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# Characteristics of ion beam converged by magnetic quadrupole lens in ion beam figuring for optical fabrication

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**Abstract**
Ion beam etching is effectively used for the fabrication of high-precision optics. To figure small or medium-sized optical surfaces, the generation of an ion beam with a small diameter is required. In a previous study, we designed a magnetic lens with permanent magnets to obtain an ion beam with a small diameter. In the present study, we actually manufactured an ion gun with a magnetic lens with quadrupole neodymium magnets. Characteristics of the ion beam converged by the magnetic lens were evaluated by measuring ion beam profiles with a Faraday cup. The measurement results showed that the ion gun with the magnetic lens we developed enables the converging of an ion beam. The ion beam was successfully converged from approximately 80 mm in width without a magnetic lens to approximately 15 mm in width at 126 mm from the outlet of the ion gun or the magnetic lens.

Keywords : Optics, Fabrication, Figuring, Ion beam, Magnetic lens, Quadrupole lens, Ion gun, Ion source

## 1. Introduction

Ion beam etching is effectively used for the fabrication of high-precision optics to correct the shape errors remaining on the polished surfaces [1-5]. This procedure is called ion beam figuring (IBF). The main application of IBF is in figuring large optical surfaces. To figure small- or medium-sized optical surfaces, the generation of an ion beam with a small diameter and high ion current is required. In previous studies [1, 4], to obtain an ion beam with a small diameter, a diaphragm with an aperture was placed at the outlet of an ion gun. One disadvantage of this placement is that the diaphragm reduces the ion current, which decreases the removal rate.

In our previous study [6], we designed a magnetic lens with permanent magnets to obtain an ion beam with a small diameter. In this design, the magnetic lens is installed between the outlet of the ion gun and the chamber, which enables the changing of the trajectory of the ion beam. The trajectories of the ion beam and the ion particle distribution on a workpiece surface were simulated, which showed that the designed magnetic lens successfully converge the ion beam.

In the present study, we actually manufactured an ion gun with a magnetic lens with quadrupole neodymium magnets. Moreover, we evaluated the converging characteristics of the ion gun with the magnetic lens by measuring ion beam profiles with a Faraday cup.

## 2. IBF device with magnetic lens

Figure 1 shows an IBF device used in this study, which mainly consists of an ion gun, a magnetic lens, a vacuum chamber, a multiaxis linear motion stage, and a controller. An ion beam extracted from the ion gun is irradiated on the workpiece surface placed on the motion stage. The magnetic lens is installed at the outlet of the ion gun. In this arrangement, the ion beam passing through the center of the magnetic lens is converged by the magnetic field. In this study, a Faraday cup was placed on the motion stage to measure ion beam current distributions. The Faraday cup has a hole with a diameter of 1 mm at its top to capture ions.

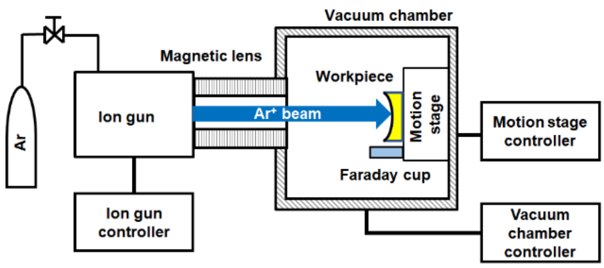


**Figure 1. IBF device with a magnetic lens.**

## 3. Principle of focusing of ion beam using magnetic lens

We designed a magnetic lens with quadrupole permanent magnets. Figure 2 shows the schematic of a doublet magnetic lens. As shown in Fig. 2(a), two quadrupole magnets are placed from upstream to downstream of the ion beam. As shown in Fig. 2(b), a single quadrupole magnet has four permanent magnets arranged with alternating S and N poles. The two quadrupole magnets are set such that the position of their magnetic poles are turned 90 degree to each other.

In the arrangement of the four permanent magnets shown in Fig. 2(b), magnetic flux density generated by the magnets varies in the radial direction from the center of the quadrupole magnet. The positively charged ion beam passing through the first quadrupole magnet shrinks in the y direction owing to the force toward the center of the quadrupole magnet, and it expands in the z direction because of the outward force to the magnet. Then, the ion beam passing through the second quadrupole magnet shrinks in the z direction and expands in the y direction. In this manner, theoretically, the magnetic lens converges and focuses the ion beam on a workpiece surface.

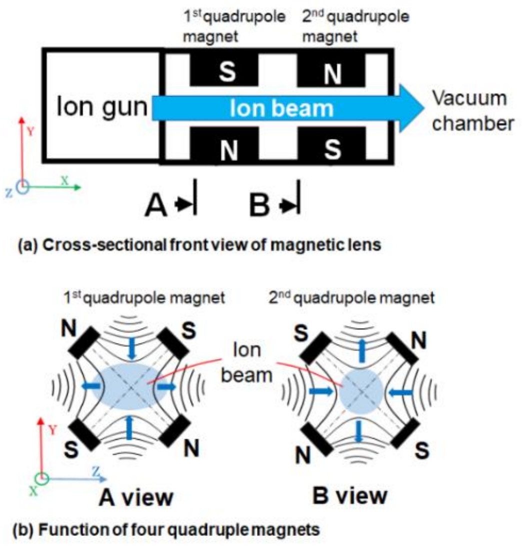


**Figure 2. Schematic of magnetic lens with quadruple magnets.**

Figure 3 shows a schematic of a magnetic lens we designed: a cross-sectional front view and a cross-sectional side view. The permanent magnets are made of neodymium. After assembling this magnetic lens, we measured magnetic flux density with a gauss meter, which reveals the desired values of magnetic flux density. A magnetic lens with quadrupole magnets is generally used in particle accelerators to converge electrically charged particles. Such a magnetic lens is large because its quadrupole magnets are electromagnets. On the other hand, our magnetic lens with permanent magnets is compact and simple, which is expected to be appropriate for industrial uses, such as optical fabrication.

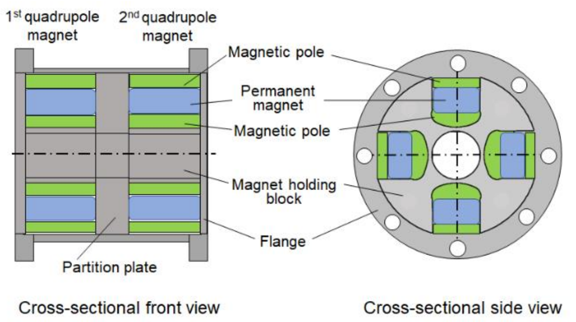


**Figure 3. Schematic of magnetic lens developed in this study.**

## 4. Results and discussion

First, we measured ion beam profiles without the magnetic lens for comparison. The ion gun was directly connected to the chamber without the magnetic lens. In this measurement, the Faraday cup was raster-scanned, in which it linearly fed 100 mm in the z direction and stepped 5 mm in the y direction.

Figure 4 (a) shows the measurement results of an ion beam profile at the position 126 mm from the outlet of the ion gun. In this study, we defined the width of an ion beam profile as the width of the cross-sectional ion beam profile at $1/e^2$ of the peak current. According to this definition, the widths of the ion beam profile shown in Fig. 4(a) in the z and y directions are 70 mm and 90 mm, respectively; the average width of the ion beam in the z and y directions is calculated to be 80 mm. Moreover, the peak ion current is $1.25\times10^{-2}$ μA.

Next, we measured ion beam profiles with the magnetic lens. In this measurement, the Faraday cup linearly fed 100 mm in the z direction and stepped 1 mm in the y direction. Figure 4(b) shows an example of the measurement results of an ion beam profile at the position 126 mm from the outlet of the magnetic lens. The widths of the ion beam profile in the z and y directions are 24 mm and 5 mm, respectively; the average width of the ion beam in the z and y directions is calculated to be 15 mm. This demonstrates that the magnetic lens we developed is effective for converging an ion beam. The peak ion current of the ion beam shown in Fig. 4(b) is $2.40\times10^{-1}$ μA, which is approximately 20 times higher than that shown in Fig. 4(a). This is because the ion beam is concentrated in a narrow area.

In addition, the measurement times of the ion beam profiles without and with magnetic lens shown in Fig. 4 were 21 min and 16 min, respectively. We measured the time variation of ion current for 210 min, which shows that the variation of the ion current was ±7.3%. This indicates that, in Fig.4, approximate profiles of the ion beams can be captured.

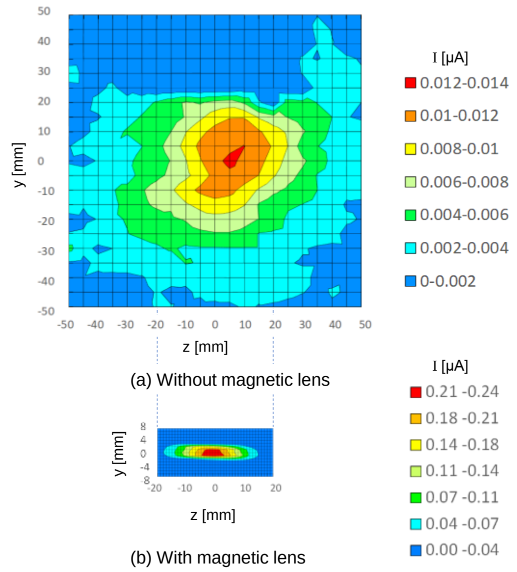


**Figure 4. Ion beam profile without (a) and with (b) magnetic lens.**

## 5. Conclusions

To figure small- or medium-sized optical surfaces by IBF, the generation of an ion beam with a small diameter is required. Thus, to converge ion beams to a small area, we designed and fabricated a magnetic lens with quadrupole neodymium magnets. The magnetic lens was installed at the outlet of the ion gun, which enabled the changing of the trajectory of the ion beam in the chamber. Our magnetic lens with permanent magnets is more compact and simpler than the conventional magnetic lens with electromagnets. We measured ion beam profiles with and without the magnetic lens. This demonstrates that the magnetic lens we developed is effective for converging an ion beam.

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## References

[1] Schindler A, et al. 2001 *Proc. SPIE* **4440** 217-227.
[2] Weiser M 2009 *Nucl. Instr. and Meth. B*, **267** 1390-1393.
[3] Takino H, et al. 2011 *Proc. ISUPEN* 5-10.
[4] Xu M, et al. 2017 Opt. Express 25, 10, 10765-10778.
[5] Arnold T, et al. 2019 Optical Fabrication and Testing, Paper# OM4A.6.
[6] Takino H, et al. 2020 Proc. euspen 165-166.