Optics and Laser Technology 102 (2018) 222–226

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Probing longitudinal modes evolution of a InGaN green laser diode

Yi-Hsi Chen [a], Wei-Chen Lin [a], Hong-Zui Chen [a], Jow-Tsong Shy [b], Hsiang-Chen Chui [a,*]

[a] Department of Photonics, National Cheng Kung University, Tainan 70101, Taiwan
[b] Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

ARTICLE INFO

Article history:
Received 6 October 2017
Received in revised form 14 November 2017
Accepted 20 December 2017

Keywords:
Emission spectroscopy
Mode analysis
Diode lasers

ABSTRACT

This study aims to investigate the longitudinal mode evolution of a InGaN green laser diode. A spectrometer with a 3-pm resolution was employed to obtain the emission spectra of a green laser diode, at a wavelength of around 520 nm, as a function of applied current and temperature. The spectral behavior of the laser modes with applied current was investigated. Right above the lasing threshold, the green diode laser emitted single longitudinal mode output. With increasing applied current, the number of the longitudinal modes increased. Up to ten lasing modes oscillated within the entire gain profile when the applied currents were tuned to $2.2I_{th}$. Subsequently, a multi-Lorentzian profile model was adopted to analyze the spectra and observe how the modes evolved with temperature and applied current.

1. Introduction

A cleaved-facet laser diode (LD) without optical feedback normally generates a multi-longitudinal-mode laser beam. A Fabry–Perot-type LD has cleaved facets that act as cavity mirrors, and the reflectivity of the facets is determined by the index difference between the gain medium and air. The mode spacing of the longitudinal modes can be estimated from the cavity length and the refractive index of the LD materials. The quasi-two-level laser system of LDs typically has broad emission spectrum; therefore, the mode number of the LD longitudinal mode can be on the order of ten to more than one hundred. More longitudinal modes lower the coherent length of laser beams. The competition among the longitudinal modes could induce laser power stability. Although, many laser applications do not consider the coherent length, it needs to be taken into account to obtain a single frequency laser beam. Analysis of the mode evolution of an LD with applied current and environmental temperature is critical when choosing the LD for some applications.

With the rapid development of blue and green GaN-based LDs, researchers have demonstrated that these types of LDs exhibit higher power, higher efficiency, and longer wavelength. Eichler et al. [1] have reported high-resolution spectral measurements of two continuously driven InGaN-based laser diodes. The study of the high resolution spectral lines from the emissions of a blue laser diode has been performed by Al-Basheer [2]. Subsequently, Al-Basheer [3] obtained laser spectra and tracked the longitudinal mode evolution as a function of applied current and temperature within the wavelength range of 440–450 nm. The need for direct green lasers has pushed the LD wavelength to the green region. Avramescu and coworkers [4,5] demonstrated that direct green laser diodes lase at 515 and 524 nm with an output power of more than 50 mW. Harge et al. [2] pushed the output power to more than 100 mW. Green diode lasers have the potential to replace traditional green lasers, such as Ar-ion and solid-state lasers. Using intracavity frequency-doubled design, diode-pumped solid-state lasers can emit 532 nm green beams with a power on the order of sub-milliwatts to tens of watts. The green laser can be applied in many areas such as laser pump source, sensing, ranging, and undersea communications. Some research works regarding to tunable plasmonics sensor [6–8] using the laser pumping needed the laser mode information, and phase control. The detailed analysis of the LD mode evolution is essential for those applications.

In this work, we performed spectral measurements of a green InGaN-based LD as a function of the applied current and LD temperature. A simple experimental scheme was employed to observe and record the spectra. We adopted a multi-Lorentzian lineshape model to analysis the spectra and observed the evolution of modes with temperature and current. The measurements as a function of temperature and the model analysis showed that the lasing modes were insensitive to temperature. A detailed analysis of the LD spectra as a function of applied current was also performed.

* Corresponding author.
E-mail address: hcchui@mail.ncku.edu.tw (H.-C. Chui).

https://doi.org/10.1016/j.optlastec.2017.12.037
0030-3992/

2. The optical setup and design

Fig. 1 shows the experimental scheme for monitoring the output power and obtaining the whole spectrum of the green InGaN LDs. A green LD (OSRAM PLP520 B1) was mounted on a temperature-controlled aluminum plate, and driven by a low-noise QCL (Quantum Cascade Laser) driver (Wavelength Electronics QCL500). The 7-V operating voltage could not be driven by a common diode laser driver. We kept the room temperature at 25 °C, and mounted the LD system on an air-floated optical table to avoid the mechanical vibration. According to the display of LD temperature controller, the temperature instability of the aluminum plate was less than 0.02 °C. The maximum output power was up to 100 mW at 340 mA applied current. The laser beam from the LD was collimated into a multimode fiber using a fiber collimator (Thorlabs F220SMA-A). A 10/90 fiber coupler was used to divide the laser beam into two arms. The weaker beam with 10% power was sent into a power meter (Thorlabs S120C) to monitor the laser output power. The stronger beam with 90% power was sent into an ultrahigh resolution monochromator (Jobin Yvon iHR550, Horiba) to record the whole spectrum for different applied currents and LD temperatures. The width of the exit slit was 2 μm, the grating was 1800 line/mm, and the integration time was 0.1 s. The resolution was estimated as 0.003 nm, about 3.3 GHz at the central wavelength 522 nm. The power-current (L-I) curve under different temperatures is shown in Fig. 2(a). The threshold current was 138 mA when the temperature (T) was 25 °C. The spectra of the green LD under operation currents of 150 and 220 mA at 25 °C operation temperature, are shown in Fig. 2(b). The longitudinal mode number of the green LD increased with increasing applied current. The spectrum of the LD laser mode was composed of several longitudinal modes and was, therefore, not a pure Gaussian profile.

3. Experiment results and discussions

Eichler and coworkers [1] have presented the longitudinal mode patterns of a 410 nm laser diode. Furthermore, the spectral and spatial dynamics of InGaN blue-violet lasers have been reported by Ropars [5], and the evolution of blue laser diode spectral lines with applied current in the wavelength range of 446–448 nm was studied by Al-Basheer [6]. In the present work, we aimed to study the spectra of a green LD as a function of applied current and LD temperature.

3.1. Mode evolution as a function of applied current

The longitudinal mode number of the green LD increased with increasing applied current. When the LD temperature was fixed at 25 °C, the LD spectra were recorded as a function of applied current in 2 mA steps from 134 mA ($0.96I_{th}$) to 170 mA ($1.21I_{th}$), and are plotted in Fig. 3(a). Typically, the lasing spectra of LD as a function of applied current is divided two parts: under the lasing threshold, and above the lasing threshold. But we found some unique optical features of the lasing spectra when the applied current was just above the lasing threshold. The evolution of the LD spectra can be divided into (1) the spontaneous emission under the lasing threshold, (2) single-longitudinal-mode output when the applied current was just above the lasing threshold, and (3) multi-longitudinal-mode output at higher applied currents. The output spectrum is composed of one or two longitudinal modes and the peak location is independent of the allied current. Mode evolution with applied current from 170 mA ($1.21I_{th}$) to 300 mA ($2.14I_{th}$) is shown in Fig. 3(b). The current interval of this measurement was 10 mA. The output power of this LD increased from 17 mW (170 mA) to 73 mW (300 mA). To avoid intensity saturation on the photoreceiver of the monochromator, the incident power was lowered by a polarizer. Thus, the intensity distributions plotted in Fig. 3(b) have been normalized to 30,000.

Furthermore, the mode evolution as a function of LD temperature was recorded. In Fig. 4(a), the applied current of the LD was fixed at 150 mA, close to the lasing threshold. With an increase in LD temperature, the lasing spectra changed from single frequency (at T = 10 °C) to spontaneous emission (at T = 30 °C). When the applied current was tuned to 300 mA (as shown in Fig. 4(b)), much higher than the lasing threshold, the lasing spectra contained several peaks. Some peaks were located at individual frequencies, and were insensitive to temperature tuning. When the LD was driven by the applied current at 150 mA, the power decreased with the temperature, and the output power stability was estimated as 4.3%. When the applied current was raised up to 300 mA, the output power stability was estimated as 2.6%.

3.2. The LD operated near the lasing threshold

The green LD spectra under operational currents of 140, 150, and 160 mA are shown in Fig. 5(a), when the temperature was fixed at 15 °C. The spectrum at 140 mA appeared to be from a light-emitting diode with dominant spontaneous emissions and can be regarded as the LD operating under the lasing threshold. Only a single longitudinal mode was observed when the LD current increased to 150 mA. The mode linewidth was measured as 3.3 GHz using a spectrometer, and 41 MHz using a scanning Fabry–Perot interferometer (Thorlabs SB200-3B). When the LD current was tuned to 160 mA, the spectra showed 0.24 THz mode spacing between two longitudinal modes.

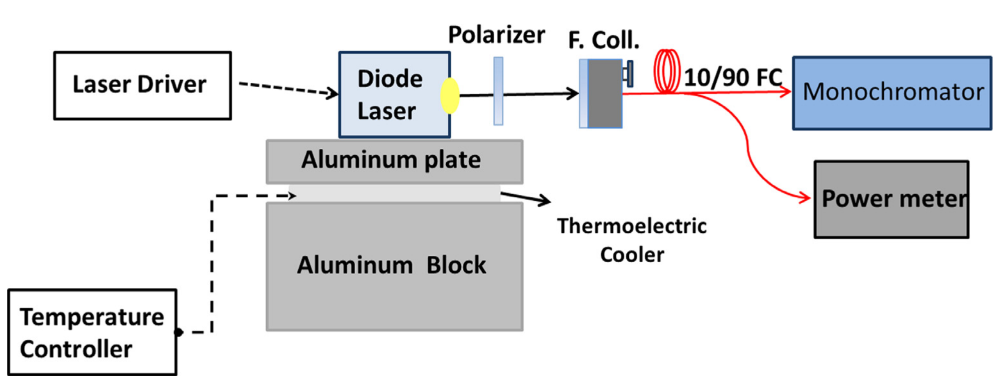

Fig. 1. Experimental scheme for green diode laser monitoring. F. Coll: Fiber Collimator; FC: Fiber Coupler. The measurement conditions of the monochromator: the width of the exit slit: 2 μm, the grating groove number: 1800 line/mm, and the integration time: 0.1 s.