A bright future – LED assembly technology

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The light yielded by LEDs is comparable in efficiency to that yielded by fluorescent tubes, but solid-state light sources such as LEDs have a lifespan that is significantly longer than incandescent lamps and fluorescent tubes. The motivation for the application of this technology is, therefore, high, and will contribute to new developments in the near future. Assembly technology, which we will discuss further in the following article, plays an important role in the development of LEDs.

Ever since the first light-emitting diodes (LEDs) were developed in 1957, this technology has continued to be enhanced at record speed. In 1962, General Electric introduced the first red GaAsP luminescence diodes into the market [1]. In the first few years research focussed primarily on the improvement of semiconductor materials. It was possible to reduce the density of defects and impurities more and more. Initially, primarily GaAs and GaP were used [2]. In the years that followed more and more experiments were performed with different semiconductor material combinations and dopings in order to adapt the colour of the light emitted to new applications.

Further developments were geared toward (and are still geared toward) lowering production costs and increasing efficiency. The quality of the semiconductor structures used and a high level of competency in assembly technology are required to achieve optimal LED beam characteristics.

Assembly technology

Today semiconductor chips can be bought in large quantities. Inexpensive LEDs that yield very little light are primarily used in display panels or similar applications.

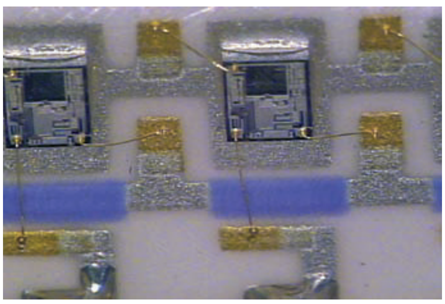

Figure 2: Close-up of LED chip assembly

However, chips with a large variety of special features are also available commercially. Many customer-specific requests concerning LED products can, therefore, be met (e.g. in reading lamps (**figure 1**) or safety lighting used in seafaring and airfields, etc.). Here the added value lies in the processing of these products using optimised assembly technology (**figure 2**). The development objective is quite simple: maximum energy efficiency with both the longest lifespan possible and full compliance with all specified technical properties.

Figure 1: LEDs for general lighting

For a long time it was not possible to efficiently produce light at short wavelengths with semiconductors. This changed with developments introduced by companies such as Akaskai (in 1988) and, more notably, Nichia (in 1992), where Shuji Nakamura became director of R&D in 1993. Mr. Nakamura developed the first commercially available blue-emitting GaN-based LEDs that were then produced in series in 1999 [3]. The production of GaN is still complicated and thus expensive. An ideal method of production has yet to be developed [4].

One of the most important design parameters of powerful LED arrays today is the distance between the individual chips. The dense packing of these chips has four advantages: increase in light emissions, efficient application of beam-shaping optics, facilitation of smaller designs and reduction of system costs. Due to the intensity of the light yielded by LEDs, more and more inefficient light sources can be replaced by LEDs.

In 2006 Opto Technology introduced a UV LED into the market that produced an optical output power of 244 mW at a peak wavelength of 365 nm. Here 50 LEDs (**figure 3**) were applied as an array to a beryllium oxide (BeO) substrate. This bonding process made it possible to achieve said output power with only 300 mA.

Further innovations in the field of assembly technology led to so-called multi-wavelength LEDs. In multi-wavelength LEDs several high power LEDs with customer-specific wavelengths are mounted in a very small space on a ceramic substrate and equipped with focussing optics. The small dimensions (2–3 mm) of illumination units built in this manner, which contain a combination of many different wavelengths, are particularly impres-

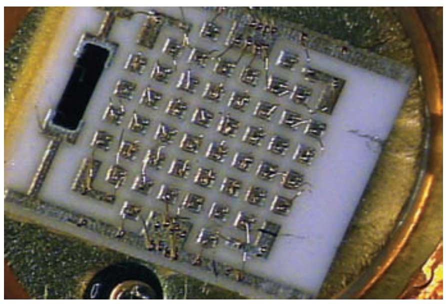

Figure 3: High packing density is a prerequisite for high power LEDs

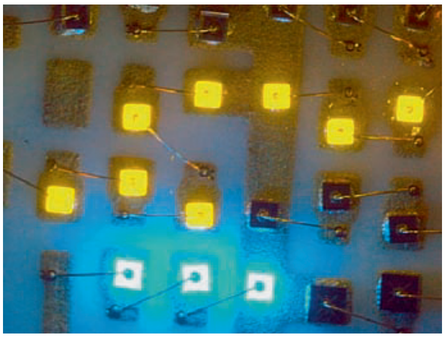

Figure 4: The individual control of several LEDs with different wavelengths makes it possible to achieve variable emissions spectra

sive. The individual control of single LEDs makes it possible to produce different lighting combinations (**figure 4**).

LED housing

For demanding customer-specific LED products there are several design variations available depending on the application specifications, target price and connection methods. By default, these LEDs come in plastic or TO housings that are available in different sizes both for single LED chips and up to 80 chips in 8-pin housings.
Chip carriers without a connection (so-called "I.C. style packages", **figure 5**) are a sound, widespread solution for up to approximately 100,000 units. They make inexpensive surface mounting (SMD) in large volumes possible. At the same time, carrier materials such as ceramic, FR4, etc. are not only used in the mounting of chips, but they also serve as protective material around the LED array. The LED is sealed with epoxy or a glass window to protect it against environmental influences or destruction.
Further options for customer-specific LED housings include fiber coupling, pre-mounted customer-specific optics, integrated photodetectors or filters.

Several wavelengths combined

Chips of different colours are used in multi-wavelength LEDs (**figure 6**). The introduction of a second printed circuit board (PCB) is beneficial in cases where a white LED is integrated into the design: one PCB for all coloured chips and a joined twin PCB for the white LED. Through this combination the coloured LEDs from the first board supplement the wavelengths that are "too weakly" represented in the spectrum of the white LED (**figure 7**). This is necessary, for example, for applications in colour measurement or in biomedical devices.

Controlling colour and intensity

Applications in colour measurement and analytical instruments require special LEDs with precise peak wavelengths (e.g. ±5 nm) and intensities that typically lie between ±50%. This is achieved by selecting LEDs using intensity classification, colour selection and temperature examination as well as by applying optical filters.
There are three ways to obtain an LED classification:

- Purchase from certified LED semiconductor manufacturers
- Purchase from a distributor that pre-selects wafers
- Perform in-house inspection

Because the purchase price of suitable testing equipment is approximately US$ 500 000, working with suppliers who can constantly guarantee high quality can be extremely beneficial.
However, the distribution of colour and intensity of an LED is also dependent upon temperature. Temperature stabilisation cannot only be achieved passively with a heat sink, but also with Peltier elements (thermoelectric cooling), the active regulation of feedback and the application of a constant temperature above the environmental temperature to prevent variations from affecting the emission parameters.

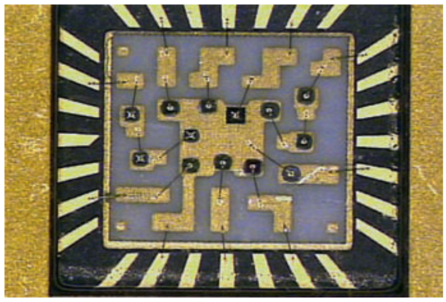

Figure 5: Lead-free chip carrier for several wavelengths

When selecting LED chips, it is important to assess the reliability of the chip supplier against the background of the end product's life cycles. Many medical devices have a life cycle of 10 years and an additional 10-year guarantee on the availability of spare parts. However, the output power of LEDs continues to be improved and old batches continue to be replaced by enhanced products. If this was not considered in advance, a redesign of the product may be necessary in the event that an LED malfunctions in an "old" device. For this reason, an LED strategy is required for each individual product. The risk that a chip is no longer reproducible can be reduced by a pulse modulation circuit that limits the operating current to the required level. In addition, equivalent LEDs from different suppliers can be qualified or, alternatively, a sufficient supply of semiconductor elements kept in stock.

Optical measurement technology in LED production

The inspection of LEDs using optical measurement technology requires equipment calibrated according to, for example, American NIST or German PTB standards.

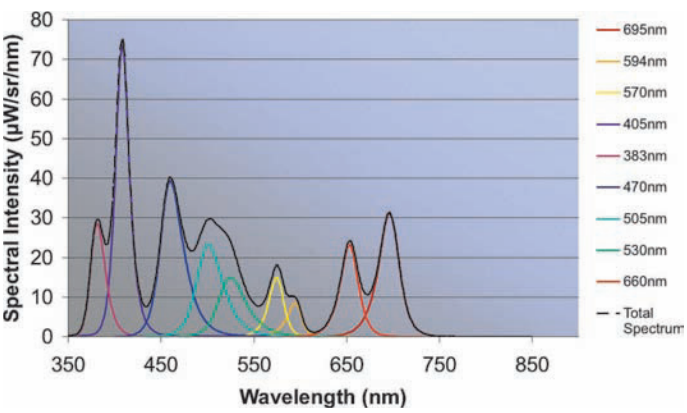

Figure 6: Individual spectra and complete spectrum of a multi-wavelength LED with nine chips

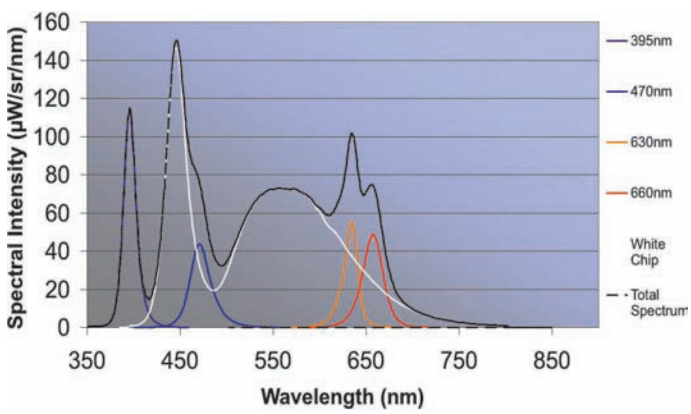

Figure 7: Spectra of a multi-wavelength LED with five chips and an additional white light LED

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Figure 8: Efficient interior lighting with high power LEDs as used e.g. in galleries

This allows for comparability between the measuring instruments used by manufacturers and customers. The methods of measurement used in product development generally differ from those used in series production. In the latter for the most part only calibrated photosensors are used in order to facilitate high throughput and low production costs.
In LED development, however, spectrometers are used to measure intensity and wavelength profiles. Integrating spheres measure the entire output power of the LED while goniometers allow angle-dependent measurements to be made.

Optics for optimal LED fixtures

To maximise the light efficiency of an LED (lumen per euro), a special optic is often integrated into the component. The number of LED chips can be reduced accordingly, which leads to less heat being produced, energy savings, and cheaper end products. This applies in particular when LED technology competes with incandescent lamps and fluorescent tubes (**figure 8**). In addition to the collimation of light, optics can be used in the homogeneous mixing of colours.

Applications

LEDs are of great advantage compared to conventional light sources, especially where the shorter lifespan of these sources leads to increased costs or safety risks and where energy use is particularly relevant. Current application fields are both broad and surprising.
Navigation lights for transportation on the open water are necessary to prevent accidents, especially in large freighters. The malfunction of these lights endangers both the ship and its crew. The absolute functionality of these lamps must be ensured. LEDs are the perfect solution here because the semiconductor materials are extremely stable and long lasting.
Aviation is also a large market for LEDs. In runway lighting the application of LEDs is advantageous due to their long lifespan. Closing a runway for maintenance is extremely expensive. The same is true for airplane warning lights on top of masts, towers, and tall buildings near airports (**figure 9**). Even the simple replacement of a light bulb on a radio mast can cost up to € 300–500. Here it is not only the replacement of defective lamps that is problematic and expensive, but just trying to locate lamps that have failed is challenging. Monitoring systems could be installed, but they cause costs to skyrocket.
Numerous light sources are also used in traffic safety. In conventional traffic lights three 100 W bulbs are used (one per colour). These bulbs can be replaced by LED sources that consume less than 10 W of electrical power – an equivalent of 90% savings. The amortisation period of such LED traffic lights lies between two and four years depending on energy and maintenance costs. In applications such as lane indicators on bridges, in tunnels or at highway tollbooths, the largest saving potential of LEDs can be seen in the heavily reduced maintenance costs.
In analytical measurement technology LEDs have also been successfully used, for example, in colorimeters. Through these LEDs it is no longer necessary to recalibrate measuring devices after the replacement of incandescent bulbs, thus reducing downtime.
In medical technology LEDs are used in surgical operation lamps and head lamps, in lights used in dentistry, or in endoscopes. Depending on the configuration of the chips, colour mixtures can be achieved that produce light suitable for a specific task. White light LEDs, for example, not only produce light that is brighter than that of incandescent lamps, they also emit less heat.

Conclusion

In order to connect different LED chips and house them in the smallest space possible, comprehensive experience in assembly technology, optoelectronic design, and material engineering of different semiconductors, metals, and epoxies is necessary. The integration of optics optimised for both the application and the component can increase the applicability of the LED products in lighting and measurement technology. Low energy consumption contributes to the protection of the environment and the long lifespan of LEDs brings with it calculable cost savings. Currently, the worldwide production volume of LEDs doubles every 18–24 months, which proves their increased use. Therefore, LEDs can look forward to a bright future.

Figure 9: LED safety lighting on a mast

Literature:

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