Solid Metal Cathodes for a Virtual Cathode Oscillator[1]

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Abstract – Results are presented on the performance of both chemically etched and machined, solid metal, grooved cathodes operated in a virtual cathode oscillator (300 kV, 10 kA, 30 ohm at 50 nsec pulse length). The chemically etched cathodes, with grooves tens of µm wide on a >100 µm pitch, were created with a standard metal-specific etch using a pattern, defined photolithographically. The machined cathode was fashioned from aluminum and constructed on a CNC milling machine. All cathodes had emitting areas ~30 cm^2. The chemically etched cathodes were fashioned from both aluminum and copper, while the machined cathode was made from aluminum. Basic cathode performance was observed from the diode voltage, diode current, and vircator microwave generation. Additional diagnostics include ICCD imaging of the emitted x-rays providing indirect observation of e-beam uniformity. Solid metal cathode performance is compared with that of a velvet cathode.

1. Introduction

A common type of cathode material in virtual cathode oscillators (Vircators) and other HPM sources is cloth velvet. Advantages of cloth velvet cathodes include ease of use, low cost, and single shot current emission. However, several important disadvantages of cloth velvet exist including poor lifetime and impedance collapse. An example of poor lifetime performance of a velvet cathode is shown in Figure 1. The image is of a cloth velvet cathode operated in a reflex triode vircator after 100 shots.

Alternatives to cloth velvet as a cathode material are carbon and metal. Various forms of carbon cathodes include carbon knife edge [1], carbon fiber [2], and cesium iodide doped carbon fiber [3]. Recent development by Gilgenbach [4] of an all solid metal cathode, termed the Projection Ablation Lithography (PAL) cathode, has been reported.

We are presently employing two methods of fabrication, a chemical etching technique [5] and mechanical machining. Optical images show uniformity using both methods, but especially so with the mechanical technique. We report on the performance of chemically etched, mechanically machined metal cathodes as well as a cloth velvet cathode. Performance is evaluated by monitoring diode current, diode voltage, and microwave output power. In addition, e-beam uniformity is evaluated with visual and x-ray imaging.

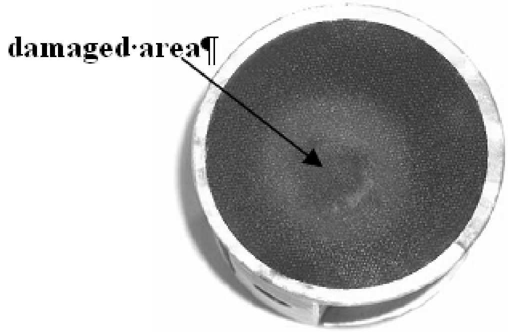

Fig. 1. Image of a cloth velvet cathode damaged after more than 100 shots.

2. Fabrication

Four different cathodes were fabricated for testing: chemically etched copper and aluminum, mechanically machined aluminum, and cloth velvet. All cathodes had a circular emission area of approximately 33 cm^2 (6.5 cm diameter).

The velvet cathode was fashioned from cloth velvet wrapped about and adhered to an aluminum backing plate. The plate was then bolted to a brass block. An image of the velvet cathode is shown in figure 2(a).

The chemically etched aluminum and copper electrodes, shown in figures 2 (b) and (c), were fashioned with a standard aluminum and copper etch, respectively. A simple pattern of linear trenches were etched using a photoresist pattern. For both cathodes, trench depth was ~100 µm. The trench pitch was 150 µm for the aluminum and ~350 µm for the copper. A surface image, taken from an optical interferometer, of the aluminum etched cathode is shown in figure 3 (a). A surface profile, taken from a profilometer, of the copper etched cathode is shown in figure 3 (b). Optical interferometer images of the copper cathode are not shown due to inadequate reflections from the trenches.

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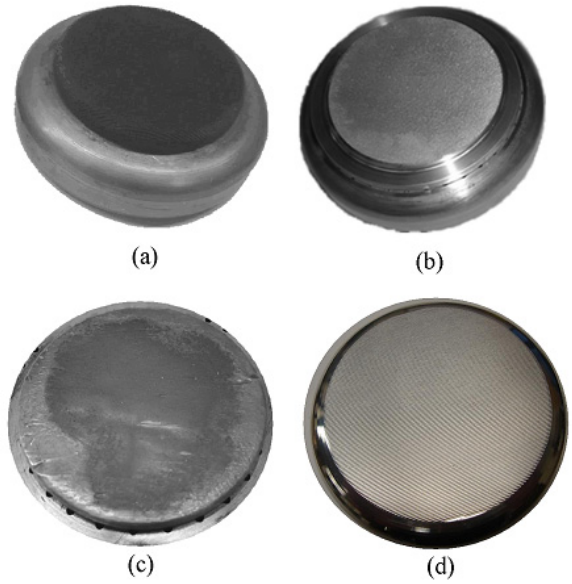

Fig. 2. Image of cloth velvet cathode used for testing.

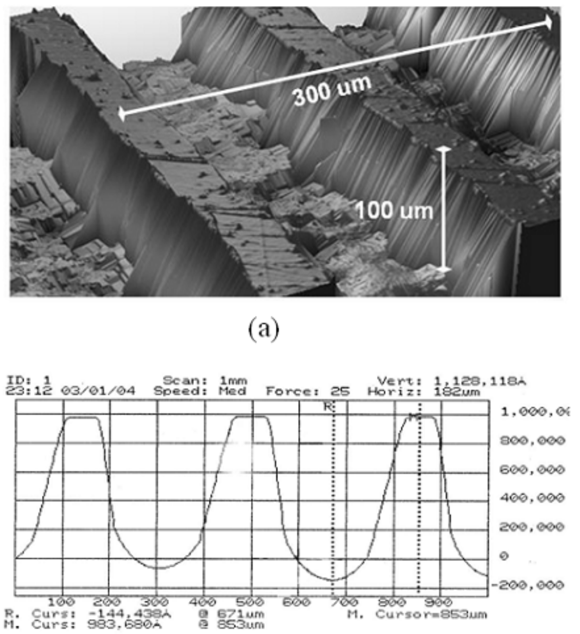

Fig. 3. Images of the etched cathodes (a) optical interferometer image of the aluminum cathode (b) profilometer results of the copper cathode

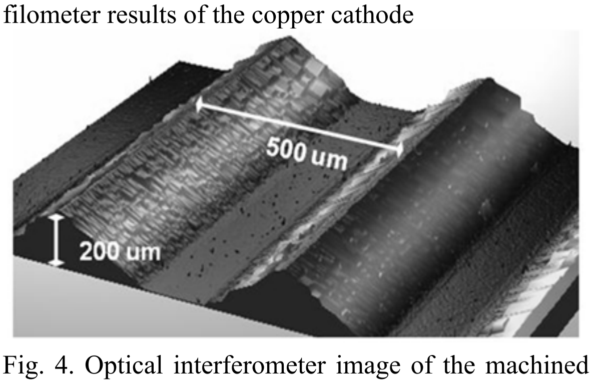

Fig. 4. Optical interferometer image of the machined aluminum cathode.

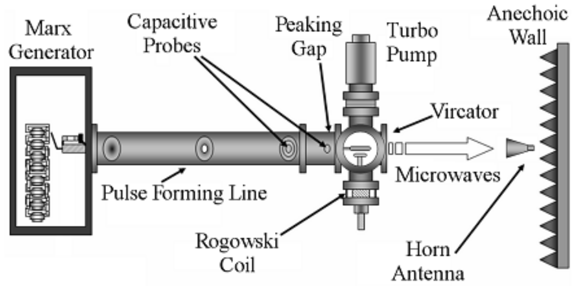

Fig. 5. Schematic of the Marx generator with PFL and vircator assembly.

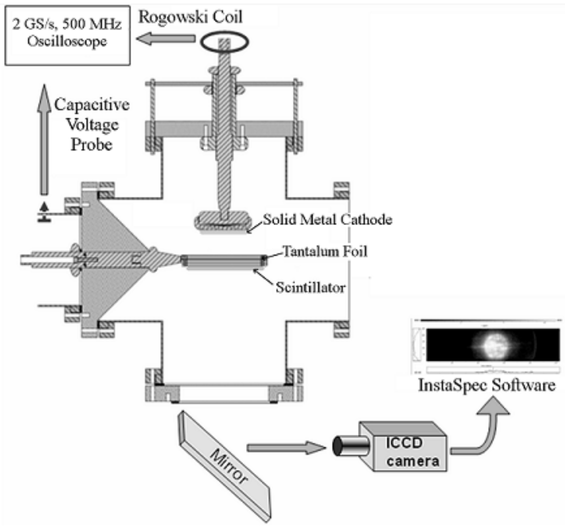

Fig. 6. Schematic of the x-ray emission diagnostic.

Another solid aluminum cathode was constructed with a machining process. The piece was machined on a CNC with a T8 milling tool in the same linear trench pattern with a 200 µm deep trench and a 500 µm pitch. An optical interferometer image is shown in figure 4. Note the more exaggerated V-shaped trench which is caused by the shape of the milling tool bit.

3. Experimental Setup

Testing of the cathodes was conducted on a Marx generator with a pulse forming line normally used for driving a triode vircator [5], see figure 5. The 5 kJ, 8 stage Marx and oil filled pulse forming transmission line outputs a 2 ns risetime, 60 ns wide, 400 kV square pulse into a 30 Ohm load.

Two methods were employed for testing the cathodes. The first method was to use the cathodes within a triode vircator and observe the vircator performance, as shown in figure 5. Diode voltage and current was monitored via capacitive voltage probe and Rogowski coil, respectively. Microwave output was observed from a pyramidal horn antenna located in the far-field into a 6 GHz oscilloscope.

The second method was an observation of the x-ray emission, as shown schematically in figure 6. Observation of x-rays indicates the degree of uniformity of the e-beam. Setup involved removing the anode mesh normally employed for vircator operation and replacing it with a 0.1 mm thick sheet of tantalum foil. Directly behind the foil 2 mm away is located a 2 mm thick, 12.5 cm plastic scintillator (EJ-260 manufactured by Eljen Technologies). The EJ-260 is a green emitting, Polyvinyltoluene based polymer scintillator. Emission from the scintillator is captured with an Oriel InstaSpec V ICCD camera. The InstaSpec V is capable of gate times as low as 5 nsec. This allowed us to image x-ray emission during portions of the 50 nsec diode voltage pulse which gave an indication of e-beam development.

4. Experimental Results

Significant differences in HPM generation exist between the four electrodes. Typical microwave waveforms from each of the electrodes are shown in figure 7. Velvet cathodes consistently produced the highest peak power microwave output along with the longest microwave pulsewidth. The shortest microwave pulsewidth was observed from both of the chemically etched cathodes.

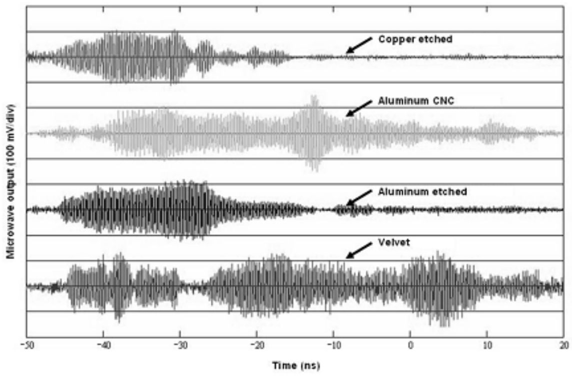

Fig. 7. Typical microwave output from the vircator with different cathodes.

The most coherent microwave generation was observed from the velvet cathodes, as seen in the microwave power spectrum in figure 7.

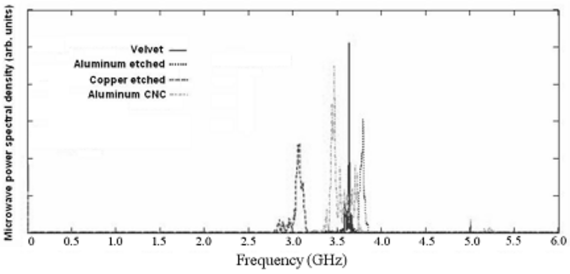

Fig. 7. Microwave power spectrum from the vircator with different cathodes.

Peak microwave output power was measured from the vircator for a number of shots varying both the AK gap distance and the cathode, see figure 8. Gap spaces were 6, 8, 10, and 12 mm, with 3 shots taken at each position. For AK gaps of 6, 8, and 10 mm, the velvet cathode outperformed the solid metal cathodes. At 12 mm, all cathodes output similar peak power.

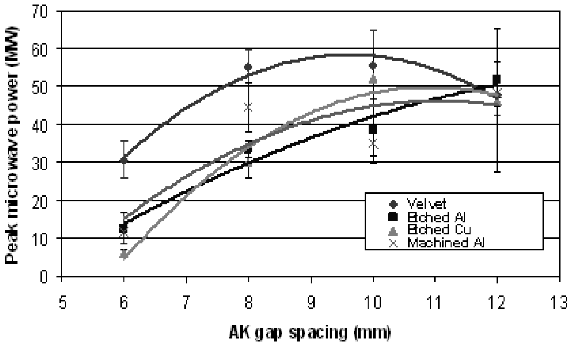

Fig. 8. Microwave power spectrum from the vircator with different cathodes.

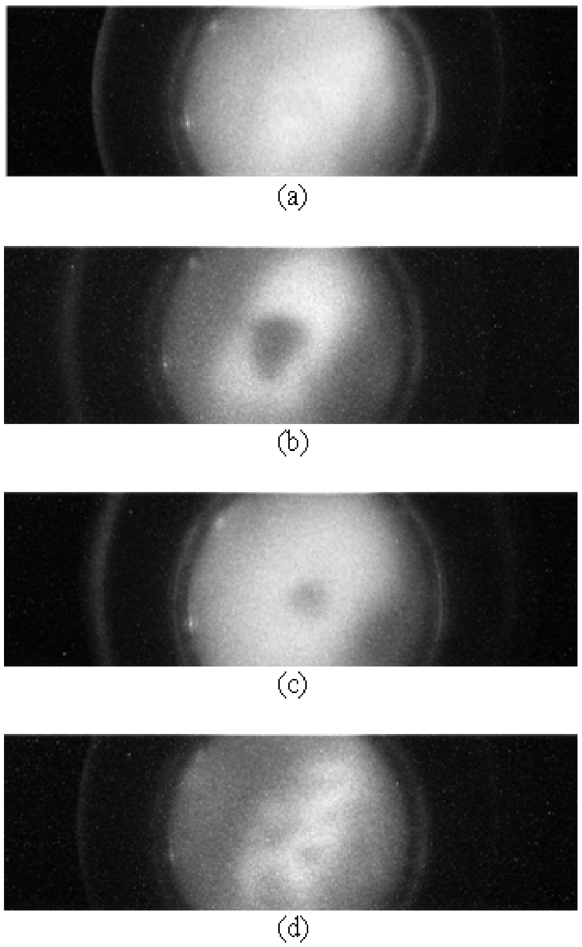

Fig. 9. Four different images of x-ray emission from various cathodes (a) velvet (b) CNC Al (c) Etched Al (d) Etched Cu.

Images of x-ray emission from the four different cathodes are shown in figure 9. Images from the solid cathodes, figures 9(b) to (d), show definitive structure and non-uniformity. The x-ray image from the velvet cathode in figure 9(a) is relatively uniform. Gate time on all of these images was 20 nsec.

5. Summary

We have presented results on the testing of four different cathodes within a vircator; cloth velvet, machined aluminum, etched aluminum, and etched copper. For microwave generation, cloth velvet outperformed the solid metal cathodes, however, the solid metal cathodes nearly performed as well as the cloth velvet under certain conditions, particularly at larger AK gap spacing. Additionally, we showed x-ray emission from all for cathodes comparing beam uniformity.

In the future we plan on constructing metal cathodes with more complicated surface structure in an effort to maximize potential emission sites. For the x-ray imaging, we plan on observing x-ray emission from different time regimes within the 50 nsec of the diode voltage.

References

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