Static wavelength scanning using tunable external cavity laser diode

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Abstract. An external-cavity laser diode that performs static wavelength scanning eliminates problems such as repeatability and tuning rate that arise due to mechanical movements induced in the external cavity of conventional systems, because it requires no mechanical elements. Experiments reveal that the scanning range and tuning rate are 1.1 nm and 1 kHz, respectively.© 2010 Society of Photo-Optical Instrumentation Engineers.
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1 Introduction

Wide-range wavelength scanning is one of the key techniques to improve the performance of optical devices such as spectroscopic instruments, optical coherence tomography systems, and interferometers. Generally, wide-range wavelength scanning can be carried out by using a wavelength-selective element such as a diffraction grating and tuning mirror with a gain medium. Since the cavity of a laser diode (LD) is compact and susceptible to the external cavity, it is favorable for use as a gain medium. In particular, if an output facet of the LD is processed with an antireflection (AR) coating, the LD is strongly coupled to the external cavity, and it is favorable for use as a gain medium. In particular, if an output facet of the LD is processed with an antireflection (AR) coating, the LD is strongly coupled to the external cavity, and it is favorable for use as a gain medium.

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In this work, we propose another type of ECLD that consists of an acousto-optical element instead of an electro-optical crystal. As our system also requires mechanical movements to be restricted, static wavelength scanning can be carried out; thus, the problems arising from the mechanical movements are resolved.

2 Principle

Generally, wide-range wavelength scanning can be carried out with the configuration shown in Fig. 1(a), in which a mechanical rotating mirror driven by a PZT is used. The fundamental equation in Fig. 1(a) is represented by

\[
\theta = \theta_0 + \Delta \theta
\]
\( \lambda = d(\sin \theta_i + \sin \theta_d) \),

(1)

where \( \lambda \) is the wavelength, \( d \) is the groove spacing, and \( \theta_i \) and \( \theta_d \) are the incident and diffraction angles, respectively. When the incident angle is constant, the wavelength varies, as given by

\[ \Delta \lambda = d[\sin(\theta_d + \Delta \theta_d) - \sin(\theta_d)] \],

(2)

depending on \( \Delta \theta_d \), which is the change in the diffraction angle. In this case, the cavity length is nearly unchanged.

Our proposed system is shown in Fig. 1(b). As seen in the figure, wavelength scanning is controlled by the incident angle. The scanning is accomplished statically because an acousto-optic deflector (AOD) is used for the incident angle control. In this case, the wavelength change \( \Delta \lambda \) is given by

\[ \Delta \lambda = d[\sin(\theta_i + \Delta \theta_i) - \sin(\theta_i)] \].

(3)

The cavity length varies slightly with the change of incident angle in this setup.

3 Experiments

In the setup shown in Fig. 2, we used a commercial LD having an AR-coated facet. The central wavelength and typical threshold current of the LD is 658 nm and 65 mA, respectively. The output power is proportional to the operating current that is larger than the threshold current. It reaches 80 mW at 150 mA of operating current. The changes in the temperature of the LD were restricted to deviations of \( \pm 0.01 \) °C by means of a Peltier temperature controller. The output beam from the LD is collimated with a microscope objective lens. The central frequency of the acoustic wave is 75 MHz. The deflection angle observed at the AOD varies by 0.18°/V with the control voltage. The diffraction efficiency of the AOD is 75%. The groove spacing of the holographic diffraction grating, initial incident angle \( \theta_i \), and diffraction angle \( \theta_d \), were 1/1800 mm, 63 deg, and 18 deg, respectively. The diffraction efficiency at the grating is 45%. Since the first-order beam diffracted by the grating is reflected on the stationary mirror and fed back to the LD, the oscillating wavelength is strongly affected by the external cavity. To realize the resonant condition, we adjusted the position of the fixed mirror with the activated AOD. The laser beam collimated by the objective lens passes a polarizing beam splitter (PBS), AOD, grating, and is reflected back from the fixed mirror. We can estimate that 9% of fraction is fed back to the LD. The length of the external cavity is 340 mm. It changes by 0.27 mm/V, because the distance between the AOD and the grating is 76 mm. The zero-order beam is detected by an optical spectrum analyzer (OSA) having a wavelength resolution of 0.005 nm. M1, M2, and BS configure an unbalanced Twyman-Green interferometer, whose optical difference is \( \sim 1 \) mm for observing wavelength tunability.

We observed a wavelength shift by using the OSA. When the control voltage applied to the AOD was varied from 13.0 to 16.2 V, a wavelength shift was observed, as shown in Fig. 3. The solid line in Fig. 3(a) shows the theoretical calculation using Eq. (3). Stable spectra were observed in the region from 659.5 to 658.8 nm in the lower control-voltage area (13.0 to 13.9 V), and in the region from 657.8 to 656.7 nm in the higher control-voltage area (14.8 to 16.2 V). No stable spectra were observed in the middle range of the control voltage, because the power of the deflected beam decreased considerably in this region, and the oscillation mode could not be coupled to the external cavity. However, in the lower and higher voltage areas, tuning ranges of 0.7 and 1.1 nm were observed. It was determined that the wavelength scanning rate was 0.78 nm/V. A trace of part of the observed spectra is shown in Fig. 3(b). These were observed between 15.4 and 15.8 V in the higher voltage area [Fig. 3(b)] that is indicated in Fig. 3(a). The interval of these spectra and the full width at half maximum (FWHM) were \( \sim 0.04 \) and \( \sim 0.06 \) nm, respectively. The observed FWHM is almost the same as that of the external cavity less standard operation.

In applications such as spectroscopic instruments, opti-
cal coherence tomography, and interferometers, continuous wavelength scanning and tuning speed are important characteristics. We observed an interference signal by using the unbalanced interferometer, and proposed ECLD to confirm these important characteristics. When triangular wavelength scanning was employed as shown in Fig. 4, we observed a continuous interference signal $S(t)$ that exhibits a partially sinusoidal waveform in the linear region of the triangular wave. The modulation frequency in Fig. 4 was 1 kHz, and we were able to observe a stable interference signal up to this frequency. Since the amplitude of the triangular control voltage ($V_m$) was 0.5 V, the change in the wavelength of the linear part is estimated to be 0.78 nm from the wavelength-scanning rate, as discussed earlier. This observation of the interference signal confirms that continuous and high-speed wavelength scanning is possible using our system.

4 Conclusions

In conclusion, we propose and demonstrate a static type of wavelength-scanning ECLD. Wide-range and continuous wavelength scanning can be carried out under a high tuning rate. In addition, it is found that the use of a special AR-coated LD instead of a standard LD improves the scanning range.

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References