Sinusoidal phase modulating laser diode interferometer using a photo-thermal modulation

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ABSTRACT

A laser diode interferometer that uses accurate photo-thermal modulating technique is proposed. Since this technique of photo-thermal method modulates just a wavelength of the laser diode, measurement accuracy is not affected by an intensity modulation that is used to be appeared in the current modulation. The fundamental characteristics of this technique is investigated in detail. The new setup is tested, and its accuracy compared with that of an earlier system.

Keywords: interferometer, current modulation, photo-thermal modulation, laser diode

1. INTRODUCTION

The wavelength of the LD can be modulated by changing the injection current; -a feature that is commonly used in the construction of a variety of interferometers[1,2]. That is called the "current", or "C-" modulation. Unfortunately, injection current affects not only the wavelength, but also the optical power of the LD, which in turn, affects the measurement accuracy.

There is however, another technique, which uses what is called "photo-thermal", or "P-" modulation, wherein a high-power laser beam is directed at the active region of the LD, is proposed[3] and analyzed[4]. The change of the optical power is dramatically reduced in this P-modulation. But it is not perfect to suppress the change of the optical power, as laser-chip temperature-variations affect optical power, even when the driving current is constant.

Our technique effectively unites the two methods; -while the latter is used to modulate the LD, the former functions as a means of compensating for photo-thermal modulation-induced changes in optical power. This two-pronged approach the "current and photo-thermal", or "CP-" modulation enables us to use a purely phase-modulated laser beam. The modulating characteristics of this combined approach are investigated in detail. C-, P-, and CP-modulated measurements of interference are analyzed and compared for accuracy.

2. PRINCIPLE

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LD wavelength and optical power vary, according to the amount of injection current supplied, as shown in Fig.1. The wavelength tunability illustrated in Fig.1(a) is used to modulate the interference signal in the C-modulation. At this point, however, undesirable change occurs in the optical power as shown in Fig. 1(b). When a sinusoidal modulating current

$$I_m(t) = a_1 \cos(\omega_c t + \theta_1) \tag{1}$$

is injected into the LD in the Twyman-Green interferometer, the interference signal is given by

$$S_1(t) = [1 + \gamma_1 a_1 \cos(\omega_c t + \theta_1)]\left\{S_{11} + S_{12} \cos\left[\frac{2\pi}{\lambda_0 + \lambda_1} l\right]\right\}, \tag{2}$$

where

$$\lambda_1 = a_1 \beta_1 \cos(\omega_c t + \theta_1), \tag{3}$$

λ_0 is a central wavelength, l is an optical path difference, β_1 and γ_1 are the LD's coefficients of wavelength modulation and the optical-power modulation in the C-modulation, respectively. S_{11} and S_{12} are the dc and ac components of the interference signal, respectively. The second term of the coefficient $[1+\gamma_1 a_1 \cos(\omega_c t+\theta_1)]$ in Eq. (2) gives the intensity modulation. This intensity modulation figure is identified as the source of the measurement error.

As stated above, and shown in Fig. 2, wavelength varies according to temperature. This characteristic is applicable to P-modulation, as well. When the temperature of the LD is modulated by

$$T_m(t) = a_2 \cos(\omega_c t + \theta_2), \tag{4}$$

we obtain the modulated interference signal;

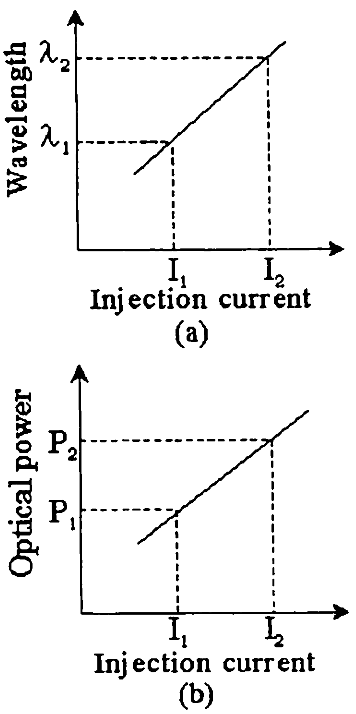

Fig. 1 Dependency of (a) wavelength and (b) optical power on the injection current.

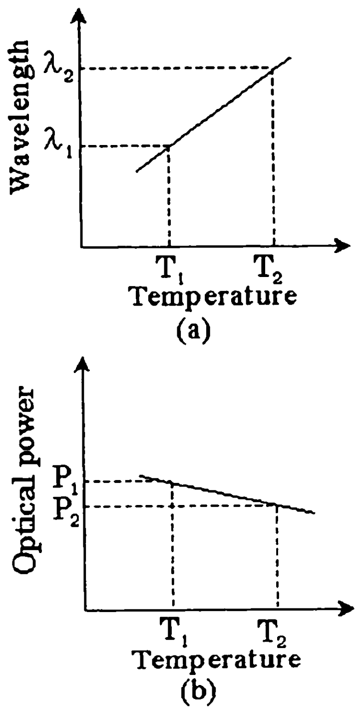

Fig. 2. Dependency of (a) wavelength and (b) optical power on the temperature of the LD's active layer.

$$S_2(t) = [1 - \gamma_2 a_2 \cos(\omega_c t + \theta_2)]\left\{S_{21} + S_{22} \cos\left[\frac{2\pi}{\lambda_0 + \lambda_2} l\right]\right\}, \quad (5)$$

where

$$\lambda_2 = a_2 \beta_2 \cos(\omega_c t + \theta_2), \quad (6)$$

β_2 and γ_2 are the LD's coefficient of wavelength modulation and optical power modulation in P-modulation, respectively. Since the injection current remains in P-modulation, the change of the optical power is small. Therefore, the modulation depth in the intensity is so small. This intensity modulation, however, is not negligible, when a precise measurement is called for.

Note that sign of the coefficient β_1 and β_2 share the same sign but those of γ_1 and γ_2 are opposite. By employing the C- and P-modulation simultaneously, the intensity modulation derived from the latter can be compensated by the formaer, while the amount of the phase change increases. Then, the interference signal is given by

$$S_3(t) = [1 + \gamma_1 a_1 \cos(\omega_c t + \theta_1) - \gamma_2 a_2 \cos(\omega_c t + \theta_2)]\left\{S_{31} + S_{32} \cos\left[\frac{2\pi}{\lambda_0 + \lambda_1 + \lambda_2} l\right]\right\}. \quad (7)$$

If the conditions of $\gamma_1 a_1 = \gamma_2 a_2$ and $\theta_1 = \theta_2$ are held, by adjusting amplitude a_1 and phase θ_1 in the modulating current, intensity

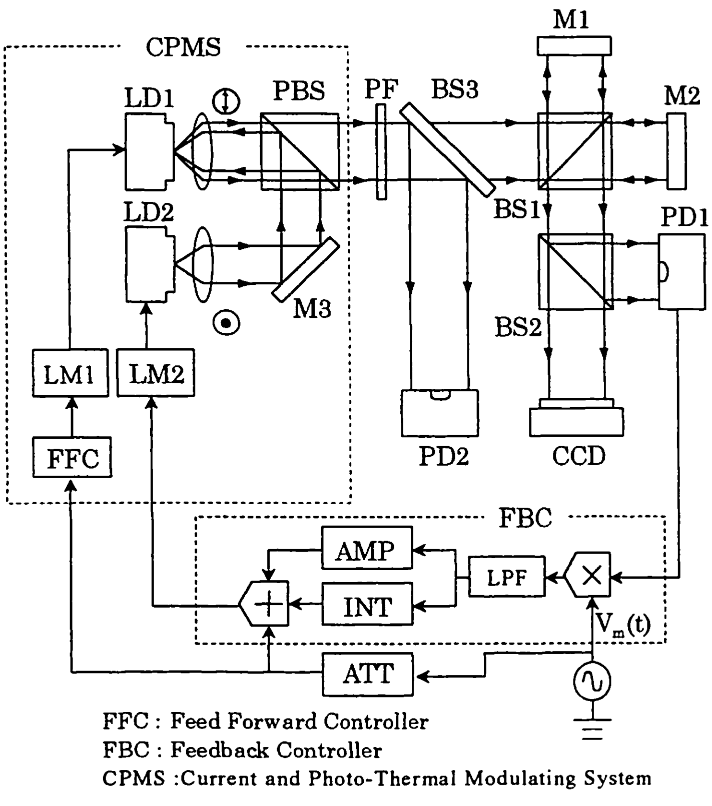

Fig. 3 Experimental setup: LM1, LM2, Laser modulators; PBS, Polarizing beamsplitter; PF, Polarization filter; LPF, Low-pass filter; AMP, Amplifier; INT, Integrator; ATT, Attenuator.

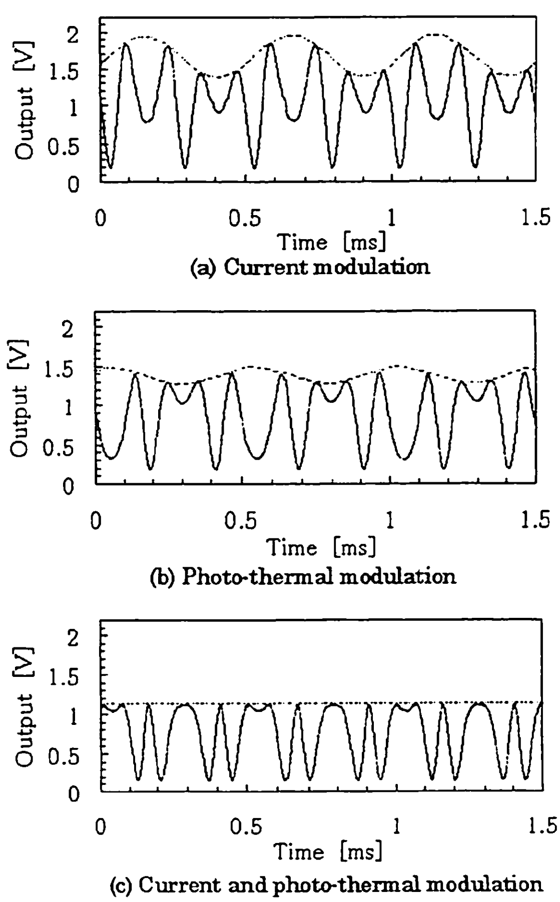

Fig. 4 Waveform of the interference signal.

modulation is assumed to have no effect.

3. EXPERIMENTS

Experimental setup is shown in Fig. 3. LD1 is a light source of the interferometer. The laser beam emitted from LD2 is injected to the LD1 from its exit face. The central wavelength and the maximum output power of the LDs are shown in Fig. 3. The optical path difference is 60 mm. The polarization of the LDs is perpendicular each other to avoid the interference between LDs. Any changes in the output intensity of LD1 are monitored by photodetector 2 (PD2). Temporal changes in the interference signal are detected by PD1, and relayed to the feedback controller to eliminate external disturbance[5]. Spatial change of the interference signal is detected by the one-dimensional CCD image sensor. The sinusoidal signal $V_m(t)$ is added to the feedback signal, and injected into the heating laser LD2.

The modulating signal $V_m(t)$ is transmitted to the feedforward controller (FFC) to compensate for the intensity variation in the interference-signal. The amplitude and phase of LD1's injection current are adjusted by the FFC to satisfy the conditions described in previous section.

The interference signals obtained by the three methods described above are shown in Fig. 4. Figure 4(a) and (b) are obtained by means of C- modulation and P-modulation, respectively. The effect that intensity modulation exerts on P-modulation is much smaller than that in the C-modulation. But it is hard to make a precise measurement with this interference signal which has the intensity modulation. The trace obtained by the CP-modulation is shown in Fig. 4(c). The effect of the intensity modulation is completely removed.

4. CONCLUSION

We have proposed a mechanically simple, yet highly accurate modulating technique that uses both current modulation and photo-thermal modulation, simultaneously, to remove undesirable intensity modulation from the interference signal. This technique is very simple and easy to realize, since it does not need particular parts. It is useful to construct an interferometer with high accuracy.

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