

Research on high-precision processing techniques of Nd-phosphate glass laser rods

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Received 7 Oct. 2025; Revised 4 Dec. 2025; Accepted 10 Dec. 2025; Published 25 Dec. 2025.

DOI: <https://doi.org/10.54939/1859-1043.j.mst.108.2025.113-121>

ABSTRACT

This research presents techniques for fabricating cylindrical laser rods from raw glass using specialized glass cutting, grinding, and polishing machines. A square-cross-section glass rod, cut from a raw glass, is first transformed into an octagonal cross-section by grinding off its four corners. The octagonal rod is then processed into a circular cross-section using a precision cylindrical glass grinder. To polish the end faces of the glass rods, a dedicated holder was designed to securely hold the rods during processing. The fabricated laser rods were then inspected using specialized optical measurement instruments to ensure the highest machining accuracy. The inspection results show that the proposed fabrication method can produce laser rods with a perpendicularity deviation to the cylindrical axis of up to 3 arcminutes, an end-face parallelism deviation of 7.5 arcseconds, and a surface figure error as low as 0.042λ . These parameters are 3–4 times smaller than the standard quality requirements for laser rods, demonstrating that this method can achieve superior quality suitable for high-precision or specialized laser applications.

Keywords: Glass laser rod; Raw glass laser; Glass shaping; Glass grinding; Glass polishing; Optical testing.

1. INTRODUCTION

In solid-state laser systems, the laser gain medium rod is a critical component that directly converts the pump lamp energy into laser emission. Operating under severe conditions, it is often among the first elements to experience failure and therefore requires periodic replacement. Consequently, the laser gain rod can be regarded as a consumable component [1]. As a specialized optical element, it demands extremely high accuracy in its geometric parameters, which is difficult to achieve using conventional machining techniques. For this reason, detailed technologies and methods for the fabrication of laser rods are rarely published or disclosed [2]. At present, only a limited number of technologically advanced countries are capable of manufacturing and supplying laser gain rods, making the development of domestic machining solutions both urgent and essential [3].

Neodymium-doped phosphate glass is the most commonly employed material for glass laser rods. Compared with silicate glass, it offers a lower nonlinear refractive index and a higher absorption cross-section, making it more suitable for high-power laser systems [4].

This paper presents a fabrication technique for laser rods from raw glass, utilizing a simple holder and polishing accessories developed in the laboratory [5]. The proposed method is applicable to different types of laser rods and is effective for both the shaping and polishing of newly fabricated rods as well as the repolishing of end faces in damaged rods. Previous publications mainly provide general descriptions and often lack detailed information regarding the holder's design and optical inspection procedures. A notable contribution of this work is the development of a specialized edge-grinding holder that minimizes setup time and eliminates the need for thermal bonding during machining. Additionally, the choice of auxiliary glass plates used in the end-polishing holders has been optimized to improve machining quality.

During the machining process, the optical parameters of the laser rods are measured using specialized instruments to ensure high accuracy [6, 7]. Detailed descriptions of the fabrication and measurement procedures are provided in the following sections.

2. FABRICATION AND QUALITY INSPECTION METHOD FOR LASER RODS

2.1. Shaping technique

In this research, the authors investigate a machining method for Nd-phosphate laser rods used as active media in the resonant chamber of solid-state laser emitters. The fabrication process of the laser rods is carried out following the steps illustrated in figure 1.

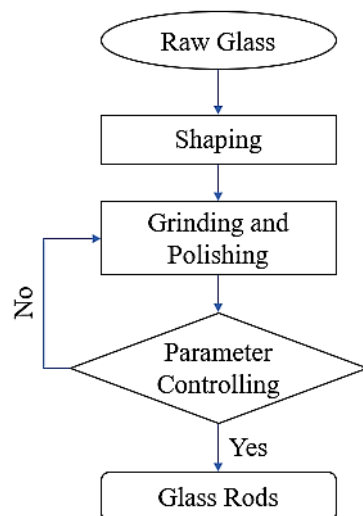


Figure 1. Fabrication process of the laser rods.

The laser rods with circular cross-sections were fabricated through a series of machining operations such as cutting, edge grinding, and cylindrical grinding. Subsequently, the two flat end surfaces of the rod are meticulously ground and polished to achieve the required optical precision. The objective is to meet stringent optical specifications, including surface figure accuracy and end-face parallelism error. The optical parameters of the laser rod are continuously monitored throughout and after the polishing process. The details of these procedures are discussed in the following sections [8].

Glass cutting: The research team employed a GC400T glass-cutting machine (Fulan Optics Machine Co.) to saw a rectangular raw glass block into square cross-section glass rods, as illustrated in figure 2b.



a) Glass cutting.



b) Square cross-section glass rod.

Figure 2. Cutting of raw glass into square cross-section glass rods.

The dimensions of the rods after cutting are determined according to the following formula:

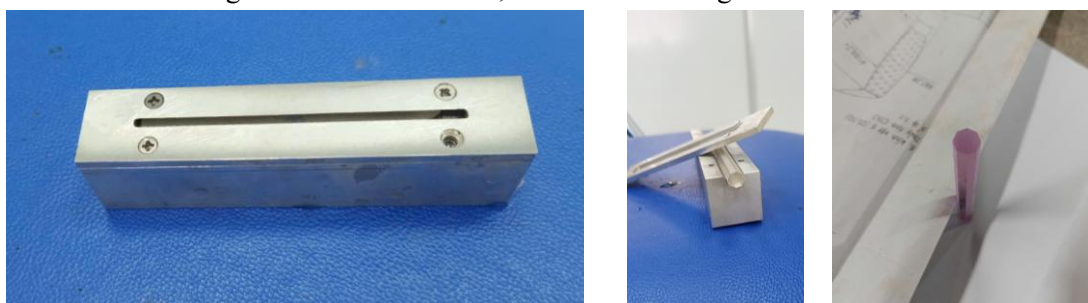
$$a_p = D_0 + \rho_1 \text{ (mm)} \quad (1)$$

$$L_p = L_0 + \rho_2 \text{ (mm)} \quad (2)$$

where a_p and L_p denote the side length of the square cross-section and the length of the glass rods, respectively. D_0 and L_0 represent the diameter and length of the finished laser rod after machining. ρ_1 and ρ_2 correspond to the machining allowances for the cylindrical grinding process and the end-face grinding and polishing process, respectively.

The cutting process is performed using a circular metal saw blade embedded with diamond abrasives along its outer rim. A blade with a diameter of 350 mm and a thickness of 2 mm (grit size approximately 350 - 400 μm) is used for cutting rods larger than 40 mm. For smaller rods (with dimensions up to 20 mm), a 250 mm-diameter blade with a thickness of 0.8 mm is employed. The saw blade operates in a vertical plane at a high rotational speed ranging from 2000 to 4000 rpm, as shown in figure 2a.

Edge grinding: After sawing, the square cross-section glass rod is processed into a polygonal rod in preparation for the subsequent cylindrical grinding step (figure 3). A specialized holder was employed to precisely grind the square edges flat, resulting in the transformation of the square glass bar into an octagonal cross-section rod, as illustrated in figure 3a.



a) Holder for edge grinding of the glass rod. b) Octagonal cross-section laser glass rod.

Figure 3. Edge grinding of the laser glass rod.

This new machining method for laser rods utilizes a custom-designed holder that clamps and secures the glass rod while exposing only the corners to be ground. The thickness of the exposed glass portion is carefully calculated and adjusted according to the required final dimensions. The holder and rod were then ground on a SAIDAI LSP-1 surface grinding machine with free abrasive particles. This holder design, introduced and applied for the first time only in this study, offers several advantages. The thickness of the exposed portion is determined by the following formula:

$$d = 0,5a_p(\sqrt{2} - 1) \approx 0,2a_p \quad (3)$$

where a_p is calculated according to equation (1).



Figure 4. Cylindrical grinding process of the glass laser rod.

Cylindrical grinding: The glass rod is ground into a circular shape using a RM240 external cylindrical grinding machine manufactured by Fulan Optics Machine (figure 4). This process employs a cylindrical metal grinding wheel with a diameter of 75 mm, embedded with diamond abrasives of 0.01 mm grain size. The diamond grinding wheel rotates at high speed (up to 8400 rpm), whereas the glass rod rotates at a slower speed (15 - 200 rpm) and is axially translated along the grinding table at an adjustable feed rate ranging from 1 to 1000 mm/min.

2.2. End-face grinding and polishing technique

To perform the grinding and polishing of the two end faces of the laser rod, a specialized holder was designed to securely clamp the rod throughout the machining process (figure 5a). This is a newly developed design, applied for the first time to laser rods, and it offers several significant advantages. The holder consists of two main parts: a cylindrical body (2) and two flat auxiliary plates (1) positioned at both ends. Although the ideal material for the auxiliary plates would be the same as that of the glass rod, alternative materials with similar physical properties were used in order to reduce fabrication costs. In this research, the two auxiliary plates were made of NPK51 glass, while the cylindrical body (2) was fabricated from aluminum, brass, or stainless steel. When the glass rod (3) is mounted within the holder, it is held firmly yet allows smooth and free movement during the grinding process.

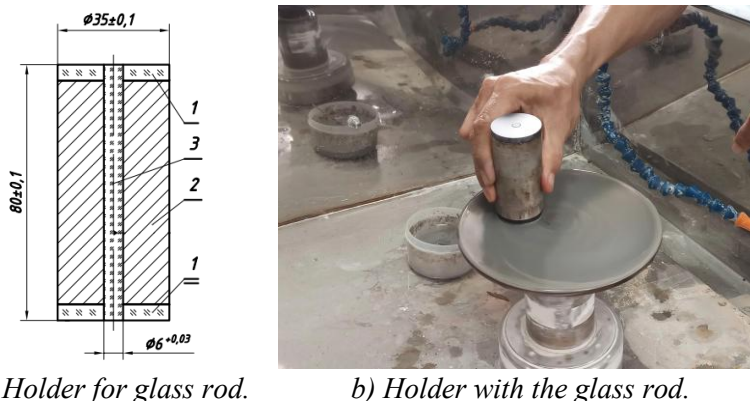


Figure 5. Grinding and polishing of the end faces of the laser glass rod.

The glass rod is secured within the holder using a resin–beeswax mixture. To prevent thermal shock damage during assembly, both the glass rod and the holder are uniformly heated in a furnace to a temperature of 60 - 70 °C prior to mounting. The end-face grinding process is carried out on a SAIDAI LSP-1 surface grinding machine, while the polishing step is performed using a SAIDAI HSCGM-4 polishing machine. The two end faces of the glass rod are ground and polished by these machines through the uniform rotational motion of the polishing disk (figure 5b). Specialized abrasive powders with varying particle sizes are employed sequentially at different stages of processing, accompanied by a continuous water supply system to cool both the workpiece surface and the polishing disk [9].

2.3. Method for evaluating the quality of laser rods

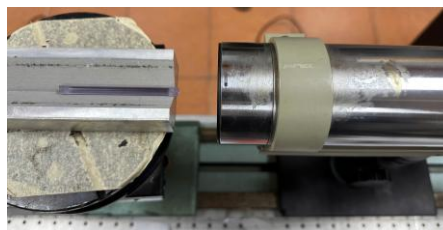
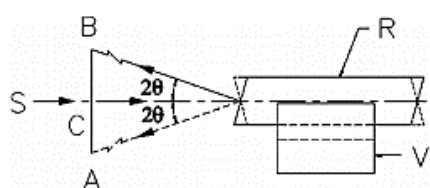
The quality of a laser glass rod is typically assessed based on several key parameters, including the perpendicularity between the end face and the rod axis, the parallelism error between the two end faces, the surface figure error of the end faces, and the polishing quality. The specific acceptable values for these parameters depend on the manufacturing technology and the operational requirements of the laser system. In general, the required precision values for these parameters are summarized in table 1 [6, 8, 10]. These values also serve as reference criteria for comparing and evaluating the quality of the laser glass rod machining method developed in this research.

Table 1. Quality parameters of Nd: phosphate glass laser rods.

No.	Quality parameter	Unit	Required value
1	Perpendicularity error between the end face and the rod axis	arcmin	$3 \div 10$
2	Parallelism error between the two end faces	arcsec	$10 \div 30$
3	Surface figure error of end face at $\lambda = 632,8 \text{ nm}$	-	$\lambda/10 \div \lambda/6$
4	Surface quality according to MIL-PRF-13830B standard [13]		
	- Width of the largest scratch:	μm	10
	- Maximum diameter of dot:	μm	50

Measurement of the perpendicularity between the end face and the optical axis of the glass rod: The perpendicularity error between the end face and the optical axis of the laser glass rod is measured using a collimator tube AKT-15, manufactured by the Novosibirsk Instrument Making Plant, as illustrated in figure 6a.

The glass rod is placed on a precision V-groove support with a 90° V-angle. The contact surface between the glass rod and the V-groove is carefully aligned to be perpendicular to the optical axis of the AKT-15 collimator, as shown in figure 6b. When the glass rod is rotated within the V-groove, the image of the reticle (target pattern) produced by the reflected beam from the end face moves around the optical center. The displacement of the image from its original center position corresponds to the angular deviation (θ), which represents the perpendicularity error between the end face and the rod's optical axis.

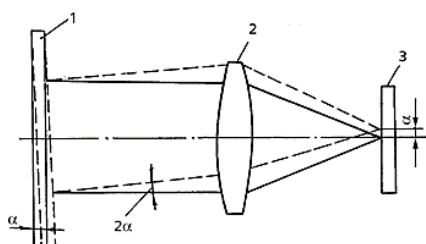


a) Inspection diagram on V-groove.

b) Glass rod placed on V-groove.

Figure 6. Perpendicularity error between the end face and the axis of the glass rod.

Measurement of the parallelism between the two end faces of the glass rod: The parallelism between the two end faces of the glass rod is monitored and adjusted throughout the grinding process. The parallelism error is measured using a high-precision autocollimation system AKT-15 [13]. The experimental setup of the autocollimation system used to measure the parallelism deviation between the two end faces of the glass rod is illustrated in figure 7.



a) Schematic diagram of the AKT-15.

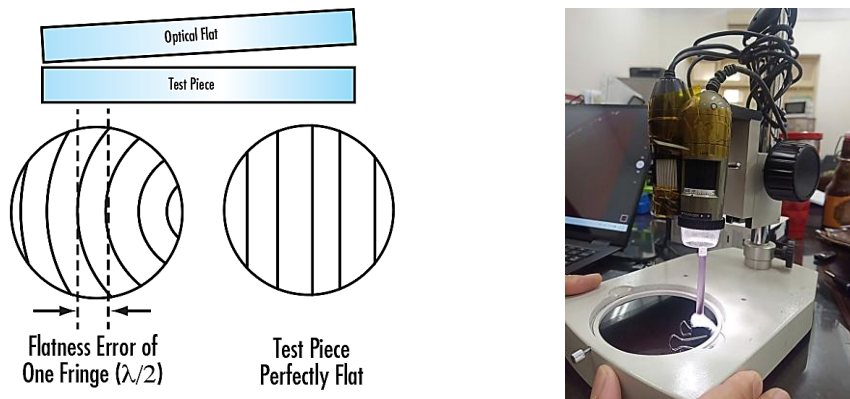
b) Experimental setup diagram.

Figure 7. Determination of the parallelism error between the two end faces of the glass rod.

A crosshair reticle is placed at the rear focal plane of a calibrated double telephoto lens, illuminated by a suitable light source through a collimating lens system. To measure the parallelism error during the grinding of the second end face of the glass rod, the first polished surface is aligned perpendicular to the optical axis of the AKT-15 autocollimation system. This

alignment is achieved by superimposing the reflected image of the crosshair from the first surface with its real image. The light reflected from the second surface of the glass rod produces another crosshair image. The displacement between the two reflected crosshair images corresponds to the parallelism deviation between the first and second end faces of the glass rod.

Inspection of surface figure error of the two end faces: During the polishing process, the surface figure error of the glass rod is continuously monitored using an optical reference flat with a surface accuracy of $\lambda/20$, by observing interference fringes (Newton's rings). The principle and typical results of the surface figure measurement using the optical flat are illustrated in figure 8a. If the interference fringes appear as nearly straight and parallel lines, it indicates that the surface is highly flat and well-polished. This indicates that the test surface and the reference optical flat are nearly identical in shape, meaning that the overall surface figure error of the tested surface is very small. Therefore, it can be preliminarily concluded that the polishing process meets the required quality standards. A quantitative evaluation of the surface figure error is then performed using a ZYGO VeriFire XP/D interferometer.



a) Testing diagram with reference flat. b) Surface inspection under a microscope.

Figure 8. Examination of the surface errors on both end faces of the glass rod.

In addition to surface figure measurement, scratches and pits often appear on the end faces of the glass rod during the grinding and polishing processes. These defects can act as damage initiation sites during the operation of the laser rod. Therefore, it is essential to inspect and evaluate the size of local surface defects, particularly scratches and dots, on the end faces. The inspection of local surface defects on both end faces of the glass rod is carried out using a Dino-Lite digital microscope with a magnification of $250\times$, as shown in figure 8b.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In this research, by applying the machining techniques described above, the research team successfully fabricated laser rods that meet the required physical and dimensional specifications as well as the optical quality standards necessary for use as laser-active medium rods (figure 9).



Figure 9. Glass laser rod.

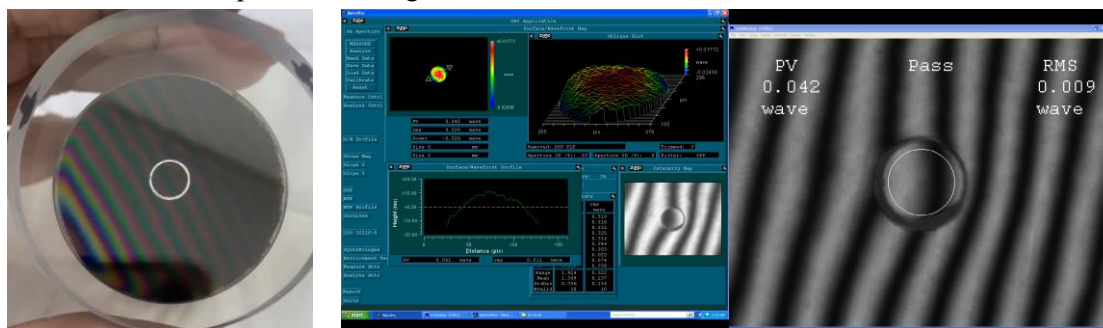
The results of the machining quality inspection for the laser rods are summarized in table 2.

Table 2. Measured results of the quality of the laser rods.

No.	Quality parameter	Rod 1	Rod 2	Evaluation
1	Perpendicularity error between end face and rod axis, arcmin	3	4	Pass
2	Parallelism error between the two end faces, arcsec	7,5	3,75	Pass
3	Surface figure error of end face at $\lambda = 632,8\text{nm}$	0,042 λ	0,044 λ	Pass
4	Surface quality according to MIL-PRF-13830B standard			
	- Width of the largest scratch, μm : - Maximum diameter of dot, μm :	7 18	5 17	Pass Pass

The measurement results of the perpendicularity error between the two end faces and the optical axis of the glass rod indicate that, after the machining process, the deviation is approximately 3 arcmin. This value is well below the specified tolerance for laser rods, which should not exceed 10 arcmin. The parallelism error between the two end faces of the glass rod, measured after machining, is approximately 7.5 arcsec. This result also satisfies the technical requirement for laser rods, which specifies that the parallelism deviation between the two end faces must be less than 30 arcsec. Therefore, the application of the proposed machining techniques in this research has resulted in a laser rod quality that is comparable to that achieved by leading international manufacturers in terms of precision and surface quality.

The inspection of the overall surface figure error on both end faces of the glass rod using a reference flat shows that the interference fringes are nearly straight and parallel (figure 10a). This indicates that the overall surface figure error of both end faces is very small. A quantitative evaluation of the surface figure error was then conducted using the interferometer, and the measured results are presented in figure 10b.



a) Testing with reference.

b) Testing with an interferometer.

Figure 10. Results of surface figure error measurement.

The surface figure error measured using the interferometer was approximately 0.042 λ . This result is consistent with the qualitative assessment performed using a reference flat and is significantly lower than the specified requirement for a laser rod, where the overall surface figure error must not exceed $\lambda/6$. This finding indicates that, during the machining process, it is feasible to select a reference flat with appropriate accuracy based on the required surface tolerance of the laser rod for inspection and adjustment purposes. Such an approach helps reduce processing time while maintaining surface quality. Therefore, by applying the proposed machining techniques, the obtained surface figure error is approximately four times smaller than the actual requirement, demonstrating the high precision, stability, and effectiveness of the machining process developed in this research.

In addition, the results of localized surface defect inspection on the laser rod, performed using

a high-magnification digital microscope, are presented in figure 11. The images of surface scratches were displayed on the monitor, and the measurements indicated that the diameters of circular dots did not exceed 0.007 mm, while the scratches had widths below 0.018 mm.

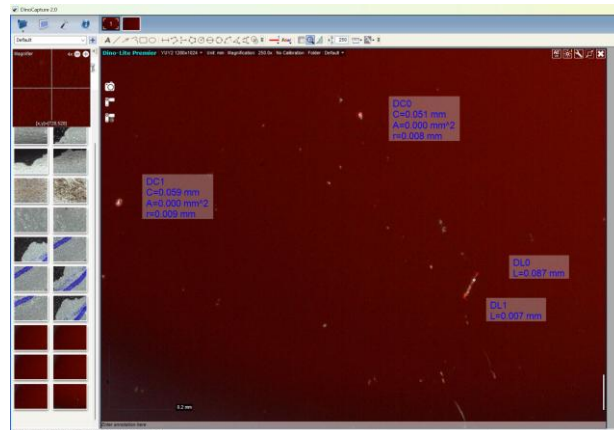


Figure 11. Results of local surface errors measurement.

These dimensions are well within the specified limits for laser gain media and are comparable to the surface quality achieved by leading manufacturers, confirming the effectiveness and competitiveness of the proposed machining and polishing methods.

4. CONCLUSIONS

A fabrication method for Nd:phosphate laser rods from raw glass has been presented in this research. The results demonstrate that the proposed machining technique can produce laser rods with a perpendicularity error of approximately 3 arcmin, a parallelism error of about 7.5 arcsec, and a surface flatness error as low as 0.042λ . These values are 3–4 times smaller than the standard quality requirements for laser rod, indicating the high precision and effectiveness of the developed method.

To achieve these results, grinding and polishing holders specialized were designed and implemented with precisely calculated dimensions, ensuring convenient machining procedures compatible with domestically available equipment. In the future, the machining techniques will be optimized to enable the processing of smaller-diameter laser glass rods, simultaneous polishing of multiple rods, and enhancing automation to reduce dependence on the operator.

Acknowledgment: The authors would like to thank the “Academy of Military Science and Technology” for financial support.

REFERENCES

- [1]. M. Yammane, Y. Asahara, “*Glasses for photonics*”, Cambridge University Press, 1st ed., p. 30, Cambridge, UK, (2000).
- [2]. G. W. Fynn, W. J. A. Powell, “*The cutting and polishing of electro-optic materials*”, Adam Hilger, 2nd ed., pp. 64–74, 170–181, Bristol and Philadelphia, (1988).
- [3]. W. L. Bond, “*Making crystal elements for optical maser*”, Review of Scientific Instruments, Vol. 33, No. 3, pp. 372–375, (1962).
- [4]. G. A. Bennett, R. B. Wilson, “*Precise polishing technique for optics and microwave acoustics*”, Journal of Scientific Instruments, Vol. 43, pp. 669–670, (1966).
- [5]. P. P. Hed, “*Laser rod holder during grinding and polishing*”, Applied Optics, Vol. 21, No. 9, pp. 1539–1540, (1982).
- [6]. S. Chatterjee, “*Simple technique for polishing laser rods*”, Centre for Advanced Technology, Department of Atomic Energy, Government of India, (2002).
- [7]. S. Chatterjee, Y. Pavan Kumar, “*Simple technique for fabrication of Nd-phosphate laser glass rods for high power lasers*”, Journal of Optics, Vol. 41, No. 4, pp. 187–197, (2012).

- [8]. D. J. Dentz, “*Manufacturing methods and technology engineering for batch processing neodymium-doped YAG laser rods*”, US Army Electronics R&D Command, Night Vision & Electro-Optics Laboratory, (1980).
- [9]. M. V. Mantravadi, D. Malacara, “*Newton, Fizeau and Haidinger interferometers*”, in *Optical Shop Testing*, D. Malacara (Ed.), Wiley, pp. 23–25, (2007).
- [10]. G. A. Bennett, R. B. Wilson, “*Precision polishing technique for optics and microwave acoustics*”, Department of Electrical Engineering, University of Glasgow, Technical Report, (1966).
- [11]. H. H. Karow, “*Fabrication methods for precision optics*”, John Wiley & Sons, 1st ed., pp. 704–721, New York, (2004).

TÓM TẮT

Nghiên cứu kỹ thuật gia công độ chính xác cao cho thanh thủy tinh laser Nd-phosphate

Bài báo này trình bày các kỹ thuật để chế tạo các thanh thủy tinh laser hình trụ từ một phôi thủy tinh laser thô, bằng cách sử dụng các máy cưa, mài và đánh bóng thủy tinh chuyên dụng. Một thanh thủy tinh laser có tiết diện vuông, được cưa từ phôi thủy tinh thô, được chuyển thành tiết diện hình bát giác bằng cách mài phẳng bốn góc của thanh tiết diện vuông. Thanh có tiết diện bát giác sau đó được gia công thành thanh có tiết diện hình tròn bằng máy mài tròn thủy tinh. Để đánh bóng các mặt phẳng ở hai đầu của các thanh thủy tinh laser một bộ gá chuyên dụng đã được thiết kế để cố định các thanh thủy tinh. Thanh thủy tinh laser được tiến hành kiểm tra các thông số quang học trên các máy đo chuyên dụng để đảm bảo quá trình gia công được tiến hành chính xác nhất. Kết quả sau kiểm tra cho thấy phương pháp gia công trình bày trong nghiên cứu này có thể tạo ra được thanh thủy tinh laser với độ sai số vuông góc với trục hình trụ đạt tới 3 phút góc, sai số song song hai mặt đầu đạt tới 7,5 giây góc và sai số hình dạng bề mặt có thể đạt tới $0,042\lambda$ các thông số này đều nhỏ hơn 3-4 lần so với yêu cầu chất lượng của một thanh hoạt chất laser và có thể đạt được chất lượng tốt hơn cho các ứng dụng đặc biệt.

Từ khoá: Thủy tinh laser; Thanh hoạt chất; Gia công tạo hình; Phôi thủy tinh; Mài thủy tinh; Đánh bóng thủy tinh.