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Key-Hole Type Quadrupole Lens Test for Advanced Operation of a Microcolumn†

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An electron lens is an important part of a microcolumn for focusing electron beam on a sample plane. In this study, we introduced a new type electron lens with a key-hole type quadrupole electrode to improve the microcolumn for advanced operation. And, we analyzed electron beam characteristics of the electron lens using a 3-D simulation analysis.

Keywords: Microcolumn, Electron beam size, Quadrupole lens, Einzel lens.

INTRODUCTION

A conventional microcolumn consists of an electron emitter tip, source lens, double deflector, and an electron beam focusing lens[1-6]. As shown in Fig. 1, the double deflector plays a role of an electron beam scanner as well as an electron beam shape reform from a distorted beam. For the conventional microcolumn, each deflector consists of eight electrodes. To scan electron beam with the deflector, a suitable bias voltage is applied on the every electrode. It makes a complicate work on an activation of a microcolumn.

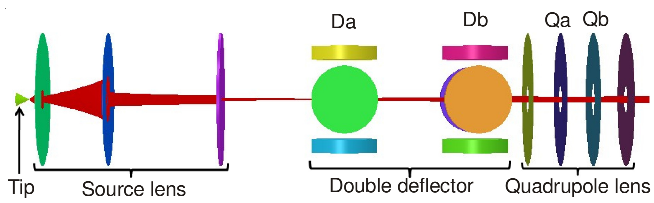

Fig. 1 Simulation model of a microcolumn with a quadrupole lens.

In this study, we investigated simple operation of a microcolumn with modified structure. The eight-electrode deflector is replaced by a four-electrode deflector. We introduced a new type electron beam focusing lens. An electron focusing lens, called Einzel lens, consists of combination of the three electrodes. Each electrode has a few hundreds micrometer size cylinder hole on its center.

However the modified Einzel lens consists of four electrodes as shown in Fig. 2. The first and the last electrode are conventional electrodes with a cylinder hole, while the two electrodes, located between the first and the last electrode, have key-hole type hole. The two key-hole type electrodes named as Qa and Qb, aligned vertically each other to control electron beam horizontal and vertical axis, respectively[7].

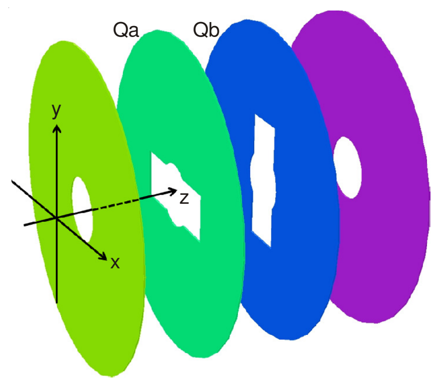

Fig. 2. Quadrupole lens

EXPERIMENTAL

Simulation analysis

Deflector effect: We can deflect electron beam passing through a microcolumn by a bias voltage applied on a deflector. In general, a microcolumn has double deflector for deflection

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of electron beam and also restoration of beam shape from distortion caused by deflection.

Fig. 3 shows electron beam on the sample plane perpendicular to the optical axis of microcolumn. Center of electron beam is shifted by deflector with bias voltage, VDa or VDb. The center positions of Fig. 3 (a) and (b) are not same. A difference between center positions of Fig. 3(b) and (c) is caused by bias voltage applied on the deflector, VDb. Higher bias voltage makes a larger deflection of electron beam from the optical axis.

Bias voltage effect applied on the quadrupole lens: While a conventional electrode of Einzel lens has a circular hole, an electrode for quadrupole lens has rectangular hole for its own purpose. Electron beam deflected by deflector shows distorted shape with elliptical envelope. The distorted beam can't be recovered to circular symmetric beam by action of a symmetric electrode. Only an asymmetric electrode can recover beam shape.

Fig. 4 shows changing of beam shape on the sample plane with increasing bias voltage applied on the quadrupole electrode. The beam distortion increases with bias voltage. Using the result conversely, we can recover circular symmetric beam from distorted one.

It is necessary to check the possibility of using the quadrupole lens as a beam shape compensator, mentioned above. For this purpose, we applied a bias voltage on the second

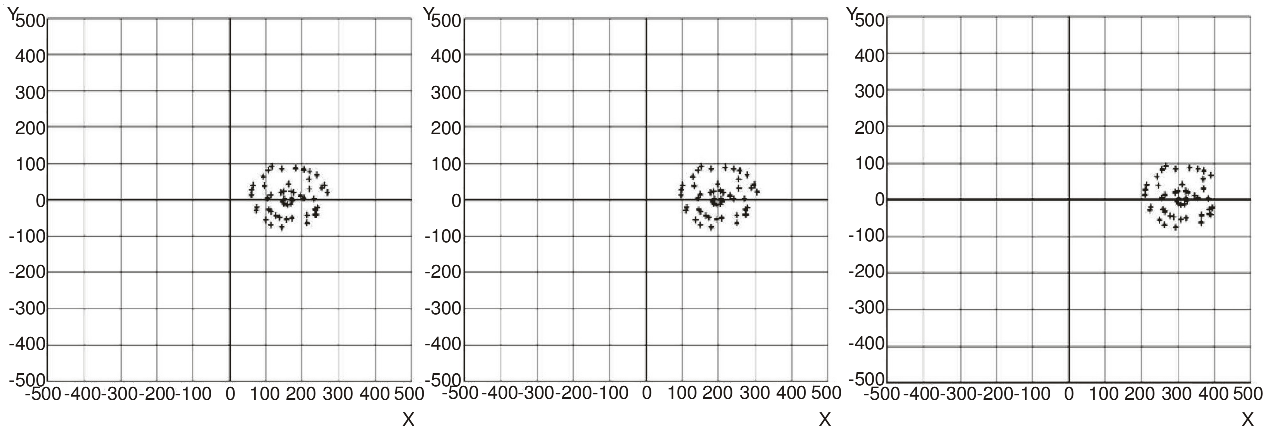

Fig. 3. Electron beam shape on the sample plane. VDa = 5V (a) VDb = 0V (b) VDb = 5V (c) VDb = 10V

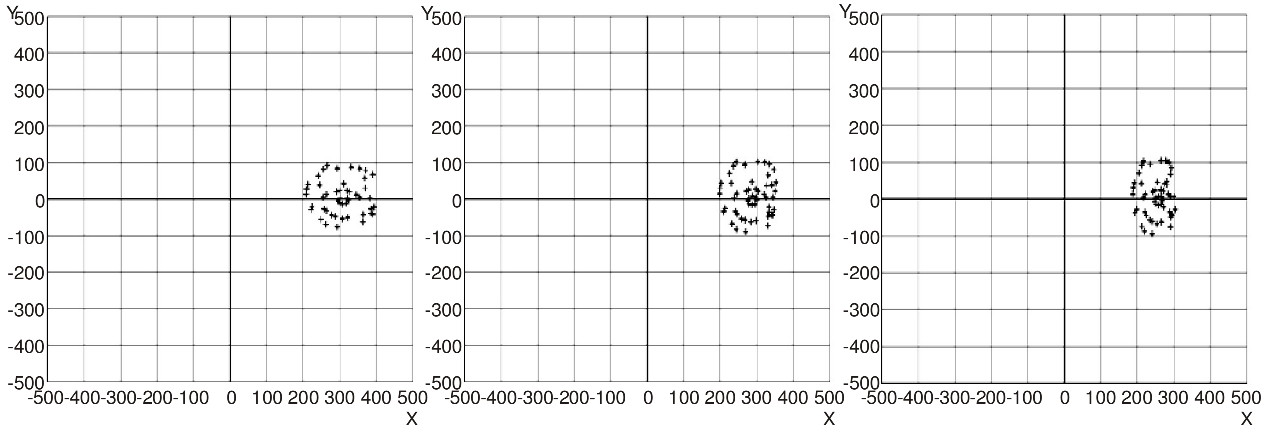

Fig. 4. Electron beam shape on the sample plane. VDa = 0 V, VDb = 10 V, (a) VQa = 0 V (b) VQa = 50 V (c) VQa = 100 V

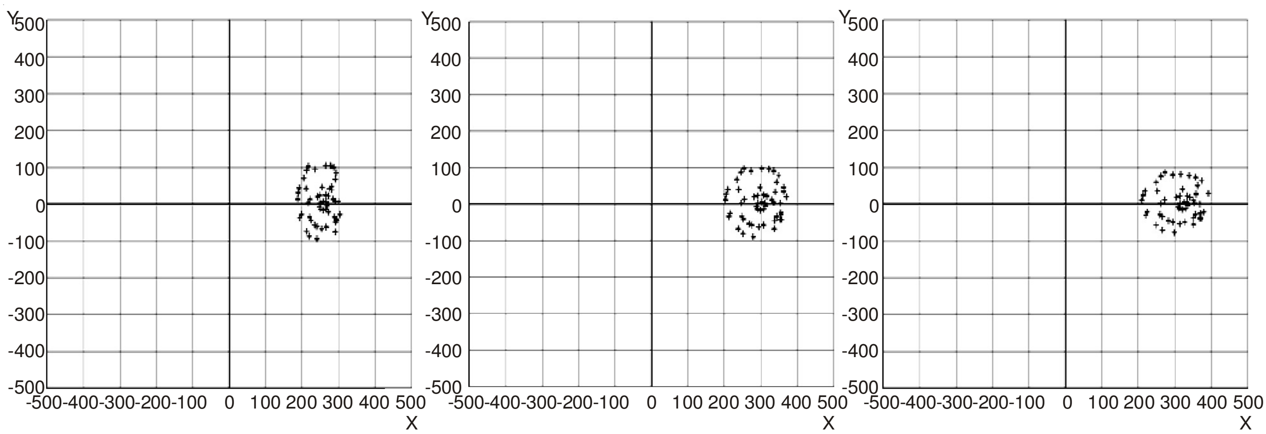

Fig. 5. Electron beam shape on the sample plane. VDa = 0 V, VDb = 10 V and VQa = 100 V (a) VQb = 0 V (b) VQb = 50 V (c) VQb = 100 V

quadrupole lens, Qb, after distorting electron beam intentionally with bias voltage applied on the first quadrupole lens, Qa. Here we set the intentional bias voltage VQa = 100 V. As the bias voltage VQb increases, beam shape becomes more and more symmetric as shown in Fig. 5. At last, electron beam recovered to almost circular shape at an appropriate voltage VQb. Therefore we verified the quadrupole lens could be a beam shape compensator.

Quadrupole electrode length effect: In general, an electrode has a rectangular shape hole at its center. However, we introduced a key-hole type electrode in this study. Fig. 6 shows a quadrupole key-hole type electrode structure. The key-hole type electrode is designed for simplicity of align the electrodes alignment.

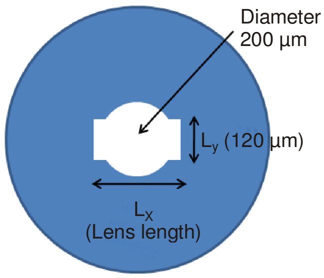

Fig. 6. Quadrupole electrode structure with key-hole type hole

Every electrodes consisting of a microcolumn must be aligned in a line along the optical axis of the microcolumn to keep electron beam properties good. The dimension of the hole fabricated on the electrode center is very small, from a few micrometers up to a few hundred micrometers. Thus, a precision technology is needed to align the electrodes.

In this study, we used a laser beam diffraction patterns from the electrodes to align electrodes. When the electrodes with circular holes are aligned well, diffraction patterns are symmetrical concentric circles. This technology enables us to align electrodes accurately without expensive equipment. This is the reason that we fabricated a key-hole type electrode not a rectangular shaped electrode.

In this section, we analyzed quadrupole electrode size effect on electron beam. We fixed y-axis length, Ly = 120 µm but varied x-axis length, Lx = 240-400 µm of the first quadrupole lens, Qa. Fig. 7 shows electron beam shape on a sample plane. As the length is increasing, beam shape crushing is intensifying. That is, beam waist on the x-axis is decreasing as the length is increasing, while the beam waist on the y-axis is increasing as shown in Fig. 8.

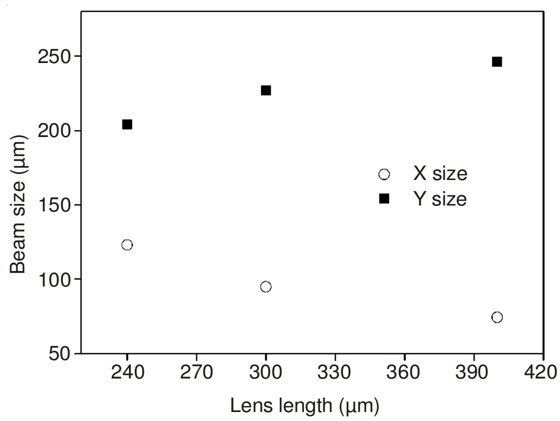

Fig. 8. Electron beam spot size *versus* quadrupole lens length

Quadrupole lens potential effect on beam spot size: To get a small size of beam spot is very important for precision measurement or inspection[8,9]. As mentioned in previous section, the quadrupole lens can control electron beam shape. Thus the quadrupole lens could be a focusing lens. Fig. 9 shows beam on a sample plane with various bias voltages of quadrupole electrode, VQa and VQb. As increasing bias voltage, beam spot size is decreasing. It is an evidence of action as a focusing lens of the quadrupole lens. Fig. 10 show a distribution of electron beam spot size with bias voltage VQa. As predicted above, electron beam spot size is reduced linearly with bias voltage.

A quadrupole electrode could recover symmetric beam shape from distorted beam by a deflector or the other quadrupole electrode. Because the quadrupole electrode shape is asymmetric, the electrode cause braking of symmetric beam shape again at a excessively high bias voltage (Fig. 11). It comes from asymmetric potential distribution inside a quadrupole electrode for a given bias voltage as shown in Fig. 12.

RESULTS AND DISCUSSION

We introduced a new type electron lens, quadrupole lens, for advanced operation of microcolumn. The quadrupole electrode has a key-hole type shape, an asymmetric form.

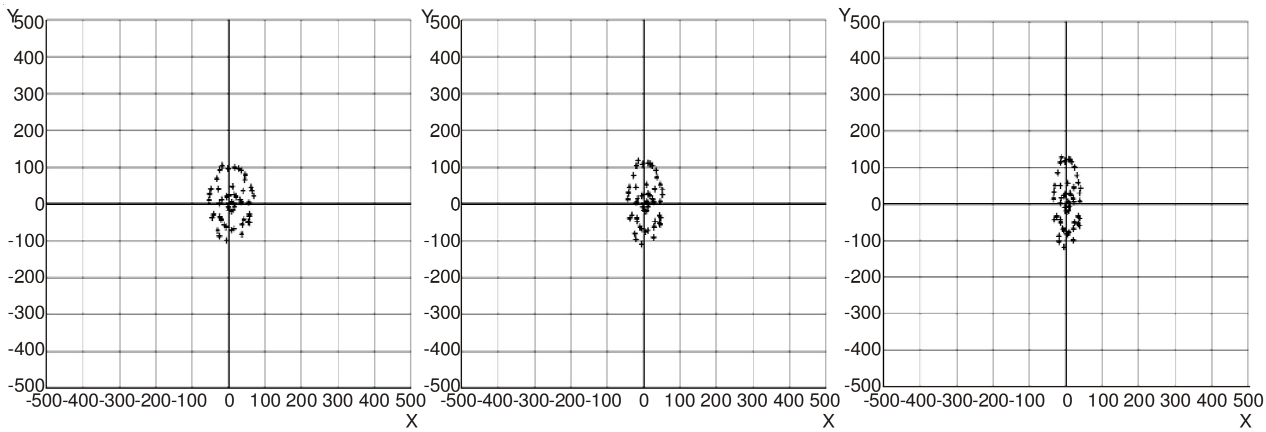

Fig. 7. Electron beam shape on the sample plane. VQa = 100 V, VQb = 0 V, LyQa = 120 µm (a) LxQa = 240 µm (b) LxQa = 300 µm (c) LxQa = 400 µm

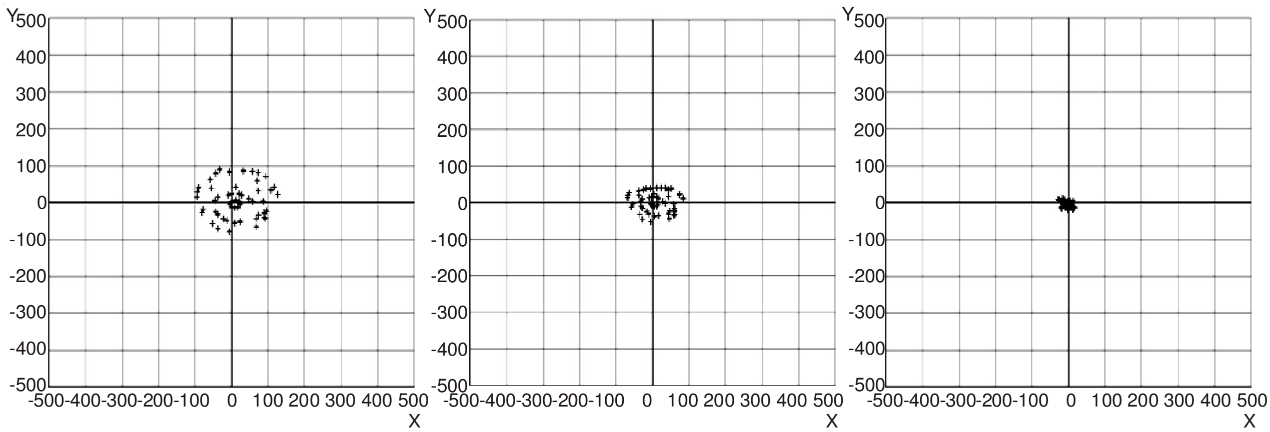

Fig. 9. Electron beam shape on the sample plane. VDa = 0 V, VDb = 0 V, LxQa = 240 μm (a) VQa = VQb = 50 V (b)VQa = VQb = 200 V (c)VQa = VQb = 350 V

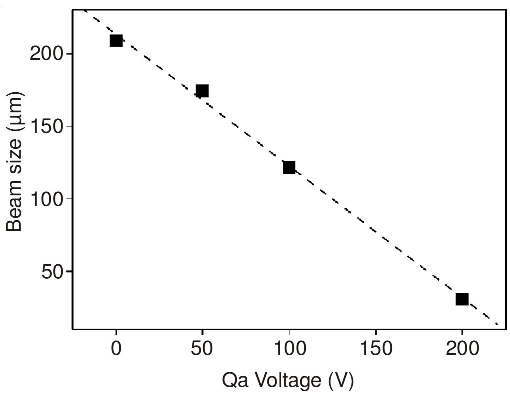

Fig. 10. Electron beam spot size *versus* bias voltage applied on the quadrupole lens

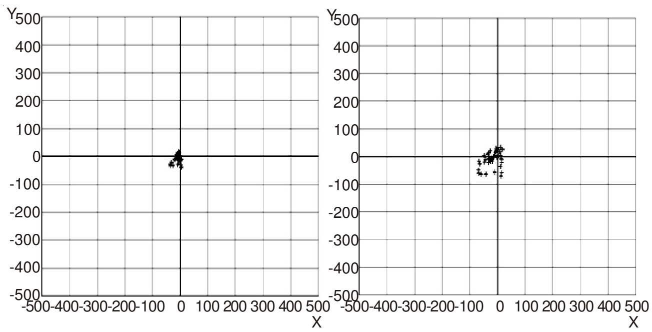

Fig. 11. Electron beam shape on the sample plane. VDa = 0 V, VDb = 0 V, LxQa = 240 μm (a) VQa = VQb = 400 V (b) VQa = VQb = 500 V

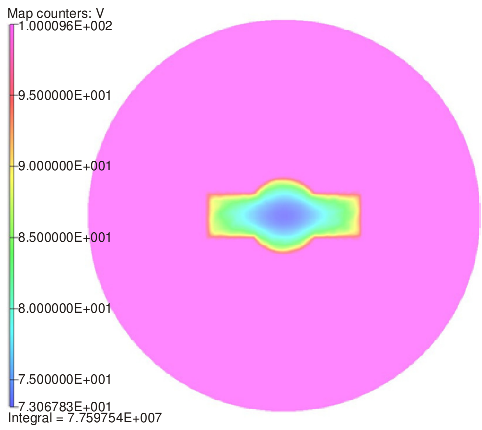

Fig. 12. Electrostatic potential distribution inside the quadrupole electrode

The key-hole type electrode has two advantages, easy alignment and beam shape control. Since the quadrupole electrode has center circle hole, we can align electrodes along the optical axis using laser diffraction pattern. This method is very simple and need not any expensive align equipment.

We investigated electron beam properties to confirm possibilities of the quadrupole lens as a beam shape compensator and a focusing lens. Asymmetric shape of the lens induces also asymmetric electric field and potential distribution inside the electrodes. By using the asymmetry, we can control electron beam passing through the quadrupole lens.

We proved the possibilities by investigation of electron beam with a 3-D simulation analysis. The distorted beam by an asymmetric electrode is recovered to circular symmetric beam at the adequate bias voltage applied on the quadrupole electrode. And also beam spot size is reduced on a sample plane by an action of asymmetric quadrupole lens. Thus we validated that the quadrupole lens can be used for precise electron beam equipment.

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