends up lowering electron mobility. And one usually has little freedom to choose the dopants. For AlN, it's silicon for n-type and magnesium for p-type.

And there's another problem with AlN. LEDs are built up in layers by wafting hot gases over a substrate. For optical LEDs, sapphire and silicon carbide are favored substrates because their lattices are roughly commensurate with III-V lattices: The closer the match, the lower the density of defects that promote non-radiative transitions and reduce efficiency. Unfortunately, tightly bound AlN fits poorly on the more spacious sapphire and SiC.

How did Taniyasu coax light out of AlN? To combat defects, he developed a new, high-temperature, high-purity deposition technique. At 10^8 defects per cm^2 , the defect density is still high, but Taniyasu believes it can be reduced further.

Reducing defects also helped mitigate the doping problem. Taniyasu found that the higher the AlN purity, the easier it became to determine and set the optimum doping level: enough to promote recombination, but not enough to choke mobility.

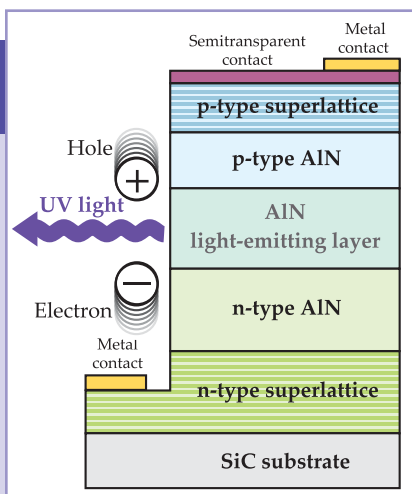
Device architecture also boosts performance. As the accompanying figure shows, the NTT device, like other optical LEDs, is multilayered. The superlattices—nanometer-thick alternating layers of AlN and AlGaIn—promote conduction between the metal electrodes and the active layers. The layer of undoped AlN at the center serves as the recombination site.

Before the NTT LED, the previous wavelength record was held by AlGaIn, which emits at 250 nm. Now commercially available, AlGaIn LEDs typically put out 200 microwatts. Whether NTT's AlN device meets commercial success isn't clear, but, with just boron nitride left, it could well represent the end of the wavelength line for III-V LEDs.

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Reference

1. Y. Taniyasu, M. Kasu, T. Makimoto, *Nature* **441**, 325 (2006).



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