A Compact Extended-Cavity Diode Laser With a Littman Configuration

Sang Eon Park, Taeg Yong Kwon, Eun-joo Shin, and Ho Seong Lee

***Abstract*—We have constructed a compact extended-cavity diode laser (ECDL) that is based on a Littman configuration with a grating and a reflector. The whole structure is installed in a 2-inch kinematic mount. ECDLs operating at 852 nm (Cs D_2 line), 894 nm (Cs D_1 line), 780 nm (Rb D_2 line), and 794 nm (Rb D_1 line) were fabricated and tested. As a result of the performance test, up to 9 GHz continuous tuning without mod-hop could be obtained by tuning with a piezoelectric transducer only. The linewidth from the beat-note spectrum of two ECDLs was about 200 kHz.**

***Index Terms*—Diode laser, external-cavity diode laser (ECDL), extended cavity, grating, laser linewidth, tuning range.**

I. Introduction

DIODE lasers are very important tools in many experiments and optical communications. Over the past several decades, atomic cooling and trapping experiments have been accomplished using diode lasers. They are inexpensive, compact, and easy to operate compared with other lasers, but they have some disadvantages, such as a poor spectral quality and a broad linewidth. Currently, distributed feedback (DFB) and distributed Brag reflector (DBR) laser diodes provide narrow linewidths and wide tuning ranges, but are available only at limited wavelengths for optical communications.

The spectral quality of diode lasers can be greatly improved by means of optical feedback [1]–[3]. Reflection gratings are usually used for the optical feedback and, recently, external-cavity diode lasers (ECDLs) equipped with gratings have become available commercially. The ECDL usually comprises the grating in the Littrow configuration [3]–[9]. This type of configuration is simpler than that of the Littman configuration [10], [11]. However, in the Littrow configuration, the direction of laser beam changes as the grating rotates for tuning of the laser frequency. This makes a big problem when the ECDL is used for atomic fountain frequency standards where the laser beam path is relatively long. Even if a new method without change of the beam direction has been suggested [9], it requires manual adjustment for lateral shifting of the beam.

We have some experience to construct the ECDL with a Littman configuration on a base plate where all components, such as lenses, mirrors, a grating, and a laser diode, are glued. In that system, although the temperature of a laser diode is well stabilized, the frequency of the laser might be changed by variations in ambient temperature, which caused the cavity length to vary [8]. This makes it difficult for the ECDL to operate steadily for a long period. To overcome these problems, we designed a new compact ECDL with a Littman configuration.

Many reports providing the mechanical design of ECDL were for the Littrow configuration [3]–[9]. In this paper, we describe the compact and robust cavity structure of the Littman configuration ECDL, which sustained operation steadily for above six months. In addition, the results of performance test are described in Section III.

II. Design and Construction

The laser cavity with the Littman configuration is shown in Fig. 1. The length of the extended cavity is approximately 30 mm, which corresponds to a mode spacing of 5 GHz. All components of the ECDL are built on a custom kinematic mount of 5.1 cm $\times$ 5.1 cm. The mount consists of three pieces: a laser mounting block, a movable stage, and a fixed stage, all made of aluminum. The three-dimensional drawing of our ECDL is shown in Fig. 2.

The laser-mounting block is used for fixing both a laser diode and a collimation lens (Thorlabs C230TM-B). A retaining plate is used for fixing the laser diode to the laser-mounting block by four screws. The collimation lens is fixed to the mounting block with glue after the laser beam is properly aligned. A thermistor is glued near the laser diode to measure its temperature. After the laser-mounting bock is assembled, it is fixed to the fixed stage by two screws. The contact surfaces of the laser module and fixed stage are polished, and thermal grease is spread on them for good thermal contact.

On the movable stage, a full reflectance mirror (25 mm $\times$ 15 mm wide and 5 mm thick) and a piezoelectric transducer (PZT) element (6.5 mm $\times$ 6.5 mm wide and 10 mm long) are fixed. One side of the PZT is glued on the mounting plate and the other side is attached to a sapphire disk (Lees HS250-10). The sapphire disk is placed between the PZT and a ball bearing of the adjustment screw for rigid contact. The movable stage has a conical indent and a v-slot for contact with two other adjustment screws [12].

The movable stage is mounted to the fixed stage by the three adjustment screws (Newport AJS127-02H) and two tension springs. These screws have a pitch of 50 threads/cm. A holographic diffraction grating (Edmond L48-215: 12.5 mm $\times$ 2 mm wide and 9.5 mm thick) is inserted in the rectangular hole

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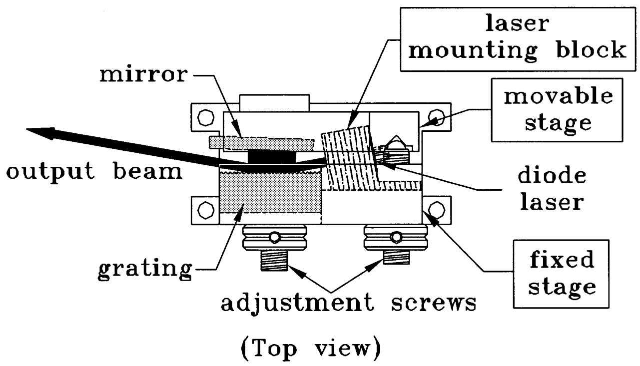

Fig. 1. Mechanical structure of our Littman cavity ECDL. The pivot location, coarse tuning and alignment are achieved by rotating the three adjustment screws, and the fine-tuning is achieved by the PZT on one of the ball bearings of the adjustment screws.

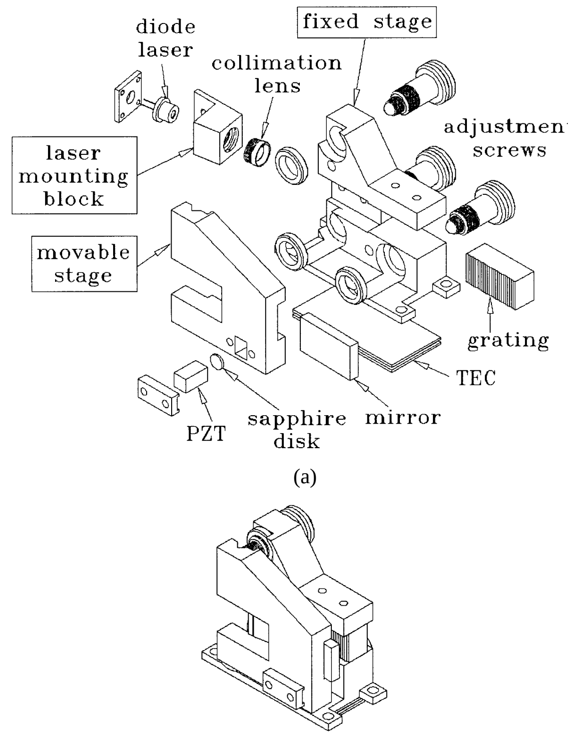

Fig. 2. Three-dimensional drawing of the ECDL (a) before and (b) after assembling. The screws used for fixing the components are not shown.

of the fixed stage and clamped by two screws. The grating has grooves of 1200 lines/mm, and its first-order diffraction angle is nearly normal to the grating surface for grazing incidence. This makes it possible to set the mirror almost parallel to the grating surface.

To stabilize the temperature of the mount, including the laser diode and the extended cavity, a thermoelectric cooler (TEC) is attached to the bottom of the fixed stage. The TEC with a size of 50 mm $\times$ 25 mm is fixed on a base plate with four screws made of plastic for both thermal and electrical isolation. The bottom of the fixed stage and surface of base plate are polished, and thermal grease is spread on them. The base plate (190 mm $\times$ 190 mm wide and 50 mm thick) is made of brass. A saturated absorption spectrometer consisting of a cesium vapor cell, reflectors, beam splitters, and photo-diodes are also mounted on the base plate for monitoring the laser frequency. The base plate, on which all components are fixed, is covered with a cap made of acrylic so as to be isolated from airflow in the environment. A rubber ring is used as a gasket between the base plate and the acrylic cap.

An anti-reflection coated window is glued on the acrylic cap to allow the laser beam to pass through without reflection. As well, there are three tapped holes having stoppers to allow access to the adjustment screws of the ECDL from outside of the acrylic cap. With the three adjustment screws, both the cavity length and tilt angle of the ECDL can be adjusted.

III. Result of Performance Test

Using the design described in Section II, we constructed several ECDLs operating at 894 nm (Frankfurt FIDL-50S-894A), 852 nm (SDL 5401-G1), 794 nm (SDL 5311-G1), and 780 nm (Hitachi HL7851G), which correspond to wavelengths of the cesium D_1 and D_2 and rubidium D_1 and D_2 transitions, respectively. The output power of these ECDLs is approximately 10 mW.

The cavity mode of the ECDL is determined by the angle of mirror as well as the cavity length between the mirror and the laser diode. To achieve single-mode tuning without mode hops the extended cavity modes by the cavity length and the dispersion bandwidth by the mirror angle should be shifted at the same time in unison such that the laser oscillates in the same mode at all wavelengths throughout the tuning range [13], [14]. There is an optimum pivot point to satisfy this condition. It is the point of intersection between extension lines of the end facet of diode laser and the grating surface. However, it is difficult to find that point because of the complex structure of the cavity design. Recently, there was a theoretical report showing another pivot point in the vicinity of the optimum pivot point that can provide wide continuous tuning range [15]. We chose this pivot location by translating the movable stage using three adjustment screws, and could achieve 9-GHz continuous tuning using the PZT alone without changing the injection current. We found that the tuning range was not sensitive to the pivot location. The present laser diodes in our ECDLs were not anti-reflection (AR) coated on the output facet. If an AR-coated laser diode is used in the ECDL, we expect that a wider tuning might be achieved.

Fig. 3 shows the saturated absorption spectrum of cesium atoms observed by the ECDL as the cavity mode is scanned by the PZT. The PZT was directly driven by the output voltage of -12 to $+12$ V of the operational amplifier without any additional voltage amplifier. The frequency scan rate of the PZT was found to be approximately 450 MHz/V. We have been monitoring the saturated absorption spectrum for six months, and it is still operating stably and maintaining its spectral features.

Very recently, we reported a new method to produce a dispersion-like signal that can be used as a frequency discriminator for frequency-stabilization of lasers [16]. This method, based on the velocity-selective saturated absorption spectroscopy, was applied to the present ECDLs. All optical components, including the saturated-absorption spectrometer, were positioned on the brass base plate so that there was no need to reconstruct the spectrometer when the ECDL was rearranged.

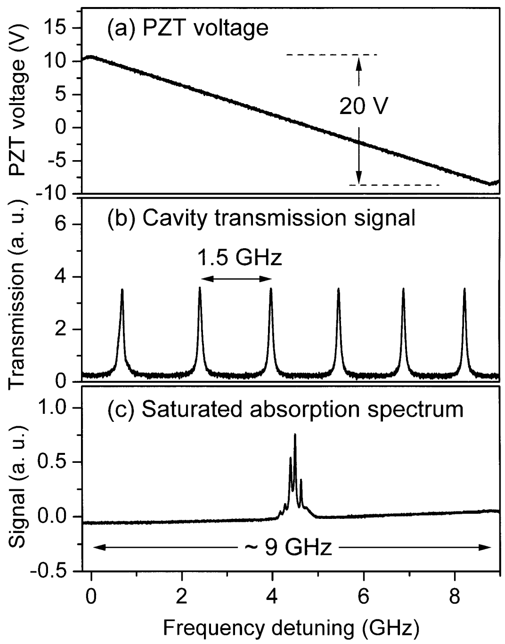

Fig. 3. (a) PZT voltage, (b) transmission signal of the Fabry–Perot cavity with a free spectral range of 1.5 GHz, and (c) saturated absorption spectrum of cesium hyperfine transition of D_2 line ($F = 4$ to $F' = 3$, 4, 5) measured by scanning the PZT.

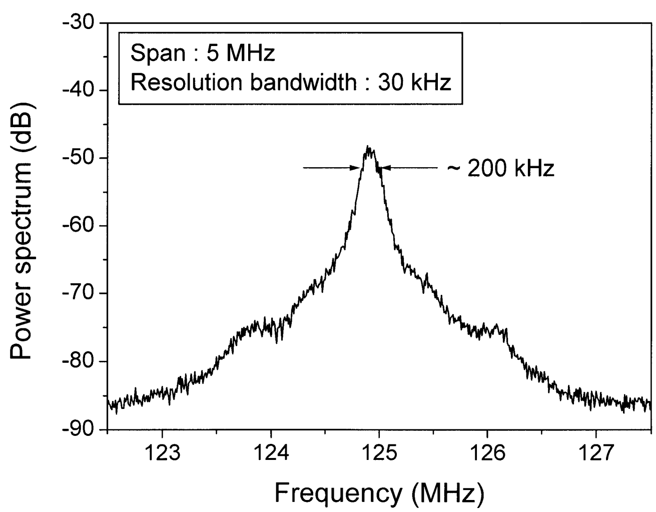

Fig. 4. Beat-note spectrum between two independent ECDLs operating at 852 nm.

The linewidth of our ECDLs has been measured with a heterodyne method using two ECDLs operating at 852 nm. The two ECDLs were loosely frequency-locked to the zero-crossing points of the dispersion-like signal with an integrator only. As shown in Fig. 4, the 3-dB linewidth of the beat-note spectrum was measured to be less than 200 kHz. The residual broadening in the spectrum might come from mechanical vibrations and/or noise in the injection current.

Our new compact ECDLs are going to be used for an atomic fountain clock [17] and an atomic clock using a laser-cooled slow atomic beam [18] under construction in Korea Research Institute of Standards and Science (KRISS).

IV. Conclusion

We constructed ECDLs, operating at 852 nm, 894 nm, 780 nm, and 794 nm, based on the Littman configuration. The structure was installed in a 2-inch kinematic mount. As results of performance tests, the continuous tuning range was 9 GHz without mod-hop with a PZT only, and the linewidth was about 200 kHz. In addition, they could steadily run for above six months. These characteristics show that the ECDLs are adequate to be used for atomic fountain clocks and slow atomic beam frequency standards.

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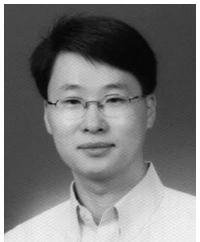

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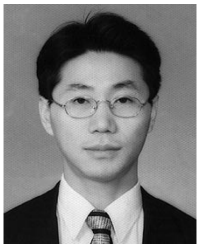

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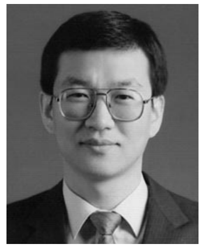

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