Basic structure of LED

LEDs are solid state light emitting devices. Compared to conventional light bulbs, it generates less heat and has a longer life. In addition, the compact and all-solid-state light source can be formed, so it has excellent impact resistance and greatly increases the flexibility of design for customers. This article will explain the basic structure of LED devices.

What is LED ?
Light Emitting Diodes (LEDs) are light emitting devices made of semiconductor materials. LEDs that are formed in various packages so that they can be used as electronic components are collectively called LEDs.
In this paper, a package containing a die is called an LED (or LED device), and a semiconductor chip is called an LED die.
LED applications have been used for LED displays, as well as indicators for electronic devices that take advantage of their small size and low power consumption. These days, it has been used for LCD backlights, camera flashes, general lighting and automobile headlights as the brightness of white LEDs has increased progress.

Types and structures of LED devices

Through-hole type LEDs

The main material is LED die, lead frame, bonding wire (Au / gold wire) and molding resin. (Fig.1)

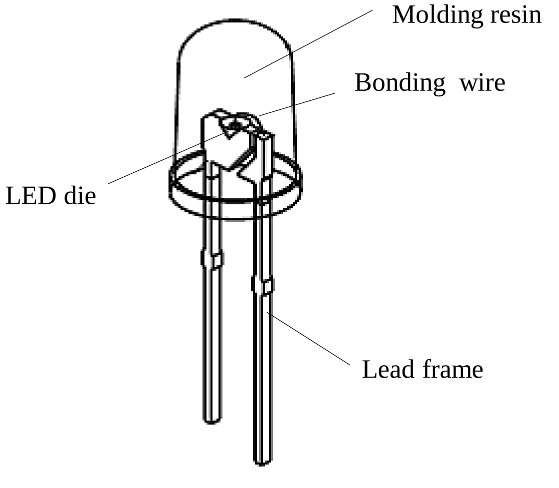

Fig.1 Through-hole type LEDs

Surface mount LEDs : Chip type (PCB type)

Chip type LED was developed as a surface mount device for electronic circuit board. (Fig.2)
The structure is an LED die on a small printed circuit board (PCB), connected to PCB with bonding wire, and then around the die is molded with resin.

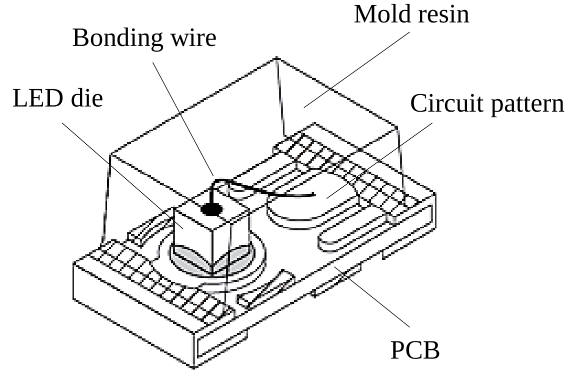

Fig.2 Surface mount LEDs : Chip type (PCB type)

Surface mount LEDs : Reflector type (PLCC type, ect.)

The LED die is mounted in a package in which a lead frame with a reflector (lamp house) molded, and after connecting to the lead frame with a bonding wire, the sealing resin is injected into the lamp house and the inside is hardened.
The lamp house is used as a light reflector, and controls the light distribution characteristics to increase the light efficiency. (Fig.3)

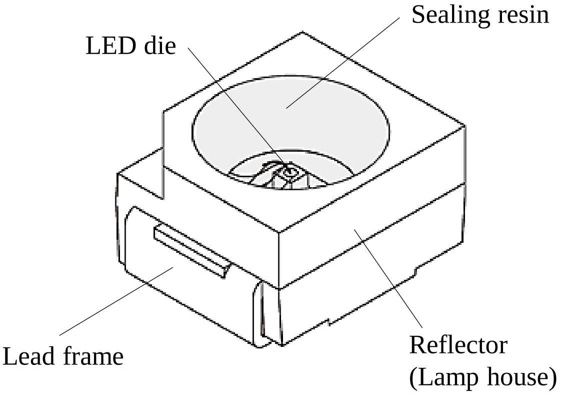

Fig.3 Surface mount LEDs : PLCC type

Other surface mount LEDs

There are some variations, such as a lamp house made of ceramic or other materials, or used a glass cover instead of a sealing resin.

Component materials for LED devices

<u>LED die</u>

The main material of LED devices. A type of semiconductor chip that converts electrical energy into light. The basic structure is a combination of p-type and n-type semiconductors with different electrical conduction types, and it belongs to a device called a diode. (Fig.4)

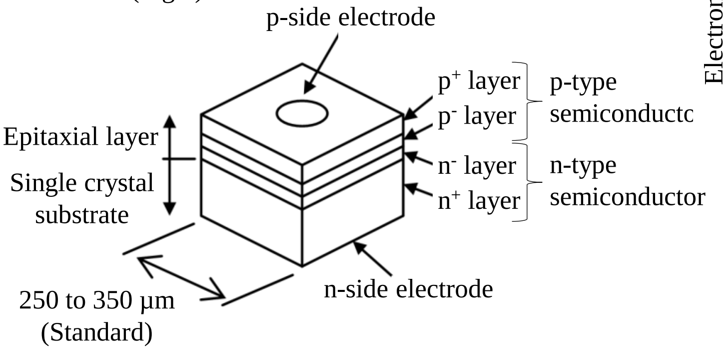

Fig. 4 Basic structure of LED die

While ordinary diodes are mainly made of silicon or germanium, LEDs are made of compound semiconductors such as GaAs, GaP, AlGaInP, and InGaN. Compound semiconductors have an electron energy state inside a solid depending on the constituent materials. When the energy of electrons is converted into light energy inside this, the wavelength of light has the property of being inversely proportional to the electron energy. LEDs made of compound semiconductors can emit light with wavelengths from infrared to visible and ultraviolet, depending on the constituent materials.

To convert electron energy into light energy, a current is passed through the device, and electric carriers are injected into the P-N junction. Electric carriers are electrons in n-type semiconductors and electron holes in p-type semiconductors (a group of electrons in a special state behaves like a single particle with a positive charge due to quantum mechanical action). When electrons and electron holes recombined at P-N junction, the energy that the electron had is released. Energy is released in the form of electromagnetic waves and emitted as light.

LED die is improved to luminous efficiency by various measures. The luminous efficiency can be divided into the efficiency when changing the electron energy to light energy (internal quantum efficiency) and the efficiency to extract light energy from the die. In general, the efficiency of the photoelectric conversion phenomenon is expressed as quantum efficiency because both electrons and light are handled as quantum that can be counted one by one.

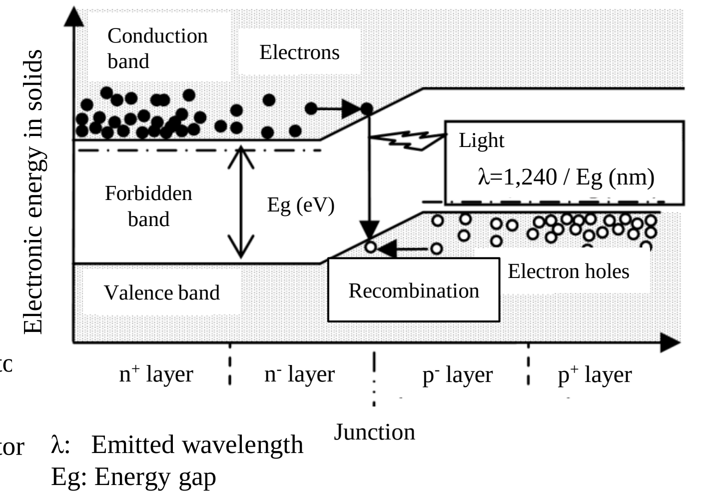

Fig.5 Light emitting structure of LED die

External quantum efficiency

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

η_e : Internal quantum efficiency

E : Light extraction efficiency

Measures to improve internal quantum efficiency

- Primarily due to the improvement to the P-N junction.
- Enhance crystallinity, heterojunction, quantum well structure, etc.

Measures to improve light extraction efficiency

Remove of light-absorbing elements in LED die and reduce of internal reflection components.

- Removal of light-absorbing elements:
  Adoption of transparent substrate
- Reduction of internal reflection components:
  Surface texture processing
  Trapezoidal shape, etc.
- Other: Reflective layer etc.

Since the LED die is completely solid, a mechanically strong all-solid-state light-emitting device can be realized. In addition, since the light emission is not caused by heat, high luminous efficiency can be expected.

Lead frame, printed circuit board (PCB)

Holds the LED die, receives electric power from the outside, and provides electrical continuity to the die. For through-hole type LEDs and PLCC packages, lead frames made of copper or iron alloys are used. Plating with high reflectivity is usually applied, and measures are taken to suppress light absorption inside of LED package. Printed circuit board (PCB) is often used for chip LEDs. In order to suppress light absorption, a highly reflective substrate material is used.

An important function of the lead frame and PCB is heat dissipation of the die. These are in direct contact with the die and provide an important escape path for the heat generated by the die. For applications that require a high brightness, it is necessary to pass a large current, and various measures has been made on the package, such as a wide lead frame and a PCB with a metal core.

Bonding wire

The electrical pattern of lead frame or PCB and the electrode of die are connected gold wires. Ultrasonic waves are used for connection. When connecting for the first time, the tip of the gold wire is ball-shaped and is rubbed against the electrode of die or lead frame with ultrasonic waves. The ball is made by applying heat to discharge and melting the tip of the gold wire. (Fig.6)

At this time, the wire near the ball also partially melts, and it becomes as different state with other parts when cooled (referred to as recrystallization region). Since this part forms crystal grain boundaries, care must be taken from an electrical point of view. For example, if a large current is passed, it may break. The LED rating is designed with a sufficient margin so that this disconnection does not occur.

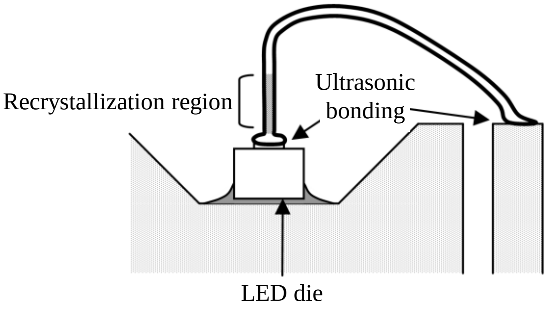

Fig.6 Bonding wire

Bonding wire is one of the weak parts of LEDs in terms of mechanical strength, but it is protected by sealing around of the wire with resin.

Die bonding material

The LED die is fixed to the lead frame etc with die bonding material. Many LED devices have a structure in which current flows from the epitaxial growth layer side to the conductive substrate side. So the die is put on the electrical pattern of the lead frame or PCB, the substrate side is bonded with a die bonding material. The bonding wires join to the epitaxial growth layer for supply power.

The die bond material is mainly a Ag paste in which silver particles are dispersed in an epoxy resin. This material has electrical conductivity after curing and has excellent thermal conductivity. However, since it is a resin material, degradation may be a problem with short wavelength LEDs. For this issue, some LEDs are used eutectic junctions with AuSn etc. Eutectic bonds are made of all metal materials, so they have excellent thermal conductivity and high reliability. There is also a die bonding method with gold balls using the flexibility and adhesiveness of gold.
These days, there are LED die with an insulating material for the substrate. In this case, both p semiconductors and n semiconductors are supplied on the epitaxial growth layer side. Conductivity is not necessarily required for bonding, so transparent resin paste is used.

Sealing resin (Mold resin)

Fill around LED die with resin and fix it. This protects the LED die from moisture and external impacts. The resin used is transparent or transmitting the light emission wavelength well. Through-hole type LEDs are one of the simplest types of structure, and epoxy resin with high hardness is often used because the entire structure is supported by a moldisealing resin. The dome shape acts as a lens and condenses the light emitted from the LED die. Fillers such as diffusing material may be mixed in the sealing resin to control the light distribution. And the blue light can be converted to other wavelength with phosphors mixed with resin. This technology realize white LEDs.

The sealing resin directly covers the LED die, so it receives light emitted from the die at a close range. For this reason, the energy density of the light around the die is extremely high, and in the case of short wavelength die such as blue and white LEDs, photodegradation of the resin becomes a major problem. The reflector type LEDs such as PLCC package has the structure with a lamp house and a lead frame, so a silicone resin that is softer than epoxy resin but highly resistant to light degradation can be used.

Other Components

Lamp house (Reflective frame)

PLCC type LEDs are made by fitting a resin lamp house around the lead frame used to conduct electricity and then mounting the LED die into the lead frame and enveloping it in sealing resin to form the package. Because the structure is supported by the lamp house, a soft resin can be used as the sealing resin. To make the most effective use of the light from the LED die, the lamp house is treated to make it highly reflective and resins with white material added as a filler are used. Like the sealing resin, part of the role of the lamp house is to protect the inside of the LED package from the outside environment, so the material used must have excellent durability. Ceramic lamp house has also been developed that offer higher durability than resin for applications where LEDs are to be used in harsh environments or particularly high levels of reliability are demanded.

Lens

Sealing resin has a high refractive index and, depending on its shape, will change the direction of light emitted from the LED die. Consequently it can be used to form a lens. In the case of through-hole type LEDs, the entire resin functions as a lens and controls the light distribution characteristics of LEDs. Surface mount LEDs can also be made into a sharp light distribution either by shaping the mold resin or by subsequently adding a lens.

Diffusing material

Light distribution characteristics of LED die have specific patterns depending on the die. The light distribution for LEDs sealed in clear resin reflect the light distribution of the LED die used. To eliminate the effects of variations in LED die and provide uniform distribution patterns, diffusing material such as silica are sometimes mixed into the sealing resin.

Fluorescent materials

With the development of LED die that emit blue light, it has become possible to use LEDs to excite fluorescent materials. This allows a single LED die to product any color. For example, by combining a die that emits blue light and yellow phosphor, white light can be achieved.

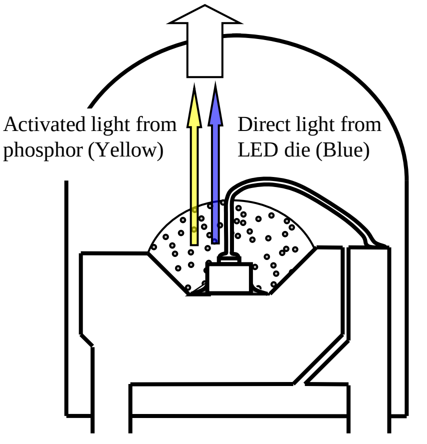

Fig.7 White LEDs

Because phosphor are weak to moisture, LED package design must take moisture resistance. Care must also be taken with the selection of the materials used, since some materials can cause other components to degrade.