

A Laser Coupler for DVD/CD Playback Using a Monolithic-integrated Two-wavelength Laser Diode

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Abstract

A new optical integrated device called a two-wavelength-beam laser coupler (2BLC), which has two-wavelength light emission/detection functions, has been developed. By using a 2BLC, an ultimate solution of the optical pickup head for the DVD/CD system is easily realized. To simplify the structure and the fabrication of the 2BLC, a new monolithic-integrated two-wavelength laser diode, called a visible and infrared laser diode, has been developed, which can be easily fabricated using only two steps of metal organic chemical vapor deposition. The newly developed 2BLC can be used in various DVD/CD systems, now being used in PlayStation 2.

1. Introduction

The DVD system is now being widely used in playback optical disc systems, such as DVD-video players and DVD-ROM drives. In the DVD system, it is important that the optical pickup of the system can play back both DVD media and CD media such as CD-DA, CD-ROM and CD-R/RW. But the 650nm laser cannot be used to play back CD-R media, because of their low reflectivity of the 650nm laser. Therefore, the optical pickup head of the DVD system requires both a 650nm and a 780nm laser. Figure 1 shows some conventional solutions, which, however, require a large number of parts, making the optical pickup head complicated, difficult to assemble and expensive.

An optical pickup head, as shown in Fig. 2, is one of the ultimate solutions, using a two-wavelength-beam laser coupler (2BLC). It has a two-wavelength light emission and detection function. There are two approaches realizing such an integrated device. One approach is using two laser chips mounted in the same package,¹⁻³⁾ but it is difficult to assure the accuracy of the emitting position, such as the space and the parallelism between the two lasers. It is difficult to make integrated device sufficiently small — essentially the same size as the conventional single-wavelength laser coupler. Another approach is using a monolithic-integrated two-wavelength laser chip,⁴⁻⁷⁾ which solves both the problem of the accuracy of the emitting position and the device size.

Such a device was reported in 1982 as a result of work in optical-fiber communications.^{8,9)} It was simply fabricated by piling two kinds of double-hetero structures. But, using this method, it is quite difficult to adopt a practical waveguide structure suitable for the optical storage systems because of the structural restriction, and also difficult to mount in junction-down configuration because of the large step-height between two laser elements, so sufficiently good performances can not be obtained. On the other hand, it is easily considered to adopt two kinds of the conventional waveguide structures, but it is usually complicated to fabricate, that is, for example, many steps of the epitaxial growth and the epitaxial growth on the structured uneven substrate are needed. So it is quite difficult to obtain high yield of such devices practically, therefore, it is considered such devices not suitable for mass production.

The original technologies of the gain-guiding laser and the epitaxial growth on the structured uneven substrate has been introduced, as a result, a new monolithic-integrated two-wavelength laser diode has been developed, which is easy to fabricate.⁶⁾ It is called a visible and

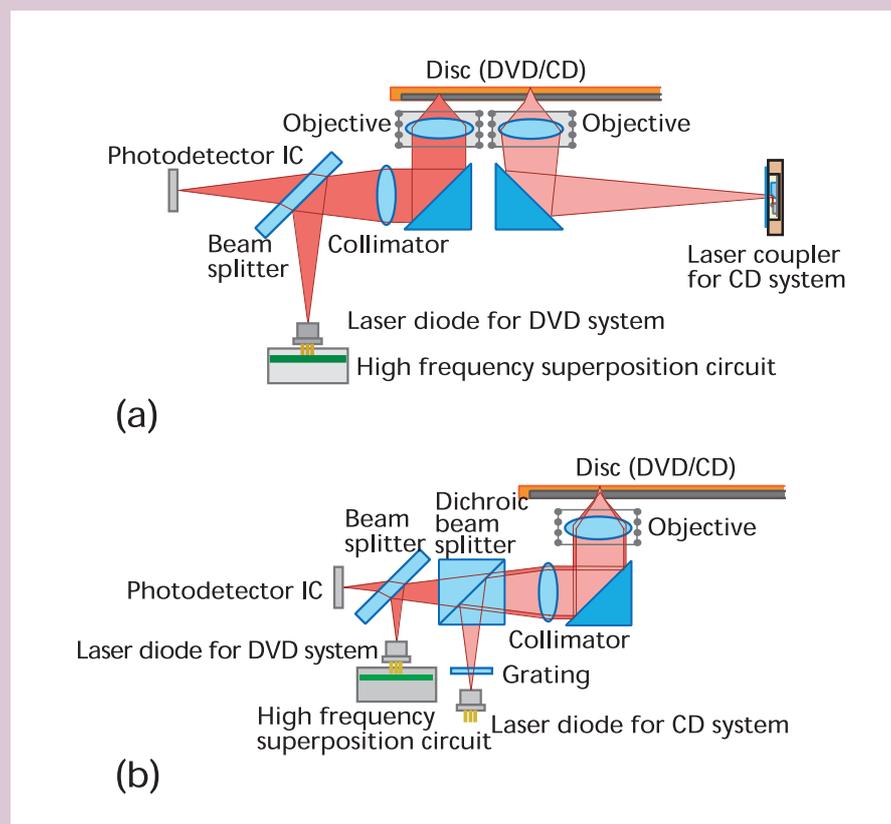


Fig. 1. Conventional optical pickup systems with two-wavelength.

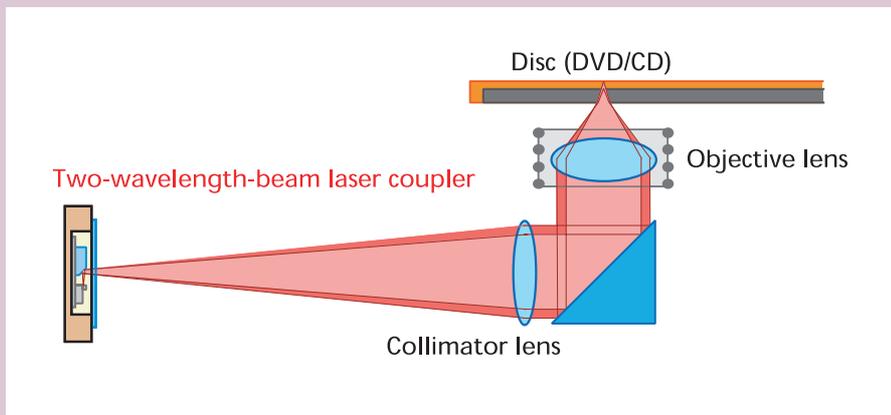


Fig. 2. Ultimate optical pickup system with two-wavelength.

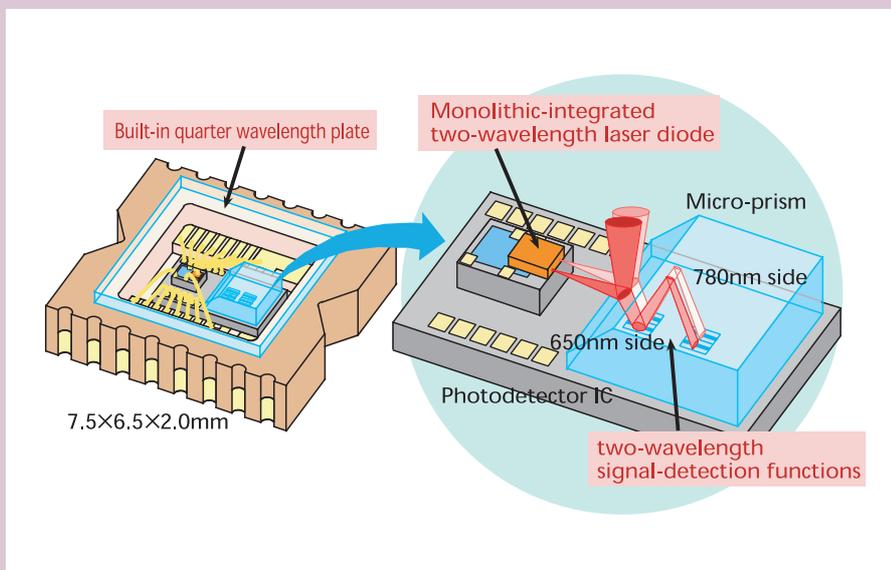


Fig. 3. Schematic representation of the 2BLC.

infrared laser diode (VILD), which can be fabricated using only two steps of metal organic chemical vapor deposition (MOCVD). Using a VILD, a new laser coupler called the 2BLC has been realized.^{4,5)} In this article, the structure and the features of the 2BLC are described, and the prospect of this device is briefly touched, as well.

2. Structure and features of the 2BLC

An optical integrated device called laser coupler (LC) has been developed and widely used in commercial products for an optical pickup head in CD system.¹⁰⁾ This device integrates a laser diode, a photodetector IC (PDIC) chip and a micro-prism in a small package. Recently, the laser coupler for MD system has been also developed and already used in commercial products.¹¹⁾

The structure of the 2BLC was followed the design concept of these LCs. Figure 3 shows

the schematic structure of the 2BLC,^{4,5)} which has a quite simple structure and is capable of very stable operation. The 2BLC is in a miniature thin ceramic package 7.5mmx6.5mmx2.0mm, which is essentially the same size as the LC for CD and MD systems that are currently in mass production. A VILD, a PDIC, a micro-prism and a quarter-wavelength-plate (QWP) are integrated in this package. The three distinctive features of the 2BLC are:

- A monolithic-integrated two-wavelength laser diode called a VILD is incorporated.
- A QWP is integrated.
- Two-wavelength signal-detection is performed by a PDIC and a micro-prism.

The details are as follows.

a. A monolithic-integrated two-wavelength laser diode (VILD) Structure of the VILD

Figure 4 shows the schematic structure of the VILD. A 780nm element and a 650nm element

are positioned side by side on the GaAs substrate and are individually addressable. Both elements have gain-guiding structures. A separated-confinement-heterostructure multi-quantum-well (SCH-MQW) structure is used for each active region to minimize the threshold current. The waveguide stripe of the 650nm element is a mesa-shaped tapered stripe, which forms a gain-guiding cavity. For the 780nm-element, the simplest and the most productive structure, the tapered-stripe gain-guiding structure, is used, which is prepared using ion implantation.^{12,13)} The length of the tapered-stripe is 170 μ m for both elements. The stripe width is 6.5 μ m at the center and 3.0 μ m at the facet edge for the 650nm element, and 8.0 μ m at the center and 5.0 μ m at the facet edge for the 780nm element. The two elements are 120 μ m apart. The cavity length of both elements is 400 μ m. The reflectivity of the front and rear facets is 28% and 75%, respectively, for the 650nm element, and 32% and 75%, respectively, for the 780nm element. The reflectivity of the front facet is optimized for both elements.

Fabrication process

Figure 5 is a schematic of the fabrication process of the VILD. First, the AlGaAs-SCH-MQW (5QWs) layers for the 780nm-laser elements, consisting of n-GaAs, n-Al_{0.47}Ga_{0.53}As, the undoped active region, p-Al_{0.47}Ga_{0.53}As and p-GaAs, were grown by first-step MOCVD on a (100)-10° off toward <011> n-GaAs substrate. Then Zn diffusion was performed to obtain high Zn concentration on the GaAs capping layer surface. The AlGaAs epitaxial layers were then partially removed using conventional wet etching, to form the land-groove-shaped structure: the land is the 780nm remaining layers and the groove is the GaAs substrate surface. Thus, the 780nm epitaxial islands parallel to the <01-1> direction were prepared. Next, the AlGaNp-SCH-MQW (6QWs) layers for the 650nm-laser elements, consisting of n-InGaP, n-In_{0.5}(Al_{0.73}Ga_{0.27})_{0.5}As, the undoped active region, p-In_{0.5}(Al_{0.73}Ga_{0.27})_{0.5}As, p-InGaP and p-GaAs, were grown by second-step MOCVD on the land-groove substrate. Then the unnecessary regions — the AlGaNp epitaxial layers on the AlGaAs islands — were selectively removed using conventional wet etching. Thus, the 650nm epitaxial islands parallel to the <01-1> direction were prepared. In this way, the 650nm epitaxial islands and the 780nm epitaxial islands were positioned side by side on the common GaAs substrate and the individually addressable

structure was formed very simply.

The waveguide stripes were formed by one-step photolithography, so the stripes for the 650nm-laser elements and the 780nm-laser elements precisely positioned. Wet etching was then used to form the 650nm stripe, then ion implantation was used to form the 780nm stripe. An extremely high accuracy of the emitting position between the 650nm and the 780nm element was obtained. In the etching process for forming the 650nm stripe, the p-cap layer was removed at the side of the 650nm stripe, so ohmic contact was formed only on the 650nm stripe and a Schottky barrier was formed at the side of the stripe after the electrode metals were evaporated. The ion-implantation depth at the side of the 780nm stripe is a little deeper than the cap-layer thickness. As the ion-implantation area had high resistivity, ohmic contact was obtained only on the stripe after evaporating the electrode metals. Finally, after cleaving and facet coating, a pelletized laser chip was mounted on the Si-submount, which has a monitor photo-diode for automatic power control (APC), in a junction-down configuration using Sn solder. The Sn soldering pattern on the submount is separated into two areas, which correspond to the electrode of the 650nm element and that of the 780nm element, for individual addressing.

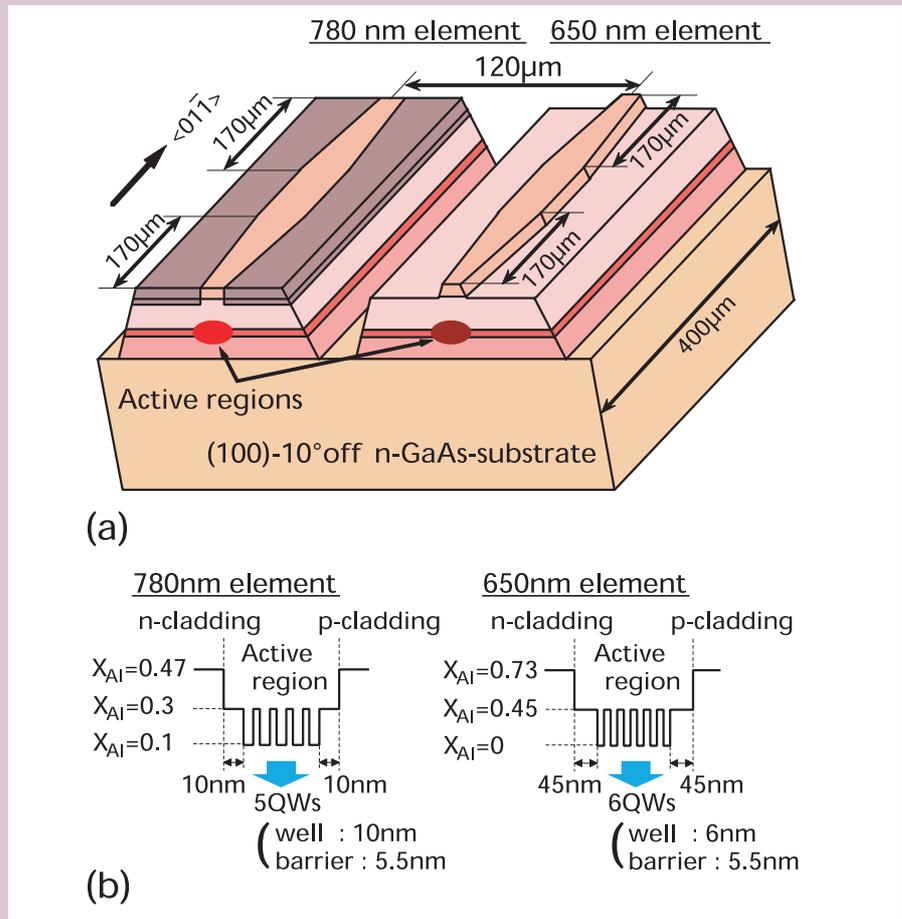


Fig. 4. (a) Schematic representation of the VILD. (b) Schematic structure of each active region.

Characteristics

Figure 6 shows typical laser characteristics for the 650nm element and the 780nm element under CW operation at room temperature. Both elements showed fundamental transverse mode operation, which was very stable because of the tapered-stripe structure. The lasing spectrum of the 780nm element showed multi-mode lasing and narrow linewidth of each longitudinal mode, typical characteristics for the tapered-stripe gain-guiding laser diode used in the CD system. The lasing spectrum of the 650nm element also showed multi-mode lasing and linewidth broadening of each longitudinal mode. It is considered that the tapered-stripe structure enhances saturable absorbing in the AlGaInP active layers, so self-pulsation occurs.

The relative intensity noise (RIN) characteristics of a 650nm and a 780nm element were estimated under optical feedback of 1% with a short optical path length of 35mm, up to 70°C. The RIN characteristics of both elements were below -130dB/Hz up to 70°C without high-frequency superposition circuits, which were low enough for practical

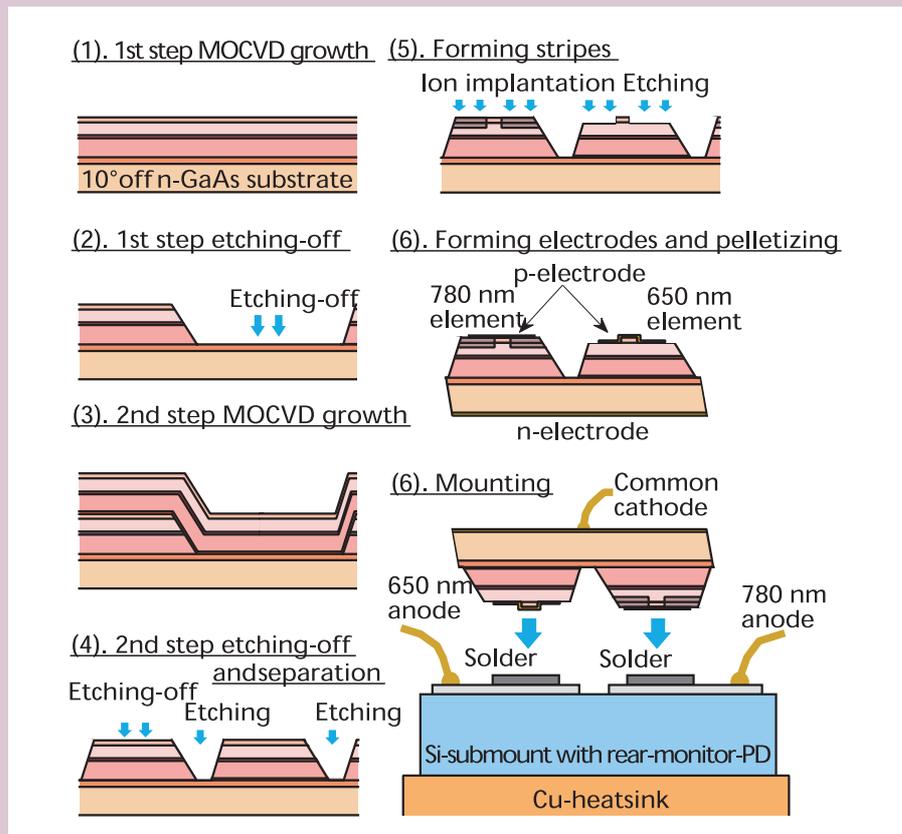


Fig. 5. Schematic of the fabrication process of the VILDs.

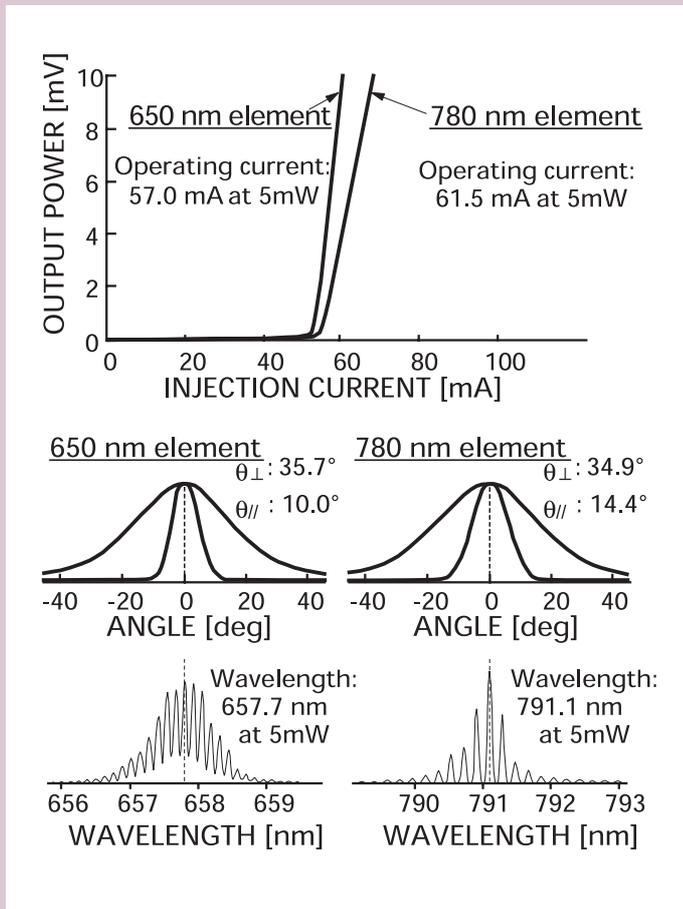


Fig. 6. Laser characteristics: light output versus injection current curves, spectrum and far field patterns.

use in the DVD/CD playback system. Figure 7 shows the aging curves of the 650nm element and the 780nm element, at 6mW and 7mW, respectively, under CW operation at 70°C. Good aging characteristics were obtained for both elements. The reliability of the 780nm el-

ement is extremely good, so it is possible to achieve a high yield for this element. In fact, the yield for the VILD is almost the same as that of the conventional single 650nm laser diode. The output laser beam from the 650nm element of the 2BLC's window is circularly polarized, as shown in Fig. 8. The circularly polarized beam is standard in the DVD system. Because some media has birefringence, which sometimes destabilizes signals, that is, increases

jitter. Thus, the 2BLC is almost not affected by variations in disc birefringence and it can implement a DVD/CD-drive with high playability. Using a QWP has another advantage, because it can minimize optical feedback noise. The VILD chip we have developed is designed to be used without high-frequency superposition circuits, therefore, the optical feedback noise is usually low enough so no other parts needs. But, some VILDs show rather higher level of the optical feedback noise due to the variation of the performance of the optical feedback noise. Figure 9 shows the output laser power versus relative intensity noise of a sample that is a little inferior to typical samples in optical feedback noise characteristics. Fig. 9(a) shows the RIN characteristics of the 650nm element. The RIN data were improved by using a QWP, especially in the low power range, up to 70°C. Because the direction of the linear polarization of the feedback light is rotated 90°, so the mode competition between the output laser light and the feedback laser light is small, in fact almost the same as with little optical feedback. The RIN characteristics of the 780nm element are shown in Fig. 9(b). This QWP is optimized for the 650nm laser, so the polarization of the output laser beam from the 780nm element is not perfectly circular, but a little elliptical. The rotation of the linear polarization of feedback light is a little less than 90°, so the influence of the feedback light is a little larger than in the case of the 650nm element. But, even this case, the mode competition between the output laser light and the feedback laser light is also very small, so the RIN data are improved by incorporating a QWP, especially in the low power range, up to 70°C.

b. The integrated QWP.

The 2BLC incorporates a newly developed QWP film at the window of the package for more stable operation of the optical pickup head. The QWP was realized in low cost, because it is made of plastic, which is put on the glass plate for sealing. The characteristic of the QWP is optimized to the 650nm laser, so the polarization of the output laser beam from the 780nm element is not perfectly circular, but a little elliptical. The rotation of the linear polarization of feedback light is a little less than 90°, so the influence of the feedback light is a little larger than in the case of the 650nm element. But, even this case, the mode competition between the output laser light and the feedback laser light is also very small, so the RIN data are improved by incorporating a QWP, especially in the low power range, up to 70°C.

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c. Two-wavelength signal-detection

In the 2BLC, various two-wavelength signal-detection functions are incorporated in one set of PDIC and micro-prism, which has a simple structure and operates very stably. The 2BLC includes a high-speed PDIC based on a newly developed ultra-high-speed highly integrated photo detector IC process and achieves a frequency bandwidth over 60MHz. This performance allows the 2BLC to support 6x-speed DVD and 48x-speed CD playback. There are two surfaces as beam splitters on the micro-prism. A 45°-surface splits emission and detection light, and a lower surface is for detecting the focus-error signal, as shown in Fig. 10. The reflectivity of both laser lights is almost the same, and the reflectivity of both s- and p-polarized light is nearly the same. This design

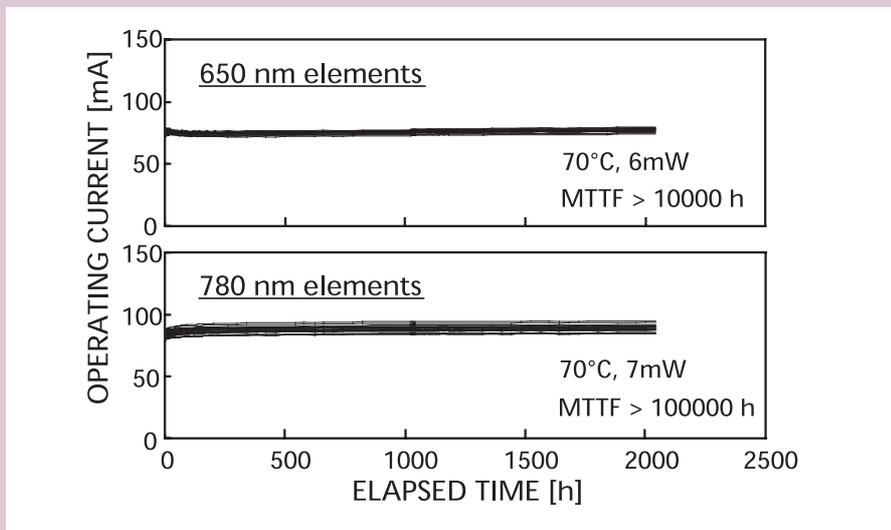


Fig. 7. Aging characteristics.

ensures that the 2BLC is almost not affected by variations in disc birefringence, so it can produce a DVD/CD-drive with higher playability. Figure 10 shows the signal-detection functions of the 2BLC. The playback signal and other systems can be switched between DVD and CD modes. While the 2BLC uses differential spot-size detection as the focus-error signal-detection method for both DVD and CD, it uses differential phase detection for DVD and push-pull detection for CD as the tracking-error signal-detection method. For the DVD playback mode, the PDIC uses a 2-stage gain switching function which allows the 2BLC to support two types of discs (single-layer and dual-layer discs) with the laser output level held fixed. Since a fixed laser output can be used, laser operating control is simplified and high stability is provided.

3. Conclusion

A new optical integrated device called the 2BLC, which has two-wavelength light emission/detection functions, has been developed. It has been especially designed for use in PlayStation 2 with many hard requirements, such as including two-wavelength functions in one integrated-device, being of small size, having a low cost, being capable of being developed quickly and being produced on a large scale. To develop the 2BLC, semiconductor laser division and game-product division have been closely collaborated each other, so an inclusive solution, thinking not only laser but also system and mechanism of the deck, has been able to be pursued. Therefore, the 2BLC has been able to be realized very efficiently and successfully.

Two different device concepts can be considered for 2BLC. One is using two laser chips, and another is using a monolithic-integrated two-wavelength laser chip called the VILD. Our choice is using the VILD. Such a device is usually difficult to fabricate and its yield is low. But by using a VILD it becomes much easier to realize a 2BLC than by using two laser chips. It is therefore important to solve the problems in producing a VILD is essential in developing a 2BLC. A newly developed VILD completely solves the problems, having very simple tapered-stripe gain-guiding structure and being fabricated using a very simple process with only two steps of MOCVD growth, almost the same as the conventional single wavelength laser, which is really suitable for mass production. In this way, the 2BLC has been successfully realized, which has superb performances. Good

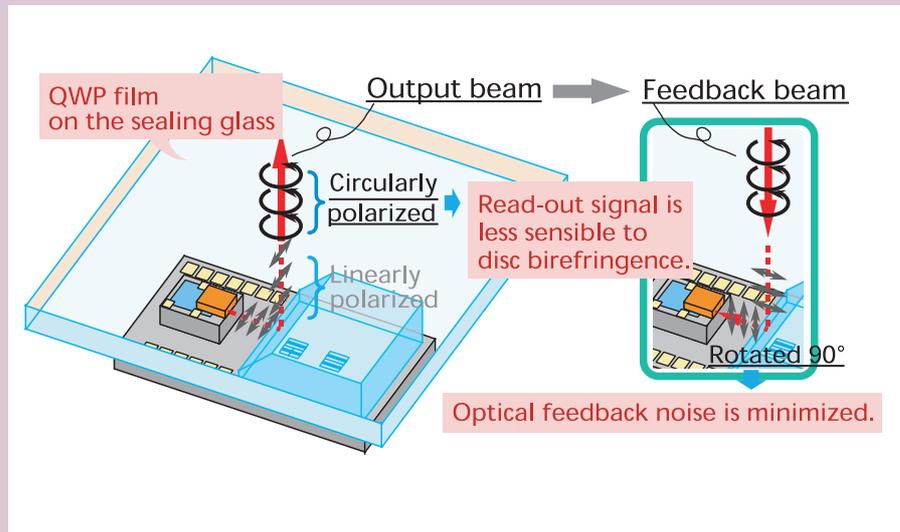


Fig. 8. Schematic of the polarization in the 2BLC.

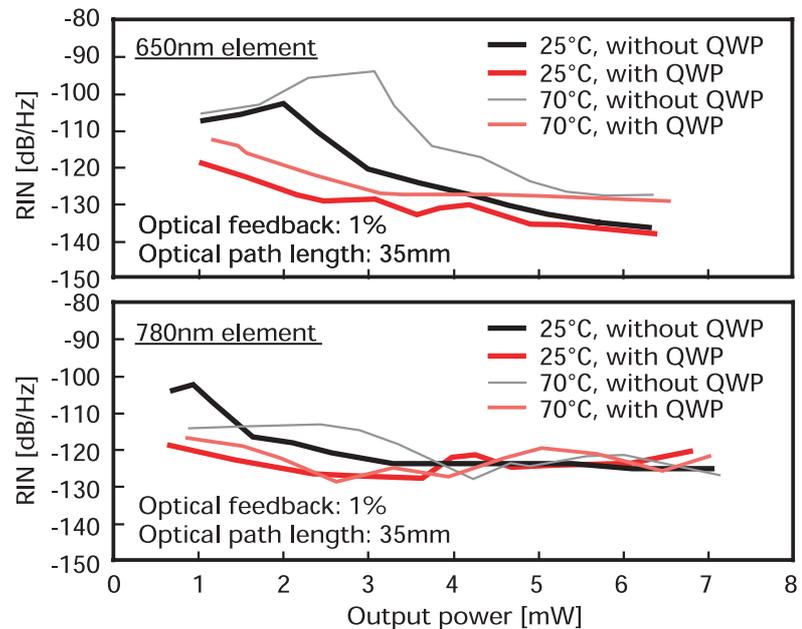


Fig. 9. RIN characteristics of a sample whose optical feedback noise is higher, using or not using a QWP.

laser characteristics were obtained up to 70°C. The RIN characteristics were also good enough up to 70°C without high-frequency superposition circuits. In addition, by integrating a QWP on the 2BLC, the 2BLC is almost not affected by variations in disc birefringence and can have wider margin of the optical feedback noise performance. Aging characteristics of the VILDs were also good, therefore, the yield for the VILD is almost the same as that of the conventional single 650nm laser diode. Figure 11 shows reproducing signals of an optical storage system

using a 2BLC. Good values of jitter were obtained for DVD readout and CD readout of 7~8% and 13~18ns, respectively. Using the 2BLC, it allows the number of components required in a two-wavelength optical pickup head to be reduced significantly, which results in a reduction in the time required for adjustment during assembly, increased reliability and other advantages. So, it contributes significantly to the implementation of simple low-cost optical pickup heads. The newly developed VILD and 2BLC, which are the industry's first

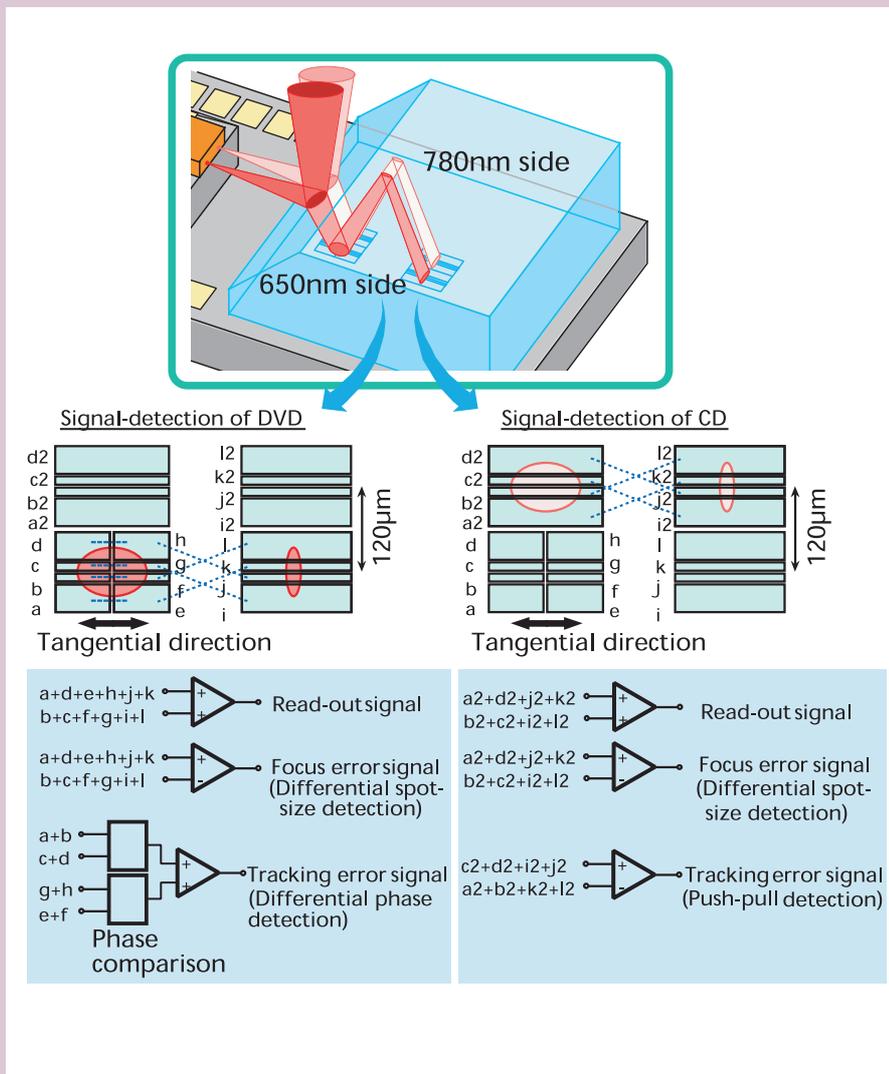


Fig. 10. Signal detection functions of the 2BLC.

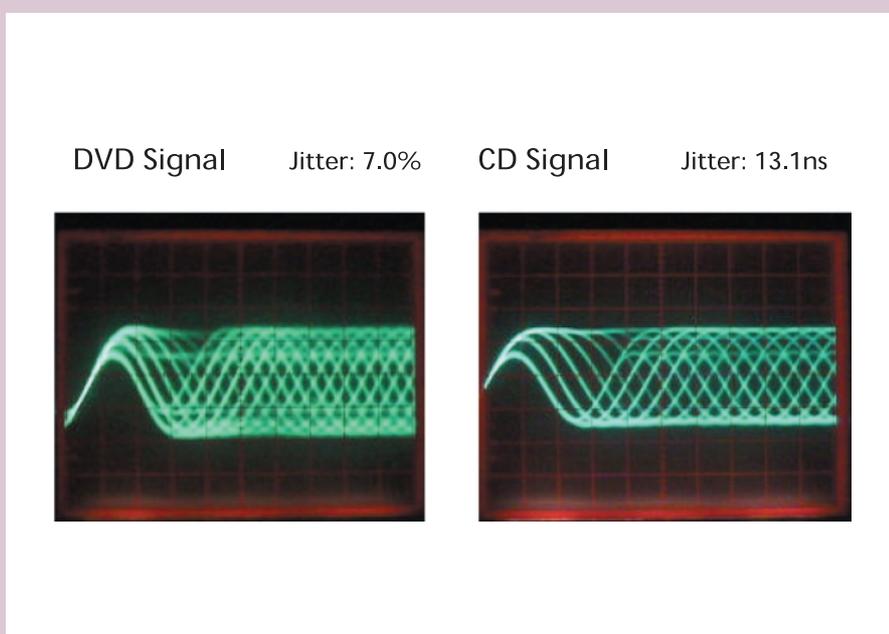


Fig. 11 Reproducing signals from DVD and CD disc.

two-wavelength integrated devices, are being now mass-produced for PlayStation 2. Then, these devices will be widely used for the other various DVD-based products. A new variation of these devices, including the functions for recording to such as the CD-R/RW-media, will be also developed in near future. Thus, it is expected that these devices will widely contribute to realizing productive optical storage systems.

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