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# อิทธิพลของอุณหภูมิต่อเลเซอร์ไดโอดในเลเซอร์ไดโอดแบบโพรงภายนอก

# Influence of Temperature on Laser Diode Inside External Cavity Diode Laser

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## บทคัดย่อ

งานวิจัยนี้ศึกษาอิทธิพลของอุณหภูมิที่มีต่อเลเซอร์ไดโอดภายในระบบเลเซอร์ไดโอดแบบโพรงภายนอกชนิดกระจกสะท้อนตาแมว เลเซอร์ไดโอดแบบโพรงภายนอกชนิดนี้ใช้การโฟกัสแสงไปที่กระจกเพื่อที่จะทำการปรับความถี่ของเลเซอร์ กระแสไฟฟ้าที่ให้กับเลเซอร์ไดโอด และอุณหภูมิของเลเซอร์ไดโอดแบบโพรงภายนอกนี้สามารถปรับเพื่อให้ได้ค่าความถี่ของเลเซอร์ที่เหมาะสมสำหรับ D2 ของอะตอมรูบิเดียม อย่างไรก็ตามอุณหภูมิของเลเซอร์มีอิทธิพลอย่างมากต่อเลเซอร์ ดังนั้นในงานวิจัยนี้ได้ศึกษาการเปลี่ยนแปลงอุณหภูมิของเลเซอร์โดยที่ระยะคาวิตี้คงที่ตลอดการทดลอง ซึ่งความยาวคลื่นของเลเซอร์ถูกวัดด้วยสเปกโตรมิเตอร์ โดยการทดลองในตอนที่สองจะทำการปรับอุณหภูมิ และกระแสที่ค่าต่างๆ โดยใช้ชุดทดลองสเปกโตรสโคปีแบบดูดกลืนอิ่มตัวของอะตอมรูบิเดียมเพื่อวัดการเปลี่ยนชั้นพลังงานแบบละเอียดยิ่งยวดที่ D2 สำหรับการปรับเงื่อนไขที่ดีที่สุดที่สามารถวัดการดูดกลืนที่ D2 สำหรับใช้ในการทดลองต่างๆกับอะตอมรูบิเดียมได้

**คำสำคัญ** : เลเซอร์ไดโอดแบบโพรงภายนอก ; กระจกสะท้อนตาแมว ; สเปกโตรสโคปีแบบดูดกลืนอิ่มตัวของอะตอมรูบิเดียม

## Abstract

We study the influence of temperature on laser diode inside an external cavity diode laser (ECDL) with a cateye reflector mirror type. This type of ECDL has a focus beam to the external mirror in order to tune the laser frequency. The input current and temperature of the ECDL can be adjusted to a proper frequency for D2 of rubidium atoms. However, the influence of the temperature has a strong effect on the laser. Therefore, the study of the temperature variation has been conducted. The cavity length of the ECDL was fixed during the experiments. The laser wavelength was measured by a spectrometer. The second experiment, the temperature and current of the laser were adjusted and a rubidium saturated absorption spectroscopy was employed to monitor the D2 hyperfine transitions for the optimization conditions which can measure the absorption at D2 for using in various experiments with rubidium atoms.

**Keywords** : external cavity diode laser ; cateye reflector ; rubidium saturated absorption spectroscopy

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## Introduction

Due to their broad wavelength tunability and high spectral purity (Cunyun, 2004), external cavity diode lasers (ECDLs) are widely utilized in various fields including optical communications, environmental and atmospheric investigations, atomic and molecular laser spectroscopy, as well as trapping and cooling microscopic particles. Many advances in development of ECDLs have been reported in recent years. A chip-scale self-injection locked ECDL comprising a diode laser and a microresonator was shown to have extremely small linewidth reaching the range of sub-Hz (Liang *et al*, 2015). Adapted from Littman/Metcalf configuration, small-sized 780- and 960-nm ECDLs based on microelectromechanical systems (MEMS) installed with a transmission grating offered the tuning range over all possible gain region of the laser diodes (Hoppe *et al*, 2019). Fabrication and characterization of an integrated optical fiber as a fiber Bragg grating ECDL were carried out (Lynch *et al*, 2016). An atomic Faraday filter was exploited as a frequency-selective part of a 780-nm ECDL which possessed the laser linewidth and stability less than 1 MHz (Keaveney *et al*, 2016). The external reference optical elements were not necessary for the Faraday laser. A Littrow configuration ECDL with the wavelength of 410 nm and the tuning range of 5 nm was built and investigated (Li *et al*, 2017). The resulting output power of this blue violet ECDL was more than 500 mW. A tunable green ECDL based on the Littrow setup was demonstrated to be an alternative for a classical diode pumped solid state laser (Chen *et al*, 2017). Study of the influences of the laser driven currents and temperatures on the laser also showed that the increase in the currents led to the decrease in the wavelength tuning range. For applications of ECDLs as monitoring systems, a gas detector based on an ECDL system with two output infrared wavelengths was used for sensing $H_2O$, $CO_2$, and $CH_4$ through the absorption spectrum (Bayrakli, 2018). A tunable Littrow ECDL incorporating with a Fabry-Perot cavity was assembled to measure vacuum to atmospheric pressures through detection of a refractive index inside the cavity (Takei *et al*, 2020). Moreover, ECDLs also play important roles in quantum optics and atomics physics. An ECDL with tapered amplifier attached at same housing was designed and produced for atomic and molecular physics laboratories (Wells *et al*, 2020). It was found that the laser temperatures needed to be carefully controlled for the laser to work properly.

As the properties of an ECDL can alter significantly, depending on the laser temperature, the effect of the temperature on the performance of our 780-nm ECDL and rubidium absorption spectroscopy was inspected in this report in order to check that our ECDL can be tuned to atomic hyperfine transitions and is ready for near future research in atomic physics. Our ECDL setup was originated from cateye reflector configuration with an interference filter (Thompson & Scholten, 2012; Temnuch *et al*, 2021).

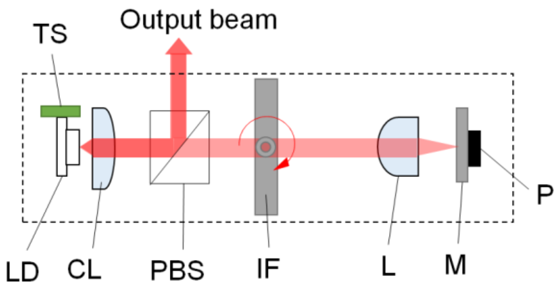

*Figure 1* (Top view) ECDL with a cateye reflector mirror type; laser diode (LD), temperature sensor (TS), collimating lens (CL), polarizing beamsplitter (PBS), interference filter (IF), lens (L), mirror (M), and piezoelectric actuator (P) (details see text).

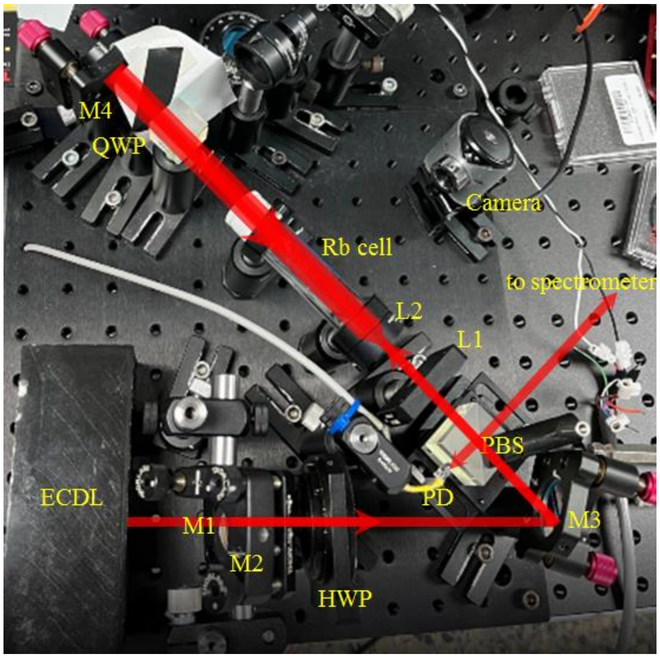

*Figure 2* Rubidium saturated absorption spectroscopy for analyzing the ECDL with a cateye reflector mirror type shown in Fig. 1 (details see text).

## Methods

External cavity diode laser is a tunable diode laser. This ECDL has the ability to adjust the frequency of the laser in a certain wavelength (Thompson & Scholten, 2012; Temnuch *et al*, 2021). The setup is shown in Fig. 1. A laser diode (L785H1, Thorlabs) with 785 nm was used as a light source in the ECDL. The laser beam was collimated with the lens, CL inside the laser holder and split into two beams by polarizing beamsplitter, PBS (PBS102, Thorlabs). The reflected beam with vertical polarization was reflected for using as the output beam. The transmitted beam with horizontal polarization was transmitted to the external cavity which comprises of an interference filter (LL01-780-12.5, Semrock), lens (A390TM-B, Thorlabs), mirror (ME05-M01, Thorlabs), and piezoelectric actuator (TA0505D024W, Thorlabs) for the frequency selection, laser beam focusing, reflector mirror and the cavity length scanning, respectively. The current injection for the laser diode was supplied by a laser diode driver (IP500, Thorlabs) and the laser diode temperature was controlled by our homemade temperature controller. This controller is based on a general PID control which obtained the feedback temperature from temperature sensor (TS in Fig. 1), attached to the laser diode to stabilize the set temperature shown in Fig. 3 and 4. The temperature accuracy of 0.1 °C was arranged in our temperature controller. Subsequently, the external cavity was scanned by our homemade servo circuit. This circuit has a ramp signal for scanning the piezoelectric actuator (P) inside the ECDL and this ramp (the yellow line in the inset of Fig. 4) can be reduced to zero when the diode laser in ECDL needs to be locked to a given laser frequency.

The output laser beam from the ECDL was used to test the laser frequency by our homemade rubidium saturated absorption spectroscopy as shown in Fig. 2. First, the mirror M1 and M2 (BB1-E03, Thorlabs) were used to adjust the laser height and then the combination of a half-wave plate, HWP (WPH10M-780, Thorlabs) and a polarizing beamsplitter, PBS (PBS202, Thorlabs) can adjust the laser intensity of the separated beams, which are the output beam reflected from this PBS and the analyzing beam transmitted to the rubidium saturated absorption spectroscopy. The output beam was measured the laser wavelength by a spectrometer (CCS175, Thorlabs). The analysing beam was expanded and collimated by two lenses L1, and L2 in order to cover the entire Rb cell (TG-ABRB, Precision Glassblowing). This expanded beam was injected to the Rb cell. The laser was tuned the frequency with the piezoelectric actuator (P) inside the ECDL until the rubidium atoms in the Rb cell can absorb the laser beam. This beam was then reflected back to the Rb cell by the mirror, M4 (BB1-E03, Thorlabs). This reflected beam can pass through the Rb cell without any absorption. Therefore, the transmitted intensity peaks (the peaks with blue line as shown in the inset of Fig. 4) can be observed by a photodiode, PD (SFH213, Osram). The quarter-wave plate, QWP (WPQ10M-780, Thorlabs) was used to change the polarization of the laser beam in such a way that the beam can be reflected from the PBS to PD. A webcam camera was used to check the fluorescent light of the rubidium atoms in the Rb cell when the laser frequency meets the requirement.

## Results

First, the wavelength of ECDL was measured with the variation of the temperature inside the ECDL. Figure 3 represents the experimental plot of tunable laser wavelength vs ECDL temperature. The laser wavelength increases with higher temperatures. With the controlled range between 17.7-23.9 °C, the laser wavelength varies from 779.1-781.0 nm taken at the injection current of 90 mA of the laser driver. Second, the scanning of the piezoelectric actuator (P) of the ECDL was applied to find the absorption spectrum of rubidium atoms in rubidium saturated absorption spectroscopy. In Fig. 4, seventeen datapoints for the laser temperatures associated with the currents of the ECDL that could provide 780.24 nm of the laser wavelength for obtaining the absorption spectrum of the rubidium atoms at the D2 hyperfine transitions of $^{85}$Rb $F = 3 \rightarrow F'$ (the inset in Fig. 4) were presented. The three hyperfine peaks ($3 \rightarrow (2,4), 3 \rightarrow (3,4)$, and $3 \rightarrow 4$) are presented to verify the spectrum.

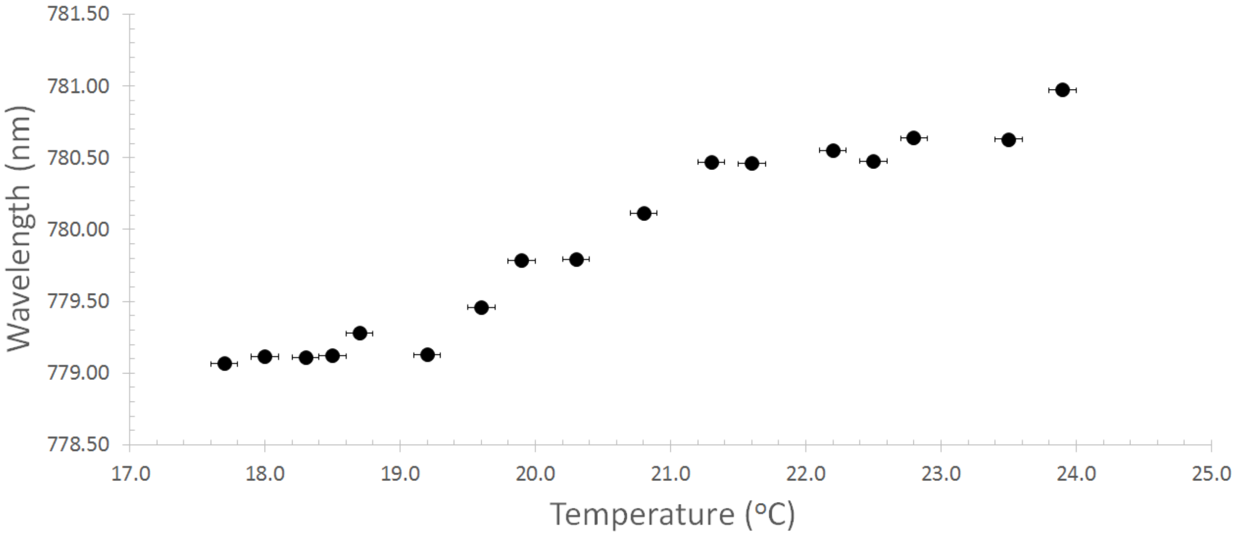

*Figure 3* Experimental plot of tunable laser wavelength vs ECDL temperature.

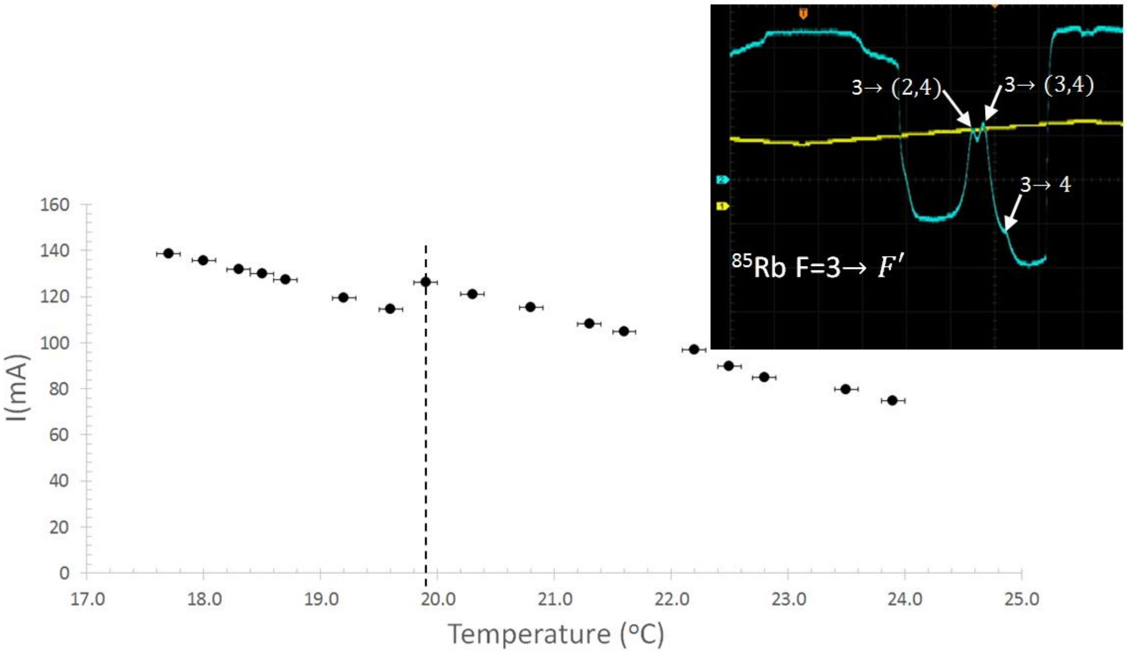

*Figure 4* Conditions of the given current power supply and the ECDL temperature to obtain the D2 hyperfine transitions of $^{85}$Rb $F = 3 \to F'$ (the blue line) as shown in the inset. The yellow line represents the ramp signal for scanning the piezoelectric actuator of the ECDL. The vertical dash line represents the mode hopping at around 19.9 $^{o}$C.

## Discussion

From the observation of Fig. 3, the wavelength of the ECDL tended to increase with its temperature. According to band theory of semiconductors, as the laser diode is heated, the band gap becomes diminished and the output photon energy decreases. Therefore, the output laser wavelength is larger. One can control and choose a proper temperature of the ECDL before using this laser from these records. As illustrated via Fig. 4, the injected laser currents were inversely varied with the laser temperatures to acquire the D2 hyperfine transitions of Rubidium atoms. This might be because the smaller temperatures require higher electrical currents for the ECDL to obtain the same wavelength. There was also an apparent discrete jump of about 20 mA at around the temperature of 19.9 $^{o}$C, where the laser setup was prone to the mode hopping and required more of the injected laser current to achieve the hyperfine transition with stable laser operation. The absorption spectroscopy could be utilized as a laser frequency calibration. The results also provide information of which laser current at selected temperature can be used for laser and atomic applications such as atom cooling, atom interferometry.

## Conclusions

The study of the influence of laser temperature on the wavelength and applied current has been conducted. We show that the laser wavelength can be varied with its temperature. Subsequently, the rubidium saturated absorption spectroscopy was used to check the laser frequency. The selected D2 hyperfine transitions of 85Rb were demonstrated. Also, the conditions of the current power supply and the ECDL temperature to obtain these hyperfine transitions were realized. Increasing the supplied current of the laser or increasing the laser intensity can be obtained by decreasing the laser temperature. This study gives the information of the laser or ECDL used in atomic physics and also laser technology.

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