Short communication

Surface roughness realized and evaluated in different dimensional range and its effect on field emission behavior

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The effect of the surface roughness in different dimensional range on the field emission behavior of Cu–Cr electrodes is studied. Hawking machining and finish machining are used to achieve the different surface conditions. The macroscopic surface roughness value of the hawking machining, measured by the conventional roughness meter, is one order of magnitude lower than that of the finish machining, however, the obvious increase of field emission tendency was found on the electrode surface obtained by the hawking machining compared with the finishing machining. The surface roughness in nanoscale was evaluated by AFM (Atomic Force Microscope), indicating that the micro-roughness of the hawking machining is higher than that of the finishing machining. These results indicated the deficiency of the conventional roughness evaluation method on the field emission tendency and suggested that hawking machining might not improve endurance voltage strength of the electrodes in vacuum.

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Electrical breakdown in vacuum is usually caused by the field emission electrons emitted from the micro-protrusions on the electrode surface [1,2]. The field emission current correlates to the breakdown field intensity, which always be recognized as following the F–N equation [3].

\[ J = A_0 \beta^2 E^2 / \phi \exp\left\{B \phi^{3/2} / E\right\} \]

where A and B are constants, J is the current density, \( \phi \) is the work function and \( \beta \) is the electric field gain factor which relative to the condition of the micro-protrusions on the electrode surface [4–9]. For this reason, the surface roughness is always expected to be decreased so as to the endurance voltage strength of the electrode in vacuum improves [10–13].

Recently, hawking machining, a new processing technologies, was developed in machining filed to decrease the surface roughness. Hawking machining is an ultrasonic machining technology which can decrease surface roughness less than one order of magnitude compared with conventional mechanical working. The machining, mixing of high frequency mechanical energy and thermal energy, could grind metallic surface by the cold plastic deformation and then decrease the surface roughness of the workpieces. It was reported that the surface roughness can decrease to 0.2 by the hawking machining (Surface roughness is expressed in arithmetic mean roughness (Ra)) [14], obviously less than most of the fine machining method.

In this paper, the effect of the surface roughness by finish machining and hawking machining on the field emission behavior of Cu–Cr electrode is comparatively studied. Meanwhile, whether hawking machining can improve the voltage withstand of electrode material is investigated.

The Cu75Cr25 electrode material was utilized as raw materials, whose preparation method and the microstructure was reported in Ref. [15]. All samples were processed by finish machining first in a CNC lathe. Subsequently, some of samples were processed by the hawking machining.

The surface roughness values are measured by KR20010 profile measurement system and Cypher AFM, whose results are marked as macroscopic surface roughness and microscopic surface roughness, respectively according to their measurement range and accuracy. The maximum measurement range of the Profile
Measurement System is 120 mm and the resolution is 0.5 μm. The maximum measurement range of AFM is 690 × 920 μm and the resolution is 0.06 nm. The field emission performance of Cu75Cr25 alloy is measured by EFG-H40-20W electron optical emission system with the distance between cathode and anode (Tungsten electrode is cathode and Cu75Cr25 alloy is anode) as 250 μm. The measurement area is in the center of sample. The vacuum degree during the measuring was kept as lower than 2.8 × 10⁻² Pa.

From Fig. 1, it can be seen that macroscopic surface roughness value of hawking machining and finish machining are 0.15 μm and 2.00 μm (measurement range is 15 mm), respectively. The macroscopic surface roughness value of the hawking machining, measured by the conventional roughness meter, is one order of magnitude lower than that of the finishing machining. The result indicates that hawking machining can dramatically decrease the conventional surface roughness value.

From Fig. 2, it can be seen that micro-roughness values are 225.3 nm (measurement range is 20 μm), 69.5 nm (7 μm) and 8.5 nm (1 μm). The surface of hawking machining is too rough to be tested by the AFM. Therefore, it can be inferred that micro-roughness value of hawking machining is obviously higher than that of finishing machining.

![Fig. 1. Macroscopic surface roughness value of Cu75Cr25 alloy (a) hawking machining (b) finish machining.](image-url)
Fig. 3 shows surface protuberance sketch of finish machining and hawking machining. It can be seen that, for finish machining, the protuberance is smooth and the curvature radius of protuberance is large. During hawking machining, smooth protuberance was broken into small and sharp protuberance. The curvature radius of protuberance decreases significantly. On the macro level, protuberance of finish machining is obviously higher than that of hawking machining. So, the macroscopic surface roughness value of the hawking machining, measured by the conventional roughness meter, is one order of magnitude lower than that of the finishing machining. On the other hand, subordinate protuberance obtained by the finish machining (at nanometer level) is small and smooth, as shown in red box. For the hawking machining, protuberance at nanometer level is large and sharp. The micro-roughness

Fig. 2. Microscopic surface roughness of finish machining Cu75Cr25 alloy.

Fig. 3. Surface protuberance sketch.
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Fig. 4. The curve of field electron emission current - voltage.

value of hawking machining, evaluated by AFM, is higher than that of finish machining. From Fig. 4, it can be seen that the inception voltage of field emission (IVFE) of hawking machining is about 1200 V and the IVFE of finish machining is more than 2500 V. When applied voltage is below inception voltage, the field emission current is stable and almost 0 A. Once applied voltage exceeds inception voltage, the field emission current increases rapidly. The electrical breakdown voltage depends on the IVFE [16]. The obvious increase of field emission was found on the electrode surface obtained by the hawking machining, which indicates that the hawking machining should not reduce field emission tendency.

The measurement range and accuracy of macroscopic surface roughness is from micron to millimeter level [17–19]. However, the field electron emission occurs at the protuberance with the size range from nanometer to micron [20–28]. Measurement range of macroscopic surface roughness and the size range of protuberance for field emission are not at the same level. On the other hand, the measurement range and measurement accuracy of the micro-roughness at micron level and nanometer level [29,30] are closer to the size of protuberance for field emission. Therefore, the micro-roughness is more suitable to evaluate the interception of field emission compared with the macroscopic one. For the electrode experienced the hawking machining, although its macroscopic surface roughness value measured by the conventional roughness meter is one order of magnitude lower than that of the finishing machining, it displays obvious increased on field emission tendency because of its higher micro-roughness confirmed by AFM evaluation. These results indicated the deficiency of the conventional roughness evaluation method on the field emission tendency and suggested that hawking machining might not improve endurance voltage strength of the electrodes in vacuum.

In conclusion, the micro-roughness is more suitable to evaluate the field emission property of electrode materials compared with the macroscopic surface roughness. The hawking machining, leading to low macroscopic surface roughness but high micro-roughness, should not be used to improve the endurance voltage strength of electrode materials.