Development of High Power Infrared LED

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We have developed the world highest optical output power infrared light emitting diode (LED) at 940nm. With a newly developed epitaxial layer structure and a p-type electrode, the optical output power was increased to 5.3 mw at 20 mA DC current, which was about 2.5 times higher than that of a conventional 940 nm LEDs. Forward voltage was 1.35V. The full width of half maximum (FWHM) of spectrum wavelength of the device was 25 nm, which is less than half of that of the conventional one. Acceleration testing showed a lifetime of over 10,000 hours with a DC current of 100 mA at 25˚C. This new high output power infrared LED is promising as a light source for future applications such as high sensitivity sensors.

Keywords: infrared light emitting diode, multi-quantum well, GaAs

1. Introduction

Infrared Light Emitting Diodes (LEDs), whose light emitting wavelength 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's).

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. In 2008, the market of the high output power infrared LED was estimated to be 60 million chips per month world-wide, including 14 million chips per month in Japan. This market is expected to expand continuously. In **Table 1**, some of the main markets for high power infrared LEDs are shown.

We targeted the development of 940 nm LEDs, instead of the 850 nm LEDs, which are widely used for high power infrared LED markets. We choose 940 nm for the reasons stated below.

Generally, the human eye is sensitive to wavelengths ranging from 380 to 780 nm. However, an 850 nm high power infrared LED emit visible red light. This is due to the broad emission spectrum of an LED, which is wide in comparison with lasers. Consequently, 850 nm LEDs are not optimal for applications such as crime prevention, as wavelength filters would also be needed. Therefore, our successful development of a high power LED 940 nm emission has an advantage which can simplify application systems.

Table 1. Markets of high power infrared LEDs

- · Surveillance cameras, outdoor floodlights·
- · Light sources for automotive cameras
- · Night vision system
- · Light sources for license plate readers
- · FA, and various sensors for domestic uses
- · Range finding sensors for digital cameras
- · Infrared data communications

There is also the potential to simplify application design for outdoor signal detection. During the daytime, solar radiation can be a source of noise in outdoor applications. At 940 nm, there is an absorption associated with water vapor. Design of outdoor low-noise sensor systems can be made simpler by setting the wavelength of the light sources at 940 nm.

Also, due to the Rayleigh scattering in the atmosphere, the scattering of light decreases in an inverse proportion to the 4th power of the wavelength. For this reason, a longer wavelength light source is advantageous against Rayleigh scattering.

The characteristic features of 940 nm infrared LEDs are shown in **Table 2** along with the conventional high power 850 nm LED.

For the conventional 940 nm LEDs with double hetero (DH) structures, the LED emission occurs at 940 nm owing to band tailing effects caused by the highly Si doped, compensated region of the p-n junction [1]. Due to the high concentrations of impurity dopants, it is essentially difficult to obtain good crystal quality and a high power LED.

Sumitomo Electric Industries, Ltd. has integrated production from bulk GaAs crystal growth to epitaxial growth on bare wafers. Due to its outstanding technology, customer partnering and global presence, Sumitomo

Table 2. Comparison characteristics of 850 nm and 940 nm infrared LEDs

Items	850 nm high power	940 nm on the market	940 nm newly developed
Output power	5 mW ○	2 mW △	5 mW ○
Invisibility	×	○	○
Tolerance for solar radiation	×	○	○
Scattering of light source	△	○	○
Frequency response	△	×	○

Electric is a leading company in the compound semiconductor industry. Especially, for the infrared LED market, its high quality and low cost products have more than 50 % share of the market. Over many years of development in epitaxial growth technology, especially multiple-quantum-well (MQW) active layer growth in infrared and red laser products [(2)], we have developed the world highest output 940 nm infrared LED. The main features of the newly developed product are summarized in **Table 3**.

In this paper, the authors report the development of 940 nm infrared LED and its characteristics.

Table 3. Features of 940 nm high power LED

· High optical output power (more than 2.5 times the output of a conventional LED)
· No visible light emission
· High signal to noise ratio for outdoor use
· Good tolerance against scattering
· Good linearity of current-output for large injection current
· Excellent high speed response
· High reliability

2. 940 nm Infrared LED Structure

The structure of a 940 nm infrared LED is shown in **Fig. 1**. On an n-type transparent semiconductor epitaxial layer consisted of AlGaAs, an LED structure with an MQW active layer is grown, followed by a p-type transparent electrode and a p-pad electrode. On the backside, n-type ohmic dot electrodes are formed to improve light output by use of light reflection [(3)].

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.

The chip size is 350 μm x 350 μm (14 mil) with a thickness of 150 μm. The diameter of the p-pad electrode is 120 μm.

Surface roughening treatment is used both on the side walls and the backside in order to increase the light extraction.

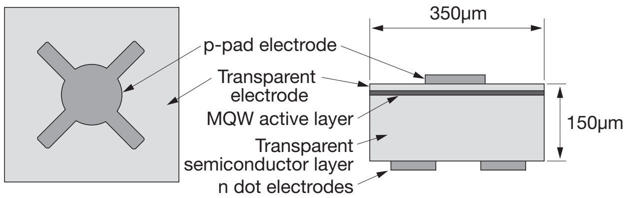

Fig. 1. 940 nm infrared LED structures

3. 940 nm LED Characteristics

3-1 DC characteristics

Figure 2 shows the current-light output characteristics of the newly developed device, where that of the conventional high output 940 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 at 20 mA was as high as 5.3 mW, which was around 2.5 times higher than the evaluated value (2 mW) of the conventional one.

The forward voltage at 20 mA DC current was 1.35V, which turned out to be sufficient for practical use.

A 5 mmø bullet LED lamp was produced with epoxy transparent resin. The view angle of the lamp was 30 degrees. **Figure 3** shows the current-light output power characteristics. Light output power was as high as 9.1 mW and the forward voltage was 1.37 V at 20 mA.

The light emission spectrum of the device mounted on TO-18 without encapsulation is shown in **Fig. 4**. This figure shows that the full width of half maximum (FWHM) of spectrum wavelength of the device is 25 nm, which is less than half of that of the conventional one. The utilization of the MQW active layer realizes the spectrum of a higher degree of purity.

Generally, the detection sensitivity of a silicon-made photo detector (PD) rapidly becomes worse as the wavelength of the signal becomes longer at the infrared region. This newly developed LED, whose spectrum is narrow at the longer wavelength in comparison with conventional one, can be detected much easier even with the same entire output power.

Also, the 940 nm light emission wavelength coincides with the atmospheric absorption of the solar radiation,

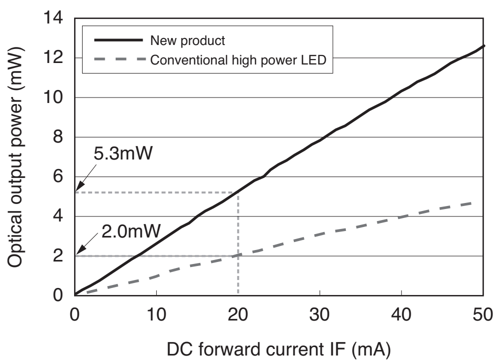

Fig. 2. Current-light output power characteristics of a 940 nm infrared LED

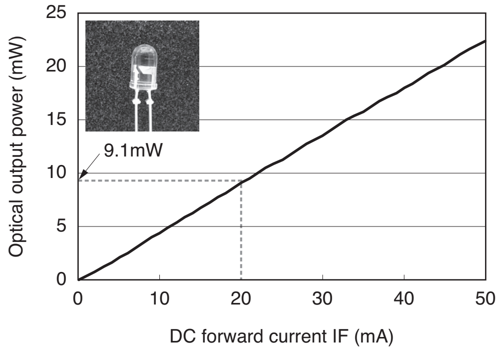

Fig. 3. Current-light output power characteristics of a 5 mmø bullet LED lamp

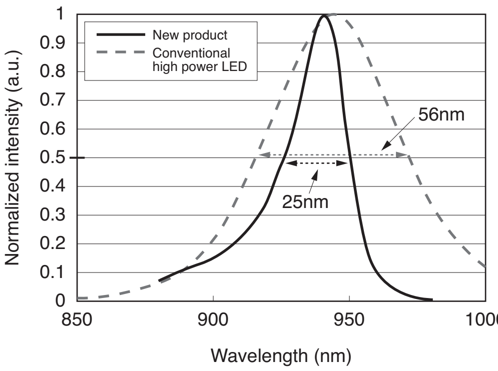

Fig. 4. Light emission spectrum of 940 nm infrared LED

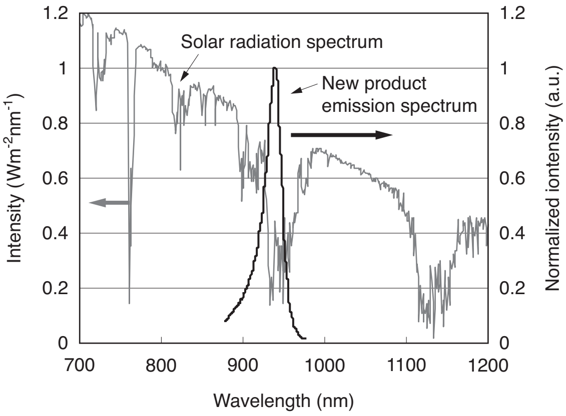

Fig. 5. Light emission spectrum of 940 nm infrared LED and solar radiation spectrum

which can be utilized to realize a more noise-resistive system much easier. The above situation is shown in **Fig. 5**.

MQW active layer is also attractive for the reason why the precise control of the emitting wavelength can be obtained easily.

3-2 Pulse characteristics

For applications with high power LEDs such as floodlights for license plate readers or surveillance cameras, LEDs are mainly used under large pulsed current condition. For these applications, the following two requirements are especially important:

· Low device voltage under the large injection current

· Linearity of current-output characteristics

The device voltage under pulsed conditions at a duty of 0.1% with a pulse width of 1μsec was evaluated. At 1 A pulse current, the device voltage was 3.5 V, and this voltage was sufficiently low for practical applications.

For the linearity of current-output characteristics, we have optimized the structures of the MQW active layers and suppressed carrier overflows. Due to these improvements, the output power reaches more than 3 times of that of the conventional high power LED at 1A.

3-3 Dynamic characteristics

The dynamic responses of the LED chips were measured. Rise time (Tr) and fall time (Tf) were 10 nanoseconds and 7 nanoseconds, respectively. Cutoff frequency of the device was over 40 MHz. These Tr and Tf values are less than one-tenth of that of the conventional structure devices, whose Tr and Tf are typically a few hundred nanoseconds.

3-4 Reliability evaluation

We carried out accelerated lifetime testing. The results are shown in **Fig. 6**. The test was carried out under an aging temperature of 85˚C, with an injection current of 100 mA using 12 samples. The circles show average values for the 12 chips. The lifetime, which is assumed as the time when the output power decreases more than 30% of the original power, reaches more than 1,000 hours.

Temperature and current dependence of the lifetime were also evaluated. From these data, we estimated the expected lifetimes at under both 25˚C, DC 100 mA and 85˚C, DC 20 mA, which were more than 10,000 hours. This result indicated that the newly developed device has good reliability from a practical point of view.

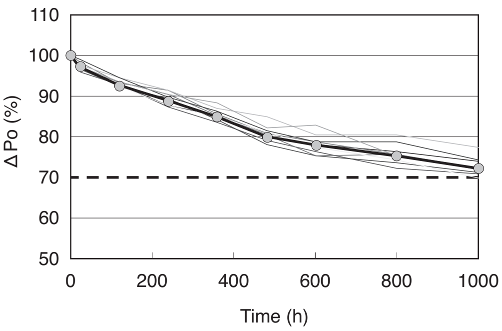

Fig. 6. Accelerated life time testing results of 940 nm infrared LEDs

4. Future Development

We have succeeded in developing the world highest output LED at 940 nm emission wavelength. And we are now under investigation for realizing ultra high power LED between 800 and 980 nm infrared regions.

In the field of a four-element LED, high brightness LED is realized by the use of the wafer bonding technology [(4)-(5)], and it is believed that the same situation would happen in the infrared region. We are under development of an original wafer-bonding-type LED through the use of high quality epitaxial growth technology and new materials. For these investigations, some patent applications have already been filed.

Although we have realized high speed response around 40 MHz with this device, we are trying to get further improvement of the device response by the optimization of the epitaxial layer structures for the high speed communication applications.

5. Conclusions

We fabricated a novel 940 nm infrared LED using our long-term development of GaAs compound semiconductor epitaxial growth technology, and developed the world highest optical output power LED.

A high output power LED at 940 nm, with no visible light emission and high noise resistance, is an essential device for applications such as crime prevention, and has an advantage that the detector design can be much easier. Therefore, both the brand-new application and the replacement of the existing 850 nm high power LED can be expected. We already started shipping these devices to some customers.

The newly developed devices, with a high quality MQW as an active layer, have other advantages such as narrow spectrum width and precise controllability of emitting wavelength, which make the design of the detector much easier.

Also, in having the excellent linearity of current-output characteristics at large current and high speed responsibility, this infrared LED is promising as a light source for the future various applications.

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