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Electron Emitter Tip-Shape Effects on the Electron Beam Trajectory in a Microcolumn†

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One of the most significant parameter for the electron beam properties of a microcolumn is the electron emitter tip shape. The electron tip shape in a microcolumn is one of the most effective factors to the behaviour of electron beam. We investigated the tip shape effect on the electron beam trajectory. To investigate the tip shape effect on electron beam properties, we analyzed the electrostatic potential and field strength inside the microcolumn and also electron beam trajectories. The divergence angle at the different tip apex such as flatted tip-shape, facetted tip-shaped, rounded shaped and triangle-shaped also discussed.

Key Words: Low voltage electron beam, Microcolumn, Field strength, Trajectory.

INTRODUCTION

Electron beam sources are in the spotlight, since it could offer a possibility of overcome the limit of the optical source resolution. A miniaturized electron beam microcolumn makes an alternative proposal of the realization of the electron beam equipment. Its compact size and simple structure make it possible drastically enhances the throughput due to the possibility of multi-array and improves the resolution due to the reduction of the aberrations. The microcolumn has been studied theoretically and experimentally[1-4].

As shown in Fig. 1, a microcolumn consists of the electron emitter tip, extractor, accelerator, limiting aperture and einzel lens. The emitter tip shape is one of the most important elements to the electron beam properties. It affect on the probe beam diameter, current stability and current density. The most preferable tip is what has high current density, stable current and small beam diameter.

Fig. 2 shows a chemical etched sharpness electron emitter tip. When a negative bios voltage applied on the emitter tip, electrons emitted from the tip apex by attractive force of electric field around the tip apex. Strength and direction of electric field near the tip apex are decided by tip shape and it affects electron beam properties. In these days, it is possible to prepare very sharp emitters, including emitters that end in a single atom[5,6]. Single-atom tips are of great interest for producing coherent and bright electron beams, as well as for producing highly focused and bright ion beams. However, fabrication of the single-atom tip would be difficult procedures.

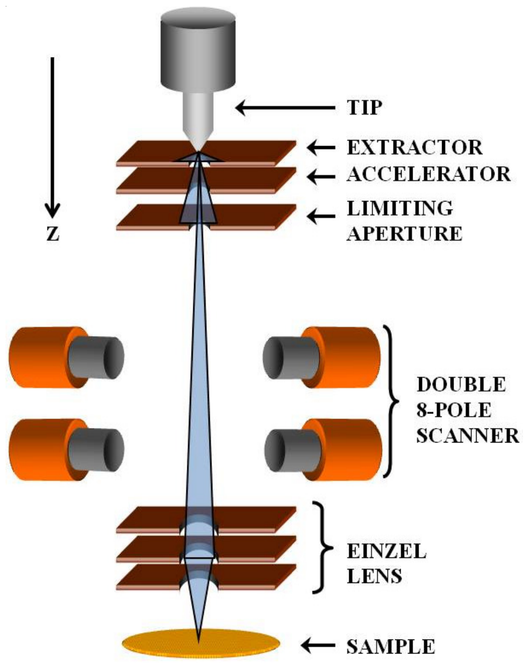

Fig. 1. Structure of a microcolumn

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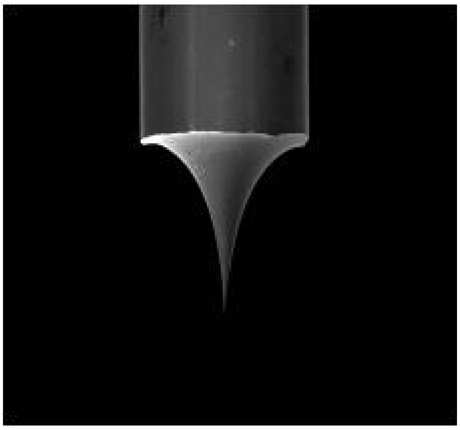


(a)

(b)

Fig. 2. SEM image of (a) a chemical etched electron emitter tip (b) 1000 times enlarged

And also the tip cannot last long, because its structure is neither thermally nor mechanically stable. Thus, it is necessary to analyze various shape of electron emitter tip for stable and long life time for an emitter tip. For example a trimer tip with three atom at the tip top more stable than single atom tip for thermally and also mechanically[7]. The trimer tip is one of the facet shaped tip[8,9]. Utsumi pointed out that the rounded whisker shape is the closest to the ideal field emitter[10]. To analyze the tip shape affect on the beam properties, we introduced the whisker tip shapes of flat, facet, round and triangle tip with the same tip length.

In the following section, we will discuss effects of the emitter tip shape on the electric field strength, equi-potential line and electron trajectory for the triangle, facet, round and flat shaped emitter tips.

RESULTS AND DISCUSSION

Electric field strength and equi-potential line: We investigated the tip shape effect for four-type emitters. For the comparison of the tip effect, the parameters of the field emitter, such as applied tip bios voltage, thickness of each electrode and position of electrodes are fixed. Thus, we can expect that electrostatic potential and electric field strength are almost the same configuration over all region of the electron-lens except around the tip apex. We examined electrostatic potential and electric field strength around the tip end in detail.

Fig. 3 shows the tip shapes, the corresponding equi-potential lines (solid-line) and electric field (arrows) around the four tips end. The results show that curvatures and spacing between equi-potential lines are nearly equal at each tip-shape. However, there is a delicate difference on potential lines at tip apex surroundings. Each tip has the unique direction and length of the arrows (stand for the electric field) at the same position. It is one of the primary causes of the difference of electron beam properties at the sample.

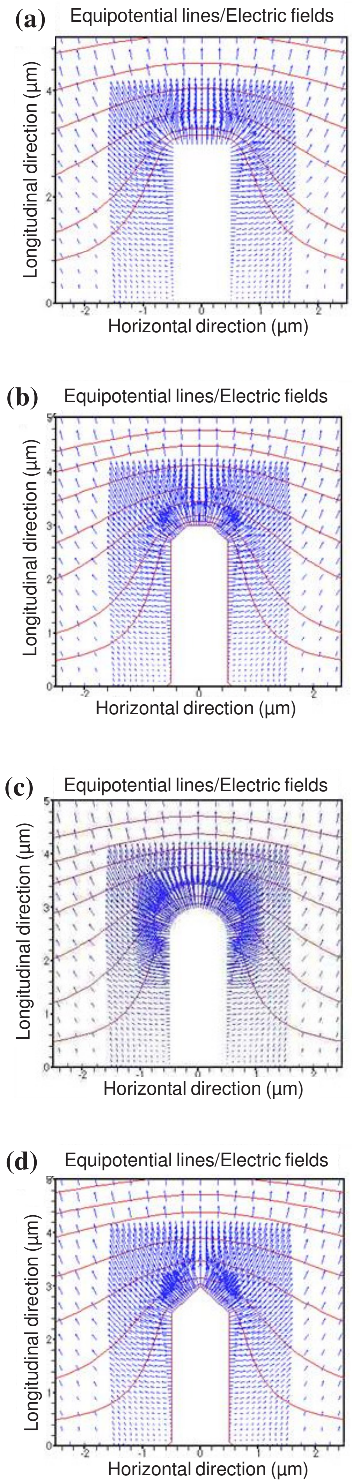


Fig. 3. Equi-potential line and electric field around the electron emitter tip apex

Fig. 4 shows simulation results of electric field distribution along the horizontal axis at the four tip-shapes. The flat-tip (solid squared) and facet-tip (circle) have a sudden change of the field strength, while minute change at the center point of the tips. The two tips have maximum values at the side edges of each tip. As result the tips have small divergence angle on the emitted electron trajectory. On the contrary, for the triangle tip have horizontal component of the electric field relatively high. One may expect the divergence angle very large for the triangle tip.

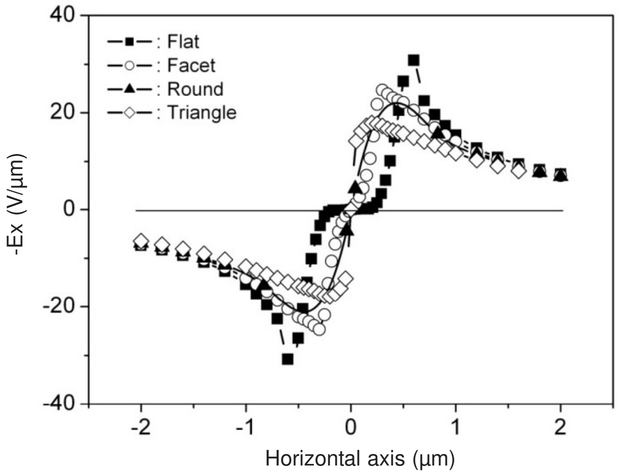
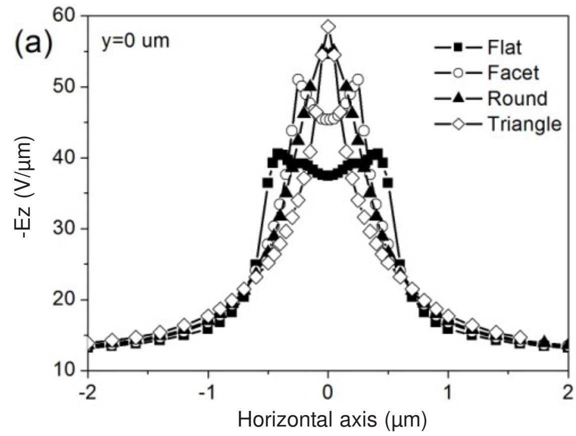


Fig. 4. Electric field strength around the electron emitter tips

Fig. 5 shows the electric field strength, -E_z at z = 0 (tip apex), 1, 2 and 7 µm, respectively. Where, the direction of 'z' is the direction of optical axis. As shown in Fig. 5(a), the difference of electric field strength distribution is definite among several tips at the tip apex. But the difference grows less and less as become more distant from the tip apex. At last, one could not distinguish the distribution of a tip from that of others in Fig. 5(d) for z = 7 µm. Therefore, it is suggested that the tip shape effective range is less than several microns form the tip apex. It is noted here want note that even though the tip shape effective range is so small, the effect on electron trajectory is not trivial because of the electron is so slow in this region. Thus the divergence angle can be made a large change by a small horizontal electro-static force.



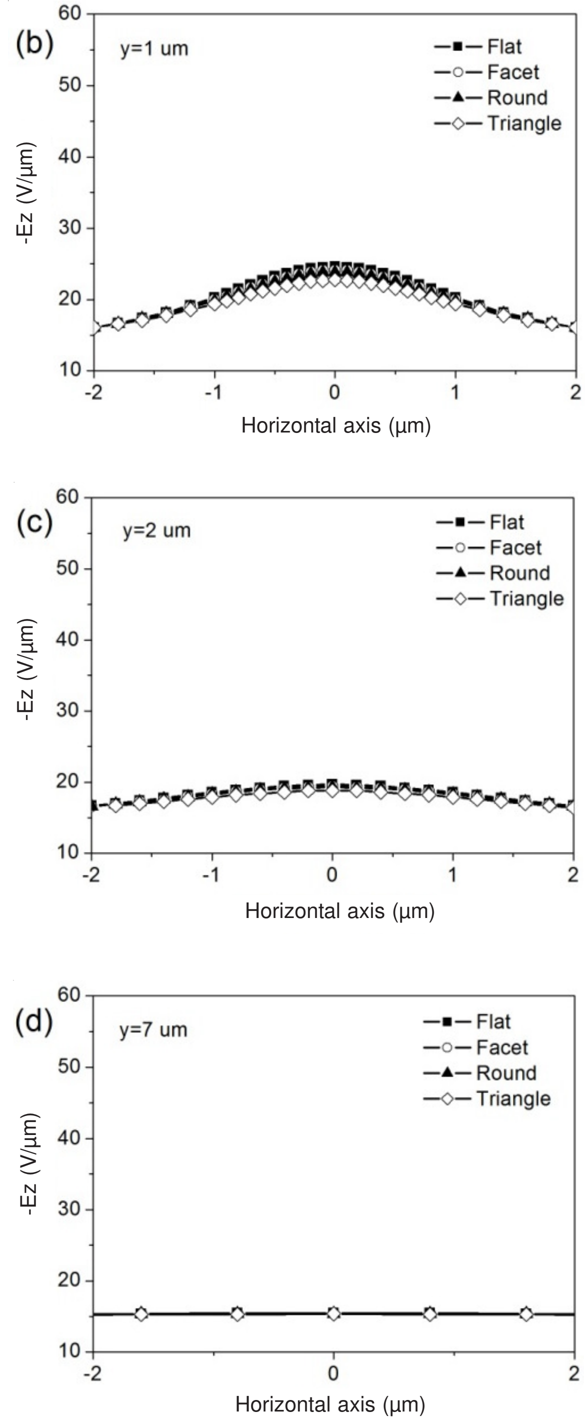


Fig. 5. Optical axis component of electric field at the apex of the electron emitter tip

Fig. 6 shows the electric field distribution of the component longitudinal to the optical axis along the column axis. Around the tip end, among the analyzed tip shapes showed somewhat difference of electric field strength. However the difference of electric field strength is decreasing as increasing the column axis coordinate quickly. At last the difference is disappeared within several micrometers. However, velocity of electrons emitted from tip is not fast in this region. Thus the affect of the small difference is a great influence on the electron trajectory, mentioned above. In the following section, we will discuss the electron trajectory.

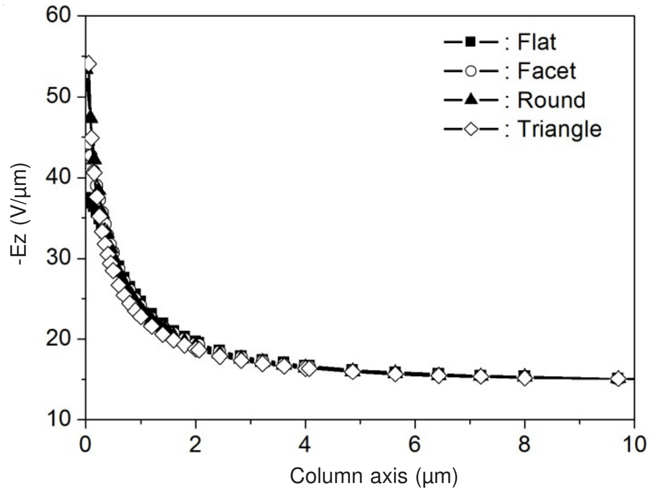


Fig. 6. Optical axis component of electric field at the apex of the electron emitter tip along the optical axis

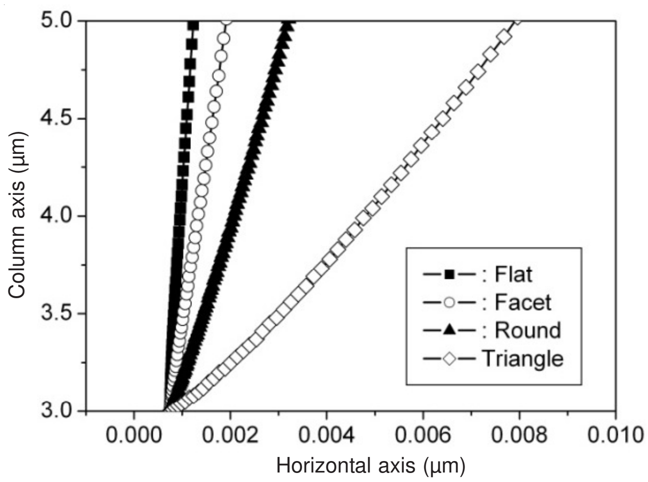


Fig. 7. Divergence of electron trajectory

Electron beam trajectory: The electron beam trajectories are determined by the curvature of the equi-potential lines and field strength. Electrons emitted from tip accelerated to the direction of electrostatic force and the electrons received force perpendicular to the equi-potential lines. Many electrons emitted from a tip are filtered by the limiting aperture if emission electrons have a large divergence angle. A central electron beam of the emission passes through the limiting aperture. And then, the beam is focused on the sample surface by a focusing lens.

The current density is very important on lithography because of it dominate throughput and beam exposure time on the sample. The current density for cold field emitter is written as[11].

$$J = 6.2\times10^{2}\left(\frac{E_f}{\varphi_w}\right)^{1/2}\frac{E^2}{E_f+\varphi_w}\exp\left(-\frac{6.83\times10^{7}\varphi_w^{3/2}}{E}\right)$$

where J is the current density in A/cm^2, E_f is the Fermi energy of electrons in a metal, φ_w is the work function and E is the electric field strength in V/m applied to the metallic surface. The current density is drastically increased as the field strength increases. And the each emitted electron takes a difference divergence angle and current density on the sample.

Fig. 7 shows beam trajectories of electrons emitted from four analyzed tips. An important region on trajectory is the tip apex because electron velocities are very slow at that region. It means that every electron has enough time to interact with electric field at this region. As shown in Fig. 5, electron beam trajectories from a point of the emitter tip surface are different divergence angles. The triangle-tip has the largest divergence angle among those of other shaped tips because the triangle tip has the strongest horizontal component of electric field.

Conclusion

The electron beam properties for flat, facet, round and triangle tips are investigated. As the results, electric field strength show that the flat and facet tips have weak field strength, while the round and triangle tips have strong electric field strength at the tip center. Thus, the triangle tip has the greatest electron divergence angle since it has the greatest horizontal component of the field strength at the tip end. On the contrary, the flat tip has the smallest divergence angle.

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