More Powerful than Ever
New Chip Technology Opens New Industrial Applications for UVC LEDs

Industrial use of UV radiation requires powerful artificial sources. About 20 years ago, the introduction of UV LED technology presented an alternative solution to high-pressure mercury vapor lamps, which had been the main source for almost a century. With their many obvious advantages, they soon led to new applications – most of them in the low-power sector. Innovations in chip technology now allow for a new generation of high-power UVC diodes.

Picture 1: UV LEDs open up many new industrial application possibilities. (© LASER COMPONENTS)

The ultraviolet spectrum is characterized by its short wavelength and the relatively high energy of its photons. Thanks to the latter, UV is able to trigger chemical reactions such as fluorescence or ionization. Many practical applications are based on its interaction with organic molecules. Since the most energetic parts of the UV spectrum are absorbed by the ozone layer of our atmosphere, all these applications rely on artificial sources. For a long time, mercury vapor lamps were the only feasible emitters, but they are bulky, fragile, and need up to ten minutes to reach their peak performance. Therefore, users have always been looking for more practical solutions, which arrived at the turn of the millennium with the introduction of the first UV LEDs.

New achievements in UVC emission

Their small form factor, low consumption, and uncomplicated power supply allow for perfect design adaptation, robustness, and easy handling. But semiconductor technology can do much more: By eliminating the use of mercury, toxicity is reduced to zero. The narrow-band peak of the LEDs enables well-defined use of specific UV wavelengths. While lamps take several minutes to warm up, UV LEDs are ready for use the instant they are switched "on" and produce significantly less heat.

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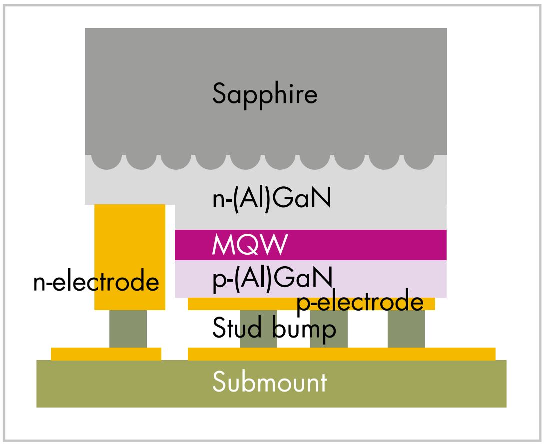
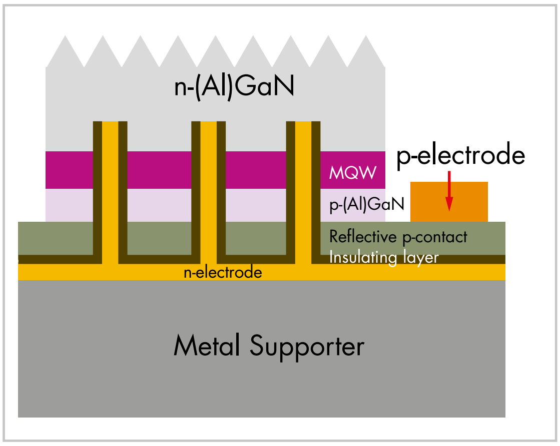
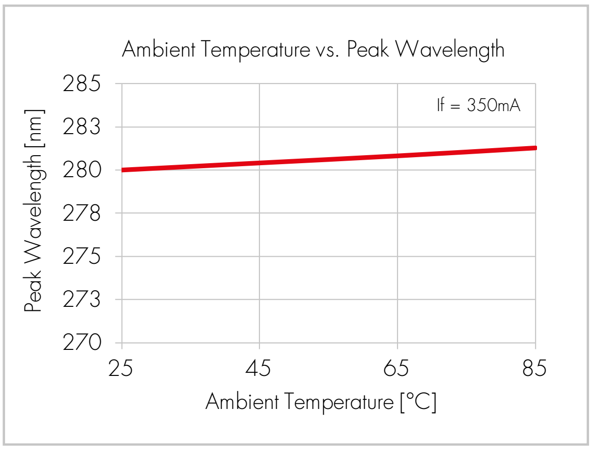




Pictures 2/3: Compared to the FlipChip design (see Picture 2), the solution by LG Innotek (see Picture 3) offers better heat dissipation and increased light output. (© LG Innotek / LASER COMPONENTS)

In the UVA and UVB bands, manufacturers are able to provide diodes with power levels that match lamps. To date, powerful UVC wavelengths have presented the largest challenge, especially where thermal management of LEDs is concerned. The main problem is their particularly low external quantum efficiency (EQE) – signifying the relationship between light output and power input. Generally, it can be stated that the EQE drops drastically with shorter wavelengths, particularly in the UV spectrum. While UVA light (365 nm ~ 400 nm) can be created at a rate of efficiency of 40%, the EQE in the UVC region (≤ 300 nm) is just 5% or less. The remaining power is converted into heat, which can cause considerable damage to the LED chip. Therefore, the main issue is to dissipate the excess heat and keep the LED chip at its optimum operational temperature.

In November of 2017, LG Innotek announced a major breakthrough: By applying the epitaxial structure and vertical chip technology, they managed to maximize light extraction and increase the ultraviolet output, while at the same time ensuring efficient heat discharge. The new chip structure allows for uniform current spreading, increasing the internal quantum efficiency and – as a consequence – the overall EQE. It also provides a greater light-emitting surface, resulting in increased light output (see Picture 3). Thanks to these improvements, they were able to introduce a single-chip UVC LED (278 nm) with an output power of 100 mW. This important landmark will not only allow for new applications but also encourage further research and increase the innovative momentum in the industry.



Picture 4: The peak wavelength is hardly affected by the ambient temperature. (© LG Innotek)

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Table1: Performance of UV LED and UV lamps

	UV LED		Mercury Vapor Lamp
	UVC / UVB	UVA	
Size	Up to 1 cm^2		Up to 1 m
Toxicity	None		Mercury
Spectrum	Single peak clearly defined wavelength		Several peaks induced by mercury and additional substances
Lifespan	Depends on wavelength; up to 20,000 h so far	Up to 50,000 h, soon up to 100,000 h	1,000-20,000 h; average: 2,000 h
Heat generation	Low		High
Heat dissipation	Heat sink on the back of the device		Homogenously across the entire surface
Heating period	None		Up to 10 min
Efficiency (Pout / Pin, %)	A few %	Up to 40%	10%-45%
Robustness	Shock-resistant		Fragile glass construction
Design	Flexible and adaptable		Long tube
Maintenance cost	Low, thanks to long lifespan, low power consumption and favorable packaging		High, due to short lifespan

Table 1 provides a detailed comparison of UV LEDs and mercury vapor lamps.

It sticks like glue – thanks to UV curing

Curing is one of the most widespread industrial applications of UV light. It is used in a wide range of industries such as smartphone production, printing, and airplane cabin production. The entire process is based on the ability of UV radiation to trigger chemical processes. In this case, an effect called polymerization is used to transform chemical compounds such as glue or paint from a liquid to a solid state: When in its liquid state, the glue is composed of monomers. These organic compounds can be considered the building blocks of the final polymeric structure. To enable photolysis, the substance also contains photoinitiator molecules, which are non-reactive when not exposed to certain wavelengths. Under the influence of UV radiation, these photoinitiators are separated into two or more free radicals, which initiate chemical reactions in the monomer molecules, causing them to form chains. The resulting polymer chains are linked in a tightly-meshed, solid polymer web (see Picture 5).

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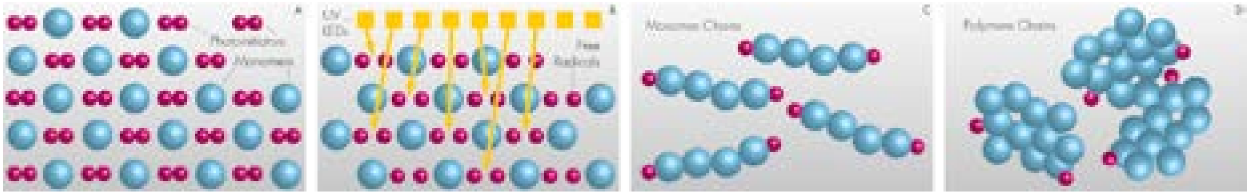

Picture 5: Photopolymerization: A) Monomers and inactive photoinitiators. B) UV radiation splits the initiators into free radicals, which C) cause monomers to form chains. D) Result: tightly-meshed polymer structures. (© LASER COMPONENTS)

Compared to other materials, UV-curable glues are highly stable and have a gap-filling capability, as well as a short curing time and chemical resistance. The best-known application for photopolymerization is the production of smartphone displays. As displays became larger and phones thinner, the pressure distribution on the touchscreen became increasingly difficult. Manufacturers came up with a new production process called full bonding, in which glass, touchscreens, and LCD displays are fully attached to each other under cleanroom conditions. The result was an ultra-thin touchscreen display that is extremely resilient to environmental conditions such as humid or dusty surroundings.

One of the most recent innovations based on photopolymerization is a new 3D printing method called continuous liquid interface production (CLIP). Compared to other conventional layering techniques, models are formed in one piece and the process is 25 to 100 times faster. The bottom of the resin tank is made of a light and air-permeable material that allows the creation of an oxygen zone on the lowest layer. The "printed" object is continuously pulled out of the tank, while photopolymerization of the liquid resin is controlled by tuning UV light (curing) and oxygen (prevents curing), respectively. The whole concept of this technology is based on easy tunability of the UV source, as it is provided by LEDs, which can easily be tuned by increasing or decreasing power supply.

For technical reasons, most of these applications use UVA light; however, in the future, short-waved UVC diodes will probably add new functionalities and increase industrial usability of UV curing systems. The light emitted by the mercury lamps covers a large portion of the electromagnetic spectrum with certain performance in the UV area. UV LEDs are relatively monochromatic. Their distinct wavelengths penetrate deep into the material and result in homogenous curing. UVA wavelengths match those of the photoinitiators, while shorter wavelengths are necessary to develop hard, scratch-resistant surfaces. Sometimes, UV LEDs even cause these materials to develop a yellow tint. With more powerful UVC LEDs, these problems would be a thing of the past.

Keeping the air clean with UV light

Industrial production has many advantages; however, pollution certainly is not one of them. To keep threats to the environment low without cutting back on productivity, companies are obliged to monitor hazardous gases such as sulfur and nitrogen oxides. Depending on their objectives, several methods of detection are employed. In many cases, UV light with its high photonic energy is preferred to the IR and visible spectra.

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Absorption photometry is one of the most common methods of gas detection. When chemical compounds react with electromagnetic radiation, molecules absorb the energy of the light at specific wavelengths. By scanning the absorption spectrum of a gas or fluid, absorption photometers are able to determine the nature and concentration of its components. When looking for specific compounds, samples are only exposed to those wavelengths with the most distinctive absorption rate. In many cases, UV light is preferred to the IR range because the absorption coefficients are usually higher and deliver a better resolution. Furthermore, there are no disturbing influences of air components such as water vapor and carbon dioxide. This is why UV has become the standard method for measuring nitrogen monoxide and dioxide, as well as sulfur dioxide (SO_2), ammonia (NH_3), and ozone (O_3). Other gases such as mercury (Hg), chlorine (Cl_2) or bromine (Br) can only be detected in the UV spectrum.

Continuous monitoring of sulfur in gases and liquids is based on the fluorescence induced by UV radiation. When exposed to the powerful but invisible UV radiation, SO_2 molecules are "raised" to a higher energy level, signified as SO_2*. Part of this additional energy is released by vibration relaxation until the molecules reach their lowest vibrational level. From there, they return to their original electronic state, emitting the rest of the induced energy as visible light. The intensity of the fluorescence is directly proportional to the concentration of sulfur. Therefore, this method makes it possible to detect even concentrations of 10 ppb. Since it is used for continuous monitoring, longevity is a major advantage and provides a better return on investment. Thus, LEDs will eventually become the preferred light sources for this type of detector.

So far, practical use of UV photometers has been a very complex issue. To achieve exact results without disturbing cross sensitivities (e.g., NO and SO_2 at 285 nm), the light sources have to emit at a clearly defined wavelength. Therefore, the broadband light of the UV lamps have to be filtered using an elaborate sets of optics. Each additional device adds to the complexity of the system and affects the overall measurement accuracy. Since fluorescence of many substances is triggered by UVC light, powerful LEDs at these wavelengths will be a strong impulse for further miniaturization and open up new applications outside the industrial world.

Conclusion

Since the turn of the millennium, LEDs have changed the world of UV light in many aspects. Thanks to their robustness, low power consumption, long lifespan, and small form factor, they brought new momentum to the industry. While diodes emitting UVA light are already used in many markets, development of powerful solutions in the short-waved UVC have proven more difficult. The introduction of new, high-power UVC LEDs will surely increase momentum as they solve many problems that have not been able to be tackled so far.

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