SEMICONDUCTOR LASER PICKUP FOR OPTICAL VIDEO DISK PLAYER

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INTRODUCTION

Almost five years have passed since the concept of the optical video disk system was first presented, and several kinds of systems have been developed these few years.[1,2,3,4] Recently, the standardization of these confused optical video disks was made and optical video disk player systems have already reached the stage of commercial development.[5] Optical video disk systems offer several advantages to mechanical and capacitive video disk systems. High image quality, still and slow motion picture capability are some of its chief attractions. Unfortunately, large, complicated, and expensive optical pickups still remain a problem. Part of the difficulties is the use of the He-Ne laser as a light source. Although the He-Ne laser is one of the most stable and compact gas laser among several commercial available lasers, its size, over 200mm length and 30mm$^{\Phi}$ in diameter, is still too large for a compact optical pickup. Moreover, high voltage power supply of over 1.5KV are not desirable for home use systems. In addition, the optical system used in the pickup is quite complex because separate laser beams are used to detect the auto-focusing signal, the tracking signal, and the video signal. These factors make for a very expensive overall cost in labor for manufacturing and maintenance.

In an effort to develop a simple and small optical pickup for a low cost video disk player system, we have developed an optical pickup which employs a semiconductor laser as a light source. Semiconductor lasers have primarily been considered as a light source of optical communication. Their small size and ease in fabrication have prompted studies as to their applicability as light sources for video disk players. One of the difficulties is that the conventional Double Heterostructure (DH) semiconductor lasers have narrow stripe-like active regions (for example 1μm x 10μm) which make it difficult to focus their laser beams into circular spots with high efficiency on video disks. This causes difficulty in the reconstruction process. We approach this problem by using the Buried Heterostructure (BH) semiconductor lasers of which active regions are small and symmetric. This results in a more manageable beam and ease in the reconstruction of the video disk.

In this paper, we first describe the optical requirements of a light source for a video disk player system. In addition, the optical characteristics of the BH lasers are described and the possibility of their application to the light source of the optical video disk player is discussed. We then present an implementation of such a semiconductor laser pickup along with the optics needed for detection of servo control and video signals. Finally, experimental results of the reconstruction of the video disks by the newly developed optical pickup are presented.

OPTICAL REQUIREMENTS FOR A LIGHT SOURCE OF A VIDEO DISK PLAYER

The standard video disk designed for He-Ne laser read-out is made of a transparent polyvinyl chloride (PVC) of 1.1m thickness.[6] Frequency modulated video and audio signals are spirally recorded as a train of pits

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each of which is 0.6-0.8μm in width, 1-3μm in length, 0.11 μm in depth (corresponding to the 1/4 wavelength depth of a He-Ne laser in PVC), and a track pitch of 1.7-2.0μm. The recorded plane is metalized (usually by aluminum) with a protective layer applied on top of this reflective coating. To read the disk, a laser beam is focused on the recorded plane through the transparent disk and the reflected beam from the recorded plane is directed to a photo-detector through a focusing lens.

The spot size required to read the information pits is determined by the following conditions. The focused spot size must resolve the length which corresponds to the bandwidth required for a signal at the innermost radius (55mm) of the recorded area.[7] That is, the numerical aperture (NA) of the focusing lens should be selected so that the cut-off frequency f_c of the Modulation Transfer Function (MTF) of the lens at the innermost radius is equal to or more than the bandwidth f_m of the encoded signal as shown in the following equation.

$$NA \geqq \frac{\lambda f_m}{4\pi f_R R_i}$$

where, λ is a wavelength of the laser, f_R is a rotation frequency of the disk (30Hz) and R_i is the innermost radius of the recorded area. In Fig. 1, the relations between the cut-off frequency f_c at the innermost radius and the numerical aperture NA of the lens are shown with the wavelength of the He-Ne laser (632.8nm) and the BH laser (830.0nm). When the NTSC directly encoding system[8] is used as a signal encoding system, f_m is about 13MHz (f_{md}) while for NTSC crossband system,[1] it is 10MHz(f_{mc}). Consequently, from Fig. 1 the required numerical apertures of the lens are 0.4 and 0.52 for the NTSC directly encoding system for He-Ne laser and BH laser, respectively. As for the NTSC crossband system, the required numerical apertures of the lens are 0.3 and 0.4 for He-Ne laser and BH laser, respectively. Spot sizes

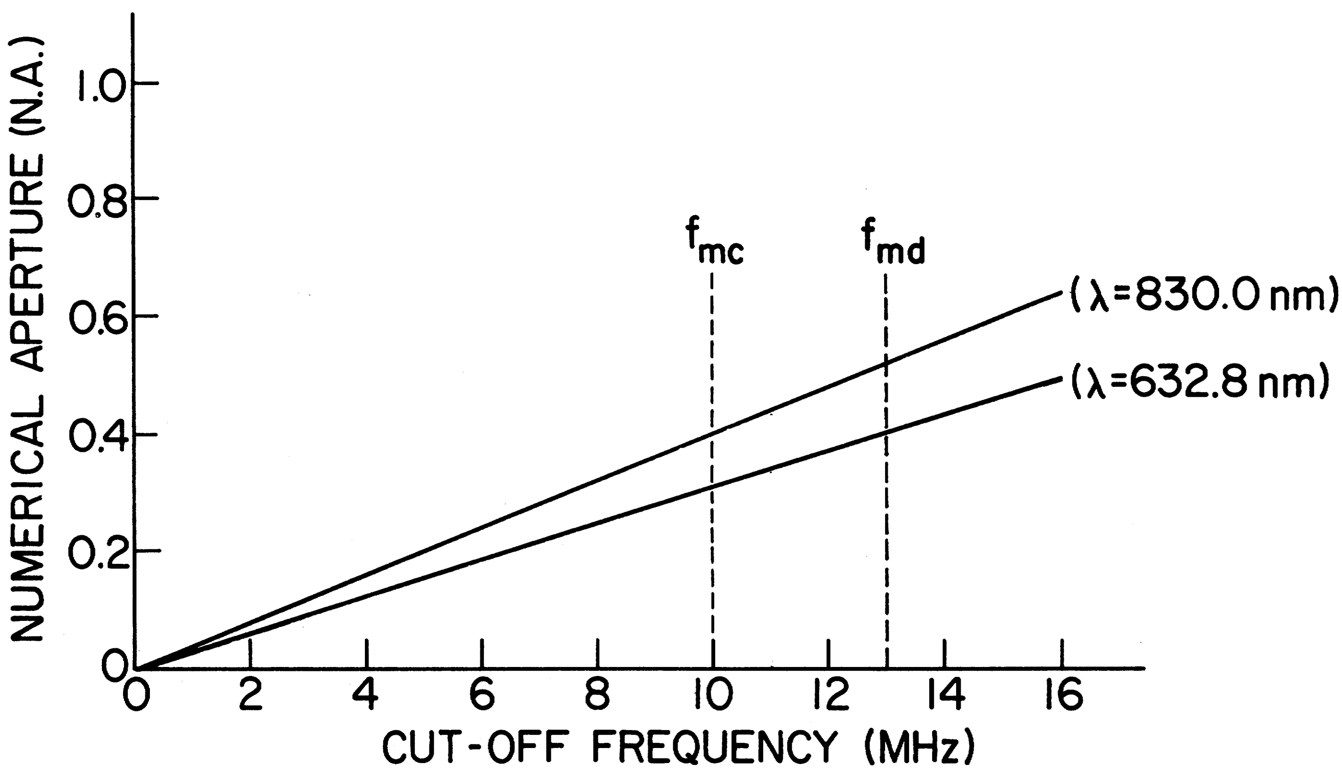

Fig. 1 Relation between the cut-off frequency and the numerical aperture of the lens.

on the disk are determined by the numerical apertures of the lens. Thus the corresponding spot sizes are about 1.2-1.3μm$^{\Phi}$ and 1.6-1.7μm$^{\Phi}$ (at $1/e^2$ intensity) for the NTSC directly encoding system and the NTSC crossband system respectively. These spot sizes are required at the innermost radius of the recorded area on the disk, while at the outer radius larger spot sizes are allowable. In addition to above conditions, the spot size in the radial direction is determined by a cross talk between adjacent tracks. For a track pitck of 1.7-2.0μm, the spot size in the radial direction should be about the same size as in the tangential direction in order to keep the cross talk to be less than -35dB. These requirements on the read spot size for the video disk implies that the radiating pattern of the semiconductor laser should be circular and small in order to enable it to be focused into a tiny spot efficiently with simple optics, such as conventional microscope objective lenses.

The required output power of the laser is determined by the following equation.

$$I_L = \frac{i_m}{M \eta \epsilon}$$

where I_L is the required minimum laser power, i_m is the minimum current which is required to get a sufficient signal-to-noise (S/N) ratio of a video preamplifier, η is a photo-sensitivity of the detector, M is the depth of the optical modulation of the video signal from the disk, and ϵ is a total optical efficiency of the pickup which is measured as a ratio of the laser power on the detector to the output power of the laser. For example, if we let $i_m = 4\mu A$, $\eta = 0.2\mu A/\mu W$, $M = 0.4$, and $\epsilon = 0.1$, then I_L is 500μW. In this case, the required output power of the laser should be about 1mW.

The wavelength of the semiconductor laser should be as close to that of the He-Ne laser as possible because a higher numerical aperture lens is required for a longer wavelength to obtain the same spot size on the disk. Moreover, the difference of the wavelength causes a decrease of the depth of modulation of the reconstructed video signal from the disk.

Polarization characteristic of the laser is utilized to increase the optical efficiency and to prevent the back talk effect in the He-Ne laser pickup. However, in case of the semiconductor laser, this characteristic is not critical since no back talk effect has been observed in the video frequency region experimentally.

Noise characteristic of the semiconductor laser should be the same as that of the He-Ne laser in order to obtain a high quality reconstructed image with a signal-to-noise ratio of over 40dB.

OPTICAL CHARACTERISTICS OF BURIED HETEROSTRUCTURE LASERS

The basic construction and the appearance of the BH laser are shown in Fig. 2. This laser has a filamentary GaAs active region completely surrounded by GaAlAs,[9] whereas the conventional DH laser has a thin and wide active region. This special structure is made by using a mesa-etching technique to leave a filamentary active region on the double heterostructure crystal grown by the continuous epitaxial method, and a liquid growth technique of GaAlAs to bury that filamentary active region. In general, the BH lasers have the following features:

1. The single lowest oscillation mode which is easy to be focused into a tiny spot is obtainable.
2. The oscillation mode is stable relative to changes in the exciting current.
3. The beam divergence is symmetric and thus easier to handle optically.
4. Working current and voltage are quite low and a small heat sink is sufficient.

The measured optical characteristics

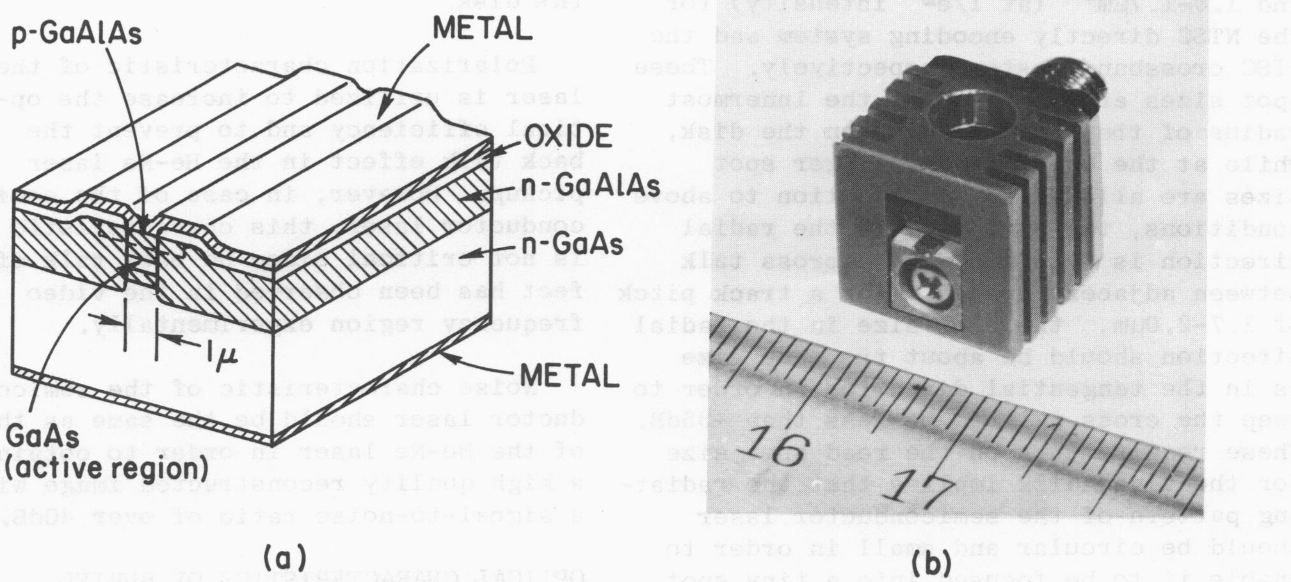

Fig. 2 (a) Basic construction and (b) the appearance of the BH laser.

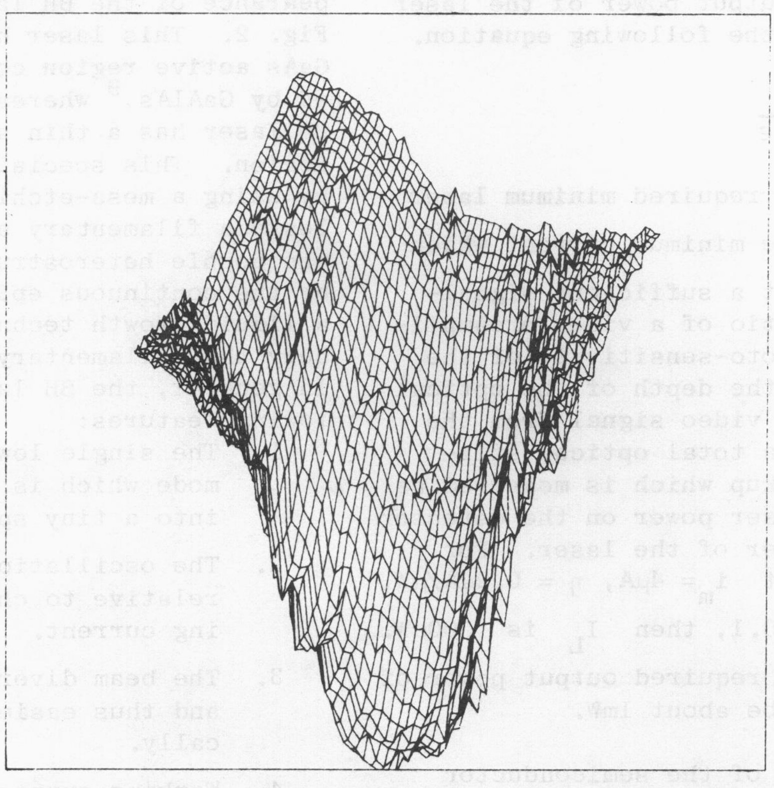

Fig. 3 3-dimensional plot of the far field pattern of the BH laser.

of the BH lasers are as follows.

Radiation Pattern of the Laser Beam

The far field pattern of the BH laser was measured. The BH laser was rotated with its active region at the center of the rotation at various angles of tilt while the radiation intensity was measured by a photo-multiplier through a pinhole which was set at points 10cm from the laser. The measured signals are processed by computer and a 3-dimensional plot of the intensity distribution is obtained as shown in Fig. 3. The intensity distribution is shown to be a rotational symmetric Gaussian-like distribution. The observed near field pattern is shown in Fig. 4. Figure 5 shows the detailed measurement of the cross section of the intensity. The cross sections in both parallel and perpendicular directions to the junction of the laser are shown to be Gaussian distributions with the same spot size of 1.6μm at $1/e^2$ intensity point. The dependence of the spot size on the output laser power is shown in Fig. 6. The spot size in the parallel direction to the junction is larger than that of the perpendicular direction in the output power region of below and around threshold (corresponding to an output power of 200μW). However, above threshold output power, both spot sizes become the same. This behavior in the range of low output power is due to the mixed radiation of the induced and the spontaneous emissions. Thus for a symmetric spot, the BH laser should be used in the output power region of more than 200μW.

Output Power Characteristic

Typical output laser power dependence on the excitation current is shown in Fig. 7. Threshold current is about 10mA which is more than one order lower than that of the conventional DH lasers (about 200mA). The output laser power of more than 1mW can constantly be maintained with 14-15mA input current with a high reliability.

Wavelength Characteristic

The typical lasing spectrum of the BH

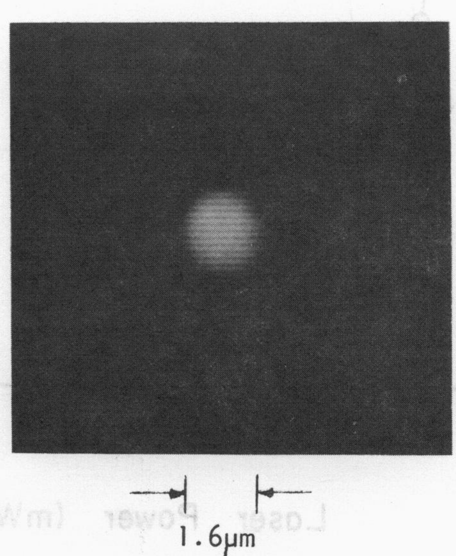

Fig. 4 Near field pattern shape of the BH laser (Displayed on the TV monitor)

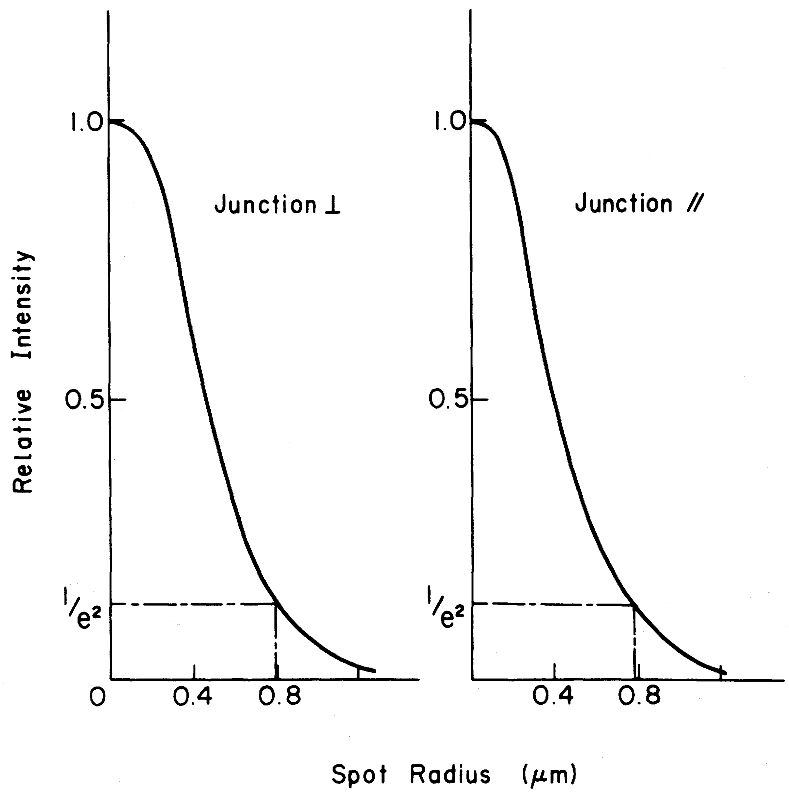

Fig. 5 Detailed cross sections of the near field pattern of the BH laser.

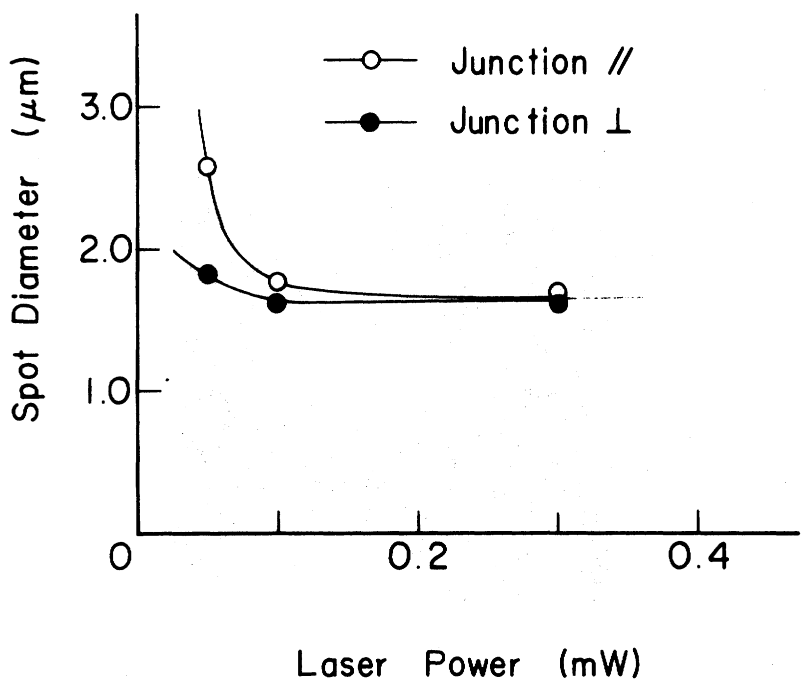

Fig. 6 Dependence of the spot size of the BH laser on the output laser power.

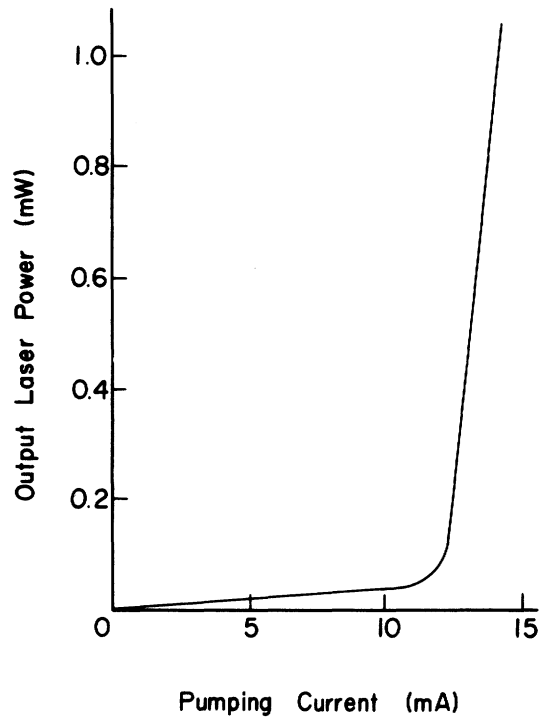

Fig. 7 Dependence of the output laser power of the BH laser on the excitation current.

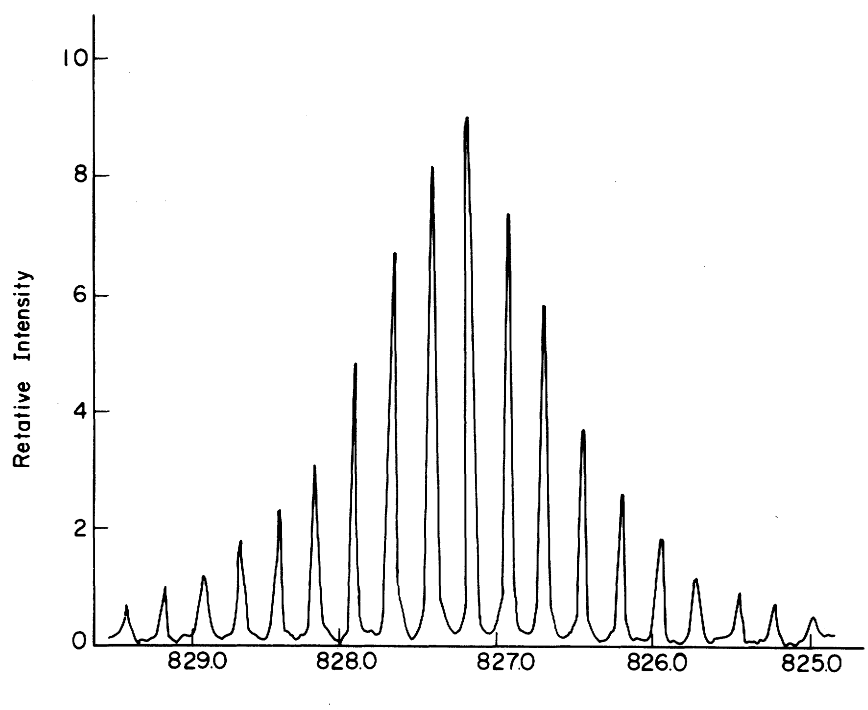

Fig. 8 Typical lasing spectrum of the BH laser

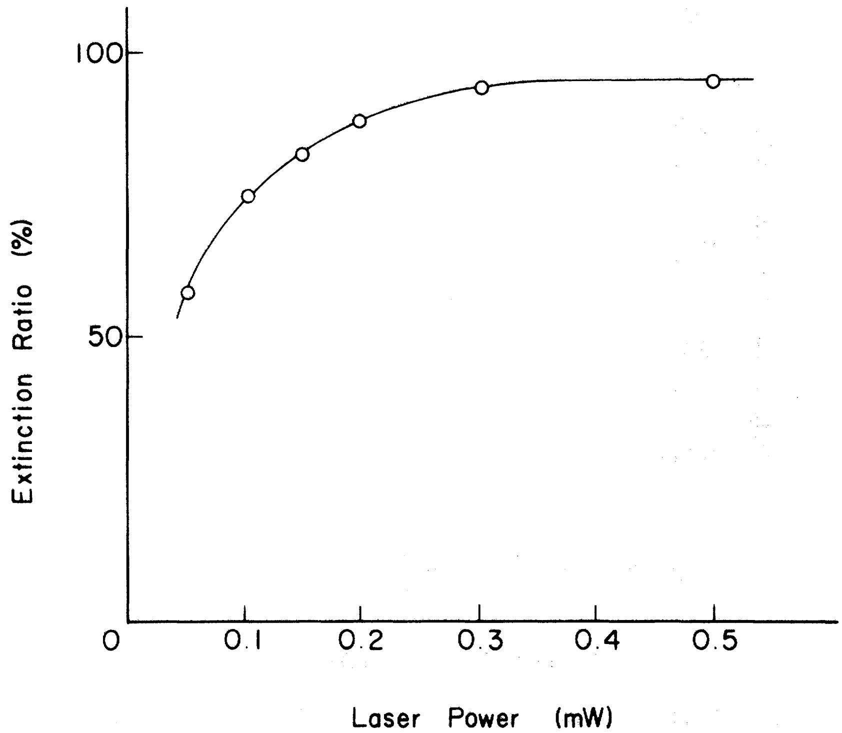

Fig. 9 Dependence of the extinction ratio of the BH laser on the output laser power

laser is shown in Fig. 8. Several lasing lines can be seen around the wavelength of 830.0nm. This wavelength of the BH laser causes about 15% decrease of the depth of the modulation to that of the He-Ne laser. However, this decrease is allowable to obtain a high quality reconstructed image with a signal-to-noise ratio of over 40dB. This wavelength difference can be positively utilized to detect the tracking signal of the pickup in a technique described later.

Polarization Characteristic

The output laser beam of the BH laser is linear polarized in the perpendicular direction to the junction. The extinction ratio depends on the output laser power as is shown in Fig. 9. The low extinction ratio seen below and around the output power corresponding to the threshold current is due to the mixed radiation of the polarized induced emission and the non-polarized spontaneous emission. Above the output power of 200μW the extinction ratio becomes constant to more than 20:1. This ratio is lower than that of the He-Ne laser (more than 100:1). If the polarization characteristic is only used to increase the optical efficiency of the pickup then this ratio is sufficient. However, to eliminate the back talk effect, this 20:1 ratio would not be sufficient. Fortunately, no back talk effect can be observed in the video frequency region (0-15MHz) when the BH laser is used in the pickup.

Noise Characteristic

The allowable relative noise power of the laser to obtain the reproduced image with a signal-to-noise ratio of more than 40dB is about 0.01% in the video frequency region. The noise characteristic of the BH laser is shown in Fig. 10. It can be seen that the noise power in the video frequency region of the BH laser shows a keen peak at the threshold current (I_{th})

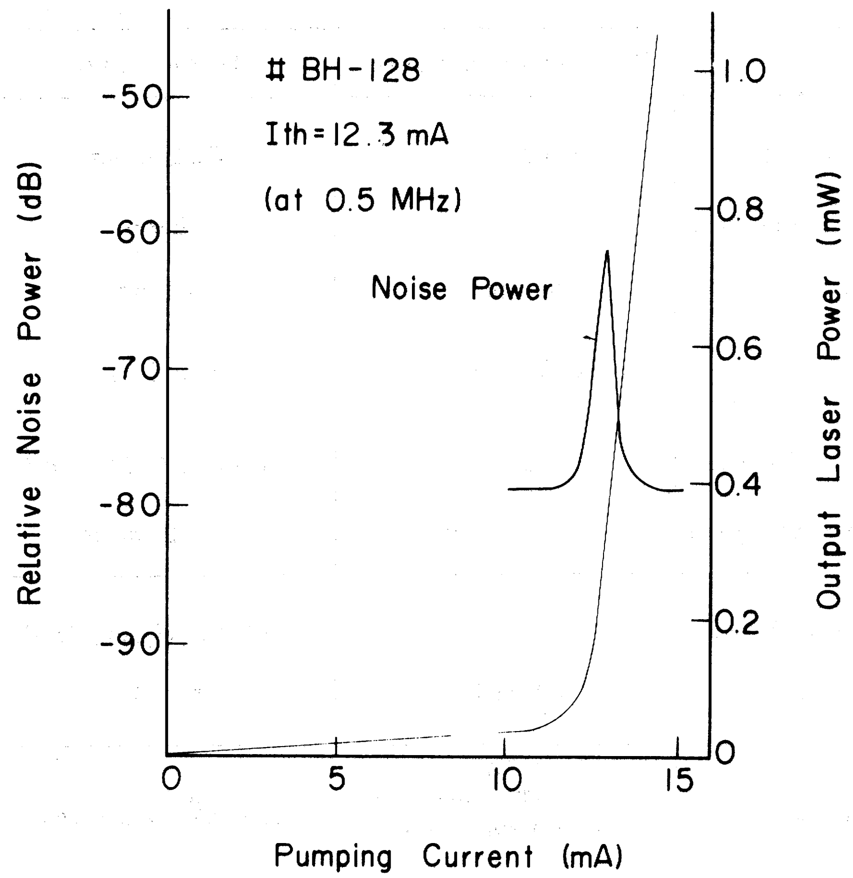

Fig. 10 Dependence of the relative noise power of the BH laser on the excitation current.

region in the same manner as DH lasers. However, noise power in the current region of more than $1.2I_{th}$ is shown to be about 0.01% (corresponding to -80dB in the figure) or the same as that of the He-Ne laser. This region is equivalent to an output power range of more than 500-600μW. Fortunately, this output power is consistent with the results of the required output power specification discussed previously.

The characteristics of the BH laser are summarized in Table 1. Through above measurements and discussion, the optical characteristics of the BH lasers are shown to satisfy the conditions required of the light source for an optical pickup.

A PRACTICAL PICKUP STRUCTURE

The basic configuration of an optical system used in the semiconductor laser pickup is shown in Fig. 11. The pickup consists of two main parts. One portion is the semiconductor laser. While the other portion is the optical system needed to direct a laser beam to the disk and to detect the reflected signal. Optical system consists of the focusing optics section which is used to project the laser beam as a tiny spot on the disk, and the servo signal detecting section which is used to detect the focusing and the tracking error signals from the rotating disk. For simplicity, these two optics sections are combined into one optical system. In addition to these optical system, there are electronics for processing the video and servo signals.

The radiating laser beam from the BH laser symmetrically diverges at about 60 degrees angle beam because of the diffraction of the nearly 1μm$^{\phi}$ aperture. This diverging beam is captured and imaged on the conjugate point by using a coupling lens. This conjugate image is focused on

TABLE 1

Summarized characteristics of the BH laser

	B-H Injection Laser	He-Ne Laser
Wavelength	830.0 nm	632.8 nm
Transverse Mode	TE_{00}	TEM_{00}
Output Power	> 1 mW	> 1 mW
Noise (video range)	≦ 0.01 %	≦ 0.01 %
Beam Diameter	< 2 μm$^{\phi}$	0.75 ± 0.05 mm$^{\phi}$
Beam Divergence	1 ~ 2 rad	1.2 mrad
Driving Voltage	2 V	1.6 KV (Trigger, 7KV)
Current	10 mA	5 mA
Dimension	Less Than 10 mm cubic (with Heat Sink)	30 mm$^{\phi}$ x 220mm

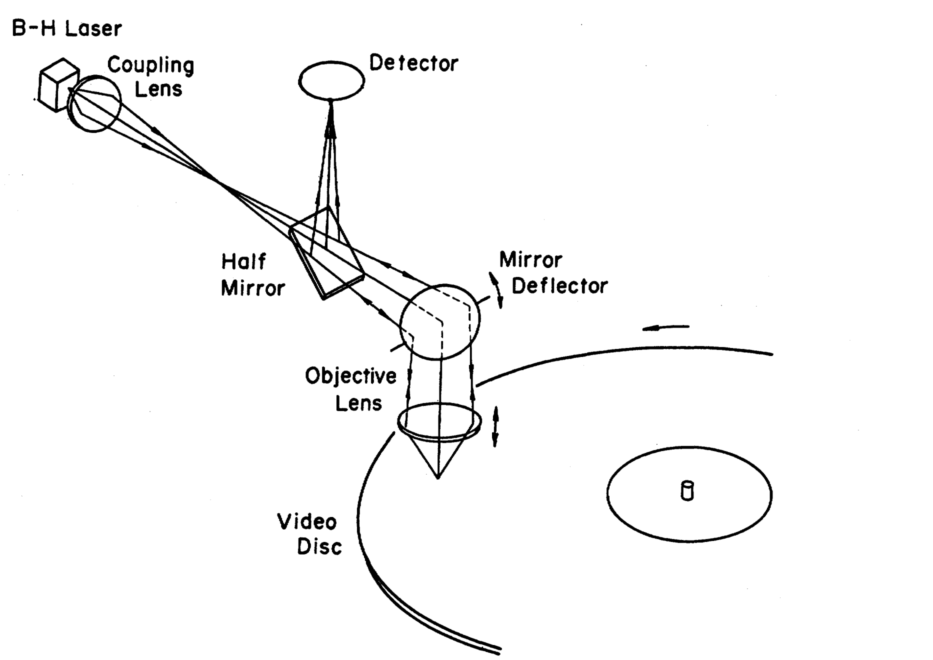

Fig. 11 Basic configuration of the semiconductor laser pickup.

the disk by using another focusing lens. The spot size on the disk is determined by the numerical aperture of the lenses and the intensity distribution of the laser beam itself. From the results of the far field and the near field patterns measurements of the BH lasers, it can be seen that the intensity distribution is Gaussian-like. Taking this distribution into consideration, the numerical aperture of the coupling lens is selected to be 0.4. As for the focusing lens, both NA 0.4 and 0.5 lenses can be used for the NTSC crossband system and the NTSC directly encoding system video disks, respectively.

The recorded surface of the disk moves several hundreds micronmeters vertically during its rotation because of the distortion and inclination of the disk. Auto-focusing servo control is required to keep a tiny focused spot on the tiny pits on the disk. The required accuracy of the focusing servo control is roughly determined by the focusing depth of the lens which is proportional to $\lambda/(NA)^2$. For an He-Ne laser system with a λ of 632.8nm and a lens of NA 0.4, the focusing depth is about $\pm 2\mu m$. In the case of the BH laser, λ is 830.0nm and NA are 0.4 and 0.5, and the focusing depths are $\pm 2.6\mu m$ and $\pm 1.7\mu m$, respectively. These values are almost equal to that of the He-Ne laser. Several simple optical methods to detect the focusing error signals have been developed.[10] By using these methods the moving lens is driven to control the focusing on the disk. It was found that the control range of the auto-focusing servo system needs to be about $\pm 100\mu m$ with an accuracy of $\pm 1.5\mu m$.

The information track moves in the radial direction 100-200μm during the rotation of the disk because of possible eccentricity and the distortion of the disk. To detect the tracking error signals, the diffraction effect of the laser beam by the information pits is utilized. The diffraction pattern of the laser beam by the pit is calculated on the plane of the focusing lens. The depth of the pit is 0.16μm (1/4 wavelength of the He-Ne laser) and the calculations are done both for the He-Ne laser (λ = 632.8nm) and the BH laser (λ = 830.0nm). In the case of the He-Ne laser, the symmetry of the pattern distribution in the direction of the spot movement is maintained. The pattern distribution of the BH laser shows an asymmetry due to the mismatching of the wavelength of the BH laser and the depth of the pit. That is to say, the laser beam diffracted by the pit is not only modulated in intensity (this effect is used to detect the video signal), but also contains the information as to the tracking error in its asymmetry distribution. It was found that the control range of the tracking servo system needs to be about $\pm 150\mu m$ with an accuracy of $\pm 0.2\mu m$.

No special optics are used for the detection of the time base error (jitter) signal. The phase shift of the horizontal sync frequency (f_H = 15734.264Hz) is detected by using an AFC circuitry. The mirror deflector (not shown in Fig. 11) for the jitter compensation is driven in the tangential direction by this time base error signal.

The video signal is obtained by detecting the total modulation of the reflected laser beam from the disk.

By using this simple optical pickup, the video and all the servo control signals can be detected. There are however some interactions between the servo control signals which would decrease the overall accuracy of the pickup servo control. These interactions can generally be eliminated by proper electronic compensation.

EXPERIMENTAL RESULTS

An engineering model of the semiconductor laser pickup based on the structure and the principle described in the previous section was designed and constructed. The appearance of the pickup is shown in Fig. 12. The pickup is shown with the BH laser mounted on a $1cm^3$ heat sink, optical components, and the

Fig. 12 Appearance of the semiconductor laser pickup.

detector. The size of the whole pickup is less than 200mm long, 50 mm high, and 20mm wide. The total weight is less than 300 grams. The total number of parts is seven including the laser and the detector. The singular optical axis considerably simplifies the alignment of the detector and the remainder of the optical system. The total optical efficiency is about 15%. The maintenance is greatly reduced due to the stability associated with the short optical path. The pickup was mounted on the experimental model video disk player as is shown in Fig. 13. In Fig. 14, the focused laser spot pattern on the information pits is shown. The laser output power is 500-600μW. An example of the reconstructed image is shown in Fig. 15. The NTSC directly encoding system and the NTSC crossband system video signals were recorded on the disk, with pits 0.8μm in width, 0.16μm in depth and tracking pitch of 2μm. The final signal-to-noise ratio of the demodulated images is more than 40dB which is comparable to conventional video signal sources. The measured characteristics of the auto-focusing servo control and the tracking servo control are as follows: Auto-focusing has a control range of ±100μm with an accuracy of ±1.5μm; and tracking has a control range of ±150μm with an accuracy of ±0.2μm. These values satisfy the conditions required to reconstruct the image of the average video disks.

CONCLUSION

The possibility of the utilization of the Buried Heterostructure semiconductor laser as a light source of the optical pickup for the optical video disks was demonstrated. Using this semiconductor laser pickup the video disks with the NTSC directly encoding system and the NTSC crossband system signals were reconstructed with a signal-to-noise ratio of more than 40dB. This pickup has the

Fig. 13 Appearance of the experimental model video disk player.

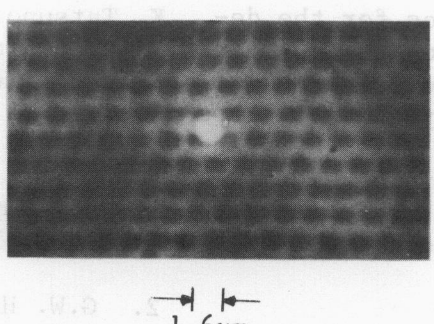

Fig. 14 Focused spot pattern on the information pits.

Fig. 15 Reconstructed image from the optical video disk by using the semiconductor laser pickup.

following features when compared with the conventional He-Ne laser pickups.

1. The total volume of the pickup is quite small since the size of the BH laser is less than $1cm^3$ even with a heat sink. Moreover, the power requirements (DC 2V, 10-15mA) are simple.

2. The single axis optics for the detections of the video, the auto-focusing and the tracking signals considerably simplify the structure of the pickup. This simplicity and compactness of the pickup significantly contribute to the commercial viability of an optical video disk player system.

3. The semiconductor laser pickup is shown to be available with the video disks made for the He-Ne laser read-out.

The lifetime of the BH lasers in the CW operation is one of the most interesting and important matters for their applications. The results of the accelerated life test of the BH laser shows a promising and encouraging data of 1500 hours at 70°C. This value corresponds to about 10^5 hours at 30°C.

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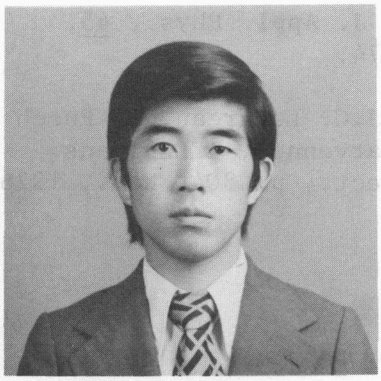
BIOGRAPHIES



Yoshito Tsunoda

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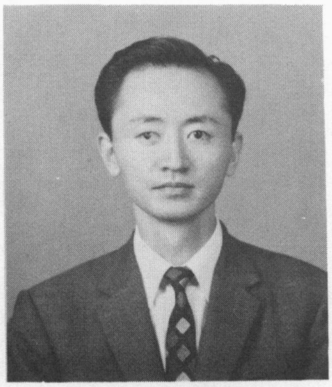

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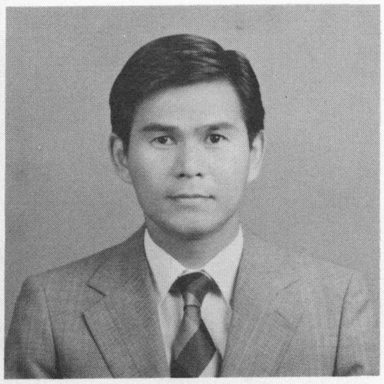

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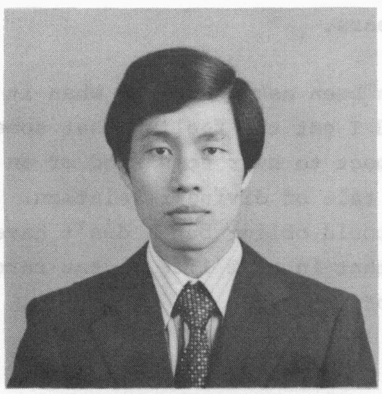

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