

LEDs are changing the world of light

Light sources should be as small as possible, produce light efficiently and have a long life. The demands of architects, light planners and operators of lighting installations have formed the basis of the research and development work of the lighting industry. Today more light sources with these properties are on the market than ever before in the history of artificial light. Until now, however, no filament or discharge lamp has combined all three properties.

Only light emitting diodes (LEDs), also called light diodes, achieve this. They conform to the lighting designer's ideal of a point-like light source: no other lamp possesses comparably small dimensions. The miniature form requires small optical systems and creates new demands for light guidance. In the LED, the light optical systems are made from synthetic materials with high refractive indices and replace the classic metal reflector.

The light gains from LEDs continue to grow, doubling about every two years. They have today already exceeded the values attainable by halogen and filament lamps. Soon they will be moving into the yield area of fluorescent lamps. It is not unrealistic to assume that in ten to fifteen years LEDs will become the sole front runner amongst efficient light sources.

Illustrations 1 to 3: coloured LED light has already quickly established itself. The rider is riding in Schloss Brake, the Weser Renaissance Museum; in the light itself, but more especially by using colour changes, he gains maximum attention from the audience.

With 50,000 operational hours, LEDs have a very long life. This results in a new conceptual approach to the design and development of lighting: there is no longer a need for equipment for changing the light source: with LEDs, light source and luminaire grow old jointly and both are changed together when the lamp has reached the end of its lifespan – except in individual cases where repair of the light source has to be possible.

The LED light source began its career as a status symbol and has since become standard for car drivers, at first in the brake lights, later in the interior lights, soon after in the headlights and now today in many traffic indicators.

The LED quickly conquered display and effect lighting as well as gaining a firm foothold in lighting for orientation purposes. Now it is proceeding to desk, standard and street lamps, making it available as 'light to see by'. When luminaires with LEDs become an established component of lighting concepts or when they can even exclusively take over general lighting for the illumination system of a space, remains to be seen. It certainly will not be much longer ...

Illustration 4: the LED coloured surfaces and the LEDs on the ramp make the Morris Minor very eye-catching; the surface colours can be changed.

Illustration 5: an attractive night time picture of the bridge in Duisburg harbour, and also showing the light to see by, both the result of LED light on the railing posts.



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The LED light source

In conventional lamps' visible light arises as a by-product of the warming of a metal helix, or by a gas discharge or by the conversion of a proportion of the ultraviolet radiation produced in such a discharge. In LEDs the production of light takes place in a semiconductor crystal which is electrically excited to illuminate (electroluminescence). In the largest available light diodes their dimensions are represented by edges of about 1 mm. LEDs thus belong to the smallest available, almost point-like, light sources.

ted on plates which enable simple electrical contact and divert the heat: as LED modules (see page 6). The semiconductor crystals can also be mounted directly onto the plates and be protected by a light pervious covering.

The LED light

LEDs produce monochromatic radiation and their colour tone is defined by the dominant wavelength. There are LEDs in the colours red, orange, yellow, green and blue.

White light can be produced as a mixture of all wavelengths, for example in LED modules (see page 6). This arises through an additive mixture of the three RGB colours (Red, Green, Blue).

Alternatively, white light can be produced by the conversion principle known in ordinary lamps (luminescence conversion). Here the light of a blue LED excites luminescent material which

changes a part of the blue light into yellow. By overlaying the unabsorbed blue light with yellow light emitted by the luminescent material white light is produced. The concentration of luminescent material must here be guided precisely so that the desired white is realised. Luminescent materials are permanently undergoing further development in order to improve the colour reproduction value (see page 4) of white LED lighting.

Light emitted by LEDs contains no ultraviolet (UV) or infrared (IR) radiation. LEDs can therefore be employed anywhere where this kind of radiation has a detrimental influence, for example in

History of light production by LED

1907 The Englishman Henry Joseph Round (1881-1966) discovers the physical effect of electroluminescence. As at the time he was actually engaged in a new radio locating process for sea traffic the discovery is at first forgotten.

1962 The first red luminescent diode of type GaAsP comes onto the market. The industrially produced LED is born.

1971 From the beginning of the seventies LEDs are available in further colours: green, orange, yellow. Performance and effectiveness is continually being improved in all LEDs.

1980s to early 1990s High performance LEDs (LED modules) in red, later red/orange, yellow and green become available.

1995 The first LED producing white light by luminescence conversion is introduced.

1997 White LEDs come onto the market.

the food industry, in the illumination of materials which fade easily or in the illumination of sensitive works of art in museums.

Diagram 1: White light at various colour temperatures (in K = Kelvin) as a result of additive colour mixture.

Diagram 3: The colour tone and emission spectrum of LED light is determined by the dominant wave length.

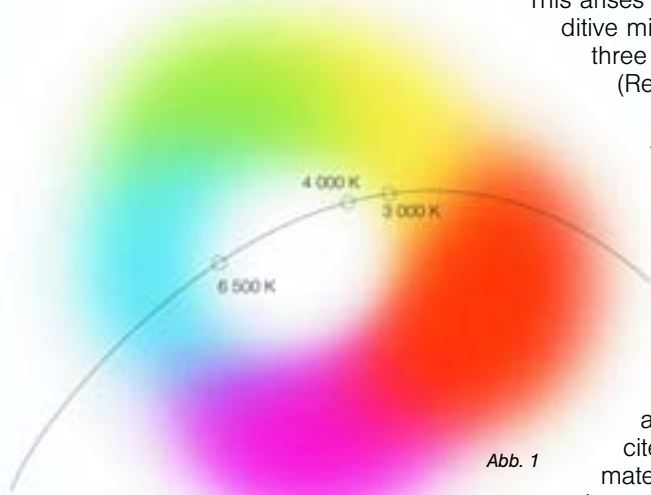


Abb. 1

As protection against environmental influences the semiconductor crystal is set into a housing. This is constructed so that the light radiates in a semicircle of almost 180 degrees (the current maximum is about 160 degrees). Guidance of the light is thus easier than in filament or discharge lamps, which generally radiate light in all directions. There are various types of housing for LEDs of low, medium and high performance; they all give good mechanical stability.

LEDs are only manageable by users if they are moun-

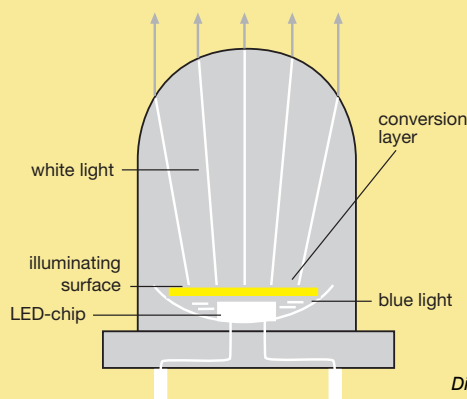
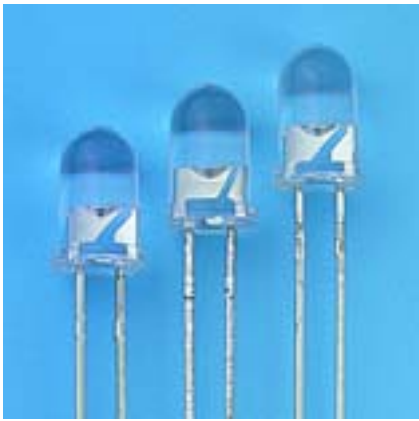


Diagram 2

Diagram 2: white LED light can also be produced with the aid of the conversion principle (luminescence conversion).



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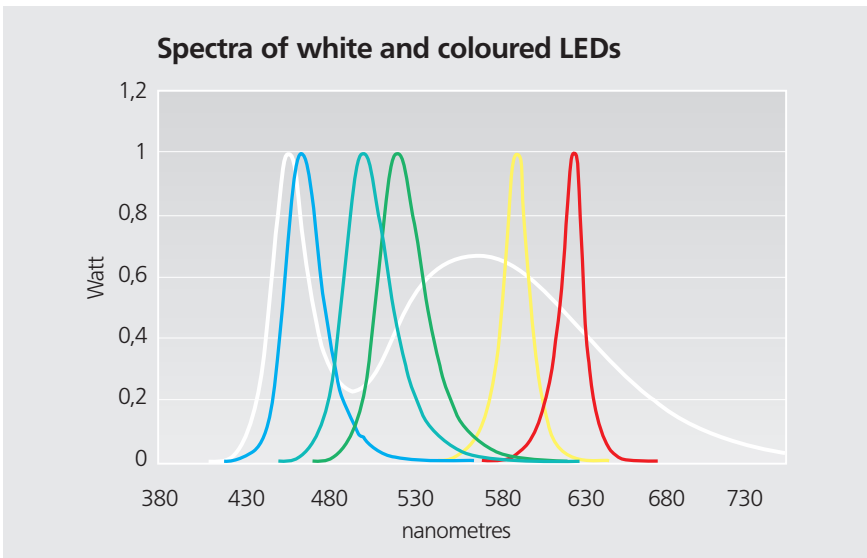
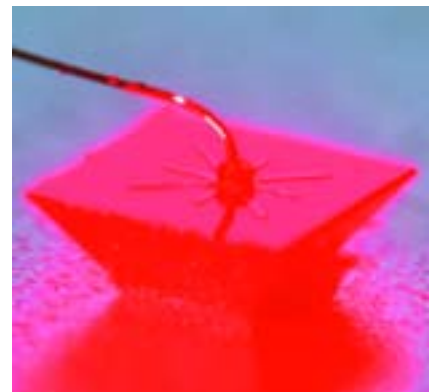


Diagram 3



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Illustrations 6 to 8: LED housings (from left) for low, medium and high performances.

Illustration 9: LED semiconductor crystal, on a carrier with electrical contacts.

LED functional principles

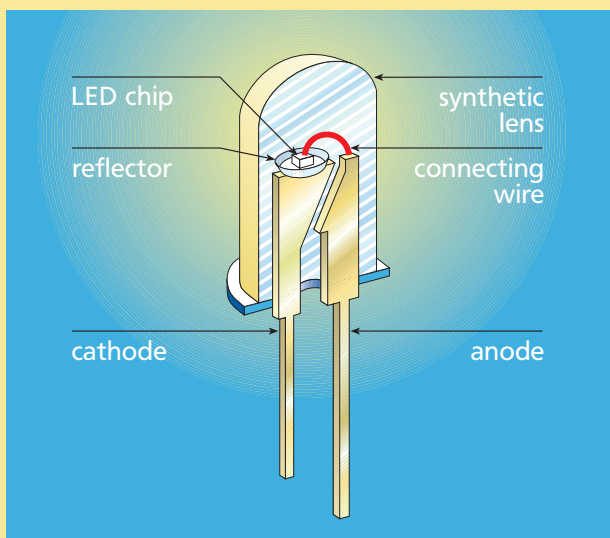


Diagram. 4

Diagram 4: tiny light diodes three to five millimetres in height – the principles of construction here are shown in sketch form – enables completely new light design.

The light of a LED comes from a semiconductor crystal. It is electrically excited to produce light: two areas exist within the crystal, a n-conducting area with a surplus of electrons and a p-conducting area with a deficit of electrons. In the transitional area – called the pn-transition or depletion layer – light is produced in a recombination process of the electron with the atom with the deficit of an electron when current is applied to the crystal.

The emission spectrum of the light thus produced is narrow banded. The dominant wavelength and the colour of the light depend on the materials used in the manufacture of the crystal. LED light contains no UV or IR radiation. The characteristic current/tension curve of an LED shows a small differential resistance in the flow voltage when compared to the lamp voltage, which makes it necessary to stabilise the working point. If the current supply is varied the luminous flux can be influenced in proportion. In practice a defined direct current is allowed to flow through the LED which, as in a lamp using luminescent material, provides an operational device.

The LED light source

Luminous Flux

The luminous flux value of currently available LEDs lies between one lumen (lm) in low performance LEDs (about 50 to 100 mW power input) and up to 120 lm in high performance LEDs (up to 5 W). Stronger evidence for end users is the information on the luminous flux packets which can be realised with LED modules.

Light colour and colour reproduction of white LEDs

White LEDs have above all a cold, neutral white light with a colour temperature > 4,500 K, (K stands for Kelvin). Further development in the area of convertible luminescent materials is making warmer light colours possible. Since 2003 there have been warm white (> 2,800 K) and neutral white (3,300 to 3,800 K) LEDs.

Convertible luminescent materials are also responsible for an improvement in colour reproduction: warm white LEDs have a colour reproduction index from $R_a \geq 70$ up to $R_a \geq 90$. For cold white LEDs the R_a value is between 70 and 80.

Efficient light sources

LEDs are extremely efficient light sources. In 2005 the light yields from white LEDs had already reached values of over 30 lumens/Watt (lm/W), and those from coloured versions 50 lm/W. In the near future light diodes with yields of up to 100 lm/W will be available. LEDs will thus soon achieve the yield values of lamps which use luminescent materials.

Future generations of LEDs will find wide employment in interior lighting, lowering the use and cost of energy

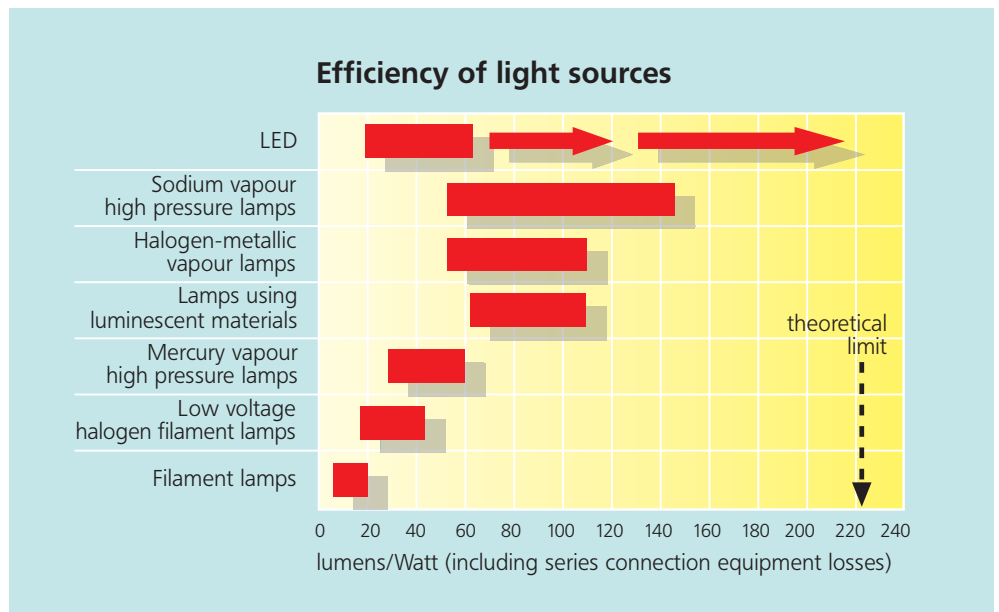


Diagram 5

and so making a contribution to ecological relief. The same applies to external lighting, where long lasting LEDs (also coupled with solar cells) can be employed in saving energy in stationary situations such as road markings, or in mobile applications.

Lifespan depends on temperature

The lifespan of an LED depends on its operational and environmental temperature. At room temperature LEDs – and thus also LED modules – have a very long lifespan of up to 50,000 working hours.

In contrast to filament lamps, where a break in the helix means the end of its life, total failure of an LED is extremely rare. Its light intensity also declines much more slowly: this property is known as degradation. The period of degradation of the original luminous flux by up to 50 % defines the lifespan of LEDs.

The degradation of the luminous flux is strongly dependent on the temperature of the light emitting surface in the semiconductor crystal. There must

therefore be no build-up of heat in the operation of an LED: the conducting plate or additional heat sink must reliably divert the heat.

A too high environmental temperature will equally lead to a decrease in the luminous flux.

Diagram 5: the light yield from LEDs is reaching ever higher values.

The colours of the LED light

According to the type and composition of the semiconductor crystal the light from LEDs has different colours. Today there are white, blue, green, yellow, orange, red, and amber, together with nuances of these colours. The narrow banded (monochromatic) light is produced without additional filters. Examples are:

Semiconductor material	Abbreviation	Colour
Aluminium-gallium arsenide	AlGaAs	red
Aluminium indium gallium phosphide	AlInGaP	red, orange, yellow
Gallium arsenide phosphide	GaAsP	red, orange, Yellow
Indium gallium nitride	InGaN	green, blue

Light intensity distribution of LEDs

The light intensity distribution curves of LEDs are determined by the construction of the housing used. The semiconductor crystals are mounted on carriers which act as mini reflectors. The angle of radiation can vary between 15 and 160 degrees.

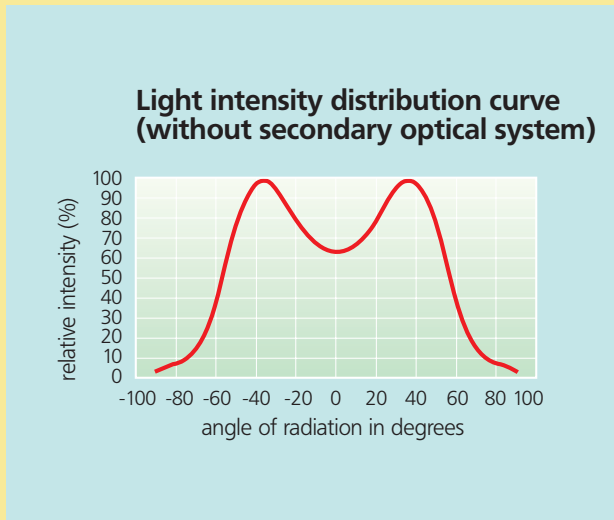


Diagram 6

Diagram 6: The light intensity distribution curve of the LED 'without secondary optical system' has two peaks of intensity. A high uniformity of illumination is achieved by the introduction of a diffusing plate.

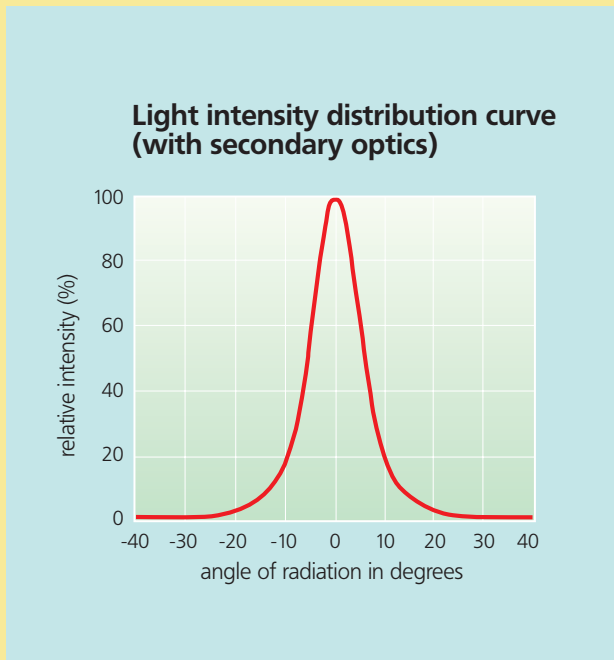


Diagram 7

Diagram 7: An additional secondary optical system focuses the light from an LED. The result is a restricted spot of light.



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Illustration 10: the point-like LED light is especially suitable for illumination – even in the smallest format.

Illustration 11: the light from ground mounted lights with LEDs which mark out the pattern of the site creates an interesting night picture.

LED modules

An LED module consists of several semiconductor crystals or single LEDs (semiconductor crystals with their housings) which are placed in series next to one another, or combined in some other form, on a conductor plate. The plate is not only a carrier but also makes possible the easy fixing of the LEDs and other optical, electronic or mechanical components.

The electrical layout of the conductor plate can be adapted to a particular application: as well as single operation, coloured LEDs can also be separately fixed using an appropriate layout so that plays of colour and sequences are possible within a module. Colours can be produced with an additive colour mixture because the LED module combines the three RGB colours (red, green, blue). The mixing of basic colours leads to the creation of every favourite tone or to various colour effects.

LED modules are obtainable on the market in differing shapes and sizes, the most important distinguishing features being their construction technology such as:

- modules with wired LEDs mounted through holes on the printed circuit board.
- modules in SMD technology (Surface Mounted Device) – these allow for more miniaturisation than is possible with wired LEDs.
- modules based on innovative CoB technology (Chip-on-Board) – in these modules the semiconductor crystals are placed directly onto a conductor plate and with contacts. This allows high equipment density, best miniaturisation and good thermal management for a long lifespan.
- SMD or CoB modules for high performance LEDs (high performance mod-



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ules) – high performance light diodes demand a module concept which makes possible the easy diversion of the heat arising in the semiconductor crystal. For example, the conductor plate contains a metal core made of aluminium for this purpose.

Conductor plates are prepared from diverse materials. The range extends from

standard conductor plates to those with organic material with interwoven threads for stabilisation and again to highly flexible foil material with a thickness of 0.15 mm or to ceramics, glass or metal core conductor plates.

High performance modules

The high performance modules are especially

Illustrations 12 and 13: LEDs make it possible – living with light now also means living with coloured light.

innovative. The trend is clearly aiming towards these efficient light sources and to being able to replace current general lighting by LEDs in the near future. High performance modules with a light yield

in the region of 30 lm/W can in fact already be manufactured but as yet, however, some technological development remains to be accomplished.

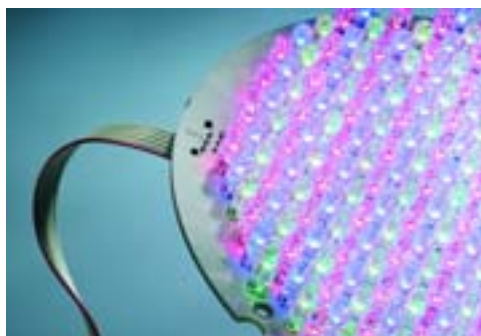
The most important aim of the LED manufacturers is to further optimise efficiency. This must also lead to an improvement in the sale price/lumen relationship so that LED modules, which cannot currently hold their own with cheaper conventional means of lighting, become a force to be reckoned with.

Further efficiency increases

Due to the higher performances of LED modules an increase in efficiency by means of optical components is becoming ever more important. Above all these will be improved by the integration of optical technology, as for example nano-structured semiconductor surfaces, special chip design and optimised reflector/micro-optic systems within LEDs, as well as by the use of special materials such as optical polymers.

Another important aspect of high performance modules is thermal management. Heat affects the wavelength of the light radiated by LEDs and thus also its colour, as well as the life of the light diodes. This decreases with rising temperatures. The currently available thermally optimised designs can and must be improved in view of the higher performances of LED modules.

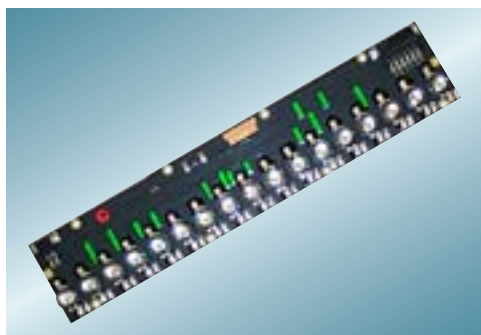
The colour reproduction properties of high performance modules with LEDs will steadily be improved by optical and thermal converter optimisation and specially calculated mixtures of suitable LED spectra.



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Illustration 14: module with wired LEDs.

Illustration 15: module in SMD (Surface Mounted Device) technology.

Illustration 16: high flexibility module in SMD technology.

Illustration 17: module based on innovative CoB (Chip-on Board) technology.

Illustration 18: high performance SMD module.

Illustration 19: high performance CoB module.



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LED modules – light sources with advantages

The essential advantages of LED modules as compared to conventional light sources:

- They have a low profile.
- Their beam is IR free. LED modules therefore radiate no heat in the direction of the illuminated object.
- They have a very long life.
- The semiconductor crystals integrated into the module or individual LEDs can be directly controlled, thus reacting very quickly, and are easily dimmed even in RGB (red, green, blue) phases.
- The high lamp density and compactness of LEDs opens up completely new possibilities in optical design: from secondary optic and reflector systems to aimed light guidance and homogenisation of light ray distribution.