Optik - International Journal for Light and Electron Optics 172 (2018) 540–544

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Improving the performance of single point diamond turning surface with ion beam figuring

Yuetian Huang[a,b,*], Bin Fan[a], Yongjian Wan[a], Shijie Li[c]

[a] Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu, Sichuan 610209, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, China
[c] Shaanxi Province Key Laboratory of Thin Film Technology and Optical Test, Xi'an Technological University, Xi'an, Shaanxi 710032, China

A R T I C L E I N F O

Keywords:
Single point diamond turning
Turning marks
Ion beam figuring
Surface precision

A B S T R A C T

Single point diamond turning (SPDT) can directly produce high precision optical parts, but some regularity micro structure in residual surface, and turning processing characteristics limit the surface quality to further improve. Ion beam figuring (IBF), as the last process of optical processing, can remove certain mid and high frequency errors, improve the surface performances without destroying their forms. Therefore, it is proposed to combine SPDT and IBF to manufacturing ultra-high precision surface. Two samples of diamond-turned sphere aluminum mirror were used in this experiment. One samples with surface PV and RMS 226 nm and 12.6 nm decreased to 113 nm and 7.7 nm after ion beam figuring, another sample was improved in the same degree, and the turning marks is removed with surface roughness decreased to 2.8 nm from 3 nm. The experimental results indicate that IBF can remove the turning marks and improve the surface precision in a certain range without destroying the surface form.

1. Introduction

Single Point Diamond Turning (SPDT) is able to fabricate ultraprecision surface directly with single crystal diamond cutting tools under the control of computer. It has been widely applied to manufacturing various optical surface for many years [1,2]. The materials it can process contain nonferrous metals, plastics and infrared material. And metal mirrors have been widely used in optical system in recent years, such as aluminum (Al) reflector mirrors. SPDT is one of the most efficient processing of manufacturing metal mirrors. However, the residual turning marks affect the performance of optical surface, which produces a diffraction effect and stray light. The turning machine platform accuracies and processing parameters limit the precision of surface processed by SPDT [3,4]. Therefore, to get ultra-high precision optical surface with SPDT, the fine-figuring step to improve the surface quality after turning is required.

It is widely used smoothing techniques, such as bonnet polishing, magnetorheological finishing (MRF), computer controlled optical surfacing (CCOS) and ion beam figuring (IBF), to remove the residual marks after turning [5–8]. Bonnet polishing and CCOS can remove the error of turning marks in certain spatial frequency, but they also induce some new middle and high frequency spatial errors [9]. MRF has the same problem and destroy the forms [10]. So they are not very fit for improving surface quality as the last process after turning. IBF has the ability to improve figure and smooth spatial frequencies for its deterministic polishing process [11]. Therefore, IBF was used in this experiment to validate the improvement of IBF on the surface after turning.

Ion beam figuring (IBF) is a non-contact optical processing method, using the ion beam emitted from the ion source to

* Corresponding author at: Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu, Sichuan 610209, China.
E-mail address: hytsze@qq.com (Y. Huang).

https://doi.org/10.1016/j.ijleo.2018.07.039
Received 11 May 2018; Accepted 9 July 2018
0030-4026/

Table 1
Single point diamond turning parameters of two samples.

	1# sample	2# sample
Spindle speed/rpm	2000	2000
Feed rate/(mm/min)	10	20
Depth of cut/μm	10	10

bombardment the optical surface in vacuum. When the atoms of the surface get enough energy to get rid of the bound of surface, it will form sputtering atoms away from the surface, so as to achieve the purpose of removing materials. This process creates an extremely stable and conformable removing function, enables high precision figuring correction without edge effect and sub-surface damage. It is widely used in ultra-precision optical components processing [12,13]. The shape of the removal function of IBF is very close to the ideal Gauss function, so it can remove certain middle and high spatial frequency errors, such as the turning marks, and improve the surface performance after SPDT [14,15]. In this work reported in this paper, we use IBF process to eliminate the turning marks on aluminum (Al) sphere mirrors samples. The experimental results indicate that the IBF process can improve the surface quality after turning. The combination of SPDT and IBF can manufacture ultra-high precision optical surface.

2. Experimental setup

2.1. Single point diamond turning

In this experiment, we prepared two aluminum samples, which were made into spherical surfaces with diamond turning machine. Two samples was processed with different turning parameters to compare the improvement result of IBF. The diameter of two samples is 50 mm and the radius of curvature is 175 mm. The turning of the sample is finished on the Precitech Nanoform 700 Ultra single point diamond lathe, and the SPDT parameters are given in Table 1.

2.2. Ion beam figuring

In the IBF process, the relative position of machining points and ions source on the workpiece remains the same, which is guaranteed the incident parameters of the ion beam are the same and the removal function produced by ion beam is consistent at all points. In the ion beam figuring, the diameter of ion diaphragm is 5 mm. We use a raster polishing path, and the scanning step size was 0.2 mm. The parameters of the IBF in this experiment are like Table 2.

3. Results and discussion

3.1. Figure improvement in the IBF Process

Figs. 1(a)–(b) and 2(a)–(b) show the figure of two samples (1# Al and 2# Al) before and after IBF process. The diameter of the mirror is 50 mm, and the radius of curvature is both 175 mm. Figs. 1(a) and 2(a) shows the original surface figure of the mirror after SPDT. After 4 h of uniform IBF process, the polished figure surface is shown in Figs. 1(b) and 2(b). The initial surface PV and RMS of 1# mirror is 226 nm and 12.6 nm, after IBF process, they decrease to about 113 nm and 7.7 nm, which is much smaller compared to previous surface. The surface quality of 2# mirror is also improved by IBF process, the surface PV and RMS is decrease to 133 nm and 16 nm from 192 nm and 25 nm. The result of two samples indicate that IBF can improve the surface precision after SPDT. It can be predicted that the surface can be improved further by optimizing the experimental parameters if required.

3.2. Remove the turning marks

Fig. 3 show the views of microstructures of 1# sample before and after IBF, which were obtained by a ZYGO NewView 800. The surface is detected by interferometer before and after polishing, and the roughness of some regions is detected. Fig. 3 shows the surface roughness before and after IBF on the same Al part. The diamond turning marks are clearly visible before IBF in Fig. 3(a). After IBF, the marks are eliminated. At the same time, the surface roughness value is basically unchanged (from 3.02 nm to 2.86 nm).

We use power spectrum density (PSD) analysis to estimate the surface quality and ability to remove the turning marks before and after the IBF. The corresponding power spectrum density (PSD) curve is shown in Fig. 4. Before the ion beam processing, the red PSD curve shows that there was a significant peak at the position of f = 200 mm-1 because of the existing of periodic SPDT marks, which

Table 2
Processing parameters of ion beam figuring.

screen voltage	acceleration voltage	gas (Ar) velocity	power
1000 V	100 V	4 sccm	70W