Study on external-cavity semiconductor laser

Jie Jin (金 杰)[1], Qiang Jiao (焦 强)[2], Yi Li (李 奕)[1],
Fuyun Lü (吕福云)[3], and Guangyin Zhang (张光寅)[3]

[1]*College of Electronic Information Engineering, Tianjin University, Tianjin 300072*
[2]*Radio Factory, Tianjin University, Tianjin 300072*
[3]*Institute of Physics, Nankai University, Tianjin 300071*

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In this paper, a narrow-band tunable external-cavity semiconductor laser with the Littman set-up is reported. The laser system consists of a semiconductor laser, a blazed grating and an external mirror. Its sideband suppression ratio over 20 dB was obtained. Conveniently tuning in wavelength region of 797.38 – 807.26 nm was achieved. The laser is operating in single frequency with narrow linewidth smaller than 0.06 nm. The output beam has good directional stability when tuned.
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If an external cavity is coupled to a semiconductor laser, the output linewidth will be narrowed and the frequency-tuning characteristic of the semiconductor laser will be improved[1,2]. For some applications, such as spectroscopy, coherent measurement and atomic physics, this kind of tunable single-frequency laser is needed. External cavity semiconductor laser has been the subject in many studies, for examples, to be needed as narrow-linewidth tunable sources[3], remote sensing[4], the generation of blue-light by intracavity frequency doubling[5] and laser neural network[6] etc.

In this paper, some results of a narrow-band tunable external-cavity semiconductor laser with Littman set-up are reported. The laser system consists of a commercial semiconductor laser at wavelength of 803 nm, a blazed grating and an external mirror. An output power of 17.9 mW and sideband suppression ratio over 20 dB were obtained. The laser can be tuned conveniently in a range of 10 nm. The laser is tunable and operating in single frequency with narrow linewidth. Its output beam has good directional stability when tuned.

External cavity semiconductor laser can be divided into two types, the Littrow and the Littman set-up. The Littrow scheme uses the first order reflection of the grating directing to stabilize light; the Littman uses a second external mirror to couple the light from the grating back into the semiconductor laser. When moving the grating to change laser frequency, the direction of laser output beam of Littrow set-up will rotate and translate. But, for Littman set-up, the output beam does not change.

In our experiment, a Littman set-up is used. This experiment arrangement is shown in Fig. 1. The laser cavity is a multiple mirror cavity that consists of the rear and the front facet of the semiconductor laser, the lasing medium of the semiconductor laser, a collimating lens, a blazed grating and an external mirror. The zeroth-order reflection from the grating is the output of the laser. The first-order reflection from the grating is reflected back into the laser by the external mirror. The frequency is tuned by moving the external mirror.

The coarse tuning of the cavity is determined by the grating equation

$$\lambda_L = \frac{d}{m}(\sin\alpha + \sin\beta),$$

where λ_L is the wavelength of the laser, d is the grating constant, and m is the diffraction order. α and β are the angles as shown in Fig. 2. For grazing incidence, $\sin\alpha \approx 1$. The single-pass dispersion of the grating is intrinsically twice as great as cavities that use a grating in Littrow scheme. The single-pass linewidth (FWHM) of the cavity due to the grating is

$$\Delta\lambda_G = \frac{d\omega}{mf}\cos\alpha,$$

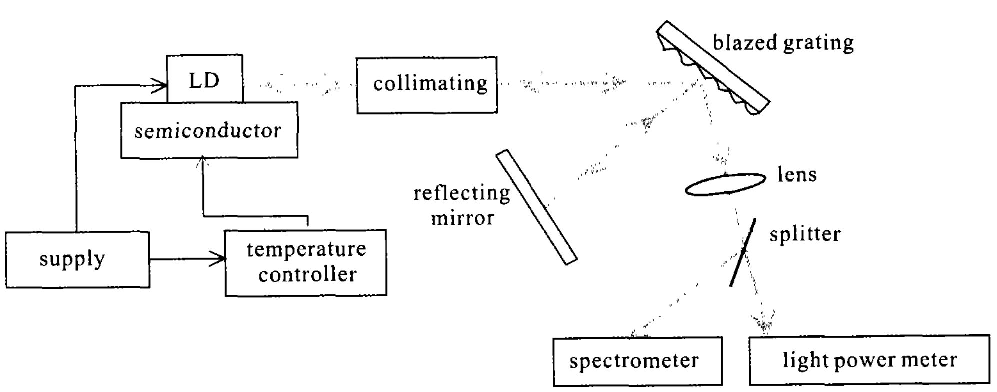

Fig. 1. Experiment arrangement of the Littman external-cavity semiconductor laser.

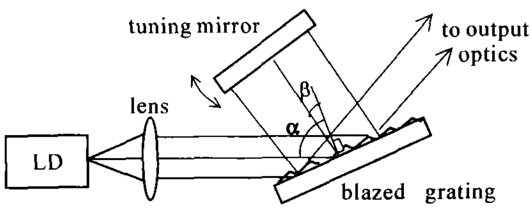

Fig. 2. Schematic diagram of the Littman laser.

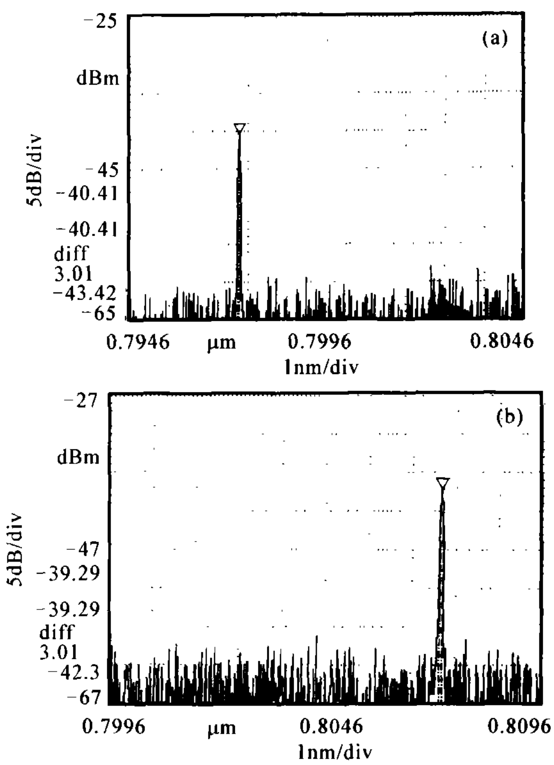

Fig. 3. Output spectra of the external cavity semiconductor laser with Littman set-up.

where ω is the beam waist at the semiconductor laser and f is the focal length of the collimating lens.

Cavities that use a blazed grating in Littrow scheme typically have a larger grating passband because the laser beam covers fewer lines of the grating. The increased dispersion by grazing-incidence to the blazed grating improves the selectivity of axial cavity modes and the grating deflects the external cavity modes to semiconductor laser cavity modes. This is useful for some linewidth-reduction techniques. The linewidth of the laser is given by the modified Schawlow-Townes formula. Additing an external cavity to a semiconductor laser will greatly reduce the linewidth because the cavity becomes much longer reducing the passive cavity linewidth and the influence of the refraction index fluctuations of the gain medium.

The Littman external-cavity semiconductor laser was constructed with a purchased semiconductor laser (QW-0300), which worked at wavelength of 803.7 nm at room temperature. The laser itself had a linewidth (FWHM) of roughly 3.2 nm. A thermoelectric cooler with its controller unit held the temperature of the semiconductor laser typically at 20 °C. The current of the semiconductor laser was supplied by a precision current source. The output of the semiconductor laser was collimated by a lens system. A 1200-line/mm blazed grating was used in grazing incidence. The diffraction angle α was measured to be approximately 85°. The junction plane of the semiconductor laser was oriented perpendicular to the grooves of the blazed grating to optimize the efficiency of the grating. The external mirror was coated to have more than 98% reflection in near infrared. To stabilize the laser cavity and reduce temperature drift, all the components of the external-cavity laser were mounted on an aluminum plate, which was cooled by semiconductor cooler. The whole device was enclosed in a box.

The spectra of the semiconductor laser were measured with a spectrometer. The tuning range of the laser is shown in Fig. 3, it is greater than 10 nm. While keeping the temperature and current constant, the frequency can be tuned as shown in this figure by rotating the external mirror. When the current of the semiconductor laser was 210 mA, the output power of this external laser was 17.9 mW with optical-to-optical efficiency of 53%. The measured linewidth and sideband suppression ratio respectively was 0.06 nm and 20 dB. The laser is operating single frequency and the output beam has good directional stability when tuned.

This Littman external-cavity semiconductor laser has definite advantages. It uses a commercial available semiconductor laser without any special coatings or modifications. It has better immunity from optical feedback than a solitary semiconductor laser. It can be tuned and has narrower laser linewidth compared with the solitary semiconductor laser. The laser beam has good directional stability, it does not move when the frequency is tuned.

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