

Development of Super High Brightness Infrared LEDs

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We have developed super high brightness infrared light emitting diodes (LEDs). The LEDs at the wavelength of 870 nm reached record-breaking output power of 9.8 mW, which was more than 1.3 times higher than the evaluated value of the conventional 850 nm LEDs. These super high brightness infrared LEDs can be fabricated without using time- and cost-consuming wafer bonding technologies such as metal bonding and glue bonding. They are also free from reliability issues possibly arising from the bonding interfaces. The new super high brightness infrared LEDs are promising as a light source for future applications such as high sensitivity sensors.

Keywords: infrared light emitting diode, multiple-quantum well

1. Introduction

Infrared light emitting diodes (LEDs), whose light emitting wavelengths are between 800 nm and 980 nm, are widely used for light sources of remote controllers, photo couplers and infrared communications such as Infrared Data Associations (IrDA).

In **Table 1**, some of the main markets for high power infrared LEDs are shown. In addition to the above applications, there are expanding markets for high output power infrared LEDs. Examples of the applications are light sources for surveillance cameras and license plate readers, sensors used in factory automation (FA), smoke detectors, and infrared range finders for digital cameras.

For these expanding infrared LED markets, Sumitomo Electric Industries, Ltd. has integrated production, such as liquid phase epitaxy (LPE) grown wafers, and also has recently developed high power 940 nm infrared LEDs⁽¹⁾. The high power 940 nm LEDs have some advantages in comparison with the conventional 850 nm LEDs. For example, the human eye is not sensitive to a high power 940 nm emission even at night time. Also, solar radiation can be a source of noise in outdoor applications during daytime. The 940 nm emission peak coincides with an absorption dip of solar radiation associated with water vapor. Therefore, design of outdoor low-noise sensor systems can be made simpler using 940 nm technology.

In general, there are two major solutions for high power LED realization as stated below. (1) To increase internal quantum efficiency by the improvement of the active layer. (2) To increase external quantum efficiency by the improvement of the extraction of the light emission from

the devices. These improvements of the external quantum efficiency include the reduction of total reflection by the use of surface texture and the reduction of light absorption inside the devices.

The chip structures of conventional high power LEDs are shown in **Fig. 1**. These are classified into substrate removed double hetero (DDH) type, metal bonding (MB) type and glue bonding (GB) type. The characteristic features of these LEDs are shown in **Table 2** along with the newly developed structures. In the table, double circles, circles and triangles mean “excellent,” “good” and “not good,” respectively.

Among these, GB type LEDs are expected to be the highest power LEDs because both transparent and insulating substrates can be used for this structure. This reduces the absorption of emitted light to its lowest limit. The highest power red LEDs produced from the AlGaInP system are realized using the GB structure⁽³⁾.

However, GB type LEDs have a long-term reliability

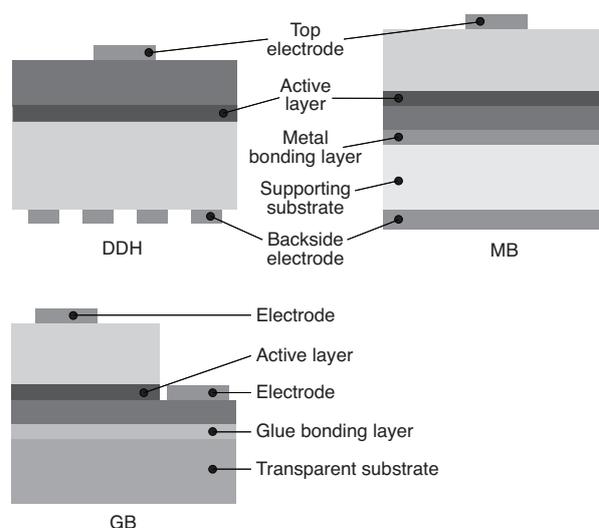


Fig. 1. Device structures for high output power LEDs

Table 1. Markets for high power infrared LEDs

- Surveillance cameras, outdoor floodlights
- Light sources for automotive cameras
- Night vision systems
- Light sources for license plate readers
- Various sensors for FA and other domestic use
- Range finding sensors for digital cameras
- Infrared data communications

Table 2. Characteristic features of various high power LED structures

Items	DDH-type	MB-type	GB-type	New product
Output power	○	○	⊙	⊙
Device process	○	△ (bonding)	△ (bonding)	○
Reliability	⊙	○	△	⊙
Axial intensity	○	⊙	○	○
Heat radiation	○	○	△	○
ESD tolerance	○	○	△	○

problem due to the glue bonding, and electro-static discharge (ESD) tolerance is not sufficient because of the use of totally insulating substrates. Therefore, GB type infrared LEDs have not yet been put into wide-spread practical use.

Under these circumstances, we have developed super high brightness infrared LEDs equivalent to GB type output power without using glue bonding. These LEDs are free from reliability issues and ESD tolerance, therefore superior to GB type. The optical output power of the 870 nm LED was more than 1.3 times higher than the conventional MB type 850 nm LED.

In this paper, the authors report the development of 870 nm and 940 nm infrared LEDs and their characteristics.

2. Schemes for Increasing Output Power of Infrared LEDs

To increase the optical output power of LEDs, the following two measures are available. One is to increase the light emission efficiency itself at the active layer. Another is to extract more emitted light from the devices. As is shown in **Fig. 2**, an LED emits light when the injected electrons and holes recombine at the active layer. The efficiency of this recombination is called internal quantum efficiency, and it is supposed to be sufficiently high resulting from the optimization of epitaxial growth condition and epi structures. There are the following causes which might decrease extraction efficiency: (i) Band-edge absorp-

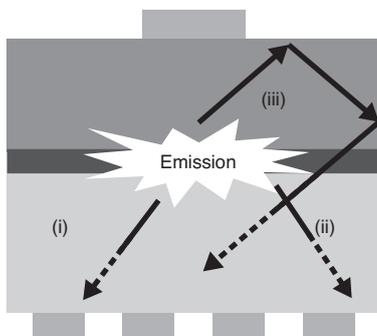


Fig. 2. Light emission and absorption mechanisms

tion, (ii) Free carrier absorption due to conduction electrons and holes, (iii) Total reflection at the device surfaces.

Among these, we focused on (i) and (ii), and developed thick, transparent AlGaAs semiconductor epi structures for high power infrared LEDs which are free from bonding process. In order to do so, we designed Al concentration and carrier density profiles along the thickness direction, and optimized both the transparency and the electrical requirements for LED use.

3. 870 nm LED Characteristics

3-1 Epi structure for infrared LED

Figure 3 shows the newly developed AlGaAs epi structure for infrared LEDs. A transparent AlGaAs epi layer of 150 μm is grown on an n-type GaAs substrate, followed by an LED structure with a multiple-quantum-well (MQW) active layer. The structure is grown by metalorganic chemical vapor deposition (MOCVD). The diameter of the structure is 50 mm.

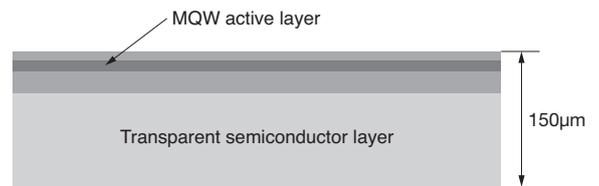


Fig. 3. AlGaAs epi structure for super high brightness infrared LEDs

3-2 870 nm infrared LED structure

The structure of the newly developed LED is shown in **Fig. 4**. On an LED epi structure, a p-type transparent electrode is grown, followed by a p-pad electrode. Optimizing the ratio of the component elements gave us a transparent electrode with low resistivity and good ohmic contact with the p-type GaAs semiconductor layer. A part of the epi layer is etched to expose the n-type layer, on which an n-type

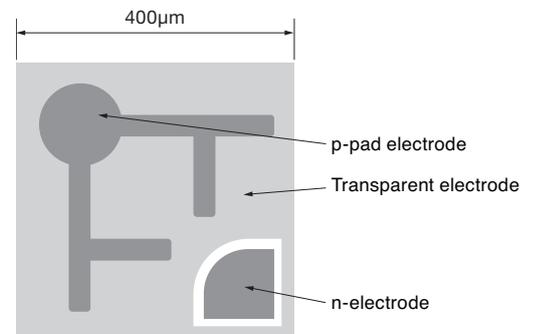


Fig. 4. Structures of newly developed infrared LEDs

electrode is fabricated.

The chip size is $400\ \mu\text{m} \times 400\ \mu\text{m}$ with a thickness of $150\ \mu\text{m}$. The diameter of the p-pad electrode is $100\ \mu\text{m}$. Both on the side walls and the backside, surface roughening treatment is used to increase the light extraction.

3-3 DC characteristics

Figure 5 shows the current-light output characteristics of the newly developed 870 nm and 940 nm devices, where that of the conventional high output MB type 850 nm LED is shown at the same time. For these evaluations, LED chips are mounted on TO-18 type stems without any epoxy resin encapsulation. The output power of the 870 nm device at 20 mA was as high as 9.8 mW, which was more than 1.3 times higher than the evaluated value (7.4 mW) of the MB-type one. The output power of the 940 nm LED was 8.4 mW, which was more than 1.5 times higher than the previously reported one⁽¹⁾.

The forward voltages at 20 mA DC were 1.43 V (870 nm) and 1.47 V (940 nm), which turned out to be sufficient for practical use.

The light emission spectrum of the 870 nm device mounted on TO-18 without encapsulation is shown in Fig. 6. This figure shows that the emission wavelength is 873.6 nm

and the full width at half maximum (FWHM) of spectrum wavelength of the device is as sharp as 19.5 nm.

A $\phi 5\ \text{mm}$ bullet LED lamp was produced with epoxy transparent resin. The viewing angle of the lamp was 30 degrees. Figure 7 shows the current-light output power characteristics of the 870 nm LED. Light output power was as high as 13.3 mW.

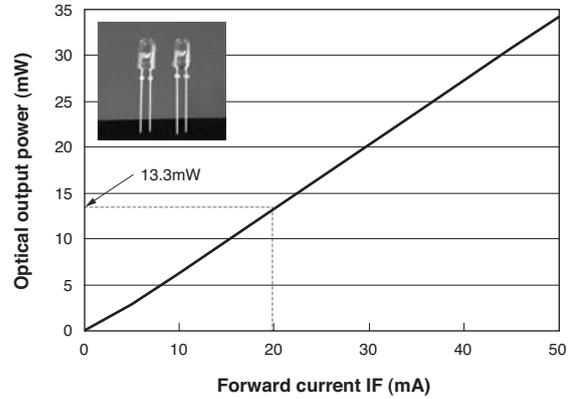


Fig. 7. Current-light output power characteristics of a $\phi 5\ \text{mm}$ bullet 870 nm LED lamp

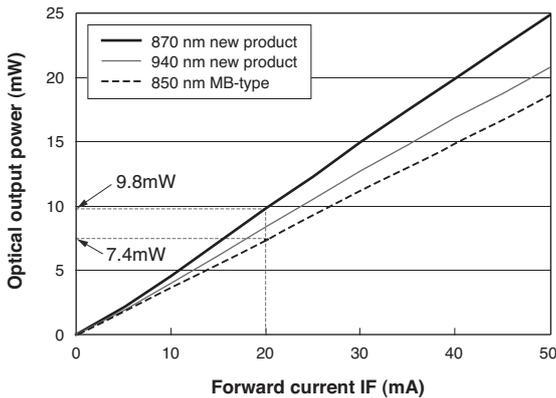


Fig. 5. Current-light output power characteristics of newly developed infrared LEDs

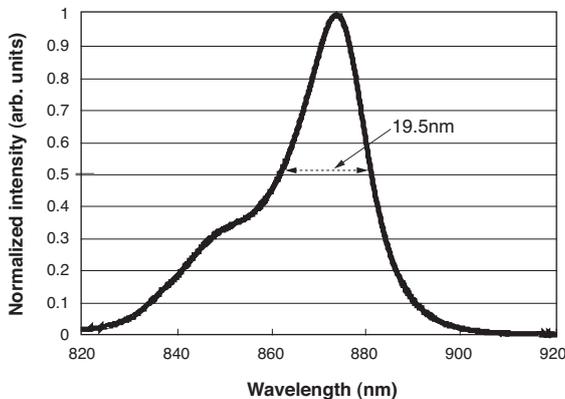


Fig. 6. Light emission spectrum of 870 nm infrared LED

3-4 Viewing angle evaluation

The viewing angle at 50% intensity of the 870 nm LED at 20 mA DC is shown in Fig. 8. The chip was mounted on TO-18 type stems without any encapsulation. The viewing angle is 158° . This value is larger than 124° , which is the evaluated value for the MB type 850 nm LED. This point is open to further improvement.

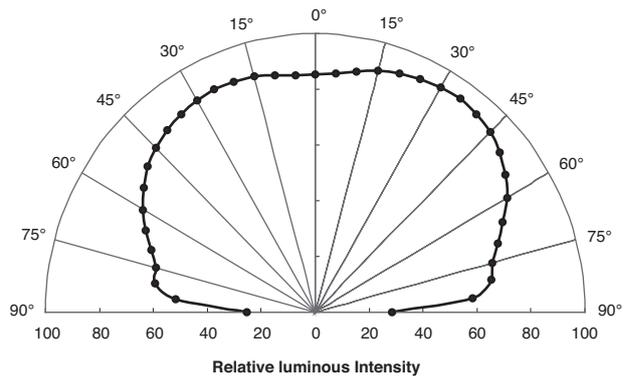


Fig. 8. Viewing angle of 870 nm infrared LED

3-5 ESD evaluation

Human body ESD was tested for the newly developed LEDs. The human body ESD model is the series RC circuit in which the body resistance, R, is 1500 ohm and the capacitance of the body, C, is 100 pF. +700 V and -700 V were

applied alternately for 5 consecutive times and the change of the reverse leak current was evaluated. The results showed enough ESD tolerance for the newly developed LEDs.

It is known that GB type LEDs on insulating substrates and Gallium Nitride LEDs on sapphire are very weak against ESD. These LEDs are mostly used with Zener diodes. The newly developed LEDs have another advantage over GB type LEDs from the ESD point of view.

4. Conclusions

We fabricated novel infrared LEDs using our long-term development of GaAs compound semiconductor epitaxial growth technology and optimization of the epi structure, and developed the world highest optical output power infrared LEDs.

The newly developed device structures can be easily applied to the wavelength range between 850 nm to 940 nm. These super high brightness infrared LEDs can be fabricated without using time- and cost-consuming wafer bonding technologies. These LEDs are also free from reliability issues possibly arising from the bonding interfaces.

This novel LED structure also provides ample room for future improvements by the optimization of the AlGaAs epi structure.

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