Bulk Molybdenum Field Emitters by Inductively Coupled Plasma Etching

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Abstract

We report on the fabrication of inductively coupled plasma (ICP) etched, diode-type, bulk molybdenum field emitter arrays (Mo-FEA). Emitter tip etching conditions as a function of etch mask geometry and process conditions were investigated. Under optimised conditions, aspect ratios of > 10 were achieved, with 25.5 nm tip radii realised.

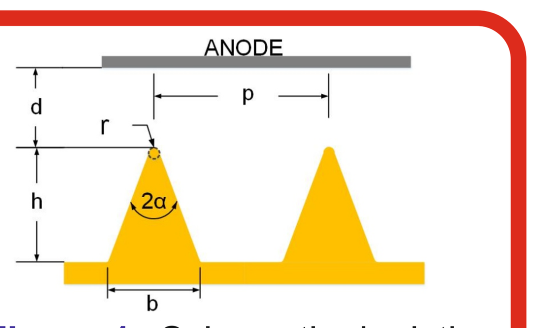

Figure 1. Schematic depicting critical emitter dimensions.

Morphology

To evaluate the optimal process conditions, the dependence of the aspect ratio and etch rate on mask shape, temperature, gas pressure, RF power, ICP power and SF_6 flow rate were investigated. Figure 2 depicts the fabrication procedure.

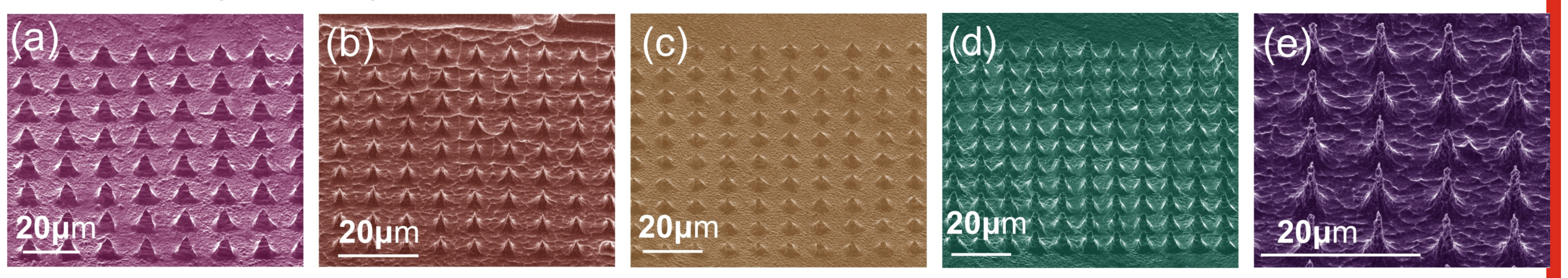

Figure 3. (a-e) Scanning electron micrographs of Mo FEAs as a function of mask shape (left to right: triangle, square, hexagon, octagon, and circular), fabricated under equivalent etch conditions. A notable variation in emitter geometry is evident. The shape of the etching mask clearly affects the resulting emitter morphology. The emitter profiles adopt a similar geometry to their defining masks; emitters with triangle pattern become pyramidal in shape.

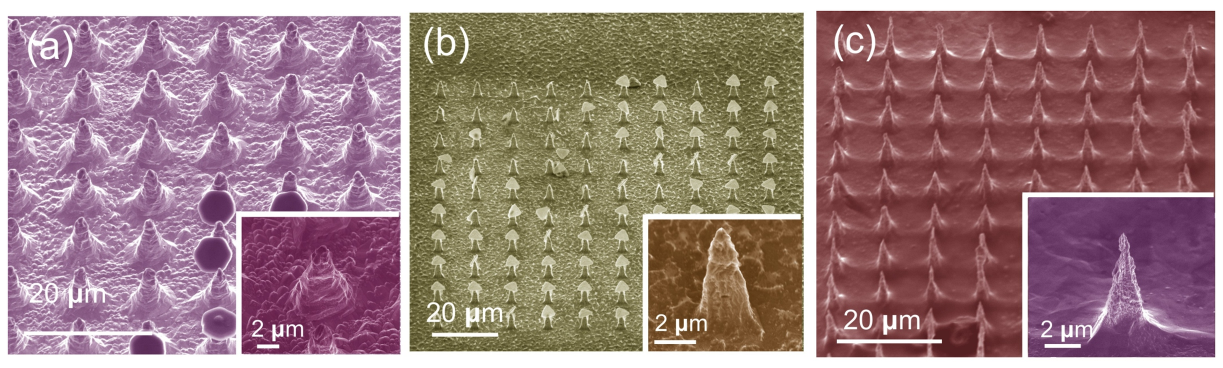

Figure 4. (a-c) Scanning electron micrographs of typical etched emitters with various shaped etch masks; (a) hexagon, (b) triangular, and (c) circular. (Process parameters: RF 30W, ICP 700W, SF_6 30sccm, 30°C, 20mTorr, etch time 1000s).

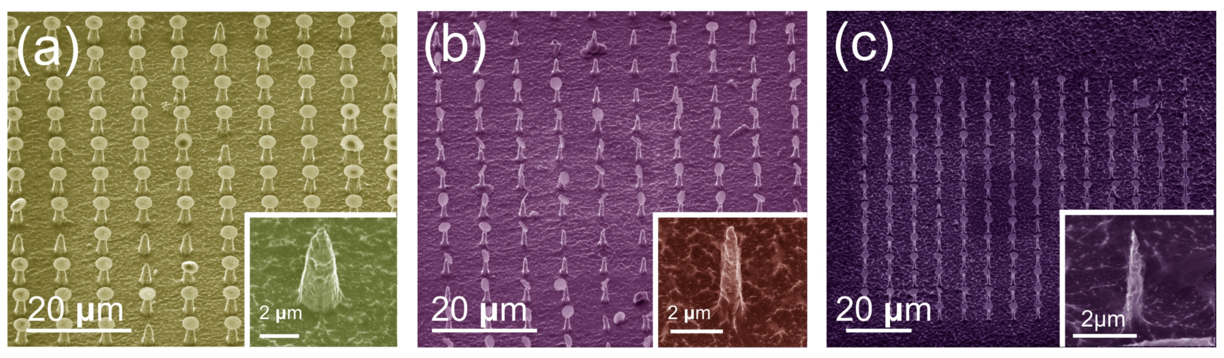

Figure 5. Scanning electron micrographs of etched emitters as a function of ICP power; (a) 700 W, (b) 800 W, and (c) 900 W. (RF 45 W, SF_6: 60 sccm, 40°C, 30 mTorr, 620s).

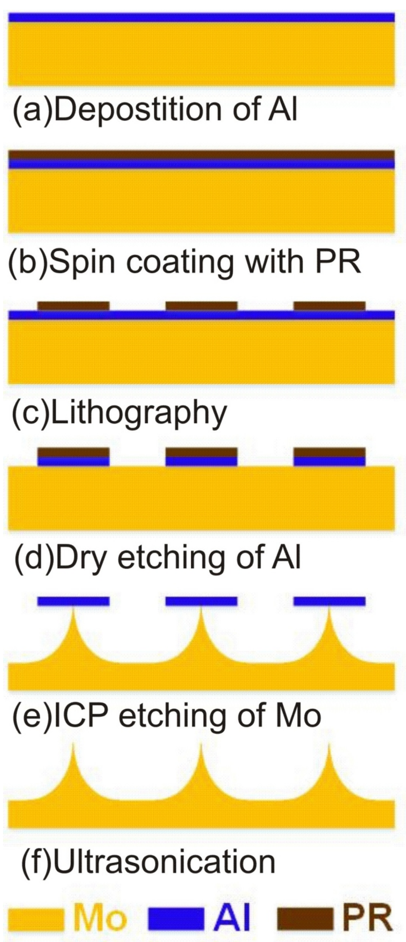

Figure 2. (a-f) Cross sectional scheme depicting the fabrication of the bulk Mo-FEAs.

Effects of Gas Flow, Temperature, Pressure, Ion Energy & Plasma Density

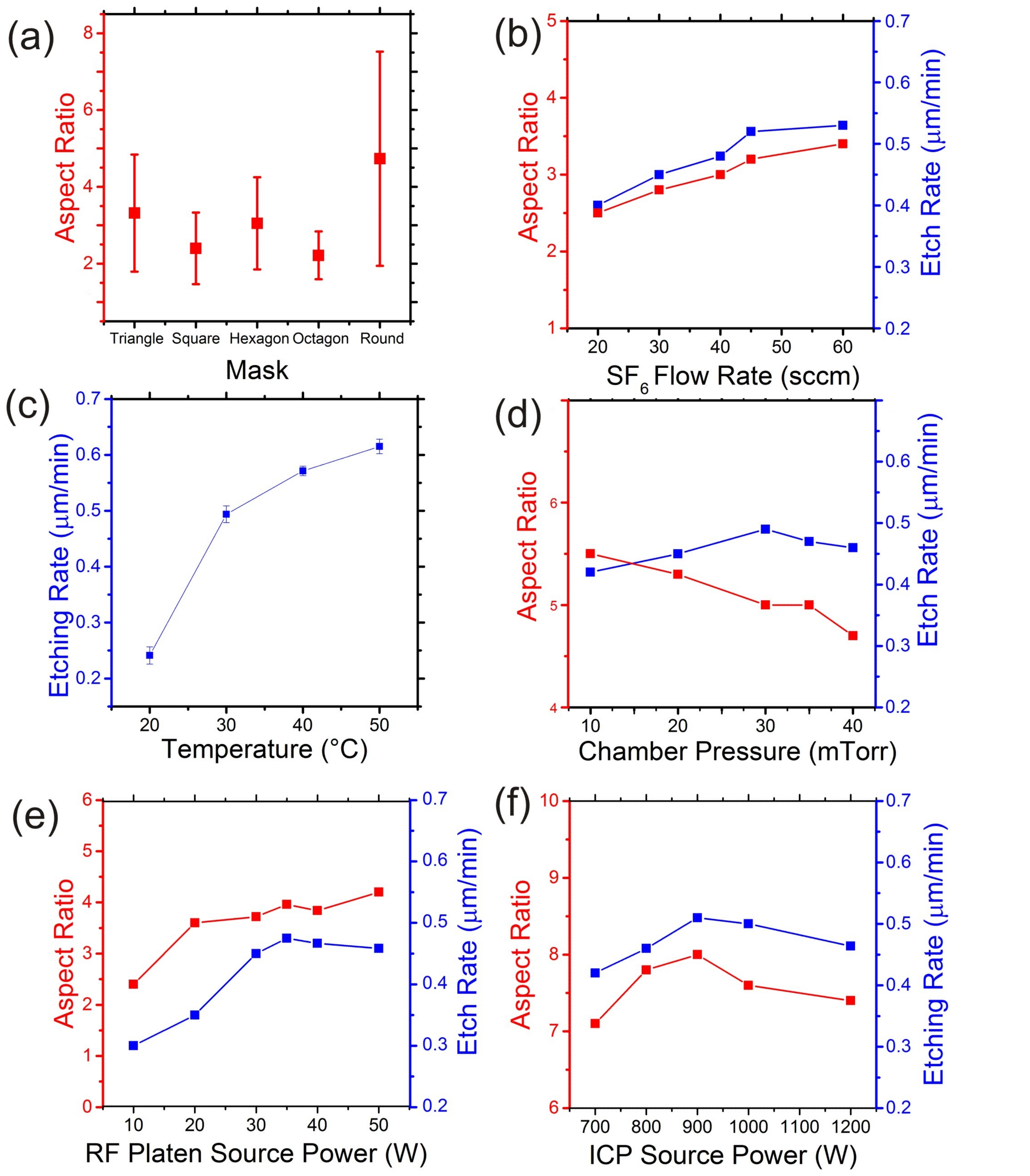

Figure 6. (a) Variation in aspect ratio as a function of mask shape. (b) Etch rate and aspect ratio variation with SF_6 flow rate. Triangular masked samples (1.25 μm) were etched with 20 W RF power, 750 W ICP power, at 30°C (c) Variation in etch rate with temperature. (d) Variation in etch rate and aspect ratio as a function of Chamber Pressure. Samples with circular masks (2.75 μm) were etched in a SF_6 plasma at 45 mTorr with 50 W RF power, 30°C. (e) Variation in etch rate and aspect ratio with RF power. Samples with square mask shape (2.5 μm) were etched in a SF_6 plasma at 20 mTorr with 750 W ICP power, 30°C.(f) Variation in emitter aspect ratio and etch rate as a function of ICP power.

Field Electron Emission

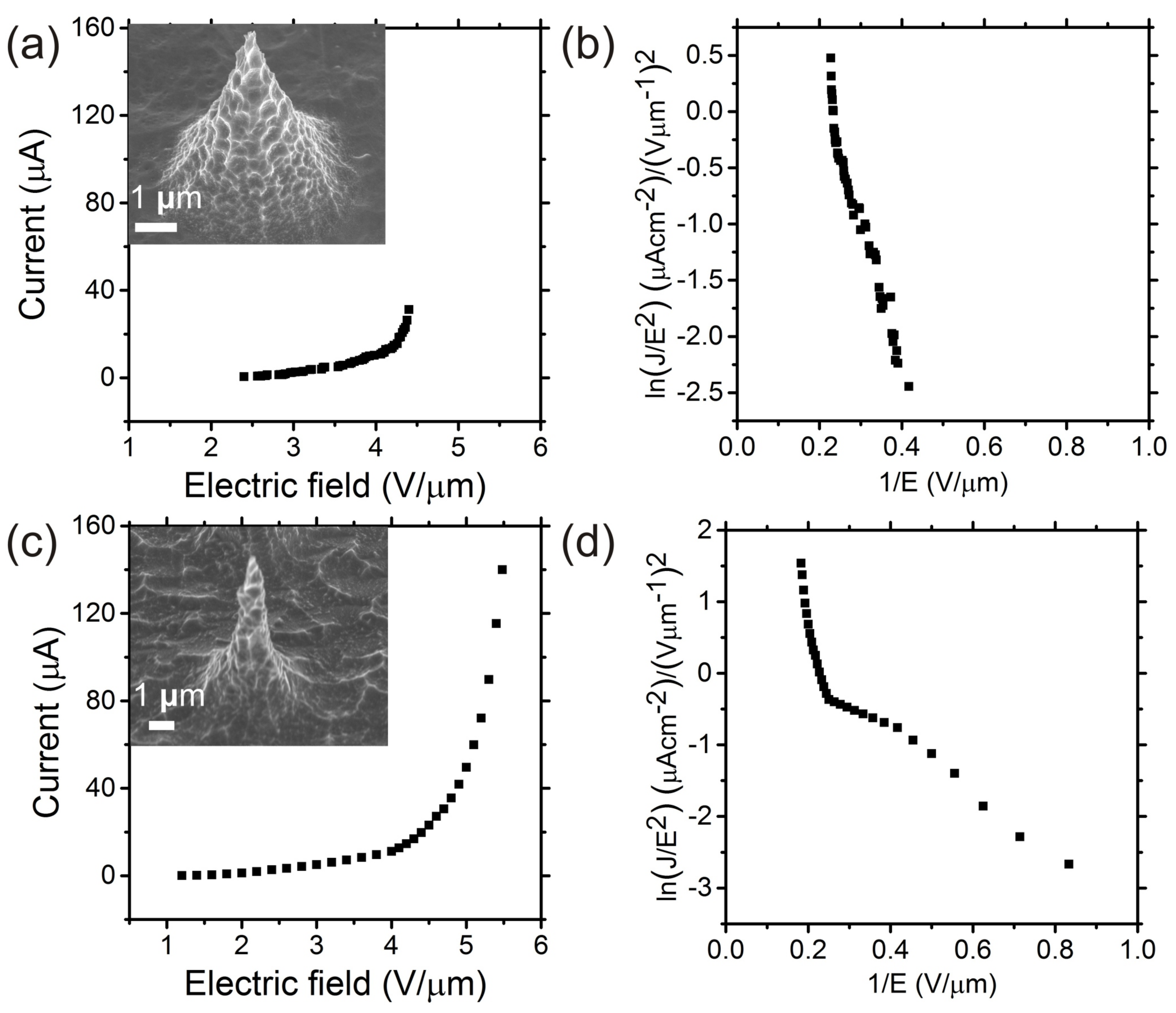

Figure 7. (a, c) Typical measured I-V curves of low- and high-aspect ratio emitters, respectively, and corresponding (b, d) Fowler-Nordheim (FN) plots. Insets (a, c): Electron micrographs of typical low- and high-aspect ratio Mo-FEAs, respectively. (Process parameters: a,b) - ICP 700W, RF 20W, 30°C, SF_6 30 sccm, 20 mTorr, 750s, round mask (2.5 μm), c,d) - ICP 900W, RF 40W, 40°C, SF_6 40 sccm, 10 mTorr, 870s, round mask (2 μm).)

FN plots of fabricated low- and high-aspect ratio samples which present notable differences in their threshold fields, E_{thr} and a in the slope of $B\phi^{3/2}/\beta$, for an assumed FN-dominated emission, from their emission profiles at the onset of emission (Figure 7). Comparison of the FN plots of these two archetypical samples indicates that E_{thr} decreases slightly with increasing aspect ratio, whilst the slope appears to decrease somewhat. A significant increase in the maximum current was noted for those samples with high-aspect ratios.

Figure 8(a-f) shows integrated intensity maps of the Mo-FEAs at applied bias of 3-4 kV. At low electric fields, there appear a few dominant emission sites, suggesting possible non-uniformity in tip geometry.

We find that as the applied bias tends to increase the integrated intensity maps become increasingly uniform, likely due to saturation.

Further studies are underway to better understand the underlying mechanisms for this observed spatial variation.

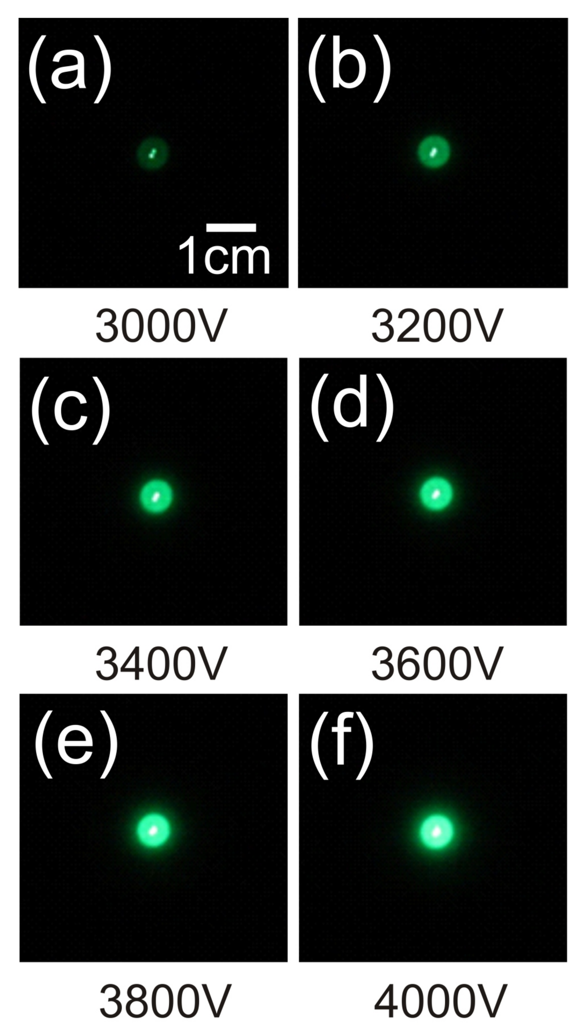

Figure 8. Integrated intensity maps as a function of anode voltage (scale bar: 1 cm).

Conclusions

A bulk molybdenum etching process has been developed to fabricate high aspect ratio field electron emission arrays. Gas chemistry, SF_6 flow rate, RIE power, ICP power, temperature, pressure and mask shape and pressure have been investigated to determine their first-order effects on etching rate, selectivity and profile isotropy. By controlling the etch mask shape, Mo emitters have been fabricated with sharpness and aspect ratio necessary for high emission currents. With a preliminary optimized bulk molybdenum ICP etching process, a high etching rate of up to 0.5 μm/min was been achieved with an aspect ratio of >10. Diode measurements showed that higher aspect ratio and smaller radius offer improved emission current. Facile fabrication make bulk Mo-FEAs promising for use in high beam current continuous emission applications.

Acknowledgements

We thank the Nanofabrication Laboratory, National Center for Nanoscience and Technology, for fabrication assistance.

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