Ultracompact RGB Laser Module Operating at +85°C

Tetsuya KUMANO*, Yohei ENYA, Kuniaki ISHIHARA, Hiromi NAKANISHI,
Takatoshi IKEGAMI and Takao NAKAMURA

We have developed a novel ultracompact RGB laser module with a wide operating temperature range. RGB laser chips, photodiode chips, a thermistor, and optical components are mounted on a thermo-electric cooler on a base mount. The base mount is hermetically sealed in an 11 × 13 × 5.7 mm metal package, from which high-quality stable collimated laser beams are emitted. Operation at +85°C was difficult with conventional RGB laser modules because the output power of laser diodes (LDs), especially red LDs, dropped at high temperatures. However, the thermal capacity was lowered by mounting LDs on a chip, thus enabled control of module temperature at a wide range of -40°C to +85°C with a Peltier cooler. The temperature is controlled at a high reply speed of less than 4 sec.

Keywords: full-color, laser, semipolar, thermoelectric cooler, collimated laser beam

1. Introduction

In recent years, a number of projects have been promoted to develop displays for innovative devices, such as pico projectors and wearable terminals including head-up displays. There is a growing demand for an ultracompact laser source that incorporates laser diodes (LDs*[1]) to emit red, green and blue (RGB) lights for use in the aforementioned display devices. Full color display capability requires RGB LDs. As for red and blue light sources, AlInGaP-LDs and InGaN-LDs are available on the market, respectively. However, proven green light sources have been limited to the 532 nm light source that exploits the second harmonic generation (SHG*[2]) from an infrared LD (1064 nm).

The use of SHG implies disadvantages in terms of size and characteristics. For this reason, expectations have been extremely high and much effort has been put into the development of a green LD. Discovering the advantages of the semipolar $\{20\bar{2}1\}$ plane of gallium nitride (GaN), in 2009, we succeeded in oscillating the world's first true green LD by using the $\{20\bar{2}1\}$ plane of a GaN substrate. We subsequently published papers on pulse oscillation at a wavelength of 531 nm and continuous wave oscillation (CW oscillation*[3]) at room temperature at a wavelength of 536.6 nm.[(1)-(5)] In the meantime, it was believed difficult to realize a green LD that incorporates the c-plane of a GaN substrate due to several engineering challenges. However, the development of such a green LD was somehow finalized. The results were reported as 1.01 W output power and 525 nm CW oscillation with 14.1% wall-plug efficiency.[(6)]

Using these green LDs, RGB laser modules have been developed for applications such as pico projectors and head-up displays.[(7)-(9)] Usually, RGB laser modules comprise separate TO-CAN*[4] packages of RGB LDs. However, this configuration results in a limited range of operating temperatures because it is difficult for this configuration to control the module temperature due to a large thermal capacity. Specifically, among RGB LDs, red LDs exhibit noticeably degraded characteristics, i.e. reduced laser output power, at high temperatures. Consequently, demand has been high for RGB laser modules that function properly in harsh temperature environments, such as under in-vehicle conditions, for the aforementioned innovative devices to be usable in such environments.

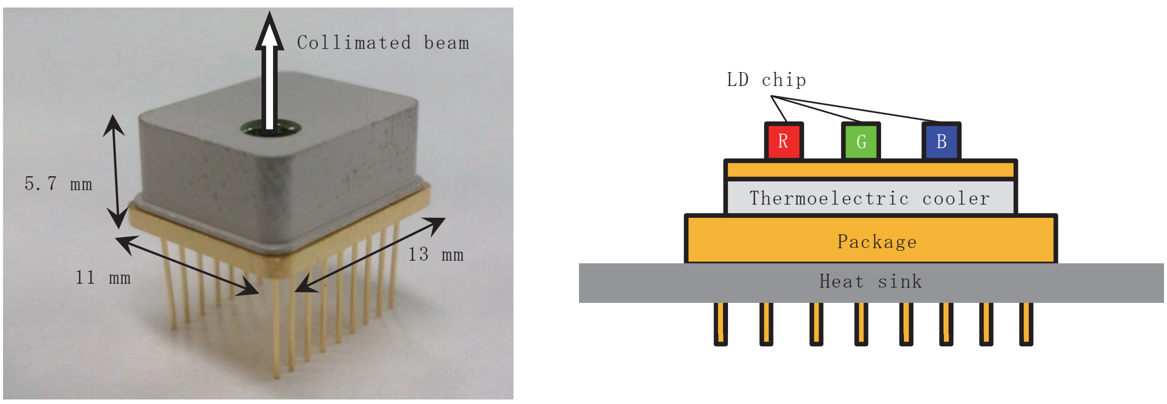


Fig. 1. RGB module structure

To meet this challenge, by combining Sumitomo Electric Industries, Ltd's experiences in visible-range laser technology and communication module technology, we have worked on the development of an ultracompact RGB laser module that operates in a wide temperature range. This paper reports on the world's first successful development of such a laser module.

2. Module Structure

The advantages of laser sources include high definition, high brightness, and focus-free projection. One of their drawbacks is that their characteristics degrade at high temperatures. To overcome this disadvantage, we built a thermoelectric cooler (TEC*5) into the module. Figure 1 shows a photo and a schematic illustration of the internal features of the ultracompact RGB laser module.

The module size is 11 x 13 x 5.7 mm. RGB LD chips, photodiodes (PDs*6), a thermistor, and optical components (lenses and multiplexer) are mounted on a TEC. The base mount for the TEC is hermetically sealed in a metal DIP.*7 The oscillation wavelengths of the RGB LDs are 640, 528, and 460 nm. The PDs monitor the outputs from the RGB LDs. Signals from the thermistor are used to control the TEC. This ultracompact package emits collimated beams*8 with light concentration and multiplexing processes taking place inside the module. The multiplexer incorporated into the ultracompact package carries out multiplexing with high precision, drawing on Sumitomo Electric's technology nourished through the development of communication modules. The thermal capacity of the LDs was reduced by mounting them not in the form of TO-CAN, but in the form of chips. Figure 2 shows correlations between temperature and TEC power dissipation. The TEC peak power dissipation reaches 3.5 W at +85°C. Direct mounting of three LDs on a base mount remarkably reduces their thermal capacity in comparison with the use of TO-CAN LDs. Doing so made it possible to control LD chip temperatures at a relatively low level of power consumption.

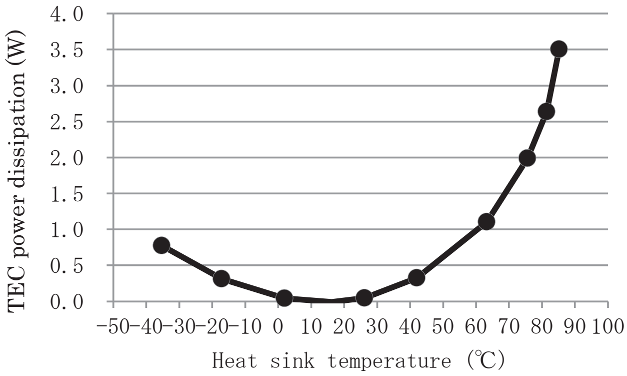


Fig. 2. TEC power dissipation

3. Module Characteristics

3-1 Laser output power characteristics

The effect of maintaining the module temperature constant by means of TEC control was verified, securing the module on a 100 x 100 x 1 mm heat sink. Figure 3 shows the temperature dependence of laser output power with the TEC not in operation. The graphs reveal that the laser output power decreases with increasing temperature. In particular, they illustrate noticeable drops in the output power of the red LD at temperatures over +40°C. Figure 4 shows the results of maintaining the LD temperature at +40°C by operating the TEC under various ambient temperature conditions. When the TEC was in operation, the output power was constant in a wide ambient temperature range.

3-2 Precision of the optical axis

The quality of collimated RGB beams was also evaluated. Figure 5 shows a histogram (L = 1400 mm) of optical axis angle deviations from the reference axis.

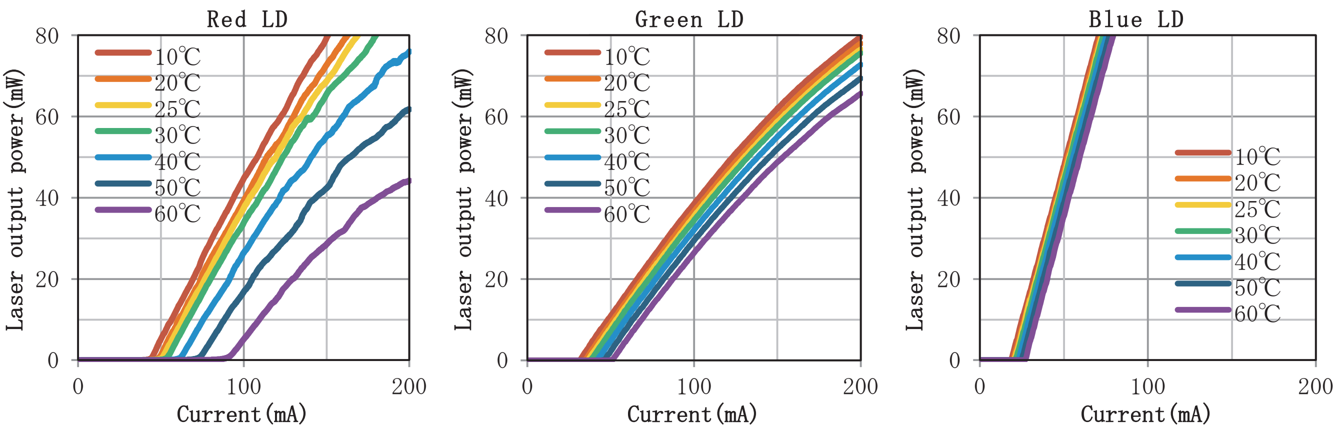


Fig. 3. RGB laser output power-temperature characteristics (with TEC not in operation)

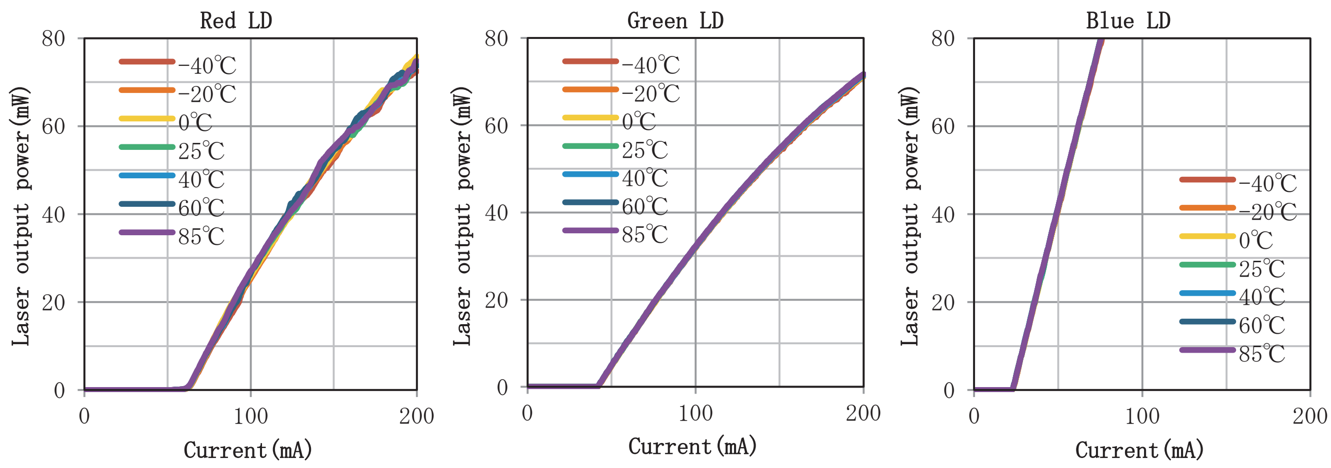


Fig. 4. RGB laser output power-temperature characteristics (with TEC in operation)

Angle deviations averaged 0.03° proving high precision in multiplexed RGB beams. Modules that multiplex beams from TO-CAN LDs produce angle deviations between 0.1° to 0.2°, being greater than the aforementioned average by an order of magnitude. Thermal expansion of optical components resulting from temperature increases causes optical axis deviations. However, these are very small in magnitude (Fig. 6). If these are taken into account, the aforementioned average is smaller than optical-axis angle deviations of TO-CAN LDs still by an order of magnitude. Moreover, because the optical components are mounted on the TEC, maintaining the LD temperature constant eliminates the effects of thermal expansion on optical axis deviation.

3-3 Responsivity

The responsivity of the RGB laser module was also evaluated. Figure 7 shows changes over time in module temperature when +40°C control was made against ambient temperatures of +85°C and -40°C. The low thermal capacity of the module is effective in reaching the desired temperature within 4 sec. This high responsivity is expected to start up the module quickly even under high or low temperature environments. Accordingly, this is an important characteristic for practical use. If TO-CAN LDs are assembled, the volume of the components to be cooled would increase about

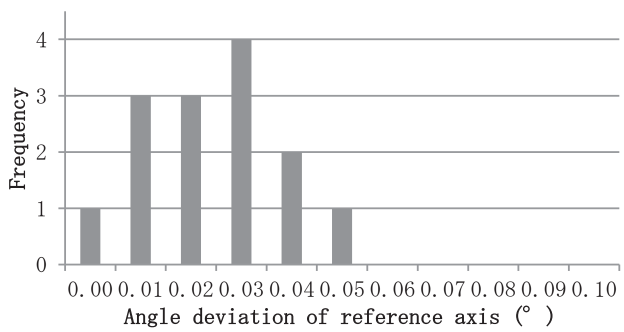


Fig. 5. Angle deviation of collimated RGB beams

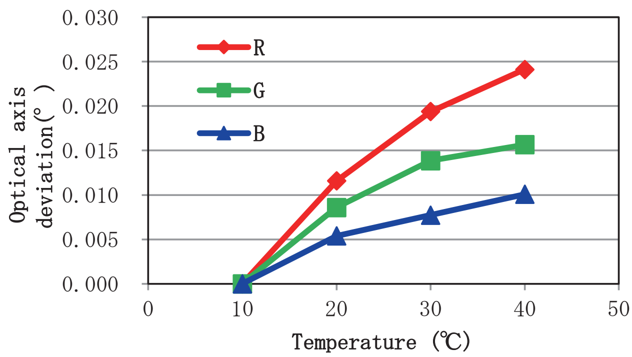


Fig. 6. Temperature dependence of optical axis deviation

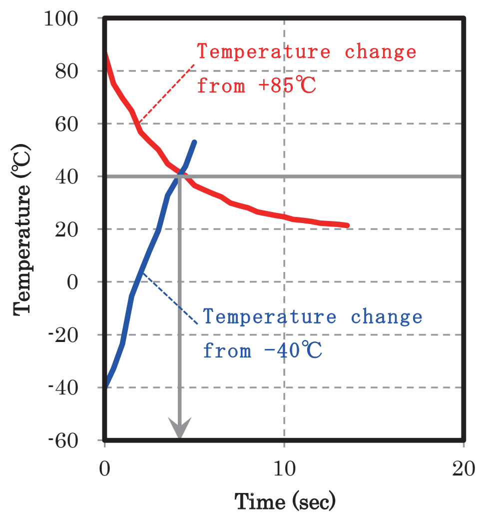


Fig. 7. Changes over time in module temperature with TEC in operation

ten-fold, with responsivity degrading by an order of magnitude.

3-4 Fiber output power characteristics

The aforementioned optical module was connected with a single mode fiber (SMF*9) (Photo 1). This connection was achieved in such a manner to ensure high connection efficiency for the three laser beams, enabling each to output at 20 mW (Fig. 8).

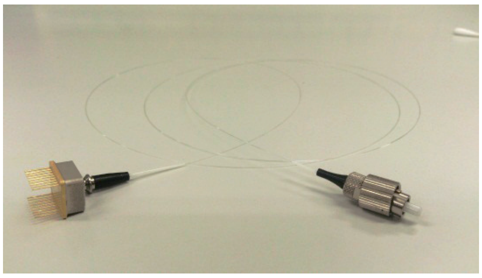


Photo 1. SMF module

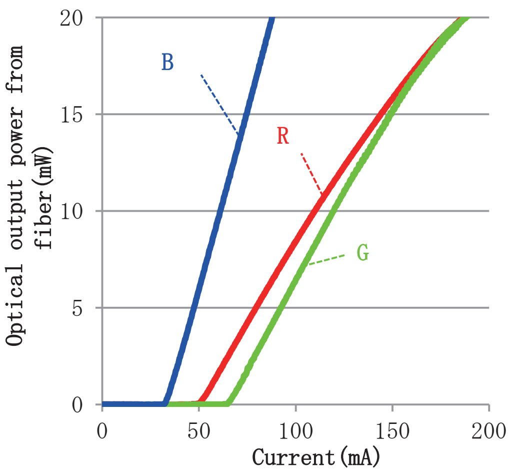


Fig. 8. RGB beam output from fiber

4. Module Applications

4-1 DIP module

The above-described DIP module is designed to achieve temperature control with a reduced power requirement due to the use of TEC and reduced thermal capacity, made possible by elaborately mounted chips and optical components. This design overcomes the drawbacks of LDs that change in output power, wavelength, and other characteristics with ambient temperature. Specifically, it enables red LDs to operate properly at high temperatures, avoiding drops in output power. The DIP module offers high reliability by hermetically sealing the chips and optical components. Possible applications include head-up displays, projectors and signage.

4-2 SMF module

An SMF module has also been developed, connecting SMF to the above-mentioned DIP module (Photo 2). High-efficiency interconnection of an RGB laser and fiber reduces the number of components and hence module size in comparison with the conventional system using individual connections between fibers and RGB-LDs along with a combiner. Applications for the SMF module include wearable terminals, illumination, high-brightness lighting and analysis.

4-3 TO-CAN module

In addition to the DIP module, a TO-CAN module has been developed (Photo 3). Using the standard 5.6 mm diameter package usually used with LDs, RGB-LDs and optical components are encapsulated to emit collimated RGB laser beams from the 5.6 mm diameter package. Controlled laser drive currents produce colorful laser beams. Uses of the TO-CAN module include pointers, wearable terminals, illumination, and industrial equipment.

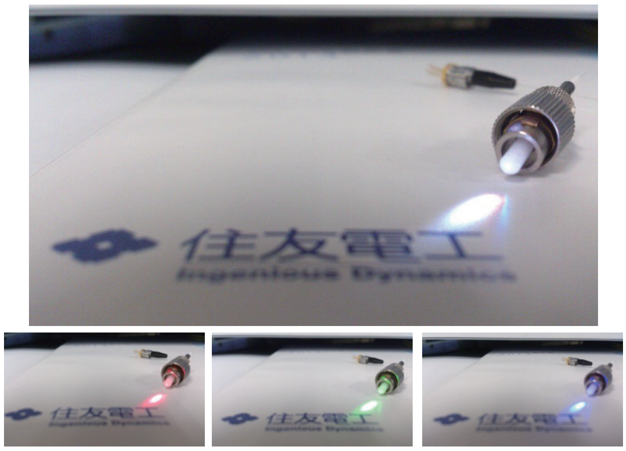


Photo 2. Light emitted by SMF module

Photo 3. TO-CAN module

5. Conclusion

We succeeded in developing an ultracompact RGB laser module with a wide operating temperature range. The size of the module is 11 x 13 x 5.7 mm, in which RGB-LD chips, PD chips, a TEC, a thermistor, and optical components (lenses and a multiplexer) are mounted on a base mount. The PDs monitor the laser output power of the RGB LDs. The thermistor placed within the package controls the TEC. This ultracompact package emits collimated RGB laser beams with high precision. Control by the TEC enables the RGB laser module to operate stably within a wide temperature range from -40°C to +85°C.

Technical Terms

∗1 Laser diode (LD): A laser diode is a device that uses an input current to convert electrons to light and amplify optical output power. Laser diodes emit light with high color purity.

∗2 Second harmonic generation (SHG): Generation of light at twice the frequency of the original light

∗3 Continuous wave (CW) oscillation: The state of temporally continuous oscillation

∗4 Transistor outline-CAN (TO-CAN): Usually, visible-range LDs are distributed, being encapsulated typically in a TO package 3.8, 5.6, or 9 mm in diameter.

∗5 Thermoelectric cooler (TEC): A small electric refrigerating element that incorporates a Peltier junction

∗6 Photodiode (PD): A diode that converts absorbed light into an electric current; The RGB laser module incorporates PDs to monitor laser output power.

∗7 Dual in-line package (DIP): A rectangular package that has rows of metal pins on two sides

∗8 Collimated beams: Light beams made parallel by means of a lens or the like; Collimated beams are highly directional and travel over a long distance.

∗9 Single mode fiber (SMF): A fiber that carries a single mode of light within it; Single mode fiber features low loss.

References

(1) T. Kyono, Y. Enya, K. Akita, M. Ueno, M. Adachi, T. Sumitomo, S. Tokuyama, T. Ikegami, K. Katayama, T. Nakamura "The world's first development of true green laser diodes on new GaN substrates I," SEI Technical Review No.176, pp.88-92 (2010)

(2) M. Adachi, T. Kyono, Y. Enya, K. Akita, M. Ueno, T. Sumitomo, S. Tokuyama, T. Ikegami, K. Katayama, T. Nakamura "The world's first development of true green laser diodes on new GaN substrates II," SEI Technical Review No.176, pp.93-96 (2010)

(3) Y. Enya, Y. Yoshizumi, T. Kyono, K. Akita, M. Ueno, M. Adachi, T. Sumitomo, S. Tokuyama, T. Ikegami, K. Katayama and T. Nakamura, "531 nm green lasing of InGaN based laser diodes on semi-polar $\{20\bar{2}1\}$ free-standing GaN substrates," Appl. Phys. Express, vol. 2, 082101-082103 (2009)

(4) S. Takagi, Y. Enya, T. Kyono, M. Adachi, Y. Yoshizumi, T. Sumitomo, Y. Yamanaka, T. Kumano, S. Tokuyama, K. Sumiyoshi, N. Saga, M. Ueno, K. Katayama, T. Ikegami, T. Nakamura, K. Yanashima, H. Nakajima, K. Tasai, K. Naganuma, N. Fuutagawa, Y. Takiguchi, T. Hamaguchi, and M. Ikeda, "High-power (over 100mW) Green Laser Diodes on Semipolar $\{20\bar{2}1\}$ GaN Substrates Operating at Wavelengths beyond 530nm," Appl. Phys. Express 5, 082102 (2012)

(5) K. Yanashima, H. Nakajima, K. Tasai, K. Naganuma, N. Fuutagawa, Y. Takiguchi, T. Hamaguchi, M. Ikeda, Y. Enya, S. Takagi, M. Adachi, T. Kyono, Y. Yoshizumi, T. Sumitomo, Y. Yamanaka, T. Kumano, S. Tokuyama, K. Sumiyoshi, N. Saga, M. Ueno, K. Katayama, T. Ikegami and T. Nakamura, "Long-Lifetime True Green Laser Diodes with Output Power over 50 mW above 525 nm Grown on Semipolar $\{20\bar{2}1\}$ GaN Substrates," Appl. Phys. Express 5, 082103 (2012)

(6) S. Nagahama: Int. Workshop Nitride Semiconductors, 2012, PL4

(7) http://www.microvision.com/technology/

(8) http://pioneer.jp/carrozzeria/products/nd_hud1/

(9) http://www.sony.co.jp/SonyInfo/News/Press/201402/14-024/

Contributors The lead author is indicated by an asterisk (∗).

T. KUMANO∗

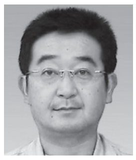

• Semiconductor Technologies Laboratory

Y. ENYA


• Assistant Manager
Semiconductor Technologies Laboratory

K. ISHIHARA


• Ph.D.
Assistant Manager, Sumiden Semiconductor Materials, Ltd.

H. NAKANISHI


• Specialist
Senior Assistant Manager, Semiconductor Technologies Laboratory

T. IKEGAMI


• Chief Engineer, Semiconductor Technologies Laboratory

T. NAKAMURA


• Ph. D.
Project Manager, Semiconductor Technologies Laboratory