

Garage Maintenance



- **Reviewing Auto Reverse Mechanisms And Why They Matter**
Reviewing Auto Reverse Mechanisms And Why They Matter Testing Photo Eye Sensors With Quick Steps Learning About Manual Release Functions Understanding UL Standards For Garage Doors Checking Safety Labels And Ratings Before Purchase Adjusting Opener Force Settings Responsibly Evaluating Backup Power Options During Outages Verifying Emergency Release Handles For Accessibility Ensuring Child And Pet Safety Near Moving Parts Examining Industry Guidelines For Proper Installation Implementing Routine Safety Drills For Households Identifying Potential Hazards Through Visual Inspection
- **Inspecting Weather Seals For Energy Efficiency**
Inspecting Weather Seals For Energy Efficiency Lubricating Tracks And Rollers With Minimal Mess Checking Door Balance For Smooth Movement Monitoring Cable Tension For Safety Identifying Common Wear Points That Need Attention Creating A Simple Maintenance Schedule That Works Reading Opener Manuals For Basic Troubleshooting Verifying Photo Eye Sensor Alignment Regularly Removing Debris From Tracks For Better Operation Evaluating Loose Hinges Before They Fail Preserving A Clean Door Surface In All Climates Gathering Essential Tools For Simple DIY Checkups
- **About Us**



Understanding UL Standards for Garage Doors: A Critical Component for Safety and Reliability

In the modern landscape of home improvement, ensuring safety and reliability is paramount, especially when it comes to garage door installations. At the heart of these concerns lies adherence to UL (Underwriters Laboratories) standards, which play a critical role in guaranteeing that these systems function safely and effectively. Understanding and implementing these standards are not just regulatory necessities but essential practices that protect homeowners and enhance the longevity of garage door mechanisms.

UL standards serve as a benchmark for safety and quality across various products and industries. In the context of garage doors, these standards ensure that all components—from openers to sensors—operate within defined safety parameters. This is particularly significant given the potential hazards associated with malfunctioning garage doors, which can lead to property damage or personal injury. Garage door windows can increase natural light in your garage space **liftmaster garage door repair** Griffon Corporation. By adhering to UL standards, manufacturers and installers demonstrate a commitment to minimizing such risks.

The reliability of garage door systems is another critical aspect bolstered by adherence to UL standards. These guidelines require rigorous testing of materials and mechanisms under different conditions, ensuring that they can withstand daily wear and tear while maintaining their functionality over time. For homeowners, this means fewer malfunctions and reduced maintenance costs, as well as peace of mind knowing their investment is built on a foundation of quality assurance.

Compliance with UL standards also bridges the gap between manufacturers' intentions and user expectations. When consumers see the UL mark on a product, it acts as an assurance that it has been independently tested for safety hazards such as electrical faults or mechanical failures. This trust extends beyond individual users; insurance companies often consider compliance with recognized safety standards when assessing risk coverage for residential properties.

Moreover, following UL standards during installation aligns with legal requirements in many jurisdictions. Non-compliance might not only expose homeowners to increased risks but could also result in penalties or voided warranties from insurers or product manufacturers.

Therefore, understanding these standards becomes an essential part of professional practice for installers who wish to avoid liability issues while delivering high-quality service.

In conclusion, the importance of adhering to UL standards in garage door installation cannot be overstated. These guidelines provide a framework that ensures safety by preventing accidents related to faulty installations while promoting long-term reliability through stringent testing protocols. Compliance fosters consumer confidence by meeting stringent regulatory benchmarks and safeguarding against unforeseen liabilities-making it an indispensable element in achieving excellence within the industry. As technology evolves, so too will these standards; staying informed about changes ensures continued protection for both workers' integrity and customers' satisfaction alike.

Key Components and Functionality of Auto Reverse Systems —

- Historical Development and Evolution of Auto Reverse Technology
- Key Components and Functionality of Auto Reverse Systems
- Safety Benefits of Installing Auto Reverse Mechanisms
- Common Issues and Troubleshooting Tips for Auto Reverse Systems
- The Role of Regulations and Standards in Ensuring Safety
- Selecting the Right Garage Door System with Effective Auto Reverse Features

Understanding UL Standards for Garage Doors

Garage doors are an essential part of modern homes and commercial spaces, serving not only as a barrier to secure properties but also as a significant component of the building's aesthetic appeal. Given their importance, it is crucial that garage doors adhere to specific safety and performance standards. Underwriters Laboratories (UL), a global safety certification company, provides these standards to ensure that garage doors meet the required levels of structural integrity, fire resistance, and electrical safety.

The structural integrity of a garage door is paramount. It must withstand various environmental factors such as wind, rain, and even potential impacts without compromising its functionality or safety. The UL 325 standard is one of the primary guidelines addressing motor-operated garage doors and gates' safety requirements. This standard emphasizes the need for robust construction materials and mechanisms that can endure daily wear and tear while maintaining

reliable operation. It ensures that the door can withstand both expected operational stresses and unforeseen challenges like high winds or accidental collisions.

Fire resistance is another critical aspect covered by UL standards applicable to garage doors. While not all garage doors require fire-resistant properties, those installed in certain environments or buildings may be subject to more stringent regulations. For such applications, UL 10B or UL 10C standards could come into play. These standards outline testing methods for assessing door assemblies' ability to resist fire penetration during specified time frames. Ensuring compliance with these standards can help prevent fires from spreading rapidly through buildings, potentially saving lives and property.

Electrical safety is also a key consideration for motorized garage doors equipped with electronic opening systems. The integration of electrical components introduces risks such as electric shock or short circuits if not properly managed. The aforementioned UL 325 standard also encompasses electrical safety provisions for automatic operators used in conjunction with garage doors. It requires thorough testing of control systems, sensors, wiring configurations, and other electronic components to minimize hazards associated with electricity.

In addition to these core areas-structural integrity, fire resistance, and electrical safety-UL standards often encourage innovation in design while ensuring optimal functionality remains uncompromised by new technologies introduced into the market continuously evolving based on emerging trends or consumer demands like smart technology integration.

Ultimately understanding which specific UL standards apply when selecting installing maintaining your particular type will give you peace-of-mind knowing they meet rigorous criteria set forth promoting safe reliable use throughout their lifecycle whether residential commercial settings alike always prioritize adhering best practices outlined them safeguard occupants investments alike thereby underscoring importance role reputable certifications play industry-wide trust assurance delivering quality products every time purchase install one yourself!

Posted by on

Posted by on

Posted by on

Safety Benefits of Installing Auto Reverse Mechanisms

Understanding the Testing Process: Description of the testing procedures that garage doors undergo to meet UL standards is an essential part of ensuring safety and reliability in residential and commercial settings. Underwriters Laboratories (UL) is a globally recognized safety certification company dedicated to promoting safe living and working environments. When it comes to garage doors, meeting UL standards involves rigorous testing procedures designed to assess their durability, performance, and safety features.

At the heart of these testing procedures is the focus on load testing. This process evaluates how a garage door performs under various weights and pressures, simulating real-world conditions that the door might encounter during its lifespan. Load testing ensures that the door can handle significant stress without failing or becoming unsafe for users. The materials used in constructing garage doors must be robust enough to withstand these tests while maintaining their structural integrity.

Another crucial aspect of UL standards involves operational cycle tests. These tests simulate repeated opening and closing cycles to mimic everyday use over time. By subjecting garage doors to thousands of cycles, manufacturers can identify potential wear and tear issues or mechanical failures that could arise from regular usage. This ensures that not only does the door operate smoothly initially but also maintains its functionality throughout its expected life span.

Additionally, safety features such as automatic reversal mechanisms are tested extensively. These mechanisms are crucial for preventing accidents by reversing the door's motion if an obstruction is detected while closing. Testing these features involves placing objects in the path of a closing door to ensure that it stops and reverses appropriately, thus protecting people and property from harm.

UL standards also require testing for resistance against environmental factors like wind, rain, and temperature fluctuations. Garage doors must demonstrate resilience against these elements to prevent damage or malfunctioning during adverse weather conditions.

Overall, meeting UL standards through comprehensive testing processes provides consumers with peace of mind knowing their garage doors are both safe and reliable. These rigorous evaluations help manufacturers improve product quality while adhering to high safety benchmarks established by UL. As technology advances and new materials emerge, continuous innovation in testing processes will further enhance the performance and safety of garage doors across different applications.

In conclusion, understanding UL standards for garage doors requires recognizing the importance of load testing, operational cycle tests, safety mechanism evaluations, and environmental resistance assessments. These procedures ensure that every aspect of a garage door's functionality meets stringent criteria before reaching consumers' hands-ultimately safeguarding lives while enhancing convenience in daily operations.





Common Issues and Troubleshooting Tips for Auto Reverse Systems

Understanding the Underwriters Laboratories (UL) standards for garage doors is crucial not only for compliance but also for ensuring optimal safety and efficiency in installation practices. UL standards serve as a benchmark for quality and safety, influencing various facets of installation techniques, material selection, and overall safety measures. By adhering to these standards, installers can significantly enhance the reliability and durability of garage door systems.

Installation techniques are profoundly impacted by UL standards. These guidelines provide detailed instructions on how various components should be assembled and integrated to ensure maximum functionality and safety. Installers who follow UL standards are more likely to adopt best practices that prevent common issues such as misalignment or improper tensioning of springs. This adherence ensures that the garage door operates smoothly and reduces the likelihood of malfunctions that could lead to accidents or injuries.

Moreover, UL standards play a critical role in material selection. They specify the types of materials that can withstand wear and tear while maintaining structural integrity over time. For instance, selecting high-quality steel tracks or reinforced panels becomes imperative under these guidelines, ensuring that the garage door can resist external forces like wind pressure. By choosing materials endorsed by UL, installers contribute to creating robust systems that meet rigorous safety requirements.

Safety measures for installers are another significant area influenced by adherence to UL standards. The guidelines emphasize protective procedures during installation to minimize risks associated with handling heavy components or working at heights. For example, they recommend using specialized tools designed to handle specific tasks safely without compromising installer well-being. Furthermore, complying with these standards typically involves routine checks and maintenance protocols post-installation-steps essential for identifying potential hazards before they escalate into serious problems.

Overall, understanding and implementing UL standards in garage door installations is not merely about following rules; it is about fostering a culture of excellence where quality craftsmanship meets enhanced safety protocols. Installers who embrace these guidelines demonstrate professionalism while ensuring that end-users receive reliable products designed with their safety in mind. Consequently, adherence to UL standards serves as a foundation upon which superior installation practices are built-practices that ultimately benefit both installers and consumers alike through increased satisfaction and peace of mind.

In conclusion, the impact of UL standards on installation practices cannot be overstated. From refining techniques to guiding material choices and bolstering safety measures, these

benchmarks are integral to achieving exemplary outcomes in garage door installations. As such, embracing UL's comprehensive framework allows installers to uphold industry best practices while prioritizing user safety-a commitment essential for advancing quality within this vital segment of home improvement solutions.

The Role of Regulations and Standards in Ensuring Safety

Understanding UL Standards for Garage Doors

In the realm of homeownership, ensuring the safety and security of one's property is a paramount concern. Homeowners invest in various systems and structures to safeguard their homes, from advanced security systems to robust roofing materials. Among these, garage doors often play an underestimated yet crucial role. Adhering to Underwriters Laboratories (UL) standards can provide homeowners with numerous advantages that extend beyond mere functionality.

The UL standards are comprehensive guidelines that assure consumers about the safety, quality, and durability of products. Specifically for garage doors, these standards encompass rigorous testing for fire resistance, wind pressure endurance, and overall operational reliability. By choosing a garage door that complies with UL standards, homeowners effectively invest in enhanced safety.

One significant advantage is the increased safety these doors provide. A UL-certified garage door undergoes meticulous testing to ensure it can withstand harsh conditions and prevent accidents. For instance, these doors are often equipped with advanced sensors that detect obstructions during operation, reducing the risk of injury or damage. This feature is particularly beneficial for families with young children or pets who may inadvertently wander into harm's way.

Moreover, compliance with UL standards offers potential insurance benefits. Insurance companies recognize the reduced risk associated with certified products; hence, homeowners may be eligible for discounts on their premiums. By demonstrating a commitment to maintaining high safety standards in their homes through such compliant installations, homeowners present themselves as lower-risk clients to insurers.

Beyond safety and financial incentives, having a UL-certified garage door can also enhance property value. Prospective buyers are increasingly prioritizing homes equipped with reliable and safe amenities. Highlighting a UL-compliant garage door during a property sale can serve as a significant selling point, reflecting both responsible ownership and attention to detail.

In conclusion, while often overlooked in favor of more conspicuous home improvements, investing in a garage door that meets UL standards presents substantial benefits for homeowners. From bolstered safety measures to potential reductions in insurance costs and increased property value, such compliance underscores an investment not just in one's home but also in long-term peace of mind. As homeowners continue to seek ways to safeguard their properties efficiently and responsibly, understanding and applying UL standards becomes an invaluable part of this endeavor.





Selecting the Right Garage Door System with Effective Auto Reverse Features

Understanding UL Standards for Garage Doors: Common Mistakes and How to Avoid Them

When it comes to ensuring the safety and reliability of garage doors, adherence to Underwriters Laboratories (UL) standards is crucial. UL standards are designed to ensure that garage doors meet rigorous safety and performance criteria, protecting both property and people. However, during installation, several common mistakes can lead to non-compliance with these standards. Understanding these pitfalls and knowing how to avoid them is essential for any installer or homeowner.

One typical error is improper alignment of the door tracks. Misaligned tracks can cause undue stress on the door mechanism, leading to premature wear and potential failure. To avoid this mistake, installers should meticulously follow manufacturer instructions for track installation, ensuring they are perfectly parallel and securely fastened. Using a level tool can help confirm precision alignment during setup.

Another frequent issue is incorrect spring tension adjustment. Springs play a vital role in balancing the weight of the garage door, making it easy to open and close. If springs are either too tight or too loose, they can create hazardous conditions or prevent the door from operating smoothly. Installers should always use the specific tension settings recommended by the manufacturer for each type of door system and perform regular checks after installation to ensure ongoing compliance.

Electrical wiring mistakes also pose significant risks when installing garage doors equipped with automatic openers. Non-compliance with UL standards often arises from using inappropriate wire types or failing to properly secure electrical connections. To mitigate these risks, it's important to use wires that meet UL specifications and adhere strictly to installation guidelines concerning grounding and insulation.

Additionally, overlooking sensor placement can lead to safety hazards that violate UL requirements. Sensors are critical for detecting obstacles in the path of a closing door, preventing accidents or injuries. Installers need to ensure sensors are installed at the correct height-typically six inches above ground level-and tested thoroughly after installation. Ensuring they align correctly will guarantee their effectiveness in stopping or reversing the garage door upon detection of an obstruction.

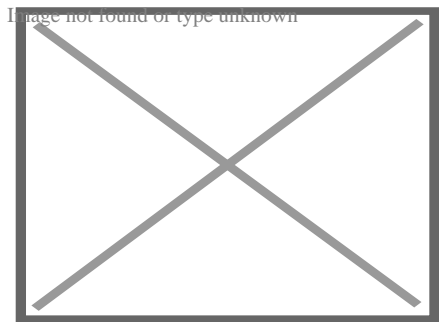
Finally, neglecting routine maintenance post-installation can result in gradual drift away from compliance over time as components wear out or become misaligned. Regular inspections should be scheduled as part of maintaining UL standard compliance; checking all mechanical parts like rollers, hinges, cables along with testing safety features such as auto-reverse functions helps identify issues early before they escalate into serious problems.

In conclusion, while achieving compliance with UL standards might seem daunting at first glance due its technical nature involving meticulous attention-to-detail throughout every phase-from initial setup through ongoing maintenance-it remains fundamentally integral not just legally but practically safeguarding end-users' well-being alongside preserving operational longevity & functionality across diverse environmental conditions encountered daily within residential settings worldwide! By recognizing common mistakes made during installations & adopting proactive measures geared towards mitigating against same future occurrences via comprehensive education/training programs targeting industry professionals alike therein lies opportunity furthering broader mission advancing collective commitment prioritizing public welfare foremost amidst ever-evolving landscape modern technological innovation redefining boundaries conventional wisdom historically associated traditional notions domestic security protection paradigms alike!

About light-emitting diode

This article is about the electronic device. For specific use in lighting, see LED lamp. "LED" and "Led" redirect here. For other uses, see LED (disambiguation).

Light-emitting diode



Blue, green, and red LEDs in 5 mm diffused cases. There are many different variants of LEDs.

Working principle

Inventor

First production

Pin names

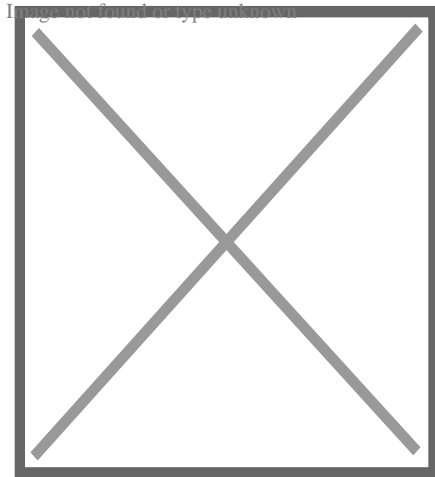
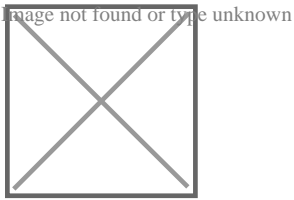
Electroluminescence

- H. J. Round (1907)^[1]
- Oleg Losev (1927)^[2]
- James R. Biard (1961)^[3]
- Nick Holonyak (1962)^[4]

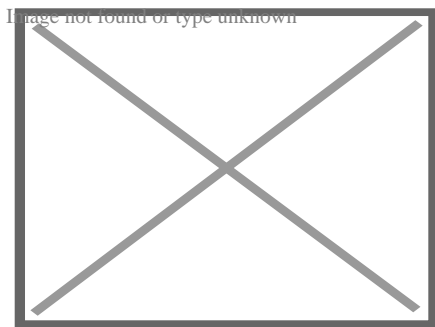
October 1962; 62 years ago

Anode and cathode

Electronic symbol



Parts of a conventional LED. The flat bottom surfaces of the anvil and post embedded inside the epoxy act as anchors, to prevent the conductors from being forcefully pulled out via mechanical strain or vibration.



Close-up image of a surface-mount LED

Close-up of an LED with the voltage being increased and decreased to show a detailed view of its operation

Modern LED retrofit with E27 screw in base

Image not found or type unknown

A bulb-shaped modern retrofit LED lamp with aluminum heat sink, a light diffusing dome and E27 screw base, using a built-in power supply working on mains voltage

A **light-emitting diode (LED)** is a semiconductor device that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor.^[5] White light is obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device.^[6]

Appearing as practical electronic components in 1962, the earliest LEDs emitted low-intensity infrared (IR) light.^[7] Infrared LEDs are used in remote-control circuits, such as those used with a wide variety of consumer electronics. The first visible-light LEDs were of low intensity and limited to red.

Early LEDs were often used as indicator lamps, replacing small incandescent bulbs, and in seven-segment displays. Later developments produced LEDs available in visible, ultraviolet (UV), and infrared wavelengths with high, low, or intermediate light output, for instance, white LEDs suitable for room and outdoor lighting. LEDs have also given rise to new types of displays and sensors, while their high switching rates are useful in advanced communications technology with applications as diverse as aviation lighting, fairy lights, strip lights, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, lighted wallpaper, horticultural grow lights, and medical devices.^[8]

LEDs have many advantages over incandescent light sources, including lower power consumption, a longer lifetime, improved physical robustness, smaller sizes, and faster switching. In exchange for these generally favorable attributes, disadvantages of LEDs include electrical limitations to low voltage and generally to DC (not AC) power, the inability to provide steady illumination from a pulsing DC or an AC electrical supply source, and a lesser maximum operating temperature and storage temperature.

LEDs are transducers of electricity into light. They operate in reverse of photodiodes, which convert light into electricity.

History

[edit]

Main article: History of LEDs

The first LED was created by Soviet inventor Oleg Losev^[9] in 1927, but electroluminescence was already known for 20 years, and relied on a diode made of silicon carbide.

Commercially viable LEDs only became available after Texas Instruments engineers patented efficient near-infrared emission from a diode based on GaAs in 1962.

From 1968, commercial LEDs were extremely costly and saw no practical use. Monsanto and Hewlett-Packard led the development of LEDs to the point where, in the 1970s, a unit cost less than five cents.^[10]

Physics of light production and emission

[edit]

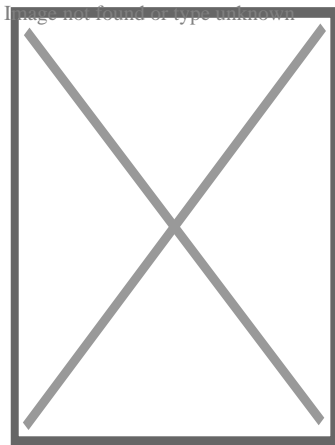
Main article: Light-emitting diode physics

In a light-emitting diode, the recombination of electrons and electron holes in a semiconductor produces light (be it infrared, visible or UV), a process called "electroluminescence". The wavelength of the light depends on the energy band gap of the semiconductors used. Since these materials have a high index of refraction, design features of the devices such as special optical coatings and die shape are required to efficiently emit light.^[11]

Unlike a laser, the light emitted from an LED is neither spectrally coherent nor even highly monochromatic. Its spectrum is sufficiently narrow that it appears to the human eye as a pure (saturated) color.^{[12][13]} Also unlike most lasers, its radiation is not spatially coherent, so it cannot approach the very high intensity characteristic of lasers.

Single-color LEDs

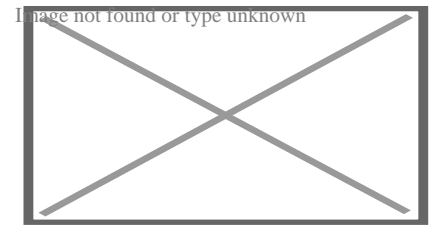
[edit]



Blue LEDs

External videos

By selection of different semiconductor materials, single-color LEDs can be made that emit light in a narrow band of wavelengths from near-infrared through the visible spectrum and into the ultraviolet range. The required operating voltages of LEDs increase as the emitted wavelengths become shorter (higher energy, red to blue), because of their increasing semiconductor band gap.



"The Original Blue LED",
Science History Institute

Blue LEDs have an active region consisting of one or more InGaN quantum wells sandwiched between thicker layers of GaN, called cladding layers. By varying the relative In/Ga fraction in the InGaN quantum wells, the light emission can in theory be varied from violet to amber.

Aluminium gallium nitride (AlGaIn) of varying Al/Ga fraction can be used to manufacture the cladding and quantum well layers for ultraviolet LEDs, but these devices have not yet reached the level of efficiency and technological maturity of InGaN/GaN blue/green devices. If unalloyed GaN is used in this case to form the active quantum well layers, the device emits near-ultraviolet light with a peak wavelength centred around 365 nm. Green LEDs manufactured from the InGaIn/GaN system are far more efficient and brighter than green LEDs produced with non-nitride material systems, but practical devices still exhibit efficiency too low for high-brightness applications.^[citation needed]

With AlGaIn and AlGaInN, even shorter wavelengths are achievable. Near-UV emitters at wavelengths around 360–395 nm are already cheap and often encountered, for example, as black light lamp replacements for inspection of anti-counterfeiting UV watermarks in documents and bank notes, and for UV curing. Substantially more expensive, shorter-wavelength diodes are commercially available for wavelengths down to 240 nm.^[14] As the photosensitivity of microorganisms approximately matches the absorption spectrum of DNA, with a peak at about 260 nm, UV LED emitting at 250–270 nm are expected in prospective disinfection and sterilization devices. Recent research has shown that commercially available UVA LEDs (365 nm) are already effective disinfection and sterilization devices.^[15] UV-C wavelengths were obtained in laboratories using aluminium nitride (210 nm),^[16] boron nitride (215 nm)^{[17][18]} and diamond (235 nm).^[19]

White LEDs

[edit]

There are two primary ways of producing white light-emitting diodes. One is to use individual LEDs that emit three primary colors—red, green and blue—and then mix all the colors to form white light. The other is to use a phosphor material to convert monochromatic light from a blue or UV LED to broad-spectrum white light, similar to a fluorescent lamp. The yellow phosphor is cerium-doped YAG crystals suspended in the package or coated on the LED. This YAG phosphor causes white LEDs to appear yellow

when off, and the space between the crystals allow some blue light to pass through in LEDs with partial phosphor conversion. Alternatively, white LEDs may use other phosphors like manganese(IV)-doped potassium fluorosilicate (PFS) or other engineered phosphors. PFS assists in red light generation, and is used in conjunction with conventional Ce:YAG phosphor.

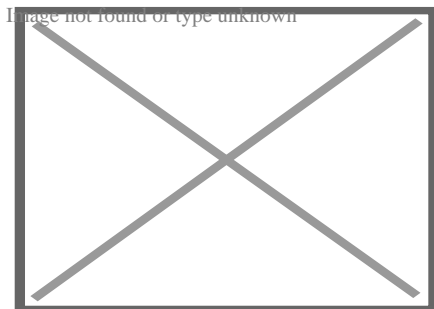
In LEDs with PFS phosphor, some blue light passes through the phosphors, the Ce:YAG phosphor converts blue light to green and red (yellow) light, and the PFS phosphor converts blue light to red light. The color, emission spectrum or color temperature of white phosphor converted and other phosphor converted LEDs can be controlled by changing the concentration of several phosphors that form a phosphor blend used in an LED package.^{[20][21][22][23]}

The 'whiteness' of the light produced is engineered to suit the human eye. Because of metamerism, it is possible to have quite different spectra that appear white. The appearance of objects illuminated by that light may vary as the spectrum varies. This is the issue of color rendition, quite separate from color temperature. An orange or cyan object could appear with the wrong color and much darker as the LED or phosphor does not emit the wavelength it reflects. The best color rendition LEDs use a mix of phosphors, resulting in less efficiency and better color rendering.^[citation needed]

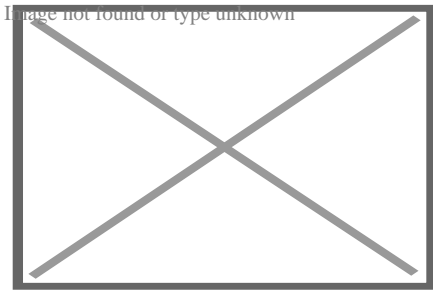
The first white light-emitting diodes (LEDs) were offered for sale in the autumn of 1996.^[24] Nichia made some of the first white LEDs which were based on blue LEDs with Ce:YAG phosphor.^[25] Ce:YAG is often grown using the Czochralski method.^[26]

RGB systems

[edit]



Combined spectral curves for blue, yellow-green, and high-brightness red solid-state semiconductor LEDs. FWHM spectral bandwidth is approximately 24–27 nm for all three colors.



An RGB LED projecting red, green, and blue onto a surface

Mixing red, green, and blue sources to produce white light needs electronic circuits to control the blending of the colors. Since LEDs have slightly different emission patterns, the color balance may change depending on the angle of view, even if the RGB sources are in a single package, so RGB diodes are seldom used to produce white lighting. Nonetheless, this method has many applications because of the flexibility of mixing different colors,^[27] and in principle, this mechanism also has higher quantum efficiency in producing white light.^[28]

There are several types of multicolor white LEDs: di-, tri-, and tetrachromatic white LEDs. Several key factors that play among these different methods include color stability, color rendering capability, and luminous efficacy. Often, higher efficiency means lower color rendering, presenting a trade-off between the luminous efficacy and color rendering. For example, the dichromatic white LEDs have the best luminous efficacy (120 lm/W), but the lowest color rendering capability. Although tetrachromatic white LEDs have excellent color rendering capability, they often have poor luminous efficacy. Trichromatic white LEDs are in between, having both good luminous efficacy (>70 lm/W) and fair color rendering capability.^[29]

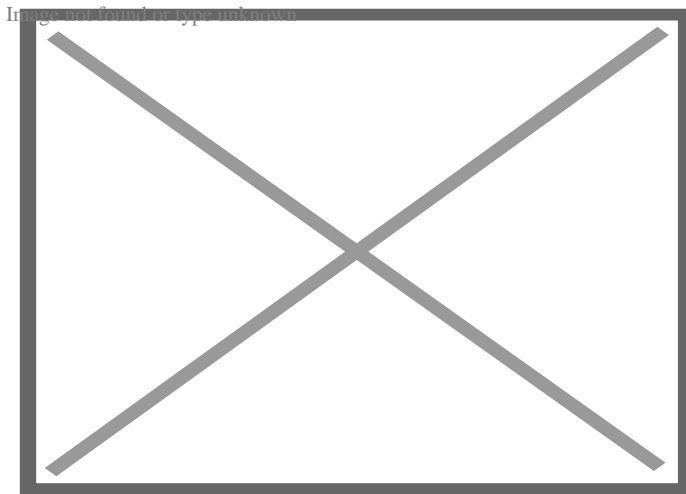
One of the challenges is the development of more efficient green LEDs. The theoretical maximum for green LEDs is 683 lumens per watt but as of 2010 few green LEDs exceed even 100 lumens per watt. The blue and red LEDs approach their theoretical limits.^[citation needed]

Multicolor LEDs offer a means to form light of different colors. Most perceivable colors can be formed by mixing different amounts of three primary colors. This allows precise dynamic color control. Their emission power decays exponentially with rising temperature,^[30] resulting in a substantial change in color stability. Such problems inhibit industrial use. Multicolor LEDs without phosphors cannot provide good color rendering because each LED is a narrowband source. LEDs without phosphor, while a poorer solution for general lighting, are the best solution for displays, either backlight of LCD, or direct LED based pixels.

Dimming a multicolor LED source to match the characteristics of incandescent lamps is difficult because manufacturing variations, age, and temperature change the actual color value output. To emulate the appearance of dimming incandescent lamps may require a feedback system with color sensor to actively monitor and control the color.^[31]

Phosphor-based LEDs

[edit]

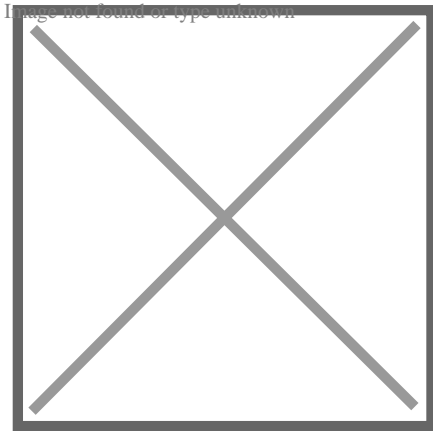


Spectrum of a white LED showing blue light directly emitted by the GaN-based LED (peak at about 465 nm) and the more broadband Stokes-shifted light emitted by the Ce^{3+} :YAG phosphor, which emits at roughly 500–700 nm

This method involves coating LEDs of one color (mostly blue LEDs made of InGaN) with phosphors of different colors to form white light; the resultant LEDs are called phosphor-based or phosphor-converted white LEDs (pcLEDs).^[32] A fraction of the blue light undergoes the Stokes shift, which transforms it from shorter wavelengths to longer. Depending on the original LED's color, various color phosphors are used. Using several phosphor layers of distinct colors broadens the emitted spectrum, effectively raising the color rendering index (CRI).^[33]

Phosphor-based LEDs have efficiency losses due to heat loss from the Stokes shift and also other phosphor-related issues. Their luminous efficacies compared to normal LEDs depend on the spectral distribution of the resultant light output and the original wavelength of the LED itself. For example, the luminous efficacy of a typical YAG yellow phosphor based white LED ranges from 3 to 5 times the luminous efficacy of the original blue LED because of the human eye's greater sensitivity to yellow than to blue (as modeled in the luminosity function).

Due to the simplicity of manufacturing, the phosphor method is still the most popular method for making high-intensity white LEDs. The design and production of a light source or light fixture using a monochrome emitter with phosphor conversion is simpler and cheaper than a complex RGB system, and the majority of high-intensity white LEDs presently on the market are manufactured using phosphor light conversion.^[citation needed]



1 watt 9 volt three chips SMD phosphor based white LED

Among the challenges being faced to improve the efficiency of LED-based white light sources is the development of more efficient phosphors. As of 2010, the most efficient yellow phosphor is still the YAG phosphor, with less than 10% Stokes shift loss. Losses attributable to internal optical losses due to re-absorption in the LED chip and in the LED packaging itself account typically for another 10% to 30% of efficiency loss. Currently, in the area of phosphor LED development, much effort is being spent on optimizing these devices to higher light output and higher operation temperatures. For instance, the efficiency can be raised by adapting better package design or by using a more suitable type of phosphor. Conformal coating process is frequently used to address the issue of varying phosphor thickness.^[citation needed]

Some phosphor-based white LEDs encapsulate InGaN blue LEDs inside phosphor-coated epoxy. Alternatively, the LED might be paired with a remote phosphor, a preformed polycarbonate piece coated with the phosphor material. Remote phosphors provide more diffuse light, which is desirable for many applications. Remote phosphor designs are also more tolerant of variations in the LED emissions spectrum. A common yellow phosphor material is cerium-doped yttrium aluminium garnet ($\text{Ce}^{3+}:\text{YAG}$).^[citation needed]

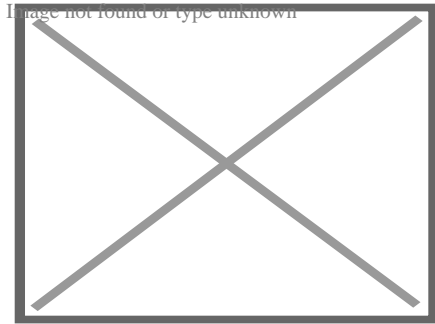
White LEDs can also be made by coating near-ultraviolet (NUV) LEDs with a mixture of high-efficiency europium-based phosphors that emit red and blue, plus copper and aluminium-doped zinc sulfide ($\text{ZnS}:\text{Cu, Al}$) that emits green. This is a method analogous to the way fluorescent lamps work. This method is less efficient than blue LEDs with YAG:Ce phosphor, as the Stokes shift is larger, so more energy is converted to heat, but yields light with better spectral characteristics, which render color better. Due to the higher radiative output of the ultraviolet LEDs than of the blue ones, both methods offer comparable brightness. A concern is that UV light may leak from a malfunctioning light source and cause harm to human eyes or skin.^[citation needed]

A new style of wafers composed of gallium-nitride-on-silicon (GaN-on-Si) is being used to produce white LEDs using 200-mm silicon wafers. This avoids the typical costly sapphire substrate in relatively small 100- or 150-mm wafer sizes.^[34] The sapphire apparatus must be coupled with a mirror-like collector to reflect light that would otherwise be wasted. It

was predicted that since 2020, 40% of all GaN LEDs are made with GaN-on-Si. Manufacturing large sapphire material is difficult, while large silicon material is cheaper and more abundant. LED companies shifting from using sapphire to silicon should be a minimal investment.[³⁵]

Mixed white LEDs

[edit]



Tunable white LED array in a floodlight

There are RGBW LEDs that combine RGB units with a phosphor white LED on the market. Doing so retains the extremely tunable color of RGB LED, but allows color rendering and efficiency to be optimized when a color close to white is selected.[³⁶]

Some phosphor white LED units are "tunable white", blending two extremes of color temperatures (commonly 2700K and 6500K) to produce intermediate values. This feature allows users to change the lighting to suit the current use of a multifunction room.[³⁷] As illustrated by a straight line on the chromaticity diagram, simple two-white blends will have a pink bias, becoming most severe in the middle. A small amount of green light, provided by another LED, could correct the problem.[³⁸] Some products are RGBWW, i.e. RGBW with tunable white.[³⁹]

A final class of white LED with mixed light is dim-to-warm. These are ordinary 2700K white LED bulbs with a small red LED that turns on when the bulb is dimmed. Doing so makes the color warmer, emulating an incandescent light bulb.[³⁹]

Other white LEDs

[edit]

Another method used to produce experimental white light LEDs used no phosphors at all and was based on homoepitaxially grown zinc selenide (ZnSe) on a ZnSe substrate that simultaneously emitted blue light from its active region and yellow light from the substrate.[⁴⁰]

Organic light-emitting diodes (OLEDs)

[edit]

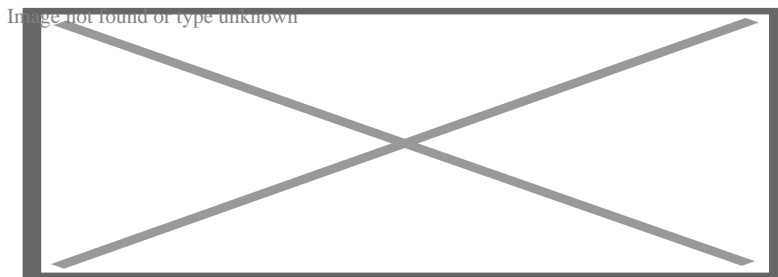
Main article: OLED

In an organic light-emitting diode (OLED), the electroluminescent material composing the emissive layer of the diode is an organic compound. The organic material is electrically conductive due to the delocalization of pi electrons caused by conjugation over all or part of the molecule, and the material therefore functions as an organic semiconductor.^[41] The organic materials can be small organic molecules in a crystalline phase, or polymers.^[42]

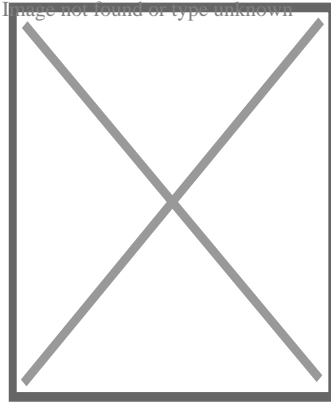
The potential advantages of OLEDs include thin, low-cost displays with a low driving voltage, wide viewing angle, and high contrast and color gamut.^[43] Polymer LEDs have the added benefit of printable and flexible displays.^{[44][45][46]} OLEDs have been used to make visual displays for portable electronic devices such as cellphones, digital cameras, lighting and televisions.^{[42][43]}

Types

[edit]



LEDs are produced in a variety of shapes and sizes. The color of the plastic lens is often the same as the actual color of light emitted, but not always. For instance, purple plastic is often used for infrared LEDs, and most blue devices have colorless housings. Modern high-power LEDs such as those used for lighting and backlighting are generally found in surface-mount technology (SMT) packages (not shown).



A variety of different diffused 5 mm THT-LEDs

- Red, 650 – 625nm
- Orange, 600 – 610nm
- Yellow, 587 – 591nm
- Green, 570 – 575nm
- Blue, 465 – 467nm
- Purple, 395 – 400nm

LEDs are made in different packages for different applications. A single or a few LED junctions may be packed in one miniature device for use as an indicator or pilot lamp. An LED array may include controlling circuits within the same package, which may range from a simple resistor, blinking or color changing control, or an addressable controller for RGB devices. Higher-powered white-emitting devices will be mounted on heat sinks and will be used for illumination. Alphanumeric displays in dot matrix or bar formats are widely available. Special packages permit connection of LEDs to optical fibers for high-speed data communication links.

Miniature

[edit]

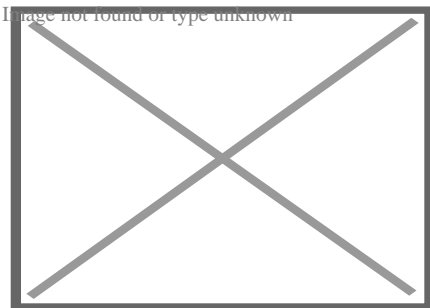
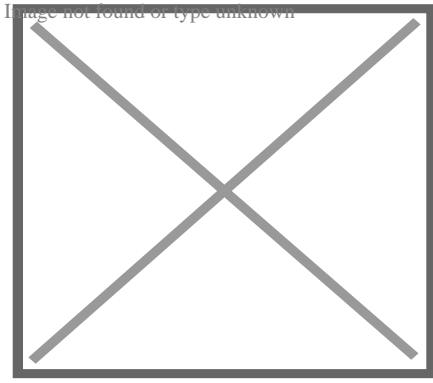


Image of miniature surface mount LEDs in most common sizes. They can be much smaller than a traditional 5 mm lamp type LED, shown on the upper left corner.



Very small (1.6×1.6×0.35 mm) red, green, and blue surface mount miniature LED package with gold wire bonding details

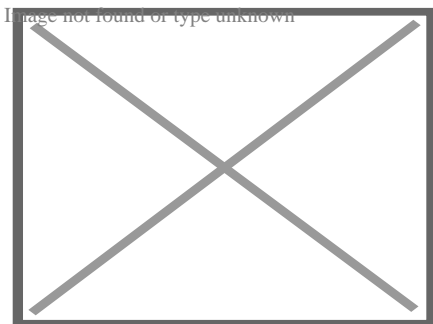
These are mostly single-die LEDs used as indicators, and they come in various sizes from 1.8 mm to 10 mm, through-hole and surface mount packages.^[47] Typical current ratings range from around 1 mA to above 20 mA. LED's can be soldered to a flexible PCB strip to form LED tape popularly used for decoration.

Common package shapes include round, with a domed or flat top, rectangular with a flat top (as used in bar-graph displays), and triangular or square with a flat top. The encapsulation may also be clear or tinted to improve contrast and viewing angle. Infrared devices may have a black tint to block visible light while passing infrared radiation, such as the Osram SFH 4546.^[48]

5 V and 12 V LEDs are ordinary miniature LEDs that have a series resistor for direct connection to a 5 V or 12 V supply.^[49]

High-power

[edit]



High-power light-emitting diodes attached to an LED star base (Luxeon, Lumileds)

See also: Solid-state lighting, LED lamp, and Thermal management of high-power LEDs

High-power LEDs (HP-LEDs) or high-output LEDs (HO-LEDs) can be driven at currents from hundreds of mA to more than an ampere, compared with the tens of mA for other LEDs. Some can emit over a thousand lumens.^{[50][51]} LED power densities up to 300 W/cm² have been achieved. Since overheating is destructive, the HP-LEDs must be mounted on a heat sink to allow for heat dissipation. If the heat from an HP-LED is not removed, the device fails in seconds. One HP-LED can often replace an incandescent bulb in a flashlight, or be set in an array to form a powerful LED lamp.

Some HP-LEDs in this category are the Nichia 19 series, Lumileds Rebel Led, Osram Opto Semiconductors Golden Dragon, and Cree X-lamp. As of September 2009, some HP-LEDs manufactured by Cree exceed 105 lm/W.^[52]

Examples for Haitz's law—which predicts an exponential rise in light output and efficacy of LEDs over time—are the CREE XP-G series LED, which achieved 105 lm/W in 2009^[52] and the Nichia 19 series with a typical efficacy of 140 lm/W, released in 2010.^[53]

AC-driven

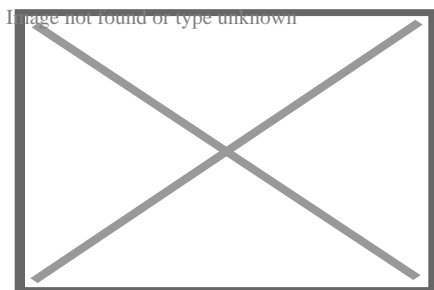
[edit]

LEDs developed by Seoul Semiconductor can operate on AC power without a DC converter. For each half-cycle, part of the LED emits light and part is dark, and this is reversed during the next half-cycle. The efficiency of this type of HP-LED is typically 40 lm/W.^[54] A large number of LED elements in series may be able to operate directly from line voltage. In 2009, Seoul Semiconductor released a high DC voltage LED, named 'Acrich MJT', capable of being driven from AC power with a simple controlling circuit. The low-power dissipation of these LEDs affords them more flexibility than the original AC LED design.^[55]

Strip

[edit]

This section is an excerpt from LED strip light.^[edit]



Several LED spots being reflected as continuous lighting strip

An LED strip, tape, or ribbon light is a flexible circuit board populated by surface-mount light-emitting diodes (SMD LEDs) and other components that usually comes with an adhesive backing. Traditionally, strip lights had been used solely in accent lighting, backlighting, task lighting, and decorative lighting applications, such as cove lighting. LED strip lights originated in the early 2000s. Since then, increased luminous efficacy and higher-power SMDs have allowed them to be used in applications such as high brightness task lighting, fluorescent and halogen lighting fixture replacements, indirect lighting applications, ultraviolet inspection during manufacturing processes, set and costume design, and growing plants.

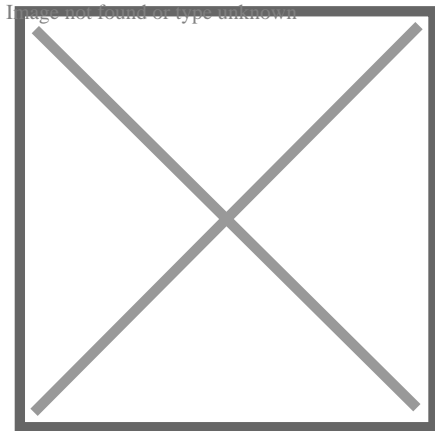
Application-specific

[edit]

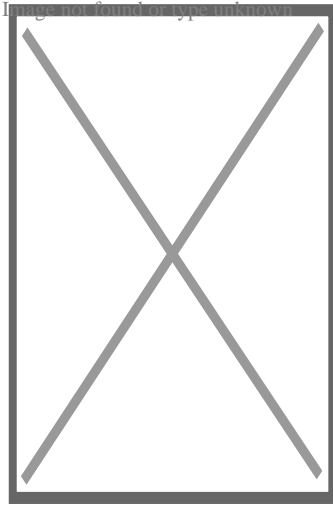


This section **needs additional citations for verification**. Please help improve this article by adding citations to reliable sources in this section. Unsourced material may be challenged and removed.

Find sources: "Light-emitting diode" – news · newspapers · books · scholar · JSTOR (October 2020) (Learn how and when to remove this message)



RGB-SMD-LED



Composite image of an 11 × 44 LED matrix lapel name tag display using 1608/0603-type SMD LEDs. Top: A little over half of the 21 × 86 mm display. Center: Close-up of LEDs in ambient light. Bottom: LEDs in their own red light.

Flashing

Flashing LEDs are used as attention seeking indicators without requiring external electronics. Flashing LEDs resemble standard LEDs but they contain an integrated voltage regulator and a multivibrator circuit that causes the LED to flash with a typical period of one second. In diffused lens LEDs, this circuit is visible as a small black dot. Most flashing LEDs emit light of one color, but more sophisticated devices can flash between multiple colors and even fade through a color sequence using RGB color mixing. Flashing SMD LEDs in the 0805 and other size formats have been available since early 2019.

Flickering

Integrated electronics Simple electronic circuits integrated into the LED package have been around since at least 2011 which produce a random LED intensity pattern reminiscent of a flickering candle.^[56] Reverse engineering in 2024 has suggested that some flickering LEDs with automatic sleep and wake modes might be using an integrated 8-bit microcontroller for such functionality.^[57]

Bi-color

Bi-color LEDs contain two different LED emitters in one case. There are two types of these. One type consists of two dies connected to the same two leads antiparallel to each other. Current flow in one direction emits one color, and current in the opposite direction emits the other color. The other type consists of two dies with separate leads for both dies and another lead for common anode or cathode so that they can be controlled independently. The most common bi-color combination is red/traditional green. Others include amber/traditional green, red/pure green, red/blue, and blue/pure green.

RGB tri-color

Tri-color LEDs contain three different LED emitters in one case. Each emitter is connected to a separate lead so they can be controlled independently. A four-lead arrangement is typical with one common lead (anode or cathode) and an additional lead for each color. Others have only two leads (positive and negative) and have a

built-in electronic controller. RGB LEDs consist of one red, one green, and one blue LED.^[58] By independently adjusting each of the three, RGB LEDs are capable of producing a wide color gamut. Unlike dedicated-color LEDs, these do not produce pure wavelengths. Modules may not be optimized for smooth color mixing.

Decorative-multicolor

Decorative-multicolor LEDs incorporate several emitters of different colors supplied by only two lead-out wires. Colors are switched internally by varying the supply voltage.

Alphanumeric

Alphanumeric LEDs are available in seven-segment, starburst, and dot-matrix format. Seven-segment displays handle all numbers and a limited set of letters. Starburst displays can display all letters. Dot-matrix displays typically use 5×7 pixels per character. Seven-segment LED displays were in widespread use in the 1970s and 1980s, but rising use of liquid crystal displays, with their lower power needs and greater display flexibility, has reduced the popularity of numeric and alphanumeric LED displays.

Digital RGB

Digital RGB addressable LEDs contain their own "smart" control electronics. In addition to power and ground, these provide connections for data-in, data-out, clock and sometimes a strobe signal. These are connected in a daisy chain, which allows individual LEDs in a long LED strip light to be easily controlled by a microcontroller. Data sent to the first LED of the chain can control the brightness and color of each LED independently of the others. They are used where a combination of maximum control and minimum visible electronics are needed such as strings for Christmas and LED matrices. Some even have refresh rates in the kHz range, allowing for basic video applications. These devices are known by their part number (WS2812 being common) or a brand name such as NeoPixel.

Filament

An LED filament consists of multiple LED chips connected in series on a common longitudinal substrate that forms a thin rod reminiscent of a traditional incandescent filament.^[59] These are being used as a low-cost decorative alternative for traditional light bulbs that are being phased out in many countries. The filaments use a rather high voltage, allowing them to work efficiently with mains voltages. Often a simple rectifier and capacitive current limiting are employed to create a low-cost replacement for a traditional light bulb without the complexity of the low voltage, high current converter that single die LEDs need.^[60] Usually, they are packaged in bulb similar to the lamps they were designed to replace, and filled with inert gas at slightly lower than ambient pressure to remove heat efficiently and prevent corrosion.

Chip-on-board arrays

Surface-mounted LEDs are frequently produced in chip on board (COB) arrays, allowing better heat dissipation than with a single LED of comparable luminous output.^[61] The LEDs can be arranged around a cylinder, and are called "corn cob lights" because of the rows of yellow LEDs.^[62]

Considerations for use

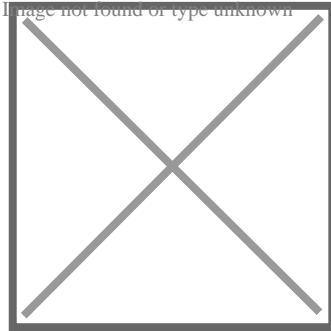
[edit]

- Efficiency: LEDs emit more lumens per watt than incandescent light bulbs.^[63] The efficiency of LED lighting fixtures is not affected by shape and size, unlike fluorescent light bulbs or tubes.
- Size: LEDs can be very small (smaller than 2 mm²^[64]) and are easily attached to printed circuit boards.

Power sources

[edit]

Main article: LED power sources



Simple LED circuit with resistor for current limiting

The current in an LED or other diodes rises exponentially with the applied voltage (see Shockley diode equation), so a small change in voltage can cause a large change in current. Current through the LED must be regulated by an external circuit such as a constant current source to prevent damage. Since most common power supplies are (nearly) constant-voltage sources, LED fixtures must include a power converter, or at least a current-limiting resistor. In some applications, the internal resistance of small batteries is sufficient to keep current within the LED rating.^{*[citation needed]*}

LEDs are sensitive to voltage. They must be supplied with a voltage above their threshold voltage and a current below their rating. Current and lifetime change greatly with a small change in applied voltage. They thus require a current-regulated supply (usually just a series resistor for indicator LEDs).^[65]

Efficiency droop: The efficiency of LEDs decreases as the electric current increases. Heating also increases with higher currents, which compromises LED lifetime. These effects put practical limits on the current through an LED in high power applications.^[66]

Electrical polarity

[edit]

Main article: Electrical polarity of LEDs

Unlike a traditional incandescent lamp, an LED will light only when voltage is applied in the forward direction of the diode. No current flows and no light is emitted if voltage is applied in the reverse direction. If the reverse voltage exceeds the breakdown voltage, which is typically about five volts, a large current flows and the LED will be damaged. If the reverse current is sufficiently limited to avoid damage, the reverse-conducting LED is a useful noise diode.^[citation needed]

By definition, the energy band gap of any diode is higher when reverse-biased than when forward-biased. Because the band gap energy determines the wavelength of the light emitted, the color cannot be the same when reverse-biased. The reverse breakdown voltage is sufficiently high that the emitted wavelength cannot be similar enough to still be visible. Though dual-LED packages exist that contain a different color LED in each direction, it is not expected that any single LED element can emit visible light when reverse-biased.^[citation needed]

It is not known if any zener diode could exist that emits light only in reverse-bias mode. Uniquely, this type of LED would conduct when connected backwards.

Appearance

[edit]

- Color: LEDs can emit light of an intended color without using any color filters as traditional lighting methods need. This is more efficient and can lower initial costs.
- Cool light: In contrast to most light sources, LEDs radiate very little heat in the form of IR that can cause damage to sensitive objects or fabrics. Wasted energy is dispersed as heat through the base of the LED.
- Color rendition: Most cool-white LEDs have spectra that differ significantly from a black body radiator like the sun or an incandescent light. The spike at 460 nm and dip at 500 nm can make the color of objects appear differently under cool-white LED illumination than sunlight or incandescent sources, due to metamerism,^[67] red surfaces being rendered particularly poorly by typical phosphor-based cool-white LEDs. The same is true with green surfaces. The quality of color rendition of an LED is measured by the Color Rendering Index (CRI).
- Dimming: LEDs can be dimmed either by pulse-width modulation or lowering the forward current.^[68] This pulse-width modulation is why LED lights, particularly headlights on cars, when viewed on camera or by some people, seem to flash or flicker. This is a type of stroboscopic effect.

Light properties

[edit]

- Switch on time: LEDs light up extremely quickly. A typical red indicator LED achieves full brightness in under a microsecond.^[69] LEDs used in communications devices can have even faster response times.

- Focus: The solid package of the LED can be designed to focus its light. Incandescent and fluorescent sources often require an external reflector to collect light and direct it in a usable manner. For larger LED packages total internal reflection (TIR) lenses are often used to the same effect. When large quantities of light are needed, many light sources such as LED chips are usually deployed, which are difficult to focus or collimate on the same target.
- Area light source: Single LEDs do not approximate a point source of light giving a spherical light distribution, but rather a lambertian distribution. So, LEDs are difficult to apply to uses needing a spherical light field. Different fields of light can be manipulated by the application of different optics or "lenses". LEDs cannot provide divergence below a few degrees.^[70]

Reliability

[edit]

- Shock resistance: LEDs, being solid-state components, are difficult to damage with external shock, unlike fluorescent and incandescent bulbs, which are fragile.^[71]
- Thermal runaway: Parallel strings of LEDs will not share current evenly due to the manufacturing tolerances in their forward voltage. Running two or more strings from a single current source may result in LED failure as the devices warm up. If forward voltage binning is not possible, a circuit is required to ensure even distribution of current between parallel strands.^[72]
- Slow failure: LEDs mainly fail by dimming over time, rather than the abrupt failure of incandescent bulbs.^[73]
- Lifetime: LEDs can have a relatively long useful life. One report estimates 35,000 to 50,000 hours of useful life, though time to complete failure may be shorter or longer.^[74] Fluorescent tubes typically are rated at about 10,000 to 25,000 hours, depending partly on the conditions of use, and incandescent light bulbs at 1,000 to 2,000 hours. Several DOE demonstrations have shown that reduced maintenance costs from this extended lifetime, rather than energy savings, is the primary factor in determining the payback period for an LED product.^[75]
- Cycling: LEDs are ideal for uses subject to frequent on-off cycling, unlike incandescent and fluorescent lamps that fail faster when cycled often, or high-intensity discharge lamps (HID lamps) that require a long time to warm up to full output and to cool down before they can be lighted again if they are being restarted.
- Temperature dependence: LED performance largely depends on the ambient temperature of the operating environment – or thermal management properties. Overdriving an LED in high ambient temperatures may result in overheating the LED package, eventually leading to device failure. An adequate heat sink is needed to maintain long life. This is especially important in automotive, medical, and military uses where devices must operate over a wide range of temperatures, and require low failure rates.

Manufacturing

[edit]

LED manufacturing involves multiple steps, including epitaxy, chip processing, chip separation, and packaging.^[76]

In a typical LED manufacturing process, encapsulation is performed after probing, dicing, die transfer from wafer to package, and wire bonding or flip chip mounting,^[77] perhaps using indium tin oxide, a transparent electrical conductor. In this case, the bond wire(s) are attached to the ITO film that has been deposited in the LEDs.

Flip chip circuit on board (COB) is a technique that can be used to manufacture LEDs.^[78]

Colors and materials

[edit]

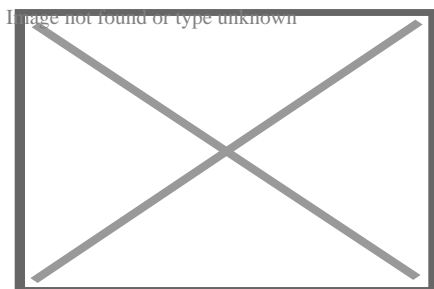
Conventional LEDs are made from a variety of inorganic semiconductor materials. The following table shows the available colors with wavelength range, voltage drop and material:

	Color	Wavelength (nm)	Voltage (V)	Semiconductor material
	Infrared	$\lambda > 760$	$\lambda V < 1.9$	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
	Red	$610 < \lambda < 760$	$1.63 < \lambda V < 2.03$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Orange	$590 < \lambda < 610$	$2.03 < \lambda V < 2.10$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Yellow	$570 < \lambda < 590$	$2.10 < \lambda V < 2.18$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)

Green	$500 < \lambda < 570$	$1.9^{[79]} < V < 4.0$	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Blue	$450 < \lambda < 500$	$2.48 < V < 3.7$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	$400 < \lambda < 450$	$2.76 < V < 4.0$	Indium gallium nitride (InGaN)
Purple	multiple types	$2.48 < V < 3.7$	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	$\lambda < 400$	$3.1 < V < 4.4$	Diamond (235 nm) ^[80] Boron nitride (215 nm) ^[81] ^[82] Aluminium nitride (AlN) (210 nm) ^[16] Aluminium gallium nitride (AlGaInN) Aluminium gallium indium nitride (AlGaInN) — (down to 210 nm) ^[83]
White	Broad spectrum	$2.7 < V < 3.5$	Blue diode with yellow phosphor or violet/UV diode with multi-color phosphor

Applications

[edit]



Daytime running light LEDs of an automobile

LED uses fall into five major categories:

- Visual signals where light goes more or less directly from the source to the human eye, to convey a message or meaning
- Illumination where light is reflected from objects to give visual response of these objects
- Measuring and interacting with processes involving no human vision^[84]
- Narrow band light sensors where LEDs operate in a reverse-bias mode and respond to incident light, instead of emitting light^{[85][86][87][88]}
- Indoor cultivation, including cannabis.^[89]

The application of LEDs in horticulture has revolutionized plant cultivation by providing energy-efficient, customizable lighting solutions that optimize plant growth and development.^[90] LEDs offer precise control over light spectra, intensity, and photoperiods, enabling growers to tailor lighting conditions to the specific needs of different plant species and growth stages. This technology enhances photosynthesis, improves crop yields, and reduces energy costs compared to traditional lighting systems. Additionally, LEDs generate less heat, allowing closer placement to plants without risking thermal damage, and contribute to sustainable farming practices by lowering carbon footprints and extending growing seasons in controlled environments.^[91] Light spectrum affects growth, metabolite profile, and resistance against fungal phytopathogens of *Solanum lycopersicum* seedlings.^[92] LEDs can also be used in micropropagation.^[93]

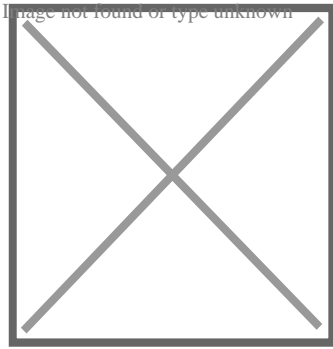
Indicators and signs

[edit]



This section does not cite any sources. Please help improve this section by adding citations to reliable sources. Unsourced material may be challenged and removed. (October 2020) *(Learn how and when to remove this message)*

The low energy consumption, low maintenance and small size of LEDs has led to uses as status indicators and displays on a variety of equipment and installations. Large-area LED displays are used as stadium displays, dynamic decorative displays, and dynamic message signs on freeways. Thin, lightweight message displays are used at airports and railway stations, and as destination displays for trains, buses, trams, and ferries.



Red and green LED traffic signals

One-color light is well suited for traffic lights and signals, exit signs, emergency vehicle lighting, ships' navigation lights, and LED-based Christmas lights

Because of their long life, fast switching times, and visibility in broad daylight due to their high output and focus, LEDs have been used in automotive brake lights and turn signals. The use in brakes improves safety, due to a great reduction in the time needed to light fully, or faster rise time, about 0.1 second faster^[*citation needed*] than an incandescent bulb. This gives drivers behind more time to react. In a dual intensity circuit (rear markers and brakes) if the LEDs are not pulsed at a fast enough frequency, they can create a phantom array, where ghost images of the LED appear if the eyes quickly scan across the array. White LED headlamps are beginning to appear. Using LEDs has styling advantages because LEDs can form much thinner lights than incandescent lamps with parabolic reflectors.

Due to the relative cheapness of low output LEDs, they are also used in many temporary uses such as glowsticks and throwies. Artists have also used LEDs for LED art.

Lighting

[edit]

Main article: LED lamp

With the development of high-efficiency and high-power LEDs, it has become possible to use LEDs in lighting and illumination. To encourage the shift to LED lamps and other high-efficiency lighting, in 2008 the US Department of Energy created the L Prize competition. The Philips Lighting North America LED bulb won the first competition on August 3, 2011, after successfully completing 18 months of intensive field, lab, and product testing.^[94]

Efficient lighting is needed for sustainable architecture. As of 2011, some LED bulbs provide up to 150 lm/W and even inexpensive low-end models typically exceed 50 lm/W, so that a 6-watt LED could achieve the same results as a standard 40-watt incandescent bulb. The lower heat output of LEDs also reduces demand on air conditioning systems. Worldwide, LEDs are rapidly adopted to displace less effective sources such as incandescent lamps and CFLs and reduce electrical energy consumption and its

associated emissions. Solar powered LEDs are used as street lights and in architectural lighting.

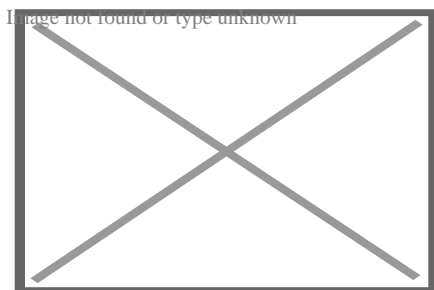
The mechanical robustness and long lifetime are used in automotive lighting on cars, motorcycles, and bicycle lights. LED street lights are employed on poles and in parking garages. In 2007, the Italian village of Torraca was the first place to convert its street lighting to LEDs.^[95]

Cabin lighting on recent^[when?] Airbus and Boeing jetliners uses LED lighting. LEDs are also being used in airport and heliport lighting. LED airport fixtures currently include medium-intensity runway lights, runway centerline lights, taxiway centerline and edge lights, guidance signs, and obstruction lighting.

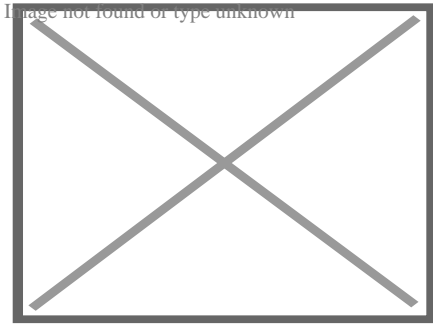
LEDs are also used as a light source for DLP projectors, and to backlight newer LCD television (referred to as LED TV), computer monitor (including laptop) and handheld device LCDs, succeeding older CCFL-backlit LCDs although being superseded by OLED screens. RGB LEDs raise the color gamut by as much as 45%. Screens for TV and computer displays can be made thinner using LEDs for backlighting.^[96]

LEDs are small, durable and need little power, so they are used in handheld devices such as flashlights. LED strobe lights or camera flashes operate at a safe, low voltage, instead of the 250+ volts commonly found in xenon flashlamp-based lighting. This is especially useful in cameras on mobile phones, where space is at a premium and bulky voltage-raising circuitry is undesirable.

LEDs are used for infrared illumination in night vision uses including security cameras. A ring of LEDs around a video camera, aimed forward into a retroreflective background, allows chroma keying in video productions.



LED for miners, to increase visibility inside mines



Los Angeles Vincent Thomas Bridge illuminated with blue LEDs

LEDs are used in mining operations, as cap lamps to provide light for miners. Research has been done to improve LEDs for mining, to reduce glare and to increase illumination, reducing risk of injury to the miners.^[97]

LEDs are increasingly finding uses in medical and educational applications, for example as mood enhancement.^[98] NASA has even sponsored research for the use of LEDs to promote health for astronauts.^[99]

Data communication and other signalling

[edit]

See also: Li-Fi, fibre optics, Visible light communication, and Optical disc

Light can be used to transmit data and analog signals. For example, lighting white LEDs can be used in systems assisting people to navigate in closed spaces while searching necessary rooms or objects.^[100]

Assistive listening devices in many theaters and similar spaces use arrays of infrared LEDs to send sound to listeners' receivers. Light-emitting diodes (as well as semiconductor lasers) are used to send data over many types of fiber optic cable, from digital audio over TOSLINK cables to the very high bandwidth fiber links that form the Internet backbone. For some time, computers were commonly equipped with IrDA interfaces, which allowed them to send and receive data to nearby machines via infrared.

Because LEDs can cycle on and off millions of times per second, very high data bandwidth can be achieved.^[101] For that reason, visible light communication (VLC) has been proposed as an alternative to the increasingly competitive radio bandwidth.^[102] VLC operates in the visible part of the electromagnetic spectrum, so data can be transmitted without occupying the frequencies of radio communications.

Machine vision systems

[edit]

Main article: Machine vision

Machine vision systems often require bright and homogeneous illumination, so features of interest are easier to process. LEDs are often used.

Barcode scanners are the most common example of machine vision applications, and many of those scanners use red LEDs instead of lasers. Optical computer mice use LEDs as a light source for the miniature camera within the mouse.

LEDs are useful for machine vision because they provide a compact, reliable source of light. LED lamps can be turned on and off to suit the needs of the vision system, and the shape of the beam produced can be tailored to match the system's requirements.

Biological detection

[edit]

The discovery of radiative recombination in aluminum gallium nitride (AlGa_N) alloys by U.S. Army Research Laboratory (ARL) led to the conceptualization of UV light-emitting diodes (LEDs) to be incorporated in light-induced fluorescence sensors used for biological agent detection.^{[103][104][105]} In 2004, the Edgewood Chemical Biological Center (ECBC) initiated the effort to create a biological detector named TAC-BIO. The program capitalized on semiconductor UV optical sources (SUVOS) developed by the Defense Advanced Research Projects Agency (DARPA).^[105]

UV-induced fluorescence is one of the most robust techniques used for rapid real-time detection of biological aerosols.^[105] The first UV sensors were lasers lacking in-field-use practicality. In order to address this, DARPA incorporated SUVOS technology to create a low-cost, small, lightweight, low-power device. The TAC-BIO detector's response time was one minute from when it sensed a biological agent. It was also demonstrated that the detector could be operated unattended indoors and outdoors for weeks at a time.^[105]

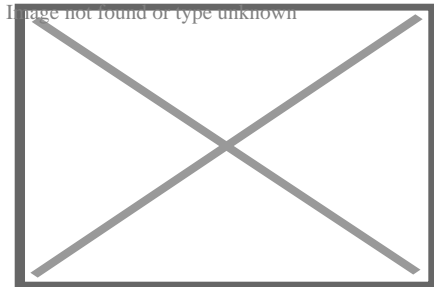
Aerosolized biological particles fluoresce and scatter light under a UV light beam. Observed fluorescence is dependent on the applied wavelength and the biochemical fluorophores within the biological agent. UV induced fluorescence offers a rapid, accurate, efficient and logistically practical way for biological agent detection. This is because the use of UV fluorescence is reagentless, or a process that does not require an added chemical to produce a reaction, with no consumables, or produces no chemical byproducts.^[105]

Additionally, TAC-BIO can reliably discriminate between threat and non-threat aerosols. It was claimed to be sensitive enough to detect low concentrations, but not so sensitive that it would cause false positives. The particle-counting algorithm used in the device converted raw data into information by counting the photon pulses per unit of time from the fluorescence and scattering detectors, and comparing the value to a set threshold.^[106]

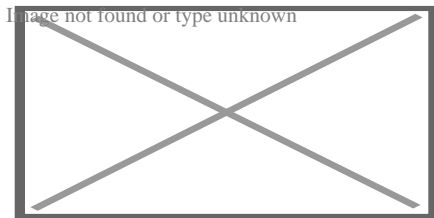
The original TAC-BIO was introduced in 2010, while the second-generation TAC-BIO GEN II, was designed in 2015 to be more cost-efficient, as plastic parts were used. Its small, light-weight design allows it to be mounted to vehicles, robots, and unmanned aerial vehicles. The second-generation device could also be utilized as an environmental detector to monitor air quality in hospitals, airplanes, or even in households to detect fungus and mold.^{[107][108]}

Other applications

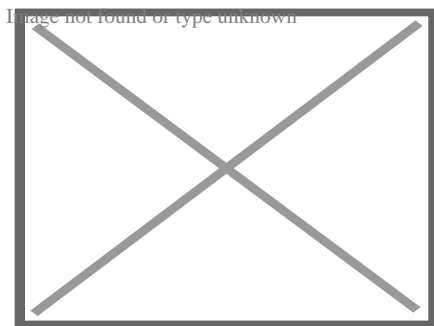
[edit]



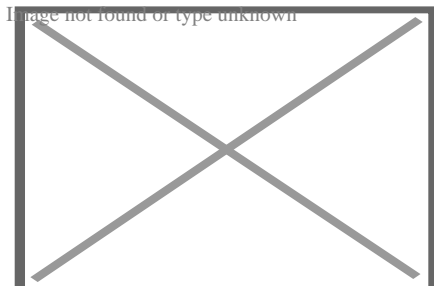
LED costume for stage performers



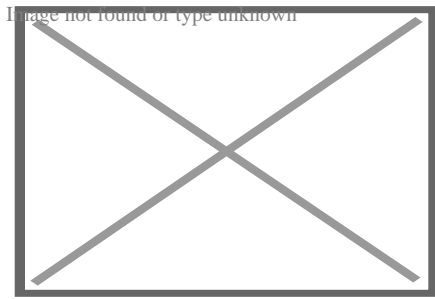
LED wallpaper by Meystyle



A large LED display behind a disc jockey



Seven-segment display that can display four digits and points



LED panel light source used in an early experiment on potato growth during Shuttle mission STS-73 to investigate the potential for growing food on future long duration missions

The light from LEDs can be modulated very quickly so they are used extensively in optical fiber and free space optics communications. This includes remote controls, such as for television sets, where infrared LEDs are often used. Opto-isolators use an LED combined with a photodiode or phototransistor to provide a signal path with electrical isolation between two circuits. This is especially useful in medical equipment where the signals from a low-voltage sensor circuit (usually battery-powered) in contact with a living organism must be electrically isolated from any possible electrical failure in a recording or monitoring device operating at potentially dangerous voltages. An optoisolator also lets information be transferred between circuits that do not share a common ground potential.

Many sensor systems rely on light as the signal source. LEDs are often ideal as a light source due to the requirements of the sensors. The Nintendo Wii's sensor bar uses infrared LEDs. Pulse oximeters use them for measuring oxygen saturation. Some flatbed scanners use arrays of RGB LEDs rather than the typical cold-cathode fluorescent lamp as the light source. Having independent control of three illuminated colors allows the scanner to calibrate itself for more accurate color balance, and there is no need for warm-up. Further, its sensors only need be monochromatic, since at any one time the page being scanned is only lit by one color of light.

Since LEDs can also be used as photodiodes, they can be used for both photo emission and detection. This could be used, for example, in a touchscreen that registers reflected light from a finger or stylus.^[109] Many materials and biological systems are sensitive to, or dependent on, light. Grow lights use LEDs to increase photosynthesis in plants,^[110] and bacteria and viruses can be removed from water and other substances using UV LEDs for sterilization.^[15] LEDs of certain wavelengths have also been used for light therapy treatment of neonatal jaundice and acne.^[111]

UV LEDs, with spectra range of 220 nm to 395 nm, have other applications, such as water/air purification, surface disinfection, glue curing, free-space non-line-of-sight communication, high performance liquid chromatography, UV curing dye printing, phototherapy (295nm Vitamin D, 308nm Excimer lamp or laser replacement), medical/analytical instrumentation, and DNA absorption.^{[104][112]}

LEDs have also been used as a medium-quality voltage reference in electronic circuits. The forward voltage drop (about 1.7 V for a red LED or 1.2V for an infrared) can be used instead of a Zener diode in low-voltage regulators. Red LEDs have the flattest I/V curve above the knee. Nitride-based LEDs have a fairly steep I/V curve and are useless for this purpose. Although LED forward voltage is far more current-dependent than a Zener diode, Zener diodes with breakdown voltages below 3 V are not widely available.

The progressive miniaturization of low-voltage lighting technology, such as LEDs and OLEDs, suitable to incorporate into low-thickness materials has fostered experimentation in combining light sources and wall covering surfaces for interior walls in the form of LED wallpaper.

Research and development

[edit]

Key challenges

[edit]

LEDs require optimized efficiency to hinge on ongoing improvements such as phosphor materials and quantum dots.^[113]

The process of down-conversion (the method by which materials convert more-energetic photons to different, less energetic colors) also needs improvement. For example, the red phosphors that are used today are thermally sensitive and need to be improved in that aspect so that they do not color shift and experience efficiency drop-off with temperature. Red phosphors could also benefit from a narrower spectral width to emit more lumens and becoming more efficient at converting photons.^[114]

In addition, work remains to be done in the realms of current efficiency droop, color shift, system reliability, light distribution, dimming, thermal management, and power supply performance.^[113]

Early suspicions were that the LED droop was caused by elevated temperatures. Scientists showed that temperature was not the root cause of efficiency droop.^[115] The mechanism causing efficiency droop was identified in 2007 as Auger recombination, which was taken with mixed reaction.^[66] A 2013 study conclusively identified Auger recombination as the cause.^[116]

Potential technology

[edit]

A new family of LEDs are based on the semiconductors called perovskites. In 2018, less than four years after their discovery, the ability of perovskite LEDs (PLEDs) to produce light from electrons already rivaled those of the best performing OLEDs.^[117] They have a potential for cost-effectiveness as they can be processed from solution, a low-cost and low-tech method, which might allow perovskite-based devices that have large areas to be made with extremely low cost. Their efficiency is superior by eliminating non-radiative losses, in other words, elimination of recombination pathways that do not produce photons; or by solving outcoupling problem (prevalent for thin-film LEDs) or balancing charge carrier injection to increase the EQE (external quantum efficiency). The most up-to-date PLED devices have broken the performance barrier by shooting the EQE above 20%.^[118]

In 2018, Cao et al. and Lin et al. independently published two papers on developing perovskite LEDs with EQE greater than 20%, which made these two papers a mile-stone in PLED development. Their device have similar planar structure, i.e. the active layer (perovskite) is sandwiched between two electrodes. To achieve a high EQE, they not only reduced non-radiative recombination, but also utilized their own, subtly different methods to improve the EQE.^[118]

In the work of Cao *et al.*,^[119] researchers targeted the outcoupling problem, which is that the optical physics of thin-film LEDs causes the majority of light generated by the semiconductor to be trapped in the device.^[120] To achieve this goal, they demonstrated that solution-processed perovskites can spontaneously form submicrometre-scale crystal platelets, which can efficiently extract light from the device. These perovskites are formed via the introduction of amino acid additives into the perovskite precursor solutions. In addition, their method is able to passivate perovskite surface defects and reduce nonradiative recombination. Therefore, by improving the light outcoupling and reducing nonradiative losses, Cao and his colleagues successfully achieved PLED with EQE up to 20.7%.^[119]

Lin and his colleague used a different approach to generate high EQE. Instead of modifying the microstructure of perovskite layer, they chose to adopt a new strategy for managing the compositional distribution in the device—an approach that simultaneously provides high luminescence and balanced charge injection. In other words, they still used flat emissive layer, but tried to optimize the balance of electrons and holes injected into the perovskite, so as to make the most efficient use of the charge carriers. Moreover, in the perovskite layer, the crystals are perfectly enclosed by MABr additive (where MA is CH_3NH_3). The MABr shell passivates the nonradiative defects that would otherwise be present perovskite crystals, resulting in reduction of the nonradiative recombination. Therefore, by balancing charge injection and decreasing nonradiative losses, Lin and his colleagues developed PLED with EQE up to 20.3%.^[121]

Health and safety

[edit]

Certain blue LEDs and cool-white LEDs can exceed safe limits of the so-called blue-light hazard as defined in eye safety specifications such as "ANSI/IESNA RP-27.1–05: Recommended Practice for Photobiological Safety for Lamp and Lamp Systems".^[122] One study showed no evidence of a risk in normal use at domestic illuminance,^[123] and that caution is only needed for particular occupational situations or for specific populations.^[124] In 2006, the International Electrotechnical Commission published *IEC 62471 Photobiological safety of lamps and lamp systems*, replacing the application of early laser-oriented standards for classification of LED sources.^[125]

While LEDs have the advantage over fluorescent lamps, in that they do not contain mercury, they may contain other hazardous metals such as lead and arsenic.^[126]

In 2016 the American Medical Association (AMA) issued a statement concerning the possible adverse influence of blueish street lighting on the sleep-wake cycle of city-dwellers. Critics in the industry claim exposure levels are not high enough to have a noticeable effect.^[127]

Environmental issues

[edit]

- Light pollution: Because white LEDs emit more short wavelength light than sources such as high-pressure sodium vapor lamps, the increased blue and green sensitivity of scotopic vision means that white LEDs used in outdoor lighting cause substantially more sky glow.^[55]
- Impact on wildlife: LEDs are much more attractive to insects than sodium-vapor lights, so much so that there has been speculative concern about the possibility of disruption to food webs.^[128]^[129] LED lighting near beaches, particularly intense blue and white colors, can disorient turtle hatchlings and make them wander inland instead.^[130] The use of "turtle-safe lighting" LEDs that emit only at narrow portions of the visible spectrum is encouraged by conservancy groups in order to reduce harm.^[131]
- Use in winter conditions: Since they do not give off much heat in comparison to incandescent lights, LED lights used for traffic control can have snow obscuring them, leading to accidents.^[132]^[133]

See also

[edit]


-  **Electronics portal**


Image of a printed circuit board
-  **Energy portal**

Image of a hand holding a glowing light bulb
- LED tattoo
- High-CRI LED lighting
- List of light sources
- MicroLED
- Superluminescent diode

- Perovskite light-emitting diode

References

[edit]

1. ^ "HJ Round was a pioneer in the development of the LED". *www.myledpassion.com*. Archived from the original on October 28, 2020. Retrieved April 11, 2017.
2. ^ "The life and times of the LED — a 100-year history" (PDF). The Optoelectronics Research Centre, University of Southampton. April 2007. Archived from the original (PDF) on September 15, 2012. Retrieved September 4, 2012.
3. ^ US Patent 3293513, "Semiconductor Radiant Diode", James R. Biard and Gary Pittman, Filed on Aug. 8th, 1962, Issued on Dec. 20th, 1966.
4. ^ "Inventor of Long-Lasting, Low-Heat Light Source Awarded \$500,000 Lemelson-MIT Prize for Invention". Washington, D.C. Massachusetts Institute of Technology. April 21, 2004. Archived from the original on October 9, 2011. Retrieved December 21, 2011.
5. ^ Edwards, Kimberly D. "Light Emitting Diodes" (PDF). University of California, Irvine. p. 2. Archived from the original (PDF) on February 14, 2019. Retrieved January 12, 2019.
6. ^ Lighting Research Center. "How is white light made with LEDs?". Rensselaer Polytechnic Institute. Archived from the original on May 2, 2021. Retrieved January 12, 2019.
7. ^ Okon, Thomas M.; Biard, James R. (2015). "The First Practical LED" (PDF). *EdisonTechCenter.org*. Edison Tech Center. Retrieved February 2, 2016.
8. ^ Peláez, E. A; Villegas, E. R (2007). "LED power reduction trade-offs for ambulatory pulse oximetry". 2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Vol. 2007. pp. 2296–9. doi:10.1109/IEMBS.2007.4352784. ISBN 978-1-4244-0787-3. ISSN 1557-170X. PMID 18002450. S2CID 34626885.
9. ^ Lossev, O.V. (November 1928). "CII. Luminous carborundum detector and detection effect and oscillations with crystals". *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*. **6** (39): 1024–1044. doi:10.1080/14786441108564683. ISSN 1941-5982.
10. ^ Yao, H. Walter; Schubert, E. Fred; United States; AIXTRON, Inc; Society of Photo-optical Instrumentation Engineers, eds. (2001). *Light-emitting diodes: research, manufacturing, and applications V: 24-25 January 2001, San Jose, USA*. SPIE proceedings series. Bellingham, Wash: SPIE. ISBN 978-0-8194-3956-7. OCLC 47203707.
11. ^ Pearsall, Thomas (2010). *Photonics Essentials*, 2nd edition. McGraw-Hill. ISBN 978-0-07-162935-5. Archived from the original on August 17, 2021. Retrieved February 25, 2021.
12. ^ "LED Basics | Department of Energy". *www.energy.gov*. Retrieved October 22, 2018.
13. ^ "LED Spectral Distribution". *optiwave.com*. July 25, 2013. Retrieved June 20, 2017.

14. ^ Cooke, Mike (April–May 2010). "Going Deep for UV Sterilization LEDs" (PDF). *Semiconductor Today*. **5** (3): 82. Archived from the original (PDF) on May 15, 2013.
15. ^ **a b** Mori, M.; Hamamoto, A.; Takahashi, A.; Nakano, M.; Wakikawa, N.; Tachibana, S.; Ikehara, T.; Nakaya, Y.; Akutagawa, M.; Kinouchi, Y. (2007). "Development of a new water sterilization device with a 365 nm UV-LED". *Medical & Biological Engineering & Computing*. **45** (12): 1237–1241. doi:10.1007/s11517-007-0263-1. PMID 17978842. S2CID 2821545.
16. ^ **a b** Taniyasu, Y.; Kasu, M.; Makimoto, T. (2006). "An aluminium nitride light-emitting diode with a wavelength of 210 nanometres". *Nature*. **441** (7091): 325–328. Bibcode:2006Natur.441..325T. doi:10.1038/nature04760. PMID 16710416. S2CID 4373542.
17. ^ Kubota, Y.; Watanabe, K.; Tsuda, O.; Taniguchi, T. (2007). "Deep Ultraviolet Light-Emitting Hexagonal Boron Nitride Synthesized at Atmospheric Pressure". *Science*. **317** (5840): 932–934. Bibcode:2007Sci...317..932K. doi:10.1126/science.1144216. PMID 17702939.
18. ^ Watanabe, K.; Taniguchi, T.; Kanda, H. (2004). "Direct-bandgap properties and evidence for ultraviolet lasing of hexagonal boron nitride single crystal". *Nature Materials*. **3** (6): 404–409. Bibcode:2004NatMa...3..404W. doi:10.1038/nmat1134. PMID 15156198. S2CID 23563849.
19. ^ Koizumi, S.; Watanabe, K.; Hasegawa, M.; Kanda, H. (2001). "Ultraviolet Emission from a Diamond pn Junction". *Science*. **292** (5523): 1899–1901. Bibcode:2001Sci...292.1899K. doi:10.1126/science.1060258. PMID 11397942. S2CID 10675358.
20. ^ "Seeing Red with PFS Phosphor".
21. ^ "GE Lighting manufactures PFS red phosphor for LED display backlight applications". March 31, 2015.
22. ^ Murphy, James E.; Garcia-Santamaria, Florencio; Setlur, Anant A.; Sista, Srinivas (2015). "62.4: PFS, $K_2SiF_6:Mn^{4+}$: The Red-line Emitting LED Phosphor behind GE's TriGain Technology™ Platform". *Sid Symposium Digest of Technical Papers*. **46**: 927–930. doi:10.1002/sdtp.10406.
23. ^ Dutta, Partha S.; Liotta, Kathryn M. (2018). "Full Spectrum White LEDs of Any Color Temperature with Color Rendering Index Higher Than 90 Using a Single Broad-Band Phosphor". *ECS Journal of Solid State Science and Technology*. **7**: R3194 – R3198. doi:10.1149/2.0251801jss. S2CID 103600941.
24. ^ Cho, Jaehee; Park, Jun Hyuk; Kim, Jong Kyu; Schubert, E. Fred (2017). "White light-emitting diodes: History, progress, and future". *Laser & Photonics Reviews*. **11** (2): 1600147. Bibcode:2017LPRv...1100147C. doi:10.1002/lpor.201600147. ISSN 1863-8880. S2CID 53645208.
25. ^ *Light-Emitting Diodes* (3rd Edition, 2018). E. Fred Schubert. February 3, 2018. ISBN 978-0-9863826-6-6.
26. ^ *Additive Manufacturing and Strategic Technologies in Advanced Ceramics*. John Wiley & Sons. August 16, 2016. ISBN 978-1-119-23600-9.
27. ^ Moreno, I.; Contreras, U. (2007). "Color distribution from multicolor LED arrays". *Optics Express*. **15** (6): 3607–3618. Bibcode:2007OExpr..15.3607M. doi:10.1364/OE.15.003607. PMID 19532605. S2CID 35468615.

28. ^ Yeh, Dong-Ming; Huang, Chi-Feng; Lu, Chih-Feng; Yang, Chih-Chung. "Making white-light-emitting diodes without phosphors | SPIE Homepage: SPIE". *spie.org*. Retrieved April 7, 2019.
29. ^ Cabrera, Rowan (2019). *Electronic Devices and Circuits*. EDTECH. ISBN 978-1839473838.
30. ^ Schubert, E. Fred; Kim, Jong Kyu (2005). "Solid-State Light Sources Getting Smart" (PDF). *Science*. **308** (5726): 1274–1278. Bibcode:2005Sci...308.1274S. doi:10.1126/science.1108712. PMID 15919985. S2CID 6354382. Archived from the original (PDF) on February 5, 2016.
31. ^ Nimz, Thomas; Hailer, Fredrik; Jensen, Kevin (November 2012). "Sensors and Feedback Control of Multicolor LED Systems". *Led Professional Review: Trends & Technologie for Future Lighting Solutions* (34). *LED Professional*: 2–5. ISSN 1993-890X. Archived from the original (PDF) on April 29, 2014.
32. ^ Tanabe, S.; Fujita, S.; Yoshihara, S.; Sakamoto, A.; Yamamoto, S. (2005). "YAG glass-ceramic phosphor for white LED (II): Luminescence characteristics" (PDF). In Ferguson, Ian T; Carrano, John C; Taguchi, Tsunemasa; Ashdown, Ian E (eds.). *Fifth International Conference on Solid State Lighting*. Vol. 5941. p. 594112. Bibcode:2005SPIE.5941..193T. doi:10.1117/12.614681. S2CID 38290951. Archived from the original (PDF) on May 11, 2011. cite book: |journal= ignored (help)
33. ^ Ohno, Y. (2004). Ferguson, Ian T; Narendran, Nadarajah; Denbaars, Steven P; Carrano, John C (eds.). "Color rendering and luminous efficacy of white LED spectra" (PDF). *Proc. SPIE. Fourth International Conference on Solid State Lighting*. **5530**: 89. Bibcode:2004SPIE.5530...88O. doi:10.1117/12.565757. S2CID 122777225. Archived from the original (PDF) on May 11, 2011.
34. ^ Next-Generation GaN-on-Si White LEDs Suppress Costs, *Electronic Design*, 19 November 2013
35. ^ GaN-on-Silicon LEDs Forecast to Increase Market Share to 40 Percent by 2020, *iSuppli*, 4 December 2013
36. ^ "All You Want to Know about RGBW LED Light". *AGC Lighting*.
37. ^ "Tunable White Application Note". *enlightedinc.com*.
38. ^ "2021 How Green Light Can Maximize the Quality of Tunable White – LEDucation".
39. ^ **a b** "Understanding LED Color-Tunable Products". *Energy.gov*.
40. ^ Whitaker, Tim (December 6, 2002). "Joint venture to make ZnSe white LEDs". Retrieved January 3, 2009.
41. ^ Burroughes, J. H.; Bradley, D. D. C.; Brown, A. R.; Marks, R. N.; MacKay, K.; Friend, R. H.; Burns, P. L.; Holmes, A. B. (1990). "Light-emitting diodes based on conjugated polymers". *Nature*. **347** (6293): 539–541. Bibcode:1990Natur.347..539B. doi:10.1038/347539a0. S2CID 43158308.
42. ^ **a b** Kho, Mu-Jeong; Javed, T.; Mark, R.; Maier, E.; David, C (March 4, 2008). *Final Report: OLED Solid State Lighting*. Kodak European Research. Cambridge Science Park, Cambridge, UK.
43. ^ **a b** Bardsley, J. N. (2004). "International OLED Technology Roadmap". *IEEE Journal of Selected Topics in Quantum Electronics*. **10** (1): 3–4. Bibcode:2004IJSTQ..10....3B. doi:10.1109/JSTQE.2004.824077. S2CID 30084021.

44. ^ Hebner, T. R.; Wu, C. C.; Marcy, D.; Lu, M. H.; Sturm, J. C. (1998). "Ink-jet printing of doped polymers for organic light emitting devices". *Applied Physics Letters*. **72** (5): 519. Bibcode:1998ApPhL..72..519H. doi:10.1063/1.120807. S2CID 119648364.
45. ^ Bharathan, J.; Yang, Y. (1998). "Polymer electroluminescent devices processed by inkjet printing: I. Polymer light-emitting logo". *Applied Physics Letters*. **72** (21): 2660. Bibcode:1998ApPhL..72.2660B. doi:10.1063/1.121090. S2CID 44128025.
46. ^ Gustafsson, G.; Cao, Y.; Treacy, G. M.; Klavetter, F.; Colaneri, N.; Heeger, A. J. (1992). "Flexible light-emitting diodes made from soluble conducting polymers". *Nature*. **357** (6378): 477–479. Bibcode:1992Natur.357..477G. doi:10.1038/357477a0. S2CID 4366944.
47. ^ LED-design. Elektor.com. Retrieved on March 16, 2012. Archived August 31, 2012, at the Wayback Machine
48. ^ "OSRAM Radial T1 3/4, SFH 4546 IR LEDs - ams-osram - ams". *ams-osram*. Retrieved September 19, 2024.
49. ^ "LED Through Hole 5mm (T-1 3/4) Red Built-in resistor 635 nm 4500 mcd 12V". *VCC*. Retrieved September 19, 2024.
50. ^ "Luminus Products". *Luminus Devices*. Archived from the original on July 25, 2008. Retrieved October 21, 2009.
51. ^ "Luminus Products CST-90 Series Datasheet" (PDF). *Luminus Devices*. Archived from the original (PDF) on March 31, 2010. Retrieved October 25, 2009.
52. ^ **a b** "Xlamp Xp-G Led". *Cree.com*. Cree, Inc. Archived from the original on March 13, 2012. Retrieved March 16, 2012.
53. ^ High Power Point Source White Led NVSx219A Archived July 29, 2021, at the Wayback Machine. Nichia.co.jp, November 2, 2010.
54. ^ "Seoul Semiconductor launches AC LED lighting source Acrich". *LEDS Magazine*. November 17, 2006. Archived from the original on October 15, 2007. Retrieved February 17, 2008.
55. ^ **a b** *Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting* (PDF). *International Dark-Sky Association*. May 4, 2010. Archived from the original (PDF) on January 16, 2013.
56. ^ Oskay, Windell (June 22, 2011). "Does this LED sound funny to you?". *Evil Mad Scientist Laboratories*. Archived from the original on September 24, 2023. Retrieved January 30, 2024.
57. ^ Tim's Blog (January 14, 2024). "Revisiting Candle Flicker-LEDs: Now with integrated Timer". *cpldcpu.wordpress.com*. Archived from the original on January 29, 2024. Retrieved January 30, 2024.
58. ^ Ting, Hua-Nong (June 17, 2011). *5th Kuala Lumpur International Conference on Biomedical Engineering 2011: BIOMED 2011, 20–23 June 2011, Kuala Lumpur, Malaysia*. Springer Science & Business Media. ISBN 9783642217296.
59. ^ "The Next Generation of LED Filament Bulbs". *LEDInside.com*. Trendforce. Retrieved October 26, 2015.
60. ^ Archived at Ghostarchive and the Wayback Machine: "LED Filaments". *YouTube*. April 5, 2015. Retrieved October 26, 2015.
61. ^ *Handbook on the Physics and Chemistry of Rare Earths: Including Actinides*. Elsevier Science. August 1, 2016. p. 89. ISBN 978-0-444-63705-5.

62. ^ "Corn Lamps: What Are They & Where Can I Use Them?". Shine Retrofits. September 1, 2016. Retrieved December 30, 2018.
63. ^ "Solid-State Lighting: Comparing LEDs to Traditional Light Sources". *energy.gov*. Archived from the original on May 5, 2009.
64. ^ "Dialight Micro LED SMD LED "598 SERIES" Datasheet" (PDF). *Dialight.com*. Archived from the original (PDF) on February 5, 2009.
65. ^ The LED Museum. Retrieved on March 16, 2012.
66. ^ **a b** Stevenson, Richard (August 2009), "The LED's Dark Secret: Solid-state lighting will not supplant the lightbulb until it can overcome the mysterious malady known as droop". *IEEE Spectrum*.
67. ^ Worthey, James A. "How White Light Works". *LRO Lighting Research Symposium, Light and Color*. Retrieved October 6, 2007.
68. ^ Narra, Prathyusha; Zinger, D.S. (2004). "An effective LED dimming approach". *Conference Record of the 2004 IEEE Industry Applications Conference, 2004. 39th IAS Annual Meeting*. Vol. 3. pp. 1671–1676. doi:10.1109/IAS.2004.1348695. ISBN 978-0-7803-8486-6. S2CID 16372401.
69. ^ "Data Sheet — HLMP-1301, T-1 (3 mm) Diffused LED Lamps". *Avago Technologies*. Retrieved May 30, 2010.
70. ^ Hecht, E. (2002). *Optics* (4 ed.). Addison Wesley. p. 591. ISBN 978-0-19-510818-7.
71. ^ "LED Light Bars For Off Road Illumination". *Larson Electronics*.
72. ^ "LED Design Forum: Avoiding thermal runaway when driving multiple LED strings". *LEDs Magazine*. April 20, 2009. Retrieved January 17, 2019.
73. ^ "Lifetime of White LEDs". Archived from the original on April 10, 2009. Retrieved 2009-04-10., US Department of Energy
74. ^ Lifetime of White LEDs Archived May 28, 2016, at the Wayback Machine. US Department of Energy. (PDF). Retrieved on March 16, 2012.
75. ^ "In depth: Advantages of LED Lighting". *energy.ltgovernors.com*. Archived from the original on November 14, 2017. Retrieved July 27, 2012.
76. ^ Stern, Maike Lorena; Schellenberger, Martin (March 31, 2020). "Fully convolutional networks for chip-wise defect detection employing photoluminescence images". *Journal of Intelligent Manufacturing*. **32** (1): 113–126. arXiv:1910.02451. doi:10.1007/s10845-020-01563-4. ISSN 0956-5515. S2CID 254655125.
77. ^ Hoque, Md Ashraful; Bradley, Robert Kelley; Fan, Jiajie; Fan, Xuejun (2019). "Effects of humidity and phosphor on silicone/Phosphor composite in white light-emitting diode package". *Journal of Materials Science: Materials in Electronics*. **30** (23): 20471–20478. doi:10.1007/s10854-019-02393-8.
78. ^ "3-Pad LED Flip Chip COB". *LED professional - LED Lighting Technology, Application Magazine*. Retrieved February 15, 2024.
79. ^ OSRAM: green LED
80. ^ Koizumi, S.; Watanabe, K; Hasegawa, M; Kanda, H (2001). "Ultraviolet Emission from a Diamond pn Junction". *Science*. **292** (5523): 1899–2701. Bibcode:2001Sci...292.1899K. doi:10.1126/science.1060258. PMID 11397942.
81. ^ Kubota, Y.; Watanabe, K.; Tsuda, O.; Taniguchi, T. (2007). "Deep Ultraviolet Light-Emitting Hexagonal Boron Nitride Synthesized at Atmospheric Pressure". *Science*.

317 (5840): 932–934. Bibcode:2007Sci...317..932K. doi:10.1126/science.1144216. PMID 17702939.

82. ^ Watanabe, Kenji; Taniguchi, Takashi; Kanda, Hisao (2004). "Direct-bandgap properties and evidence for ultraviolet lasing of hexagonal boron nitride single crystal". *Nature Materials*. **3** (6): 404–409. Bibcode:2004NatMa...3..404W. doi:10.1038/nmat1134. PMID 15156198.
83. ^ "LEDs move into the ultraviolet". *physicsworld.com*. May 17, 2006. Retrieved August 13, 2007.
84. ^ European Photonics Industry Consortium (EPIC). This includes use in data communications over fiber optics as well as "broadcast" data or signaling.
85. ^ Mims, Forrest M. III. "An Inexpensive and Accurate Student Sun Photometer with Light-Emitting Diodes as Spectrally Selective Detectors".
86. ^ "Water Vapor Measurements with LED Detectors". *cs.drexel.edu* (2002).
87. ^ Dziekan, Mike (February 6, 2009) "Using Light-Emitting Diodes as Sensors". *soamsci.or*. Archived May 31, 2013, at the Wayback Machine
88. ^ Ben-Ezra, Moshe; Wang, Jiaping; Wilburn, Bennett; Xiaoyang Li; Le Ma (2008). "An LED-only BRDF measurement device". *2008 IEEE Conference on Computer Vision and Pattern Recognition*. pp. 1–8. CiteSeerX 10.1.1.165.484. doi:10.1109/CVPR.2008.4587766. ISBN 978-1-4244-2242-5. S2CID 206591080.
89. ^ Bantis, Filippas, Sonia Smirnakou, Theoharis Ouzounis, Athanasios Koukounaras, Nikolaos Ntagkas, and Kalliopi Radoglou. "Current status and recent achievements in the field of horticulture with the use of light-emitting diodes (LEDs)." *Scientia horticulturae* 235 (2018): 437-451.
90. ^ Miler N., Kulus D.,
Wołczyński A., Rymarz D., Hajzer M., Wierzbowski K., Nelke R., Szeffs L., 2019. Application of wide-spectrum light-emitting diodes in micropropagation of popular ornamental plant species: A study on plant quality and cost reduction. *In Vitro Cellular and Developmental Biology – Plant* 55: 99-108. <https://doi.org/10.1007/s11627-018-9939-5>
91. ^ Tymoszuć A., Kulus D.,
Biały A., Nadolan K.,
Kulpiński A., 2023. Application of wide-spectrum light-emitting diodes in the indoor production of cucumber and tomato seedlings. *Acta Agrobotanica* 76: 762. <https://doi.org/10.5586/aa.762>
92. ^ Tymoszuć A., Kulus D., Kowalska J.,
Kulpiński A.,
Pańkiewicz D., Jeske M., Antkowiak M. 2024. Light spectrum affects growth, metabolite profile, and resistance against fungal phytopathogens of *Solanum lycopersicum* L. seedlings. *Journal of Plant Protection Research* 64(2). <https://doi.org/10.24425/jppr.2024.150247>

93. ^ Kulus D.,
Wołf AE' A†â€™ AŃâ€ AŃâ, -â,, AŃ AE' AŃâ, -Â AŃ AŃ AŃâ€šÂ - AŃâ€ž AŃ AŃ AE' A†â€™ AŃ AŃ AŃâ€
A., 2020. Influence of light conditions on the morphogenetic and biochemical
response of selected ornamental plant species under in vitro conditions: A mini-
review. *BioTechnologia* 101(1): 75-83. <http://doi.org/10.5114/bta.2020.92930>
94. ^ "L-Prize U.S. Department of Energy"[usurped], L-Prize Website, August 3, 2011
95. ^ LED There Be Light, *Scientific American*, March 18, 2009
96. ^ Eisenberg, Anne (June 24, 2007). "In Pursuit of Perfect TV Color, With L.E.D.'s
and Lasers". *New York Times*. Retrieved April 4, 2010.
97. ^ "CDC – NIOSH Publications and Products – Impact: NIOSH Light-Emitting Diode
(LED) Cap Lamp Improves Illumination and Decreases Injury Risk for Underground
Miners". cdc.gov. 2011. doi:10.26616/NIOSH PUB2011192. Retrieved May 3, 2013.
cite journal: Cite journal requires |journal= (help)
98. ^ Janeway, Kimberly (December 12, 2014). "LED lightbulbs that promise to help you
sleep". *Consumer Reports*. Retrieved May 10, 2018.
99. ^ "LED Device Illuminates New Path to Healing" (Press release). nasa.gov. Archived
from the original on October 13, 2008. Retrieved January 30, 2012.
100. ^ Fudin, M. S.; Mynbaev, K. D.; Aifantis, K. E.; Lipsanen H.; Bougrov, V. E.;
Romanov, A. E. (2014). "Frequency characteristics of modern LED phosphor
materials". *Scientific and Technical Journal of Information Technologies, Mechanics
and Optics*. **14** (6).
101. ^ Green, Hank (October 9, 2008). "Transmitting Data Through LED Light Bulbs".
EcoGeek. Archived from the original on December 12, 2008. Retrieved February 15,
2009.
102. ^ Dimitrov, Svilen; Haas, Harald (2015). *Principles of LED Light Communications:
Towards Networked Li-Fi*. Cambridge: Cambridge University Press.
doi:10.1017/cbo9781107278929. ISBN 978-1-107-04942-0.
103. ^ Sampath, A. V.; Reed, M. L.; Moe, C.; Garrett, G. A.; Readinger, E. D.; Sarney, W.
L.; Shen, H.; Wraback, M.; Chua, C. (December 1, 2009), "The effects of increasing
AlN mole fraction on the performance of AlGaIn active regions containing nanometer
scale compositionally inhomogeneities", *Advanced High Speed Devices, Selected
Topics in Electronics and Systems*, vol. 51, World Scientific, pp. 69–76,
doi:10.1142/9789814287876_0007, ISBN 9789814287869
104. ^ **a b** Liao, Yitao; Thomidis, Christos; Kao, Chen-kai; Moustakas, Theodore D.
(February 21, 2011). "AlGaIn based deep ultraviolet light emitting diodes with high
internal quantum efficiency grown by molecular beam epitaxy". *Applied Physics
Letters*. **98** (8): 081110. Bibcode:2011ApPhL..98h1110L. doi:10.1063/1.3559842.
ISSN 0003-6951.
105. ^ **a b c d e** Cabalo, Jerry; DeLucia, Marla; Goad, Aime; Lacis, John; Narayanan,
Fiona; Sickenberger, David (October 2, 2008). Carrano, John C.; Zukauskas, Arturas
(eds.). "Overview of the TAC-BIO detector". *Optically Based Biological and Chemical
Detection for Defence IV*. **7116**. International Society for Optics and Photonics:
71160D. Bibcode:2008SPIE.7116E..0DC. doi:10.1117/12.799843.
S2CID 108562187.

106. ^ Poldmae, Aime; Cabalo, Jerry; De Lucia, Marla; Narayanan, Fiona; Strauch III, Lester; Sickenberger, David (September 28, 2006). Carrano, John C.; Zukauskas, Arturas (eds.). "Biological aerosol detection with the tactical biological (TAC-BIO) detector". *Optically Based Biological and Chemical Detection for Defence III*. **6398**. SPIE: 63980E. doi:10.1117/12.687944. S2CID 136864366.
107. ^ "Army advances bio-threat detector". www.army.mil. January 22, 2015. Retrieved October 10, 2019.
108. ^ Kesavan, Jana; Kilper, Gary; Williamson, Mike; Alstadt, Valerie; Dimmock, Anne; Bascom, Rebecca (February 1, 2019). "Laboratory validation and initial field testing of an unobtrusive bioaerosol detector for health care settings". *Aerosol and Air Quality Research*. **19** (2): 331–344. doi:10.4209/aaqr.2017.10.0371. ISSN 1680-8584.
109. ^ Dietz, P. H.; Yerazunis, W. S.; Leigh, D. L. (2004). "Very Low-Cost Sensing and Communication Using Bidirectional LEDs". cite journal: Cite journal requires |journal= (help)
110. ^ Goins, G. D.; Yorio, N. C.; Sanwo, M. M.; Brown, C. S. (1997). "Photomorphogenesis, photosynthesis, and seed yield of wheat plants grown under red light-emitting diodes (LEDs) with and without supplemental blue lighting". *Journal of Experimental Botany*. **48** (7): 1407–1413. doi:10.1093/jxb/48.7.1407. PMID 11541074.
111. ^ Li, Jinmin; Wang, Junxi; Yi, Xiaoyan; Liu, Zhiqiang; Wei, Tongbo; Yan, Jianchang; Xue, Bin (August 31, 2020). *III-Nitrides Light Emitting Diodes: Technology and Applications*. Springer Nature. p. 248. ISBN 978-981-15-7949-3.
112. ^ Gaska, R.; Shur, M. S.; Zhang, J. (October 2006). "Physics and Applications of Deep UV LEDs". *2006 8th International Conference on Solid-State and Integrated Circuit Technology Proceedings*. pp. 842–844. doi:10.1109/ICSICT.2006.306525. ISBN 1-4244-0160-7. S2CID 17258357.
113. ^ **a b** "LED R&D Challenges". Energy.gov. Retrieved March 13, 2019.
114. ^ "JULY 2015 POSTINGS". Energy.gov. Retrieved March 13, 2019.
115. ^ Identifying the Causes of LED Efficiency Droop Archived 13 December 2013 at the Wayback Machine, By Steven Keeping, Digi-Key Corporation Tech Zone
116. ^ Iveland, Justin; et al. (April 23, 2013). "Cause of LED Efficiency Droop Finally Revealed". *Physical Review Letters*, 2013.
117. ^ Di, Dawei; Romanov, Alexander S.; Yang, Le; Richter, Johannes M.; Rivett, Jasmine P. H.; Jones, Saul; Thomas, Tudor H.; Abdi Jalebi, Mojtaba; Friend, Richard H.; Linnolahti, Mikko; Bochmann, Manfred (April 14, 2017). "High-performance light-emitting diodes based on carbene-metal-amides" (PDF). *Science*. **356** (6334): 159–163. arXiv:1606.08868. Bibcode:2017Sci...356..159D. doi:10.1126/science.aah4345. ISSN 0036-8075. PMID 28360136. S2CID 206651900.
118. ^ **a b** Armin, Ardalan; Meredith, Paul (October 2018). "LED technology breaks performance barrier". *Nature*. **562** (7726): 197–198. Bibcode:2018Natur.562..197M. doi:10.1038/d41586-018-06923-y. PMID 30305755.
119. ^ **a b** Cao, Yu; Wang, Nana; Tian, He; Guo, Jingshu; Wei, Yingqiang; Chen, Hong; Miao, Yanfeng; Zou, Wei; Pan, Kang; He, Yarong; Cao, Hui (October 2018). "Perovskite light-emitting diodes based on spontaneously formed submicrometre-

- scale structures". *Nature*. **562** (7726): 249–253. Bibcode:2018Natur.562..249C. doi:10.1038/s41586-018-0576-2. ISSN 1476-4687. PMID 30305742.
120. ^ Cho, Sang-Hwan; Song, Young-Woo; Lee, Joon-gu; Kim, Yoon-Chang; Lee, Jong Hyuk; Ha, Jaeheung; Oh, Jong-Suk; Lee, So Young; Lee, Sun Young; Hwang, Kyu Hwan; Zang, Dong-Sik (August 18, 2008). "Weak-microcavity organic light-emitting diodes with improved light out-coupling". *Optics Express*. **16** (17): 12632–12639. Bibcode:2008OExpr..1612632C. doi:10.1364/OE.16.012632. ISSN 1094-4087. PMID 18711500.
 121. ^ Lin, Kebin; Xing, Jun; Quan, Li Na; de Arquer, F. Pelayo García; Gong, Xiwen; Lu, Jianxun; Xie, Liqiang; Zhao, Weijie; Zhang, Di; Yan, Chuazhong; Li, Wenqiang (October 2018). "Perovskite light-emitting diodes with external quantum efficiency exceeding 20 per cent". *Nature*. **562** (7726): 245–248. Bibcode:2018Natur.562..245L. doi:10.1038/s41586-018-0575-3. hdl:10356/141016. ISSN 1476-4687. PMID 30305741. S2CID 52958604.
 122. ^ "Blue LEDs: A health hazard?". *texyt.com*. January 15, 2007. Retrieved September 3, 2007.
 123. ^ Some evidences that white LEDs are toxic for human at domestic radiance?. Radioprotection (2017-09-12). Retrieved on 2018-07-31.
 124. ^ Point, S. and Barlier-Salsi, A. (2018) LEDs lighting and retinal damage, technical information sheets, SFRP
 125. ^ "LED Based Products Must Meet Photobiological Safety Standards: Part 2". *ledsmagazine.com*. November 29, 2011. Retrieved January 9, 2022.
 126. ^ Lim, S. R.; Kang, D.; Ogunseitan, O. A.; Schoenung, J. M. (2011). "Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification". *Environmental Science & Technology*. **45** (1): 320–327. Bibcode:2011EnST...45..320L. doi:10.1021/es101052q. PMID 21138290.
 127. ^ "Response to the AMA Statement on High Intensity Street Lighting". *ledroadwaylighting.com*. Archived from the original on January 19, 2019. Retrieved January 17, 2019.
 128. ^ Stokstad, Erik (October 7, 2014). "LEDs: Good for prizes, bad for insects". *Science*. Retrieved October 7, 2014.
 129. ^ Pawson, S. M.; Bader, M. K.-F. (2014). "LED Lighting Increases the Ecological Impact of Light Pollution Irrespective of Color Temperature". *Ecological Applications*. **24** (7): 1561–1568. Bibcode:2014EcoAp..24.1561P. doi:10.1890/14-0468.1. PMID 29210222.
 130. ^ Polakovic, Gary (June 12, 2018). "Scientist's new database can help protect wildlife from harmful hues of LED lights". *USC News*. Archived from the original on May 19, 2020. Retrieved December 16, 2019.
 131. ^ "Information About Sea Turtles: Threats from Artificial Lighting". *Sea Turtle Conservancy*. Retrieved December 16, 2019.
 132. ^ "Stoplights' Unusual, Potentially Deadly Winter Problem". *ABC News*. January 8, 2010. Archived from the original on December 12, 2023.
 133. ^ Markley, Stephen (December 17, 2009). "LED Traffic Lights Can't Melt Snow, Ice". *Cars.com*. Archived from the original on June 6, 2019.

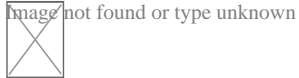
Further reading

[edit]

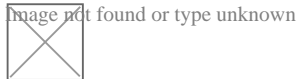
- *David L. Heiserman (1968). Light -Emitting Diodes (PDF). Electronics World.*
- *Shuji Nakamura; Gerhard Fasol; Stephen J Pearton (2000). The Blue Laser Diode: The Complete Story. Springer Verlag. ISBN 978-3-540-66505-2.*

External links

[edit]



Wikimedia Commons has media related to ***Light-emitting diodes*** and ***Light-emitting diodes (SMD)***.



Look up ***light-emitting diode*** in Wiktionary, the free dictionary.

- Building a do-it-yourself LED
- Color cycling LED in a single two pin package,
- Educational video on LEDs on YouTube
- **v**
- **t**
- **e**

Lighting

Concepts

- Accent lighting
- Color rendering index
- Color temperature
- Electric light
- Glare
- Light fixture
- Light pollution
 - Hawaii
 - Hong Kong
- Lightbulb socket
 - Bi-pin lamp base
 - Edison screw
- Luminous efficacy
- Task lighting

**Methods of
generation**

- Incandescent
 - Regular
 - Edison
 - Halogen
 - Nernst
 - Cathodoluminescent
 - Electron-stimulated
 - Chemiluminescent
 - Electrochemiluminescence
 - Electroluminescent
 - field-induced polymer
- Luminescent
 - Fluorescent
 - Fluorescent lamp (compact)
 - Fluorescent induction
 - Photoluminescent
 - Laser headlamp
 - Radioluminescence
 - Solid-state
 - LED lamp
 - Acetylene/Carbide
 - Argand
 - Campfire
 - Candle
 - Carcel
 - Diya
 - Flare
 - Gas
 - Kerosene
 - Petromax
- Combustion
 - Lantern
 - Fanous
 - Paper
 - Limelight
 - Luchina
 - Magnesium torch
 - Oil
 - Qulliq
 - Rushlight
 - Safety
 - Tilley
 - Torch
 - Carbon arc
- Electric arc
 - Klieg light
 - Yablochkov candle
 - Deuterium arc
 - Neon
 - Neon lamp
- Gas discharge
 - Plasma
 - Sulfur
 - Xenon arc

- Reflector
 - Ellipsoidal reflector
 - Multifaceted reflector
 - Parabolic aluminized reflector (PAR)
- Aviation obstruction
- Balanced-arm lamp
- Chandelier
- Emergency light
- Gas lighting
- Gooseneck lamp
- Stationary**
 - Intelligent street lighting
 - Light tube
 - Nightlight
 - Neon lighting
 - Pendant light
 - Recessed light
 - Sconce
 - Street light
 - in the US
 - Torchère
 - Track lighting
 - Troffer
 - Bicycle lighting
 - Flashlight
 - Mechanically powered
 - Tactical
- Glow stick
- Portable**
 - Headlamp
 - outdoor
 - Lantern
 - Laser pointer
 - Navigation light
 - Searchlight
 - Solar lamp

	<ul style="list-style-type: none"> ○ Automotive light bulb types ○ Daytime running lamp ○ Headlamp <ul style="list-style-type: none"> ○ hidden ○ high-intensity discharge ○ sealed beam
Automotive	<ul style="list-style-type: none"> ○ Rear position lights ○ Reversing lights ○ Safety reflector <ul style="list-style-type: none"> ○ retroreflector ○ Stop lights ○ Turn signals <ul style="list-style-type: none"> ○ trafficators ○ Aroma lamp ○ Blacklight ○ Bubble light ○ Christmas lights ○ Crackle tube ○ DJ lighting ○ Electroluminescent wire ○ Lava lamp ○ Marquee ○ Plasma globe ○ Strobe light ○ Floodlight ○ Footlight
<ul style="list-style-type: none"> ○ Display ○ Decorative 	<ul style="list-style-type: none"> ○ Gobo ○ Scoop ○ Spotlight <ul style="list-style-type: none"> ○ ellipsoidal reflector ○ Stage lighting instrument ○ Germicidal ○ Grow light ○ Infrared lamp ○ Stroboscope ○ Tanning ○ Battlefield illumination ○ Bioluminescence ○ Laser
<ul style="list-style-type: none"> ○ Theatrical ○ Cinematic 	
<ul style="list-style-type: none"> ○ Industrial ○ Scientific 	
Related topics	<ul style="list-style-type: none"> ○ Light art ○ Luminous gemstones ○ Signal lamp ○ Sources <ul style="list-style-type: none"> ○ Reflected

- v
- t
- e

Display technology

Past generation	<ul style="list-style-type: none"> ○ Eidophor ○ Cathode-ray tube (CRT) ○ Jumbotron ○ Electroluminescent display (ELD) ○ Rear-projection display ○ Plasma display panel (PDP) <ul style="list-style-type: none"> ○ ALiS ○ Quantum dot display (QLED) ○ Electronic paper <ul style="list-style-type: none"> ○ E Ink ○ Gyricon ○ Light-emitting diode display (LED) <ul style="list-style-type: none"> ○ Organic light-emitting diode (OLED) <ul style="list-style-type: none"> ○ Active-Matrix Organic light-emitting diode (AMOLED)
Current generation	<ul style="list-style-type: none"> ○ Liquid-crystal display (LCD) <ul style="list-style-type: none"> ○ TFT <ul style="list-style-type: none"> ○ TN ○ IPS ○ LED-backlit ○ Blue Phase ○ Digital Light Processing (DLP) ○ Liquid crystal on silicon (LCoS) ○ microLED ○ Electroluminescent Quantum Dots (ELQD/QD-LED) ○ Organic light-emitting transistor (OLET) ○ Surface-conduction electron-emitter display (SED) ○ Field-emission display (FED) ○ Laser TV
Video displays	<ul style="list-style-type: none"> ○ Quantum dot ○ Liquid crystal ○ MEMS display <ul style="list-style-type: none"> ○ IMoD ○ TMOS ○ Ferroelectric liquid crystal display (FLCD) ○ Thick-film dielectric electroluminescent technology (TDEL) ○ Laser-powered phosphor display (LPD)
Next generation	

	<ul style="list-style-type: none"> Electromechanical <ul style="list-style-type: none"> Flip-dot Split-flap Eggcrate Fiber-optic Nixie tube Vacuum fluorescent display (VFD)
Non-video	<ul style="list-style-type: none"> Light-emitting electrochemical cell (LEC) Lightguide display Dot-matrix display Seven-segment display (SSD) Eight-segment display Nine-segment display Fourteen-segment display (FSD) Sixteen-segment display (SISD) Stereoscopic Autostereoscopic Multiscopic
3D display	<ul style="list-style-type: none"> Hologram <ul style="list-style-type: none"> Holographic display Computer-generated holography Volumetric Fog display Monoscope
Static media	<ul style="list-style-type: none"> Movie projector Neon sign Slide projector Transparency Laser beam EDID <ul style="list-style-type: none"> CEA-861
Display capabilities	<ul style="list-style-type: none"> DisplayID Always-on display See-through display Scan line History of display technology Large-screen television technology
Related articles	<ul style="list-style-type: none"> Optimum HDTV viewing distance High Dynamic Range (HDR) Color Light Output Flexible display Comparison of CRT, LCD, plasma, and OLED displays
Comparison of display technology	

- v
- t
- e

Electronic components

Semiconductor devices	MOS transistors	<ul style="list-style-type: none"> ○ Transistor ○ NMOS ○ PMOS ○ BiCMOS ○ BioFET ○ Chemical field-effect transistor (ChemFET) ○ Complementary MOS (CMOS) ○ Depletion-load NMOS ○ Fin field-effect transistor (FinFET) ○ Floating-gate MOSFET (FGMOS) ○ Insulated-gate bipolar transistor (IGBT) ○ ISFET ○ LDMOS ○ MOS field-effect transistor (MOSFET) ○ Multi-gate field-effect transistor (MuGFET) ○ Power MOSFET ○ Thin-film transistor (TFT) ○ VMOS ○ UMOS
	Other transistors	<ul style="list-style-type: none"> ○ Bipolar junction transistor (BJT) ○ Darlington transistor ○ Diffused junction transistor ○ Field-effect transistor (FET) <ul style="list-style-type: none"> ○ Junction Gate FET (JFET) ○ Organic FET (OFET) ○ Light-emitting transistor (LET) <ul style="list-style-type: none"> ○ Organic LET (OLET) ○ Pentode transistor ○ Point-contact transistor ○ Programmable unijunction transistor (PUT) ○ Static induction transistor (SIT) ○ Tetrode transistor ○ Unijunction transistor (UJT)
	Diodes	<ul style="list-style-type: none"> ○ Avalanche diode ○ Constant-current diode (CLD, CRD) ○ Gunn diode ○ Laser diode (LD) ○ Light-emitting diode (LED) ○ Organic light-emitting diode (OLED) ○ Photodiode ○ PIN diode ○ Schottky diode ○ Step recovery diode ○ Zener diode
		<ul style="list-style-type: none"> ○ Printed electronics ○ Printed circuit board ○ DIAC ○ Heterostructure barrier varactor ○ Integrated circuit (IC)

Voltage regulators

- Linear regulator
- Low-dropout regulator
- Switching regulator
- Buck
- Boost
- Buck–boost
- Split-pi
- ĄfÆ'Ą†â€™Ąfâ€ Ąâ,¬â,,ċĄfÆ'Ąċâ,¬Ā ĄfĀċĄċâ€šĀ¬ċâ€žĀċĄfÆ'Ą†
- SEPIC
- Charge pump
- Switched capacitor

Vacuum tubes

- Acorn tube
- Audion
- Beam tetrode
- Barretter
- Compactron
- Diode
- Fleming valve
- Neutron tube
- Nonode
- Nuvistor
- Pentagrid (Hexode, Heptode, Octode)
- Pentode
- Photomultiplier
- Phototube
- Tetrode
- Triode
- Backward-wave oscillator (BWO)
- Cavity magnetron
- Crossed-field amplifier (CFA)
- Gyrotron

Vacuum tubes (RF)

- Inductive output tube (IOT)
- Klystron
- Maser
- Sutton tube
- Traveling-wave tube (TWT)
- X-ray tube

**Cathode-ray
tubes**

- Beam deflection tube
- Charactron
- Iconoscope
- Magic eye tube
- Monoscope
- Selectron tube
- Storage tube
- Trochotron
- Video camera tube
- Williams tube
- Cold cathode
- Crossatron
- Dekatron

**Gas-filled
tubes**

- Ignitron
- Krytron
- Mercury-arc valve
- Neon lamp
- Nixie tube
- Thyatron
- Trigatron
- Voltage-regulator tube
- Potentiometer

Adjustable

- digital
- Variable capacitor
- Varicap
- Connector
 - audio and video
 - electrical power
 - RF
- Electrolytic detector
- Ferrite
- Antifuse
- Fuse

Passive

- resettable
- eFUSE
- Resistor
- Switch
- Thermistor
- Transformer
- Varistor
- Wire
 - Wollaston wire

Reactive

- Capacitor
 - types
- Ceramic resonator
- Crystal oscillator
- Inductor
- Parametron
- Relay
 - reed relay
 - mercury relay

Authority control databases: National

 [Edit this at Wikidata](#)

- Germany
-  Czech Republic

About romeoville, IL

Redirect to:

- Romeoville, Illinois

This page is a redirect. The following categories are used to track and monitor this redirect:

- **From a US postal abbreviation:** This is a redirect from a US postal abbreviation to its associated municipality.

When appropriate, protection levels are automatically sensed, described and categorized.

About Overhead Door Company of Joliet

Photo



Photo



Photo



Photo

Image not found or type unknown

Photo

Image not found or type unknown

Photo

Image not found or type unknown

Photo

Image not found or type unknown

Things To Do in Will County

Photo

Image not found or type unknown

Dellwood Park

4.7 (1975)

Photo

Image not found or type unknown

Will County Historical Museum and Research Center

4.6 (23)

Photo

Image not found or type unknown

Joliet Iron Works Park

4.6 (148)

Photo

Image not found or type unknown

Gemini Giant

3.5 (27)

Photo

Route 66 Park

4.3 (435)

Photo

Image not found or type unknown

Old Joliet Prison

4.6 (1759)

Photo

Image not found or type unknown

Pilcher Park Nature Center

4.7 (728)

Driving Directions in Will County

Driving Directions From Pep Boys to Overhead Door Company of Joliet

Driving Directions From Will County Sheriff Department to Overhead Door Company of Joliet

Driving Directions From Al's Steak House Restaurant to Overhead Door Company of Joliet

Driving Directions From Joliet to Overhead Door Company of Joliet

Driving Directions From The Haley Mansion to Overhead Door Company of Joliet

Driving Directions From Red Roof Inn Chicago - Joliet to Overhead Door Company of Joliet

Driving Directions From First American Bank to Overhead Door Company of Joliet

https://www.google.com/maps/dir/MainStay+Suites+Joliet+I-80/Overhead+Door+Company+of+Joliet/@41.519399,-88.126183,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJL5w_8HZhDogRRDwfqssc88.126183!2d41.519399!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e0

https://www.google.com/maps/dir/Honorable+Robert+Brumund/Overhead+Door+Company+of+Joliet/@41.5244092,-88.0822783,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJ4ykaz7dmDogRZvLfviRz88.0822783!2d41.5244092!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e2

https://www.google.com/maps/dir/Pep+Boys/Overhead+Door+Company+of+Joliet/@41.521285,-88.127089,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJDZbetnVhDogRcQM-kE2YvsQ!2m2!1d-88.127089!2d41.521285!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e1

https://www.google.com/maps/dir/Will+County+Law+Library/Overhead+Door+Company+of+Joliet/88.0843686,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJ4ykaz7dmDogR54h2pB-wls8!2m2!1d-88.0843686!2d41.5249227!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e3

https://www.google.com/maps/dir/Dollar+General/Overhead+Door+Company+of+Joliet/88.104361,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJNQmB1UZhDogRdJIXSnA!2m2!1d-88.104361!2d41.5227028!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e0

https://www.google.com/maps/dir/Honorable+Thomas+A+Dunn/Overhead+Door+Company+of+Joliet/88.0822783,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sChIJ4ykaz7dmDogRdBGfYGr!2m2!1d-88.0822783!2d41.5244092!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e2

Driving Directions From Joliet Area Historical Museum to Overhead Door Company of Joliet

Driving Directions From Gemini Giant to Overhead Door Company of Joliet

Driving Directions From Fox Museum to Overhead Door Company of Joliet

Driving Directions From Joliet Area Historical Museum to Overhead Door Company of Joliet

Driving Directions From Illinois State Museum-Lockport Gallery to Overhead Door Company of Joliet

Driving Directions From Riverwalk Park to Overhead Door Company of Joliet

Driving Directions From Pilcher Park Nature Center to Overhead Door Company of Joliet

https://www.google.com/maps/dir/Gemini+Giant/Overhead+Door+Company+of+Joliet/88.1496993,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.1496993!2d41.30606!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e0

https://www.google.com/maps/dir/Will+County+Historical+Museum+and+Research+Center/88.0573154,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0573154!2d41.5902137!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e2

https://www.google.com/maps/dir/Will+County+Historical+Museum+and+Research+Center/88.0573154,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0573154!2d41.5902137!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e1

https://www.google.com/maps/dir/Route+66+Park/Overhead+Door+Company+of+Joliet/88.0850382,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0850382!2d41.5427013!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e3

https://www.google.com/maps/dir/Fox+Museum/Overhead+Door+Company+of+Joliet/88.0548128,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0548128!2d41.5885338!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e0

https://www.google.com/maps/dir/Pilcher+Park+Nature+Center/Overhead+Door+Company+of+Joliet/88.0219707,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0219707!2d41.5329846!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e2

https://www.google.com/maps/dir/Fox+Museum/Overhead+Door+Company+of+Joliet/88.0548128,14z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1sunknown!2m2!1d-88.0548128!2d41.5885338!1m5!1m1!1sChIJLWV_oV9hDogRGyjUaaoTEjk!2m2!1d-88.106331!2d41.5069115!3e1

Reviews for Overhead Door Company of Joliet

Overhead Door Company of Joliet

Image not found or type unknown

Hector Melero

(5)

Had a really great experience with Middleton Overhead Doors. My door started to bow and after several attempts on me fixing it I just couldn't get it. I didn't want to pay on something I knew I could fix. Well, I gave up and they came out and made it look easy. I know what they are doing not to mention they called me before hand to confirm my appointment and they showed up at there scheduled appointment. I highly recommend Middleton Overhead Doors on any work that needs to be done

Overhead Door Company of Joliet

Image not found or type unknown

Kelley Jansa

(5)

We used Middleton Door to upgrade our garage door. We had three different companies come out to quote the job and across the board Middleton was better. They were professional, had plenty of different options and priced appropriately. The door we ordered came with a small dent and they handled getting a new panel ordered and reinstalled very quickly.

Overhead Door Company of Joliet

Image not found or type unknown

Jim Chuporak

(5)

Received a notice the morning of telling me when to expect the men to come and put the door in. he was on time, answered all my questions, worked diligently in the cold. And did an absolutely awesome job. Everything was cleaned up, hauled away from the old door. I am extremely happy with the service I received from the first phone call I made through having the door put in. My wife and I are very, very happy with the door.

Overhead Door Company of Joliet

Image not found or type unknown

Andrea Nitsche

(4)

Scheduling was easy, job was done quickly. Little disappointed that they gave me a quote over email (which they confirmed was for labor and materials), but when they finished it was just over \$30 more. Not a huge deal, but when I asked why, I was told they gave me an approx cost and it depends on what is needed. I get that in general, however, they installed the door and I gave them my address and pics of the existing prior to getting a quote. I feel like they could have been more upfront with pricing. And just a heads up, it was pricey... Had them change the weather stripping, from ringing my doorbell to pulling out my driveway when done was literally 20 mins, cost was just over \$260 ?

Overhead Door Company of Joliet

Image not found or type unknown

Owen McCarthy

(5)

I called the office just by chance to see if there was an available opening for a service call to repair a busted spring. Unfortunately I didn't catch the name of the person who answered, but she couldn't have been more pleasant and polite. She was able to get a tech to my house in an hour. I believe the tech's name was Mike and he too was amazing. He quickly resolved my issue and even corrected a couple of things that he saw that weren't quite right. I would recommend to anyone and will definitely call on Middleton for any future needs. Thank you all for your great service.

Understanding UL Standards For Garage Doors [View GBP](#)

Check our other pages :

- [Gathering Essential Tools For Simple DIY Checkups](#)
- [Checking Safety Labels And Ratings Before Purchase](#)
- [Lubricating Tracks And Rollers With Minimal Mess](#)
- [Monitoring Cable Tension For Safety](#)
- [Evaluating Loose Hinges Before They Fail](#)

Frequently Asked Questions

What are UL standards for garage doors, and why are they important in installation?

UL standards for garage doors set safety and performance benchmarks to ensure that products meet rigorous testing for functionality and security. They are crucial in installation as they help ensure the door operates safely and reliably, reducing risks of accidents or

malfunctions.

How can I verify if a garage door meets UL standards during installation?

You can verify if a garage door meets UL standards by checking for the UL certification label on the product. This label indicates that the door has been tested and certified according to UL's safety requirements.

Are there specific UL standards related to garage door openers?

Yes, there are specific UL standards for garage door openers, such as UL 325, which outlines safety requirements for electric operators of doors. These include guidelines on entrapment protection, electrical components, and automatic reversal features.

Do installers need to be aware of any updates to the UL standards when installing garage doors?

Yes, installers should stay informed about any updates or revisions to the relevant UL standards as these may introduce new safety requirements or testing criteria that impact installation practices.

Can non-compliance with UL standards affect warranty or insurance coverage for installed garage doors?

Yes, non-compliance with UL standards can potentially void warranties or affect insurance claims since many manufacturers and insurers require adherence to these safety benchmarks as part of their policy terms.

Overhead Door Company of Joliet

Phone : +18157256077

City : Joliet

State : IL

Zip : 60436

Address : Unknown Address

Google Business Profile

Company Website : <https://overheaddoorjoliet.com/garage-door-repair-romeoville.aspx>

Sitemap

Privacy Policy

About Us