

## Basic Structure of LEDs

LEDs are solid-state light-emitting devices. They emit less heat and last longer than other light sources, such as conventional incandescent bulbs. Also, because they are compact and can be molded as an entirely solid-state light source, they are highly impact-resistant and afford unprecedented flexibility in the design of lighting equipment. This document explains the basic structure of an LED device.

### What is an LED?

An LED (Light-Emitting Diode) is a light-emitting element made using semiconducting materials. To allow them to be used as electronic components, these elements are molded into a range of packages as lamps, which are referred to generically as LEDs. In this document, such elements formed into packages as lamps are referred to as LEDs (or LED devices), while the semiconductor elements themselves are referred to as LED elements.

Given their characteristics of compactness and low power consumption, LEDs are widely used as indicator lamps in electronic equipment, but are also increasingly used in applications such as information display panels and LED displays. With the increases in light output from LEDs in recent years, they are now being used as lighting equipment in applications such as LCD backlights and flash units for cellphone cameras. Advances in white LEDs have also opened the way for applications such as ordinary home lighting, outdoor lighting and even vehicle headlights.

### LED Device Configuration

There are 4 main types of LED device.

#### a. Pinned LED

This is the most common type of LED device (Fig. 1). The main components are the LED element, a lead frame, a gold (bonding) wire and the encapsulating resin.

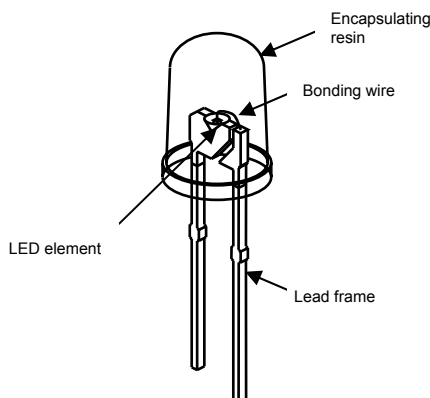


Fig. 1 Pinned LED Lamp

#### b. Chip LED (PCB type)

These were developed as LEDs that could be surface-mounted on an electronic circuit board (Fig. 2). The LED element is mounted on a small printed circuit board (PCB) and then connected to the PCB via gold bonding wire before the element and the area around it are enveloped in a resin that sets hard.

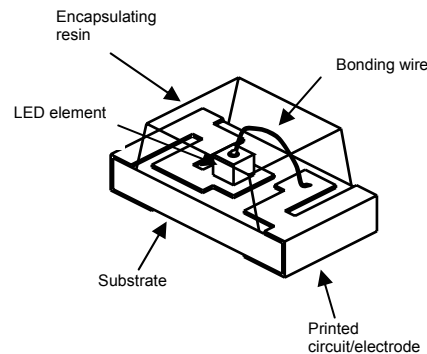


Fig. 2 Chip LED (PCB type)

#### c. Surface-mount LED (PLCC type, etc.)

Unlike PCB-type LEDs, in these devices the LED element is enclosed in a single molded package that includes the lead frame and a molded frame (lamp housing). The LED element is connected to the lead frame by a gold bonding wire, after which resin is injected into an external frame, enveloping and hardening around the components. The lamp housing is used as a reflective frame, controlling the light distribution characteristics and heightening the light utilization rate (Fig. 3).

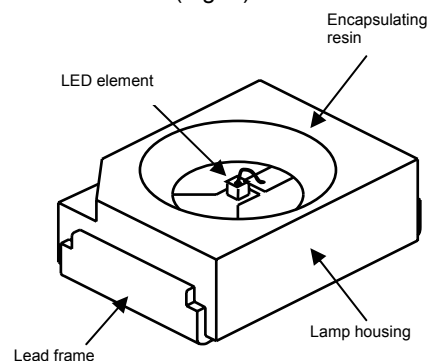


Fig. 3 Chip LED (PLCC type)

#### d. Others

These include metal stem-mounted LEDs and number-display units.

The next section describes the features of the different components in LED devices.

## LED Element

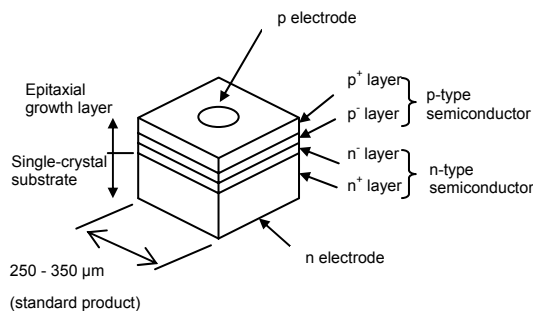


Fig. 4 Example of Basic LED Element Configuration

The LED element is the key component in an LED device. One type of semiconductor component, it is a photoelectric converter that converts electrical energy into light. LED elements are a type of electrical device referred to as diodes and are basically constructed of joined p-layer and n-layer semiconductors that have different modes of electrical conductivity. Rather than the silicon and germanium materials used in normal diodes, LED are made from compound semiconductors such as GaAs, GaP, AlGaInP and InGaN. The energy states of the electrons within the solid materials in compound semiconductors vary depending on the component materials in those semiconductors. When the electron energy in the materials is converted to light energy, the wavelength of the light is inversely proportional to the electron energy. Depending on the component materials, LEDs that use compound semiconductors are capable of emitting light in wavelengths ranging from infrared and visible light through to near-ultraviolet.

To convert electron energy to light energy, an electrical current is applied to the element and an electrical carrier is injected into the P-N junction. In the electrical carrier, electrons in the n-type semiconductor come together in the P-N junction with electron holes (where groups of electrons in a special state act as a single positively charged particle due to quantum-mechanical effects) in the p-type semiconductor. When the electrons and electron holes recombine, their electrical charges are cancelled out but the energy held by the electron is released at the same time. The energy is released in the form of electromagnetic waves and expelled as light.

Various means are used to boost the light-emitting efficiency of actual LED elements. The light-emitting efficiency of an element is made up of the efficiency

with which electron energy is converted to light energy, and the efficiency with which that light energy is extracted and projected from the element. Because the efficiency of photo-electric conversion events is generally taken to be the individual countable quanta for both electrons and light, it is expressed as the quantum efficiency.

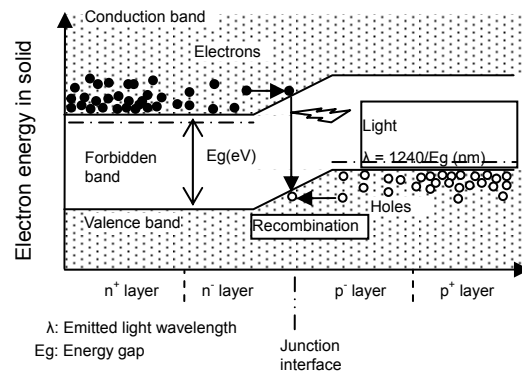


Fig. 5 LED Light Emission Mechanism (Energy Band Diagram)

External quantum efficiency:

$$\eta_{ext} = \eta_e \times E$$

$\eta_e$  : Internal quantum efficiency

$E$  : Light extraction efficiency

Measures to improve internal quantum efficiency

This is mainly achieved using measures in the P-N junction.

Measures include improved crystallinity, heterojunctions and quantum well structures.

Measures to improve light extraction

These include removing any light absorbent materials in the LED element and minimizing internal reflective components.

Measures in the element PCB —

The use of transparent substrates

Reducing internal reflectivity —

Surface texture processing, die reshaping, etc.

Other — Formation of reflective layers, etc.

Because LED elements themselves are completely solid, as discussed earlier, they can be used to create rugged, entirely solid-state light-emitting devices. And because the light emissions are not heat-derived, excellent light-emission efficiency is achievable.

## Lead Frame and PCB

These components hold the LED element and provide the electrical connections to the element that receives an external power supply. For pinned LEDs or PLCC packages, lead frames made from copper and iron alloy are used. Normally, highly reflective silver plating is applied in the immediately vicinity of the LED in order to minimize any light absorption within the lamp. Printed circuit boards (PCBs) are often used with chip LEDs. Highly reflective materials are again used in the substrate materials to minimize light absorption.

Lead frames and PCBs also play an important role in dissipating heat from the LED element. They are directly connected to the element and form an important channel for heat generated by the element to escape. In applications where high levels of light output are required, large amounts of current must be supplied. Accordingly, various package-based measures are applied, such as using a lead frame with broad feet or a PCB with a metal core.

## Bonding Wire

In most cases, a gold wire is used to connect the LED element electrode to an electrically conductive section of the lead frame or PCB. Ultrasonic waves are used to make the connection. When the bonding wire is first connected, the tip of the bonding wire is ball-shaped and ultrasonic waves are used to generate friction between the ball and the LED element electrode or lead frame. The ball is heated using the electrical discharge and the tip of the gold wire is fused into place. When this happens, the section of wire adjacent to the ball also melts partially and has a different state to the rest of the wire when it cools. (This section of the wire is referred to as the recrystallization region). Because crystal grain boundaries form in this section of the wire, care is needed with respect to its electrical characteristics. For instance, when a large current is applied, this section of the wire may break due to electromigration. LED lamp ratings are specified with a generous margin so as to ensure that such breakages do not occur.

In terms of mechanical strength, the bonding wire is one of the weakest parts of the lamp. However, because the wire is embedded in a material such as plastic resin when a solid-state lamp is formed, the lamps are extremely reliable.

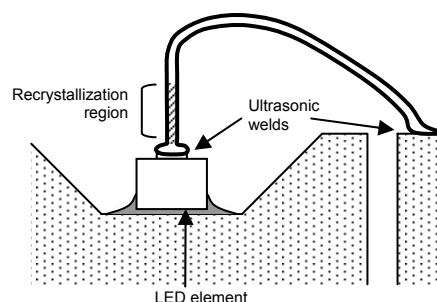


Fig. 6 Bonding Wire

## Die-bonding Material

This is the material used to fix the LED element to the lead frame. Because most LED elements are constructed so that current flows from the epitaxial growth layer to a conductive substrate, the element is located on the electrical pathway for the lead frame or PCB and the PCB side is glued in place with the die-bonding material. The bonding wire is then fused to the epitaxial growth layer to supply power. The most commonly used die-bonding material is a silver paste made up of silver granules suspended in an epoxy resin. Once this material hardens, it has excellent electrical and thermal conductivity. However, because it is a resin-based material, problems of deterioration can arise with devices such as short-wavelength LEDs. For this reason, eutectic bonding with materials such as AuSn is used for some LEDs. Like soldering, eutectic bonding uses entirely metallic materials and so features excellent thermal conductivity as well as being very reliable. Another method that offers the flexibility and adhesion of the gold in the bonding wire is to bond the LED element using gold bumps.

In recent years, some LED elements have started using insulating materials in the substrate. In such cases, power is supplied to the epitaxial growth layer as well as to the p-type and n-type semiconductors. For this reason, the bond does not need to be electrically conductive and clear resin pastes can be used.

## Encapsulating Resin

The encapsulating resin fills and seals the area around the LED element. This protects the LED element from moisture and external impacts. The resin used is either clear or at a minimum is one that is highly transparent to the emitted light wavelengths. The simplest construction is that used for ordinary pinned LEDs, where the encapsulating resin supports the

entire structure of the device. For this reason, high-strength epoxy resin is used in most cases. The resin is also used to form a dome-shaped lens that focuses the light emitted by the LED element. Fillers such as diffusing agents are mixed into encapsulating resin to control its light distribution characteristics. And with the emergence of elements that emit blue light, fluorescent materials are now being mixed into the resin to convert the blue light to other wavelengths. This has led to the production of white LEDs and LEDs that can be any color.

Because the encapsulating resin directly envelops the LED element, the light emitted from the element can be used very close to the element. Consequently, the energy concentration of the light around the element is extremely high, and with short-wavelength elements such as blue or white LEDs, light degradation of the resin is a major problem. In PLCC-type packages, because the construction is supported by a molded frame and lead frame, silicon resins can be used. While these resins are more flexible than epoxy resins, they are highly resistant to light degradation.

## Other Components

### Reflective frame

A PLCC-type LED lamp is made by fitting a resin external frame around the lead frame used to conduct electricity and then mounting the LED into the frame and enveloping it in encapsulating resin to form the package. Because the structure is supported by the external frame, a flexible material can be used as the encapsulating resin. To make the most effective use of the light from the LED element, the external frame is treated to make it highly reflective and resins with white pigment added as a filler are used.

Like the encapsulating resin, part of the role of the reflective frame is to protect the inside of the lamp from the external environment, so the material used must have excellent durability. Ceramic reflective frames have also been developed that offer higher durability than resin for applications where lamps are to be used in harsh environments or particularly high levels of reliability are demanded.

### Lens

Encapsulating resin has a high refractive index and, depending on its shape, will change the direction of light projected from the element. Consequently it can be used to form a lens. In the case of pinned LEDs, the entire resin envelope functions as a lens and controls the light distribution characteristics of the

lamp. Chip LEDs can also be made into a sharply focused lamp either by shaping the encapsulating resin or by subsequently adding a lens.

### Diffusing agents

The LED element light distribution characteristics have specific patterns depending on the product. The light distribution characteristics for lamps encased in clear resin reflect the light distribution characteristics of the LED element used. To eliminate the effects of variations in LED elements and provide uniform distribution patterns, diffusing agents such as silica are sometimes mixed into the encapsulating resin.

### Fluorescent materials

With the development of LED elements that emit blue light, it has become possible to use LEDs to excite fluorescent materials. This allows a single LED element to produce any color. For instance, by combining an element that emits blue light with a yellow fluorescent material and projecting the light from both, white light can be achieved.

Because fluorescent materials are vulnerable to moisture, lamp design must take moisture resistance into account. Care must also be taken with the selection of the materials used, since the constituent substances in some materials can cause other components to degrade.

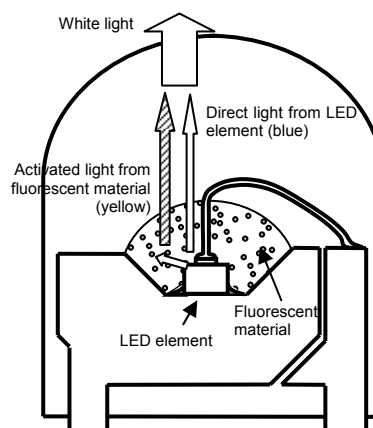


Fig. 7 White LED