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A Study on the Optical Parts for a Semiconductor Laser Module

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A semiconductor laser module consists of a LD (laser diode) chip that generates a laser beam, two cylindrical lenses to collimate the laser beam, a high-reflection mirror to produce a large output by collecting the laser beam, a collimator lens to guide the laser beam to an optical fiber and a protection filter to block reflected laser light that might damage the LD chip. The cylindrical lenses used in a semiconductor laser module are defined as FACs (fast axis collimators) and SACs (slow axis collimators) and are attached to the system module to control the shape of the laser beam. The FAC lens and the SAC lens are made of a glass material to protect the lenses from thermal deformation. In addition, they have aspheric shapes to improve optical performances. This paper presents a mold core grinding process for an asymmetrical aspheric lens and a GMP (glass molding press), what can be used to make aspheric cylindrical lenses for use as FACs or SACs, and a protection filter made by using IAD (ion-beam-assisted deposition). Finally, we developed the aspheric cylindrical lenses and the protection filter for a 10-W semiconductor laser module.

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I. INTRODUCTION

As the application of laser micro-processing technology has been spreading as of late in national strategic industries, such as displays, semiconductors and mobile devices, the demand for micro-processors is estimated to increase at an exponential rate [1]. In the case of semiconductor lasers, especially, the module output is increasing due to innovative advances in technology, and, as a result, the number of fields for exclusive applications of this technology is on the rise. In addition, this technology has come into the limelight as a source to pump the medium of another high-output laser by using its high photoelectric conversion efficiency. At present, several foreign companies are dominating most of the laser micro-processor markets in Korea and abroad. However, as of late, Korea's small- and medium-scale companies are showing movements to develop this technology. Nevertheless, the companies intending to develop this technology lack techniques to fabricate the optical parts that are used in the module. As a result, these companies depend mostly on advanced makers abroad for the supply of important optical parts.

A semiconductor laser is mainly comprised of LD (laser diode) chips that generate laser light, one or two cylindrical lenses that collect the generated laser light in the form of a beam with the desired size, a high-reflection mirror producing a high output by gathering the laser light generated from a number of LD chips to a single point, a condenser lens that guides and collects the laser light reflected from the high-reflection mirror, and a protection filter to protect the LD chips from laser light reflected by the optical fibers. A schematic diagram of a semiconductor laser module is shown in Fig. 1. One of the two cylindrical lenses used in a semiconductor laser light source module is defined as the FAC (fast axis collimator), and the other is defined as the SAC (slow axis collimator). These lenses are mounted on the system module crosswise and control the shape of the quickly- or the slowly-spreading laser beam. The FAC and the SAC lenses are used for a relatively higher output. Therefore, they are mainly made of glass in order

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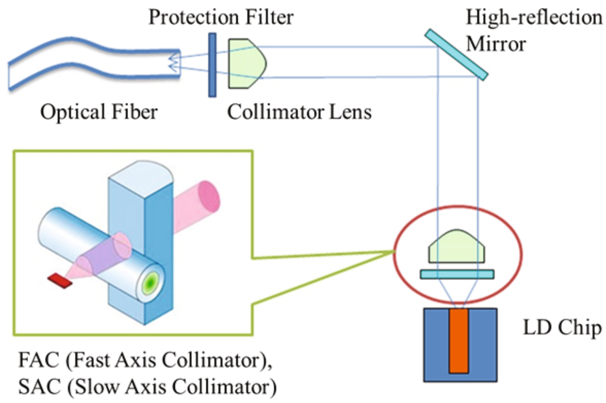

Fig. 1. (Color online) Schematic diagram of a semiconductor laser module.

Table 1. Properties of the lens material.

Material Name	K-VC89 (Sumita, Japan)
Refractive Index (nd)	1.81000
Abbe Value (vd)	41.0
Glass Transition Temperature (Tg)	528 °C
Yielding Point (Yp)	559 °C
Thermal Expansion ($\alpha \times 10^{-7}$ °C^{-1})	83 (+100∼+300 °C)

to prevent thermal deformation caused by the absorption of light energy by the material itself. In addition, these lenses are designed with aspheric surfaces that can decrease spherical aberration and improve optical performance. Also, the incidence plane of the FAC lens must have an anti-reflection coating so as to facilitate light penetration through the surface at near-infrared wavelengths, the wavelengths of the laser light incident upon the surface of the FAC lens. At the same time, the exit plane through which laser light moves towards the optical fibers must have a high-reflection coating so as to protect the LD chips [2]. Therefore, FAC lens fabrication involves a number of difficulties. In particular, FAC and SAC lenses with aspheric surfaces cannot be manufactured by using an ordinary rotational symmetrical lens and a spherical surface grinding apparatus. In addition, because the shape of the lens itself is cylindrical, the lens cannot be manufactured with ultra-precision grinding by using a DTM (diamond turning machine) [3]. Moreover, a protection filter is essential for protecting the LD chips from the laser light reflected from the optical fibers. If the laser light generated by the LD chips is to be successfully guided all the way to the optical fibers, the incidence plane of this filter must be designed to facilitate laser-light penetration. In addition, the exit plane of this filter must protect the LD chips from laser wavelengths reflected by optical fibers in the direction of the LD chips. If these roles are to be successfully played, the filter must be fabricated using multilayer thin-film coating technology. However, expecting a filter manufactured using general coating technology to fulfill these roles properly is not realistic.

Therefore, this study aimed to propose a grinding technique for a non-rotation symmetrical aspheric-surface lens mold core to mold an aspheric cylindrical lens to be used as an FAC or an SAC lens for a semiconductor laser module, the demand for which is currently being met entirely by imports from advanced foreign companies [4–13], and, thus, to propose a GMP (glass molding press) technique for precision molding of a cylindrical glass lens with an aspheric surface by using the developed mold core [2,3]. In addition, for the fabrication of a protection filter to protect the LD chips, this study proposed a multilayer high-density thin-film coating technique that uses IAD (ion-beam-assisted deposition).

II. OPTICAL DESIGN OF THE MODULE

To mold an aspheric cylindrical lens to be used in a 10-W-level semiconductor laser module, we conducted an optical design of the module by using Zemax (Ora, U.S.A.). Considering the optical loss of the module, we used a 10-W-level LD chip with a 915-nm wavelength. In addition, the module was configured with an FAC lens, an SAC lens, a high-reflection mirror, a focus lens, and a protection filter and was designed to guide the pumped laser light to the 105/125 fibers. Each lens was designed in an aspheric shape in order to reduce the spherical aberration and had an anti-reflection coating to reduce reflection at the lens's surface. For the FAC lens, the cylindrical lens with an aspheric surface to be molded in this study, K-VC89 (Sumita, Japan), an optical glass material, was used considering such characteristics as the glass transition temperature, the yield point and the softening temperature associated with the high-temperature, high-pressure environment for lens molding. In addition, the lens was designed with an aspheric cylindrical shape only on one side. The material properties of K-VC89 are given in Table 1.

For the fabrication of a protection filter, first, the protection filter's specifications were set according to the specifications of the semiconductor laser module. Then, considering the filter's specifications and fabrication method, we selected TiO_2, SiO_2 and Ta_2O_5 as coating materials to be used in the thin-film coatings. A multilayer thin film was designed by setting the design conditions with Essential Macleod (Thin Film Center, U.S.A.) to have a high transmittance in the protection filter's transmission region of 910- to 980-nm wavelengths and high reflection at the reflection region of 1030- to 1200-nm wavelengths according to the previously-set filter specifications and the coating materials selected. In order to set the design conditions for the design process, we measured the optical characteristics of the thin-film

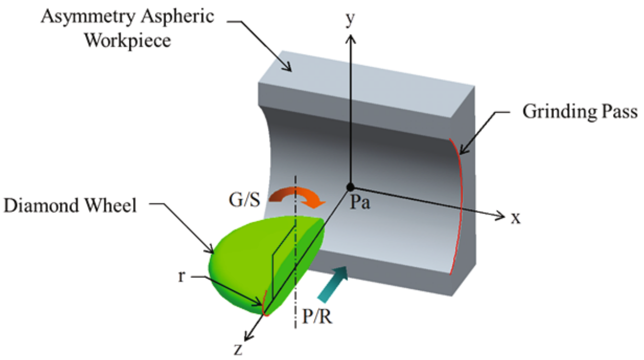

Fig. 2. (Color online) Schematic diagram of the asymmetric grinding.

Table 2. Properties of the mold core material.

Model		FB01
WC (%)		99
Co (%)		1
Hardness	(HRA)	95
	(HV GPa)	24.0
Transverse Rupture Strength (GPa)		1.6
Young's Modulus (GPa)		660
Coefficient of Thermal ($\times 10^{-6}K^{-1}$) Expansion		4.5
Density		15.4

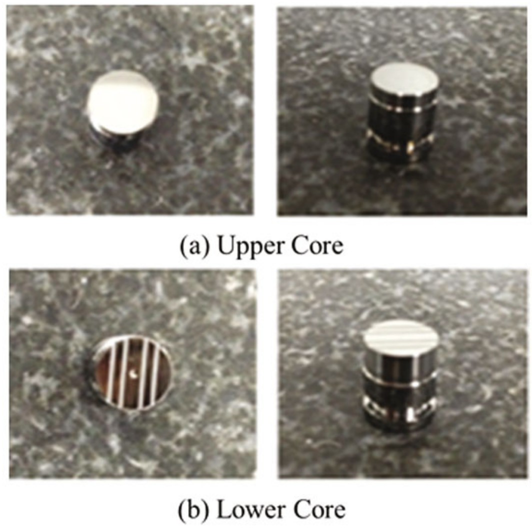

Fig. 3. (Color online) Mold cores.

Table 3. Grinding conditions for the mold core.

Item	Grinding Condition
Work Piece	Binderless WC (FB01, DIJET, Japan)
Wheel Mesh	# 800, # 2500
Wheel Diameter (mm)	ϕ 1.35
Turbine Spindle Speed (rpm)	36,000
Feed Rate (mm/min)	1.0, 0.2
Depth of Cut (μm)	1.5, 0.2
Pressure (kPa)	−72.4
Grinding Fluid	Water 95%, Rust Preventive Oil 5%

coating materials by using a variable angle spectroscopic ellipsometer (Horiba YJ, Japan). Using the measured data, we analyzed the suitability of the materials, and we implemented a design that reflected the optical design conditions.

III. FABRICATION OF AN ASPHERIC CYLINDRICAL LENS

A mold core produced with ultra-precision grinding is required to shape an aspheric cylindrical lens. To make the mold core, we used non-rotational ultra-precision grinding with the ASP30 unit (Nachi-Fujikoshi, Japan), which is capable of ultra-precision shaping by controlling three axes at once. The mold used in molding the aspheric cylindrical lens is exposed to adverse conditions, such as high pressure and high temperature, during the molding process. Therefore, it must be selected considering such factors as hardness, resistance, and strength in unfavorable conditions. Ultra-precision cutting of soft materials, such as Al and Cu, is convenient. However, these materials cannot be used in a high-temperature, high-pressure environment. Therefore, a cemented carbide alloy with a high hardness, a high compressive strength, and a low coefficient of thermal expansion was used as a mold core for the glass lens molding.

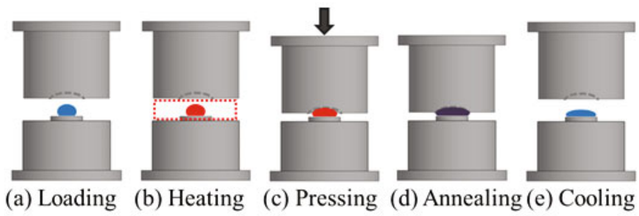

Fig. 4. (Color online) Schematic diagram of a simple GMP process.

The structure of a cylindrical lens with an aspheric surface is not rotationally asymmetric. Therefore, grinding was carried out by fixing a mold core made of tungsten carbide (WC) to the axis by using a jig and rotating only the grinding wheel at a high speed. As for the grinding wheel, a diamond grinding wheel was selected for the mechinability of workpiece materials. A schematic diagram of asymmetric grinding and the results are shown in Figs. 2 and 3, respectively. In addition, Tables 2 and 3 give the material properties of the mold core struc-

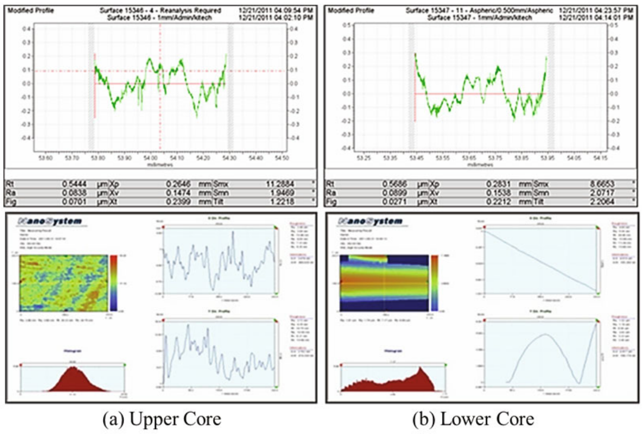

Fig. 5. (Color online) Measurement results for the form accuracy (top) and the surface roughness (bottom) of the mold core.

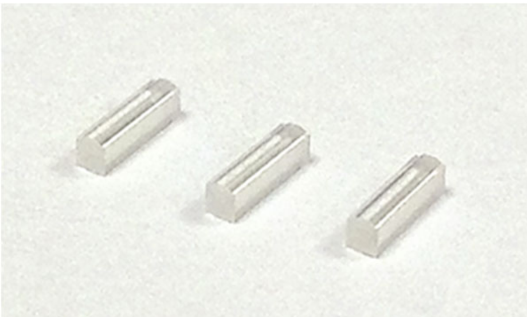

Fig. 6. Aspheric cylindrical lenses.

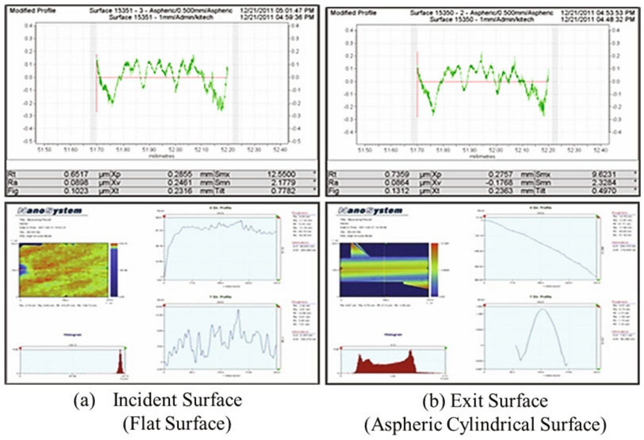

Fig. 7. (Color online) Measurement results for the form accuracy (top) and the surface roughness (bottom) of an aspheric cylindrical lens.

Table 4. Deposition conditions for the protection filter.

Material	TiO_2	SiO_2
IC/5 Thickness	200	300
Deposition Rate (Å/s)	2	5
O_2 Flow (sccm)	5, 10	5, 10
Base Pressure (Torr)	5.0×10^{-6}	5.0×10^{-6}
Substrate Temperature (°C)	150	150

ture and the grinding conditions, respectively. The aspheric cylindrical lens was molded by using the GMP technique and the mold core fabricated by using ultra-precision grinding. The GMP technique is a method that molds by loading a lens preform inside a mold comprised of an upper core, a lower core and a sleeve and by applying consistent pressure to the mold while it is exposed to heat. This technique requires neither an additional lens surface grinding nor a polishing following the lens molding. Therefore, the total processing time is reduced, and an accurate lens molding is possible as the shape of the mold fabricated by using ultra-precision grinding is transferred to the design. Figure 4 shows a schematic of a simple GMP process. Lens molding using the GMP technique must be carried out under the optimal conditions based on the materials used to make the lens. If the optimal conditions are to be ensured, the molding variables in the process must be selected by considering the glass transition temperature (Tg) of the raw materials used to make the K-VC89 lens. With the optimal molding temperature and pressure conditions fixed, each variable was optimized by measuring the change in the lens's thickness with the molding pressure at the molding temperature that was selected from data on change in the lens's thickness with the molding temperature. In order to evaluate the performance of the molded lens according to the optimized molding conditions, we measured the accuracy of the form of the lens by using Form Talysurf Series (Tylor-Hobson, U.K.), which can measure lens-shaping precision, and we measured the surface roughness by using NanoScan (NanoSystem, Korea). The form accuracy and the surface roughness of the mold core fabricated by using ultra-precision grinding to mold the cylindrical aspheric glass lens were found to be 0.57 μm (P-V) and 4.6 nm (Ra), respectively. The form accuracy and the surface roughness of the mold core are shown in Fig. 5. The form accuracy and the surface roughness of the aspheric cylindrical molded lens were 0.74 μm (P-V) and 10.76 nm (Ra), respectively. These were satisfactory results and became they were lower than the standard lens-form accuracy and surface roughness of 1.5 μm (P-V) or less and 60 nm (Ra) or less, respectively. The molded aspheric cylindrical lenses are shown in Fig. 6, and the measured form accuracy and surface roughness are shown in Fig. 7.

Then, for the designed protection filter, a primary fabrication was carried out by using a high-density multilayer thin-film coating with 40 layers or more on a substrate (bk7) by using IAD. IAD is a technique developed by combining physical vapor deposition, such as sputtering, with ion implantation and is suitable for high-density multilayer thin-film coating. A schematic of IAD is shown in Fig. 8, and the process conditions are given in Table 4. The physical and the optical characteristics

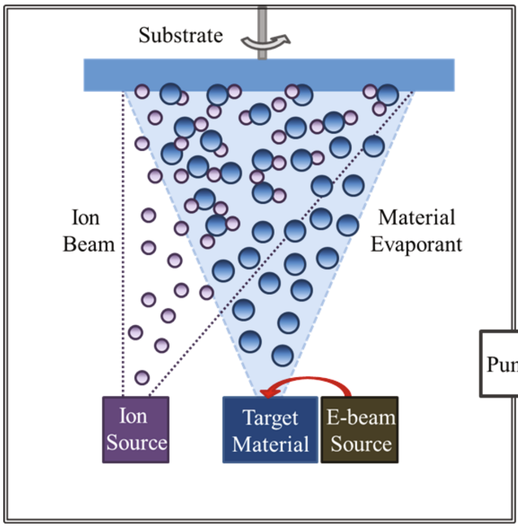

Fig. 8. (Color online) Schematic diagram of the IAD process.

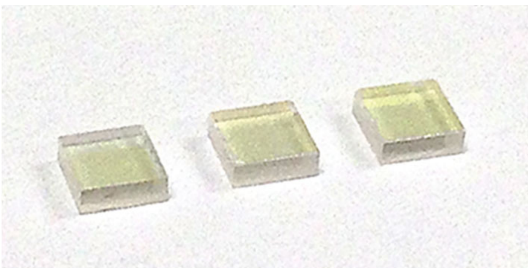

Fig. 9. (Color online) Protection filters.

of the protection filter created through this process were measured and analyzed by using SEM (scanning electron microscopy) to measure the thickness and the shape and UV-VIS-NIR spectrophotometry (Cary500Scan, Varian, Australia) to measure the transmittance and the reflection. The fabricated protection filters are shown in Fig. 9. Based on the measurements and the analysis results, we modified the thin-film design of the filter by using Essential Macleod; then, the protection filter was fabricated for a second time. As a result, as shown in Fig. 10, a transmittance close to 99% was found for wavelengths from 910 to 980 nm, and a shielding effect close to −30 dB was displayed in the reflection at wavelengths from 1040 to 1100 nm, indicating that the respective standards were satisfied.

IV. CONCLUSION

In this study, a mold core was fabricated by using an ultra-precision grinding technique in order to mold a cylindrical lens with an aspheric surface to be used in a semiconductor laser light source module, and the lens was molded by using the GMP technique. The molded

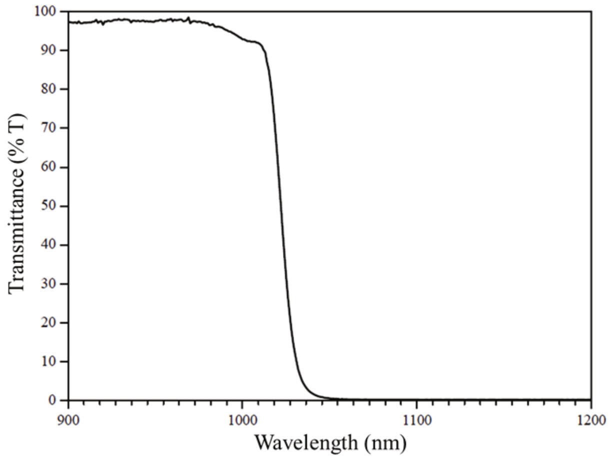

Fig. 10. Measurement results for the transmittance of the protection filter.

aspheric cylindrical lens produced results that satisfied the respective product standards. In addition, to create a protection filter, we used a multilayer thin-film coating technique along with an ion-beam-assisted deposition technique, and the protection filter created by using these techniques produced results superior to those of the respective product standards.

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