External cavity diode laser around 657 nm

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Operating a laser diode in an external cavity, which provides frequency-selective feedback, is a very effective method to tune the laser frequency to a range far from its free running frequency. For the Ca atomic Ramsey spectroscopy experiment, we have constructed a 657-nm laser system based on the Littman-Metcalf configuration with a 660-nm commercial laser diode. Continuously 10-GHz tuning range was achieved with about 100-kHz spectral linewidth, measured with beat-note spectrum of two identical laser systems.

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Diode lasers have been widely used in atomic physics. They are inexpensive, compact, and easy to operate compared with other kinds of lasers. However, they have some drawbacks such as limited frequency tuning range, poor spectral quality and broad linewidth. These characteristics can be greatly improved by optical feedback[1]. This technique is by far the most popular way to obtain a useful single-mode laser source. In fact, many laboratories have developed their own version based on a few common principles[2-5]. This kind of device is also commercially available, at some special frequency range, but at considerably higher prices than their homemade counterparts.

In this article we describe our laser system, which will be used to realize interferometry with calcium atoms[6,7]. The technical solutions that we have employed might provide useful reference for other laboratories.

Since the principles of external cavity diode lasers are well known[1], to build such a system, the main task is to select the appropriate components and configuration that work together for the particular application. To move the wavelength tuning range to 657 nm and narrow the laser spectral linewidth, we developed an external cavity diode laser system based on the Littman-Metcalf configuration[8]. The mechanical layout is shown in Fig. 1. In this system, a 30-mW, 660-nm laser diode (Toptica #LD-0658-0030-1) was employed, with no additional anti-reflection coating. The laser diode was firmly held in an "L" shape $12 \times 12 \times 3$ cm^3 aluminum block. The temperature of this block was actively controlled and stabilized by a thermistor and a Peltier module in a closed loop system, with temperature stability of 1.5 mK/h. The laser light beam was collimated by an anti-reflection coated aspheric lens (Thorlabs #C230TM-B) with a focal length of 4.5 mm and a 0.55 numerical aperture. The distance between the laser diode and lens was adjusted by a fine adjuster to optimize the collimated laser beam quality. An 1800-groove/mm holographic diffraction grating (Richardson 53-*-330H) was mounted at a grazing incidence to the light. The laser diode semiconductor junction plane was oriented to be perpendicular to the grooves of diffraction grating to optimize the efficiency of the grating diffraction. The diffraction efficiencies into the first order and the zeroth order were measured to be 60% and 20%, respectively. The first order diffraction beam was reflected back to the laser diode via the grating by a high reflective mirror, while the zeroth order reflection light serves as output beam. This means the grating and the mirror must be carefully aligned and held very stable. To achieve this condition, the grating was fixed to a brass mount and the mirror was firmly fixed to a standard commercial mirror carrier on a brass holder. All of the components were fixed to a brass base plate with screws and their positions were adjustable to satisfy the alignment. To avoid shape changes with thermal expansion, the base plate is temperature stabilized by another servo loop with the temperature stability of 0.7 mK/h. Finally, the entire laser system was enclosed in a clear Lucite box to reduce air blow to help stabilizing the temperature of the laser cavity. This box was surrounded by a layer of polystyrene foam to further insulate the laser cavity and reduce temperature drift.

The laser working wavelength could be changed by rotating the external mirror while leaving the diode temperature and the current fixed. The wavelength could be coarsely tuned by a differential adjuster and finely tuned by changing the voltage on the piezoelectric transducer (PZT).

In the laser testing setup, the laser light wavelength and mode behavior could be monitored in real time by

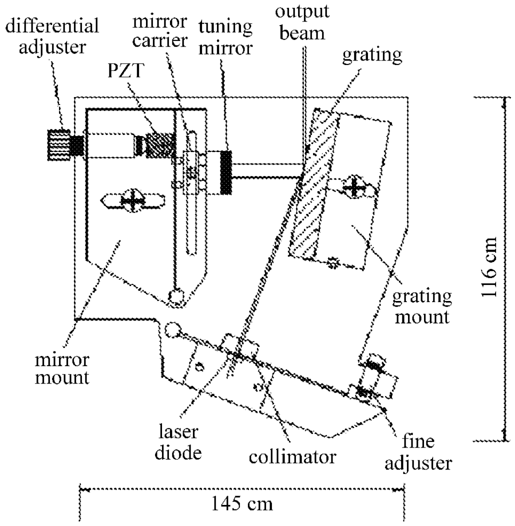

Fig. 1. Schematic arrangement of the external cavity diode laser.

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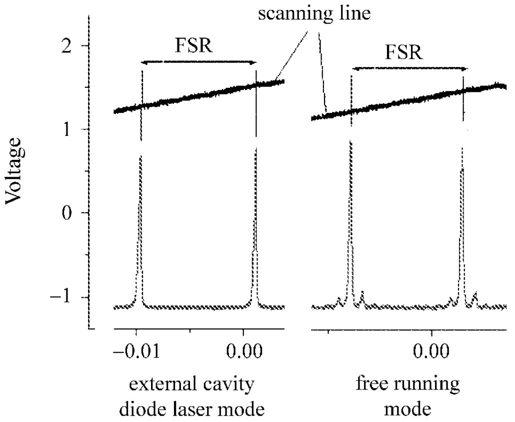

Fig. 2. Optical spectrum analyzer signals of free running laser diode and external cavity diode laser. The F-P cavity's free spectral range is 2 GHz.

a wavelength meter (Burleigh WA-1000) with the accuracy of 0.001 nm and a scanning Fabry-Perot (F-P) optical spectrum analyzer (Burleigh SA-plus series) with free spectral range of 2 GHz and finesse of 200. The wavelength of free running laser diode can be tuned from 658 to 661 nm at 20 °C, with current tuning about 5.3 GHz/mA. Without optical feedback, it cannot be tuned to the frequency of Ca intercombination line at 657 nm.

The external cavity forced the diode laser to operate in a single narrow mode. The F-P optical spectrum analyzer showed a free running laser mode quality and an external cavity diode laser mode quality in Fig. 2. Operated at an injection current of 45 mA, which is near the threshold current, the laser light wavelength could be coarsely tuned from 654 to 665 nm by rotating the grating at 20 °C.

Under this optical feedback condition, the laser wavelength is less sensitive to the injection current and temperature. For this diode, the normal variation of frequency versus temperature was at the order of 30 GHz/K, while with the external cavity it was reduced to 11 GHz/K. The dependence of frequency on injection current was similarly reduced approximately from 5.3 to 2.5 GHz/mA.

The laser linewidth was measured with a heterodyne technique. Two identical external cavity diode lasers were constructed. The beams from the two lasers were mixed in an avalanche photodiode (APD, HAMAMATSU-C5658) detector with 1-GHz bandwidth. The signal from the APD was sent to a spectrum analyzer (HP 8563-E) to observe and record the laser light spectrum. The 3-dB linewidth of the beat-note spectrum was measured to be less than 200 kHz, as shown in Fig. 3. For laser diodes, the light spectrum is usually close to Lorentzian shape[9]. The beat-note 3-dB spectral spread is about twice of the laser linewidth.

It is well known that the laser linewidth is in inverse proportion to the square of laser cavity length[10]. In our system, the laser external cavity length can be changed from 4 to 14 cm by means of adjusting the position of grating mount and mirror mount. However, we observed the enhancement of the relaxation oscillation[11] when the external cavity is longer than 8 cm. Finally we found that the external cavity laser worked best at short cavity length around 5 cm.

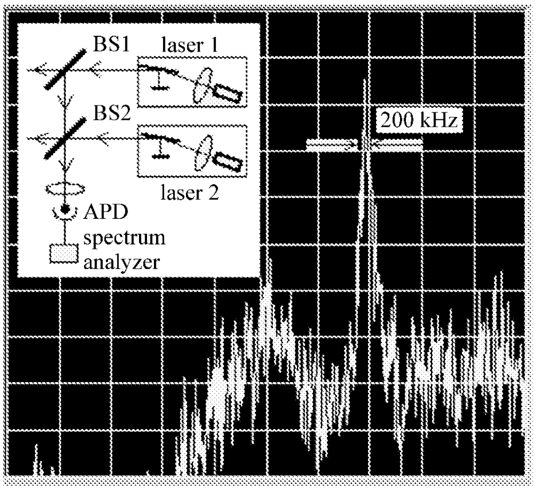

Fig. 3. Beat-note spectrum of two lasers. The horizontal axis is frequency, and each division is 2.0 MHz, center frequency is 740 MHz. The vertical axis is the signal intensity, and each division is 2 dB. Resolution bandwidth: 100 kHz; video bandwidth: 100 kHz; sweeping time: 50 ms.

We have demonstrated a simple method for modifying standard commercial laser diode to obtain widely tunable, narrow linewidth, single-mode light by operating the diode with strong feedback from an external cavity. Probably the residual noise was mainly caused by the acoustic jitter of the cavity. Further linewidth reduction can be obtained by frequency stabilization to the Ca intercombination line through using an electrical feedback method.

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