Serial mode combined polishing of high-quality flat mirror

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In order to obtain high-quality flat mirror, a serial mode combined polishing technology, consisting of continuous polishing (CP) and ion beam figuring (IBF), is presented. The function of CP technology is to get certain figure accuracy and meet the requirements of the surface roughness of the flat mirror. The final high figure accuracy of the flat mirror is achieved by the IBF technology. We introduce the polishing principles of CP and IBF and then, the polishing experiment and material removal function of IBF are studied. Finally, a **Φ** 160 mm flat mirror is polished by a serial mode combined polishing technology. After serial mode combined polishing, the surface error and roughness of the flat mirror are 2.06 and 0.42 nm RMS, respectively. The experiment results indicate that the serial mode combined polishing technology is effective for polishing ultra-precise flat mirror.

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Flat mirrors are widely used in miscellaneous optical systems. The current technology for precise flat mirror fabrication is continuous polishing (CP)[1,2], also called annular polishing[3,4]. The CP uses a large annular pitch polishing pad that is at least three times the size of the flat mirror being polished and turns continuously, so the flat mirror held on the annulus is polished continuously. There are some advantages of CP technology: 1) it can produce multiple flat mirrors at the same time, 2) it can get a certain figure accuracy of the flat mirror rapidly by increasing loads on the mirror, and 3) it can polish smoothly out to the flat mirror edges because of the uniform contact between the mirror and polishing pad. However, the disadvantage is that CP technology is excessive dependent on technician's experience, so it is not a deterministic polishing process. When the figure of the flat mirror converges to certain accuracy, it is difficult to improve it further with CP technology.

Ion beam figuring (IBF) is an advanced technology for ultra-precise optics polishing[5,6]. Material of the optics being polished is removed by physical sputtering effect, where energy is transferred from the energetic ions to the optical surface during the bombarding process[7]. IBF is highly deterministic polishing process. Edge effect and tool wear are avoided in IBF. Depending on these advantages, IBF becomes the final procedure for high-quality optics polishing. However, due to atomic or molecular form material removal, the polishing efficiency of IBF is low, and pre-polishing is required.

Optical fabrication is a very complicated process. It is difficult for a single method to complete the whole fabrication process. For the sake of polishing optical components reasonably, some combined polishing technologies are presented[8,9]. In order to polish high-quality flat mirror efficiently, combined CP with IBF, a serial mode combined polishing technology is presented. The function of CP technology is to get a certain figure accuracy of the flat mirror from initial figure rapidly. IBF technology is used for the final high precise polishing of the flat mirror.

The CP machine basically consists of a large annular pitch lap and a circular glass conditioner. A top view diagram of a CP machine is shown in Fig. 1.

During polishing process, the annular pitch polishing pad, which is driven by electric motor turns steadily and continuously. The flat mirror to be polished is placed front surface down on the annular lap in the holder. The holder and conditioner are also driven by driver system. They rotate at a certain speed. Because the flat mirror is in synchronous motion with the polishing pad,

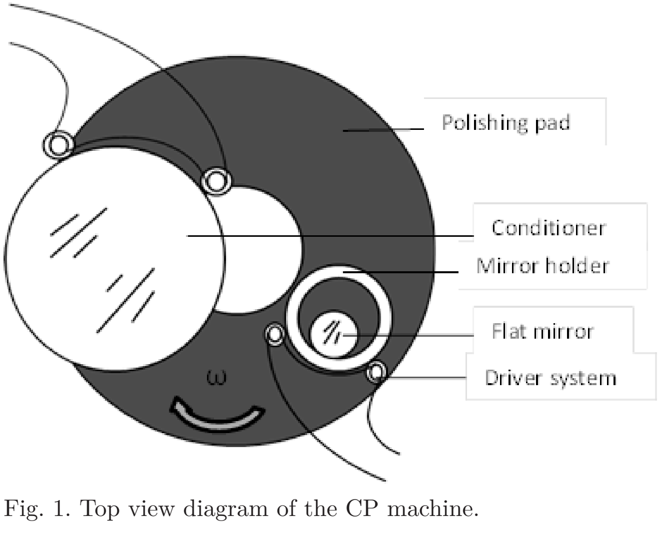


Fig. 1. Top view diagram of the CP machine.

the mirror always remains in full contact with the polishing pad, so the wear on the mirror will be uniform, which allows the mirror surface to become flat rapidly. At the same time, the mirror will destroy the surface accuracy of the polishing pad. The function of the conditioner is to repair and maintain polishing pad surface to keep it high flat accuracy through the long-polishing process. Flat accuracy is transmitted from the conditioner to the flat mirror by polishing pad. The surface accuracy relationship between the conditioner and the mirror can be described as

$$\frac{N_1}{N_2}=\left(\frac{D_1}{D_2}\right)^2, \tag{1}$$

where N_1 is the number of Newton rings of the conditioner, N_2 is the number of Newton rings of the flat mirror being polished, D_1 is the diameter of the conditioner, and D_2 is the diameter of the flat mirror being polished. Equation (1) shows that N is proportional to the square of the diameter of the optical element. The smaller value of N indicates that the surface accuracy is higher, so if the small flat mirror is polished by a big CP machine, a relative high surface accuracy will be acquired rapidly. However, the CP technology is greatly dependent on technician's experience, to further improve the surface accuracy of flat mirror, IBF technology is applied in next polishing.

IBF is a highly stable, highly deterministic, and non-contact technology for ultra-precise optical elements polishing. It utilizes the physical phenomenon of atom sputtering to remove a defined amount of material from the optical component being polished. In high-vacuum conditions, a broad beam ion source generates a defined flux profile of ions with energy in the order of about 1000 eV. Each ion that hits the surface of the optical component generates a collision cascade within the component. With a certain probability surface atoms at the end of the cascade may overcome the surface binding energy and get removed from the surface of optical element, which leads to a macroscopic removal of material. Compared with conventional polishing methods, the removal rate is lower but stability and predictability are superior, hence IBF is extremely suitable for ultra-precise optics final polishing.

Fig. 2. IBF-1500 facility.

In the vacuum chamber, ions generated by ion gun hit the surface of the optical element to make its material removed. The ion gun is fixed on the stage, which consists of a high accurate mechanical translation system with three linear axes and one angular axis. All axes are controlled by CNC controller so as to figure optical components precisely.

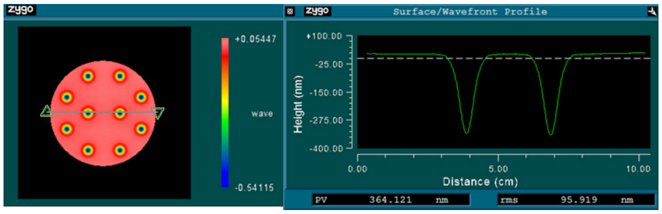
To accomplish a deterministic polishing process, the accurate and stable material removal function of this polishing method must be acquired. The material removal function of IBF is acquired by etching experiments, and the etching experiments are implemented on IBF-1500 facility which is shown in Fig. 2.

In order to test the stability of IBF removal function (footprint), on a **Φ** 100 mm fused silica flat mirror 10 footprints are etched over a period of 8 h. The etching time of each footprint is 100 s, and the two adjacent etching time interval is approximately an hour. Process parameters are as follows:

Argon:	4 sccm,
RF power:	50 W,
Beam:	1000 V, 1.5 mA,
Acceleration:	100 V, 0.25 mA,
Neutralization:	50 mA, and
Etched time:	100 s.

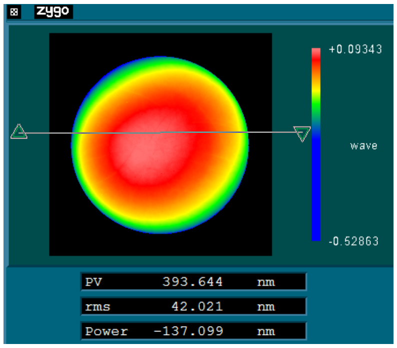
Later these footprints are measured on ZYGO interferometer. The test results are shown in Fig. 3.

According to analysis of the test results of footprints, some conclusions are drawn as follows: the mean value of maximum etching (removal) rate is 3.643 nm/s, the mean value of volume etching rate is 0.0093 mm^3/min, and the mean value of full wave at half maximum is 5.701 mm. The instability of the footprint is less than 3%. All these data build up a good basis for the application of IBF.



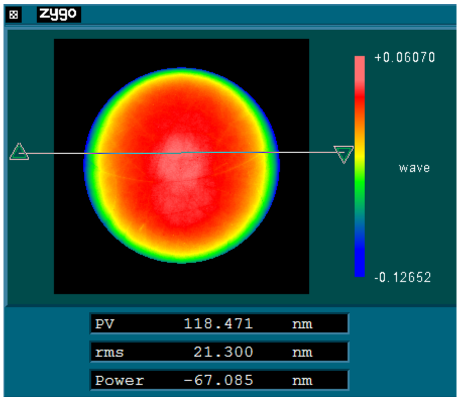
PV 364.121 nm
rms 95.919 nm

Fig. 3. The test results of footprints.



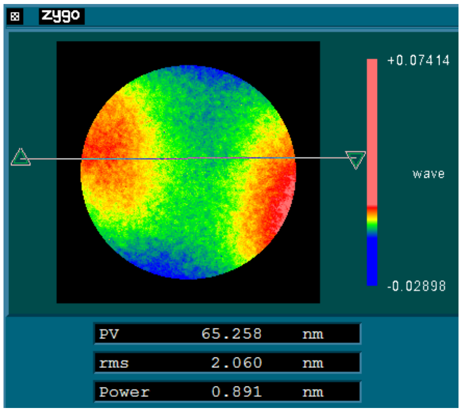
PV 393.644 nm
rms 42.021 nm
Power -137.099 nm

Fig. 4. The surface error of the flat mirror after pre-polishing.



PV 118.471 nm
rms 21.300 nm
Power -67.085 nm

Fig. 5. The surface error of the flat mirror after the second CP process.



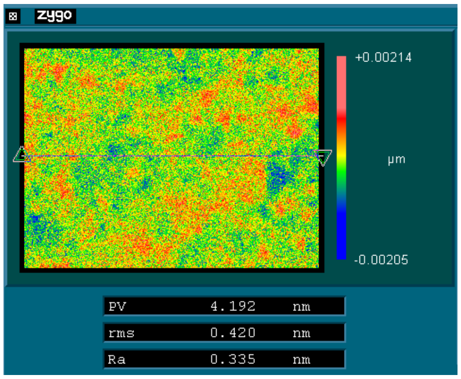
PV 65.258 nm
rms 2.060 nm
Power 0.891 nm

Fig. 6. The surface error of the flat mirror after IBF.

A **Φ** 160 mm fused silica flat mirror was polished by serial mode combined polishing. The polishing process was divided into three steps.

In the first polishing step, the flat mirror was pre-polished by 1 m CP machine for 5 days to remove subsurface damage which was produced by gridding and meet the requirements of the surface roughness of the flat mirror. After pre-polishing, the flat mirror was measured using a ZYGO interferometer. The surface error of the flat mirror is 42 nm RMS as shown in Fig. 4.

In the second polishing step, CP was used for amending the surface error of the flat mirror preliminarily. The fundamental process parameters were as follows: the rotating speed of polishing pad was 2.5 r/min, the rotating speed of the conditioner 2 r/min, the rotating speed of the flat mirror 4.2 r/min, the eccentric distance of the conditioner was 360 mm, and the eccentric distance of the flat mirror was 380 mm. In the polishing process, every parameter could be adjusted according to actual polishing situation. After 2 h CP, the surface error of the flat mirror was 21.3 nm RMS as shown in Fig. 5.



PV 4.192 nm
rms 0.420 nm
Ra 0.335 nm

Fig. 7. The surface roughness of the flat mirror.

The final polishing step was IBF. Process parameters were as the same as those of footprint experiments. Through one figuring process of 2.45 h, the surface error was reduced from 21.3 to 2.06 nm RMS as shown in Fig. 6.

The surface roughness of the flat mirror was measured using the ZYGO New View 7200 Microscope, and the test result was 0.42 nm RMS as shown in Fig. 7.

In conclusion, we present a serial mode combined polishing technology consisting of CP and IBF. The CP technology is used for polishing the flat mirror with large surface error and IBF technology is used for final ultra-precise polishing of the flat mirror. A **Φ** 160 mm fused silica flat mirror is polished by the serial mode combined polishing technology. After polishing, the surface error and roughness of the flat mirror are 2.06 and 0.42 nm RMS, respectively. The experiment results confirm that serial mode combined polishing technology is effective for polishing high-quality flat mirror.

References

1. B. Gao and W. Mao, Proc. SPIE **3785,** 94 (1999).
2. C. Cao, "Study on ultra-precision continuous polishing of large aperture optical components," Master's Thesis (Chengdu: Sichuan University, 2004) (in Chinese).
3. Q. Fan, J. Zhu, and B. Zhang, Chin. Opt. Lett. **5,** 298 (2007).
4. G. Liang Ou, L. Yang, L. Wang, M. He, and Y. Liu, High Power Laser Particle Beams **24,** 399 (2012) (in Chinese).
5. L. N. Allen and H. W. Romig, Proc. SPIE **1333,** 22 (1990).
6. Y. Dai, W. Liao, L. Zhou, S. Chen, and X. Xie, Appl. Opt. **49,** 6630 (2010).
7. C. Jiao, X. Xie, S. Li, and L. Zhou, Opt. Prec. Eng. **16,** 1343 (2008) (in Chinese).
8. B. Xuan, J. Xie, and S. Song, Opt. Prec. Eng. **19,** 41 (2011) (in Chinese).
9. F. Zhang, Chin. J. Lasers **40,** 0716001 (2013) (in Chinese).