WAVELENGTH-STABLE LASER DIODE AND PHOTODIODE ARRAY FOR LASER INTERFEROMETER POSITIONING SYSTEMS

HIRATA Takaaki [*1] ***HIHARA Mamoru*** [*1] ***NAGAYAMA Hideki*** [*1]

We have developed a wavelength-stable laser diode for light sources of laser interference positioning systems and photodiode array for photodetectors. These devices allow laser interference systems to be downsized, and expand the range of applications of such systems. A single-mode oscillation, narrow spectral linewidth and long-term wavelength stability are essential for light sources of laser interference positioning systems. In order to realize these requirements, we have employed a large-cavity structure with diffraction gratings in the cavity. Long-term stability was confirmed by performance tests for 20,000 hours or more. We employed an 18-element p-n junction silicon photodiode structure for photodiode arrays of high sensitivity and fast response. This paper describes the newly developed photonic devices.

INTRODUCTION

Laser interferometers and linear scales are used for measurement of the moved distance or positioning on the stage of precision machining equipment such as manufacturing equipment for semiconductors. The laser interferometer, in particular, features high accuracy, non-contact measurement and easy installation. It generally employs a wavelength-stabilized helium-neon laser and has a resolution on the order of nanometers for measurement ranges of several tens of meters. However, the laser interferometer is rather large and expensive as a sensor and thus is only integrated in equipment worth hundreds of million yen or used as a standard for quality control.

We have developed a small, inexpensive laser interferometer by adopting an interference-based optical system that uses a semiconductor laser as a light source and receives light interference fringes, which are generated by slightly shifting the axes of a reference light and measured light, with a photodiode array. This interferometer facilitates measurement or control on the order of sub-microns. This paper reports specifically on the key devices of the laser interferometer: the semiconductor laser and photodiode array.

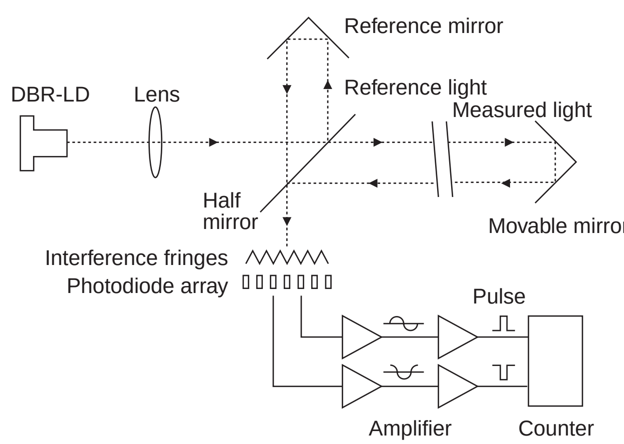

Figure 1 Interferometer

*1 R & D Center

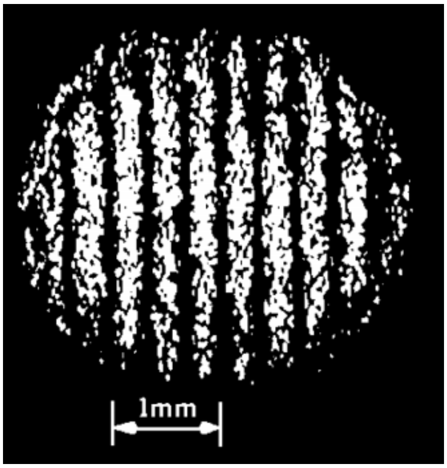

Figure 2 Interference Fringes

INTERFEROMETER

The optical system uses a single-wavelength light source and Michelson interferometer. Figure 1 illustrates the optical system. The semiconductor laser beam is branched off into measured (transmitted) light and reference (reflected) light by a half mirror, each of which is reflected by a movable or reference mirror respectively and then introduced to a photodiode array. With the optical system, we adjusted the reference mirror in such a way that the reference light has a slight angle of incidence against the measured light toward the photodiode array. This generates the interference fringes on the photodiode array as shown in figure 2. When the movable mirror moves half the wavelength of the laser beam, the interference fringes moves by one cycle to the side, and the direction of the movable mirror's movement corresponds to that of the interference fringes. As the interval at which the photodiodes are arranged corresponds to the cycle of the interference fringes, computing the signals from the photodiodes whose phases are reversed with each other allows the DC components of the signals to be eliminated and thus the signals can be reliably converted into pulses. In addition, the direction of movement can be judged by comparing the signals of the photodiodes whose phases mutually shift by 90 degrees.

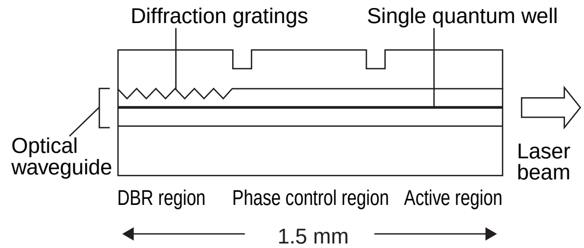

Figure 4 Structure of DBR-LD

WAVELENGTH-STABLE SEMICONDUCTOR LASER

The light source for the laser interferometer requires single-mode oscillation, narrow spectral linewidth, and long-term stable wavelength. To realize these characteristics, we have developed the gallium-arsenide (GaAs)-based distributed bragg reflector laser diode (DBR-LD) shown in figure 3. Figure 4 shows the structure of the DBR-LD. It is equipped with three electrodes: the active, phase control, and DBR regions. The three-electrode structure makes it possible to tune the oscillation wavelength with the injection currents of the phase control and DBR regions. Since the manufacturing procedures and tuning characteristics have already been reported(1), only the design point and significant characteristics of laser interferometer application will be discussed here.

A Fabry-Perot laser diode adopted for optical disks normally oscillates in multiple modes and is not practical as a light source for the interferometer. Therefore, to obtain stable single-mode

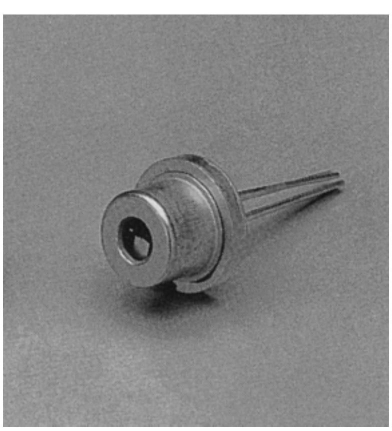

Figure 3 DBR-LD

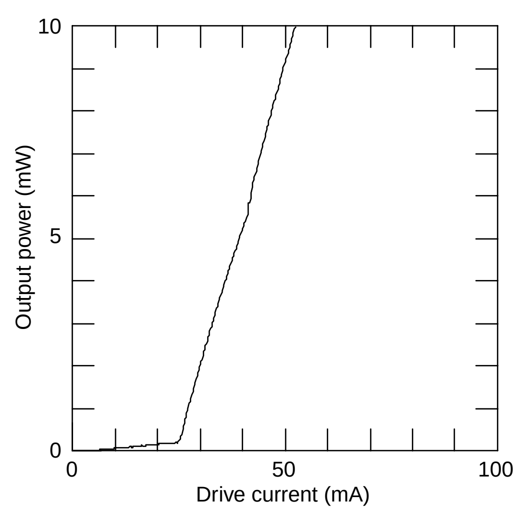

Figure 5 CW Light-current Characteristics

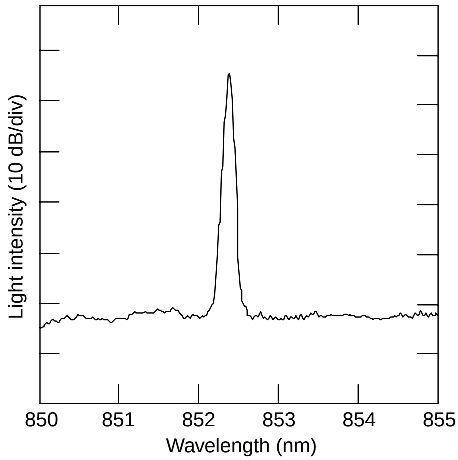

Figure 6 Lasing Spectrum

oscillation, we employed the DBR-LD structure having diffraction gratings inside the laser diode cavity. For narrowing the spectral linewidth, reducing the linewidth enhancement factor, which is special to the laser diode, and the cavity loss are effective. For these purposes, we used a single quantum well for the active layer. In order to further reduce the cavity loss, we employed the first-order diffraction grating and low-loss optical waveguide structure, which was achieved from disordering the quantum well. Therefore, we made the cavity length 1.5 mm, five times that of the normal cavities.

Figure 5 shows the CW light-current characteristics of the DBR-LD, figure 6 the lasing spectrum for an output of 5 mW, and figure 7 the spectral linewidth as a function of the reciprocal output power. These figures indicate that a side-mode suppression ratio of 40 dB or more and spectral linewidth of 1 MHz or less have been obtained at a 5-mW output. This spectral linewidth is as much as several times narrower than the normal value. Although inferior to the helium-neon laser, it is still sufficient for applications with measuring distances of a few meters.

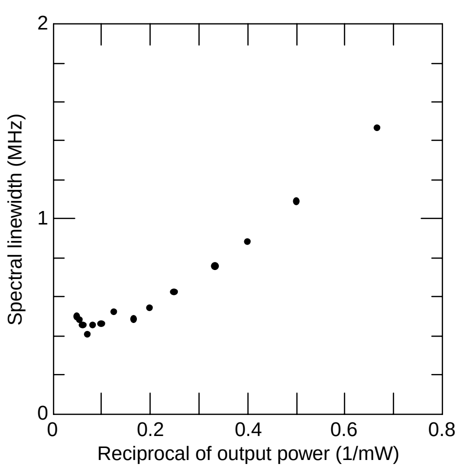

Figure 7 Linewidths versus Reciprocal Output Power

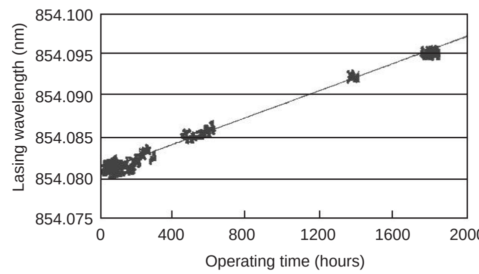

Figure 8 Drift of LD Lasing Wavelength When Mounted on Cu Stem

We will now describe the long-term operating characteristics of the DBR-LD. Not only increasing element reliability but also improving packaging is a significant challenge for the long-term stability of laser diodes. Figure 8 shows the variation of lasing wavelength with time when the laser diode is mounted to a copper stem through a bonding process. In figure 8, the missing measurement points correspond to the time period when the laser diode is not operating, but just simply stored. Because the wavelength drifts whether the laser diode is operating or not, we considered the strain caused by the bonding process to have been relieved and the cavity length varied as time passes. Therefore, in order to lower the drift we decided to use copper-tungsten (CuW) alloy with the expansion coefficient adjusted to that of GaAs as the stem. Figure 9 shows the improved wavelength drift along with the deterioration characteristics of the output power. We are still in the process of conducting this test over 20,000 hours and

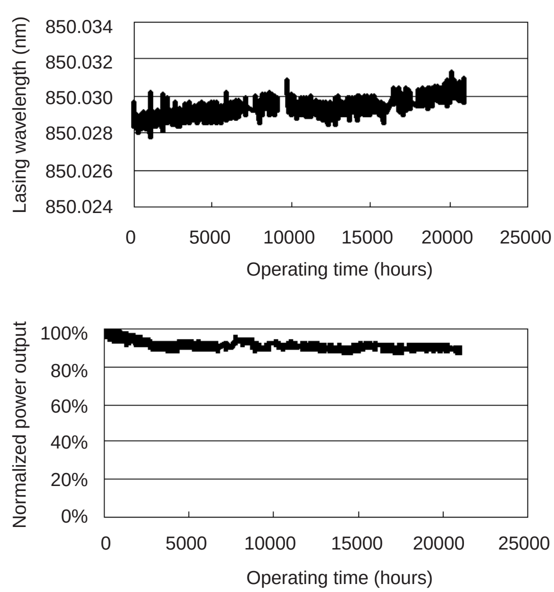

Figure 9 Drifts of LD Lasing Wavelength and Output Power When Mounted on CuW Stem

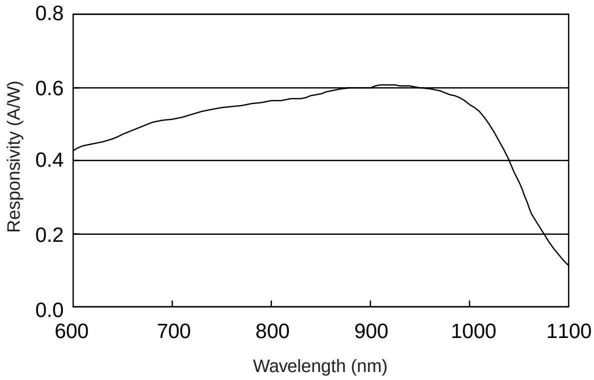

Figure 10 Spectral Responsivity of Photodiode

have so far achieved sufficient stability to warrant use in a laser interferometer: 10% of output deterioration and a wavelength drift of 2 pm.

PHOTODIODE ARRAY

A photodiode for the laser interferometer needs high sensitivity and fast response. To implement these characteristics, we developed an 18-element silicon photodiode array using our semiconductor process.

(1) Sensitivity

To increase sensitivity of the photodiode, we employed a field-proven antireflection coating[2] with a dual layer structure of oxide and nitride coatings. Figure 10 shows the spectral responsivity characteristics of the photodiode.

(2) Response

We studied the specification requirements for the operating conditions and response. Although a PIN photodiode featuring fast response is generally used, we adopted a PN-junction photodiode that can be economically manufactured using an N-type substrate with a high resistance of more than 1000 Ωcm.

(3) Packaging

We employed the TO-5 metal package and the cathode electrodes are formed on the back of the chip to reduce the series resistance.

Table 1 Photodiode Characteristics

Item	Condition	Typical Value
Dark current	V_R=12 V	4.14 nA
Responsivity	λ=850 nm	0.57 A/W
Response nonuniformity	λ=850 nm	0.82%
Junction capacitance	V_R=12 V	4.53 pF
Response Time	R_L=51 Ω	0.31 µs
Cut-off frequency	–3 dB at 100 kHz	6.8 MHz

(4) Reliability

To verify the reliability, we performed such tests as continuous operation (125°C, V_R = 12 V, 1000 hours), shelf test at a low temperature (–40°C, 1000 hours), and pressure cooker test (121°C, 100% RH, 96 hours). None of these tests showed an increase in dark current and gave satisfactory results.

Table 1 shows the characteristics of the photodiode developed. We used the same manufacturing process as that of other types of photodiode arrays and employed a dual-layer structure that can accommodate the chip-on-board (COB) technology for passivation coating.

CONCLUSION

We have developed a laser diode with a stable wavelength and photodiode array for downsizing laser interferometers and successfully verified that they have appropriate performances required for laser interferometers. We will continue development work to expand the applications for the laser interferometer. ◆

REFERENCES

(1) Hirata Takaaki, Maeda Minoru, Suehiro Masayuki, Hosomatsu Haruo, “Fabrication and Characteristics of GaAs-AlGaAs Tunable Laser Diodes with DBR and Phase-Control Sections Integrated by Compositional Disordering of a Quantum Well,” IEEE Journal of Quantum Electronics, Vol. 27, No. 6, 1991, pp. 1609-1615

(2) Yamazaki Tsutomu, Yokoyama Koji, Kawai Mayumi, Hada Seiji, “High-speed Photodetectors,” Yokogawa Technical Report, No. 17, 1993, pp. 5-9