



Computer Modelling of a Sputter-Type Negative Ion Source

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UWFDM-492

Presented at the 1982 Symposium of Northeastern Accelerator Personnel (SNEAP),
Seattle, Washington, October 6-8, 1982.

FUSION TECHNOLOGY INSTITUTE

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James H. Billen

Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

<http://fti.neep.wisc.edu>

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James H. Billen

Fusion Engineering Program
Nuclear Engineering Department
University of Wisconsin-Madison
Madison, Wisconsin 53706

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Earlier I reported¹ results of Cs^+ ion trajectory calculations that correctly predict the erosion pattern observed on the sputter cathode of our Source of Negative Ions by Cesium Sputtering (SNICS). Recently I have extended the calculations to include the negative ions sputtered from the cathode surface making it possible to construct the phase space distribution of the negative ion beam and hence calculate the beam emittance and current. A detailed description of the calculation and results will be presented at the Seventh Conference on the Application of Accelerators in Research and Industry to be held in Denton, Texas in November 1982. Here I present a few highlights of the results obtained so far with the computer model. The calculations involve a tremendous computational effort and would have been nearly impossible without the use of a very high speed machine. Since SNICS produces the beams of heavy metal negative ions used for radiation damage studies on potential fusion reactor materials I was able to run the codes on the Cray-1 computers at the National Magnetic Fusion Energy Computing Center in Livermore, California. These machines are among the fastest computers now available (several thousand times faster than the Honeywell machine on which I began this project).

In SNICS Cs^+ ions from the hot W ionizer bombard the face of the sputter cathode which is held a few KV negative with respect to the ionizer and source housing. Figure 1 illustrates the sputter rate of the cathode surface derived from the distribution of Cs^+ ions along the radius.

After tracing an exhaustive set of negative ion trajectories from the cathode surface the computer code constructs a phase space distribution of the negative ion beam such as that shown in Fig. 2 for Ni^- ions. The beam current and phase space area enclosed by these contours of equal brightness are listed in Table I. The beam current magnitudes assume an incident Cs^+ current of 5 mA and that 2% of the sputtered particles are negative ions. Figure 3 shows the normalized emittance as a function of

the percent of beam enclosed by the successive brightness contours. The results are in excellent agreement with emittance measurements.

Continued running of the ion source erodes a deep pit into the sputter cathode. Figure 4 shows the brightness contours for a 2.4-mm deep hole in the cathode whose shape matches that of a used sputter cathode. Comparison with Fig. 2 for a flat cathode indicates that the emittance increases slightly as the hole develops. This agrees qualitatively with our observation of a gradually increasing emittance as a function of running time. We also regularly observe the rather strange pinched shape of the contours on our emittance measuring system.

Figure 5 shows the emittance of 90% of the beam as a function of cathode voltage for two different exit aperture diameters. If one neglected the energy spectrum of the sputtered particles, say by assuming their initial energy to be zero, then the phase space distribution at the source exit aperture would not change as a function of cathode voltage. This would lead to an increase in normalized emittance exactly as the square root of the cathode voltage. However, the sputtered particle energy spectrum peaks near 20 eV and extends to at least 100 eV for few-keV heavy particles incident on metal surfaces. When one includes the effect of the energy spectrum of the sputtered negative ions the phase space distribution for lower cathode voltages spreads out more than for higher cathode voltages. The normalized emittance then depends less strongly than the 0.5 power of the cathode voltage. The two curves in Fig. 5 both exhibit approximately a $V^{0.31}$ dependence.

Figure 6 shows that the calculated beam current also increases as a function of cathode voltage. Here the increase is almost entirely due to the increased sputter yield as a function of the Cs^+ -ion bombarding energy. The emittance and current curves in Figs. 5 and 6 combine to yield the average brightness as a function of cathode voltage shown in Fig. 7. The current increases almost rapidly enough with voltage to offset the effect of the increasing emittance.

Figure 8 shows the essentially linear dependence of the emittance

on the diameter of the source exit aperture. The calculated beam current also increases linearly with aperture diameter so that the average brightness falls as the reciprocal of aperture diameter as shown in Fig. 9.

Reference

1. J.H. Billen, Proc. 3rd Int. Conf. on Electrostatic Accelerator Technology (Oak Ridge, Tenn. 1981) 238.

Acknowledgment

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Table I

Phase Space Contour Results

2.97 mm Aperture 2.0 kV Cathode

Brightness Contour (% of max)	Percent of Beam	Beam Current (μA)	Phase Space Area (mm mrad)	Normalized Emittance (π mm mrad MeV ^{1/2})
0.0	100.000	74.98	675.33	9.614
0.1	99.930	74.92	517.72	7.370
0.5	99.451	74.56	447.04	6.364
1.0	98.648	73.96	404.05	5.752
2.0	96.661	72.47	350.56	4.990
3.0	93.838	70.35	307.58	4.378
4.0	90.602	67.93	272.23	3.875
4.2	90.204	67.63	268.41	3.821
5.0	87.069	65.28	241.67	3.440
6.0	82.738	62.03	211.10	3.005
7.0	78.626	58.95	186.27	2.652
8.0	74.432	55.81	164.30	2.339
9.0	69.890	52.40	143.28	2.040
10.0	64.535	48.38	121.31	1.727
12.0	56.677	42.49	93.61	1.333
15.0	46.153	34.60	63.04	0.897
20.0	34.073	25.55	35.34	0.503
30.0	23.178	17.38	17.19	0.245
40.0	17.546	13.16	10.51	0.150
50.0	13.096	9.82	6.69	0.095

Sputter Rate vs. Radius

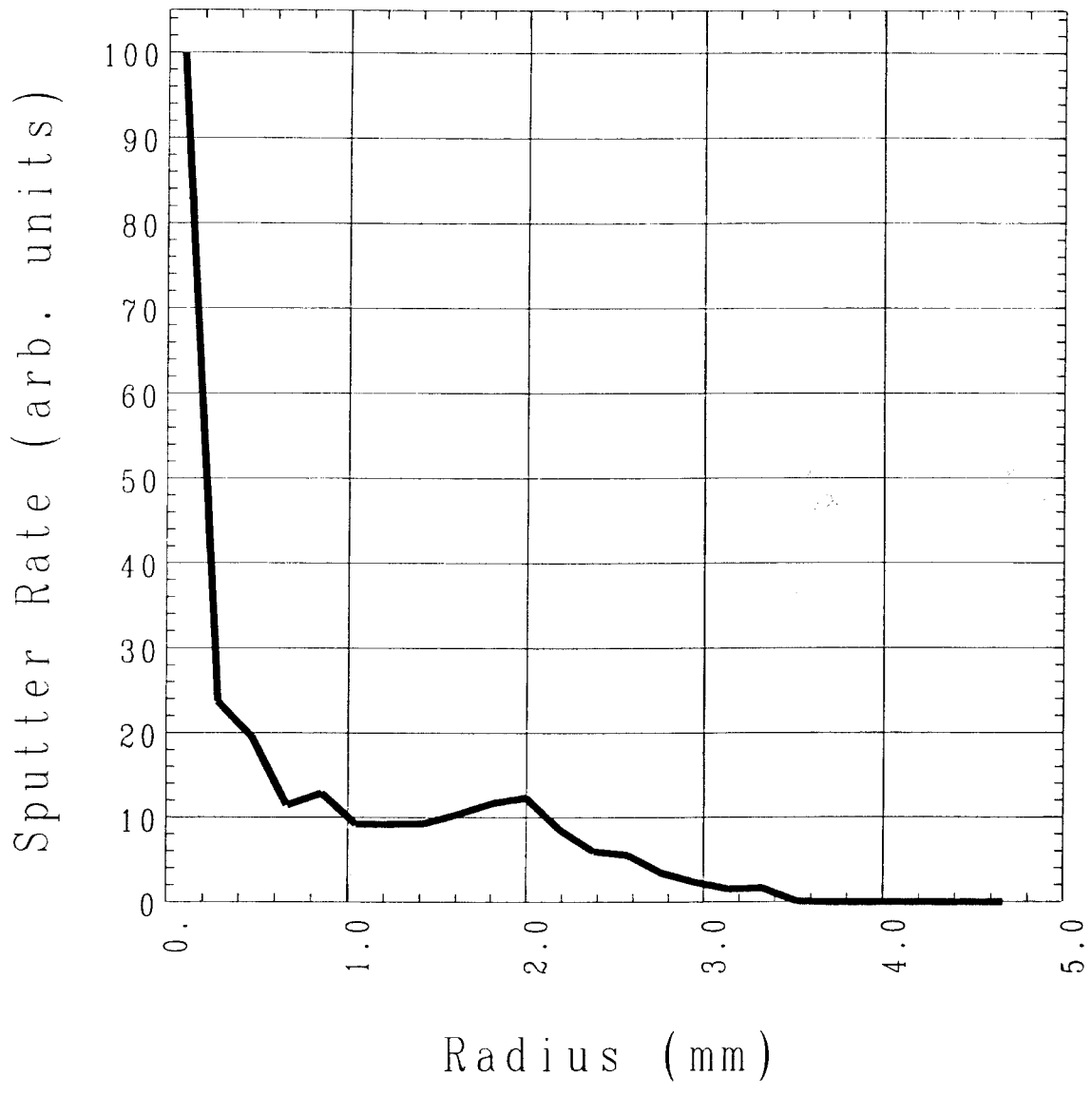


Figure 1.

Brightness Contours

2.97 mm Aperture 2.0 kV Cathode

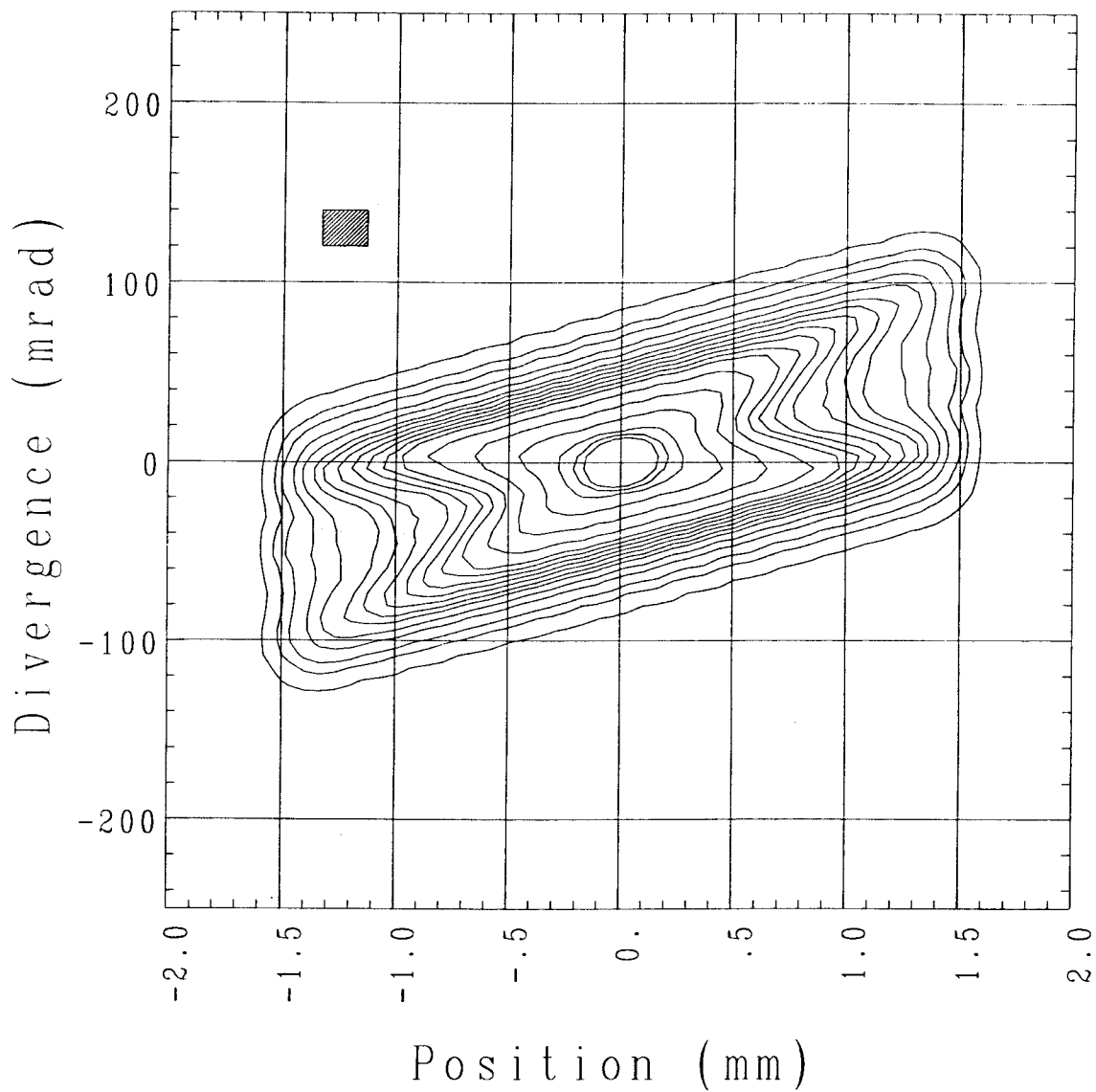


Figure 2.

Emittance vs. % of Beam

2.97 mm Aperture 2.0 kV Cathode

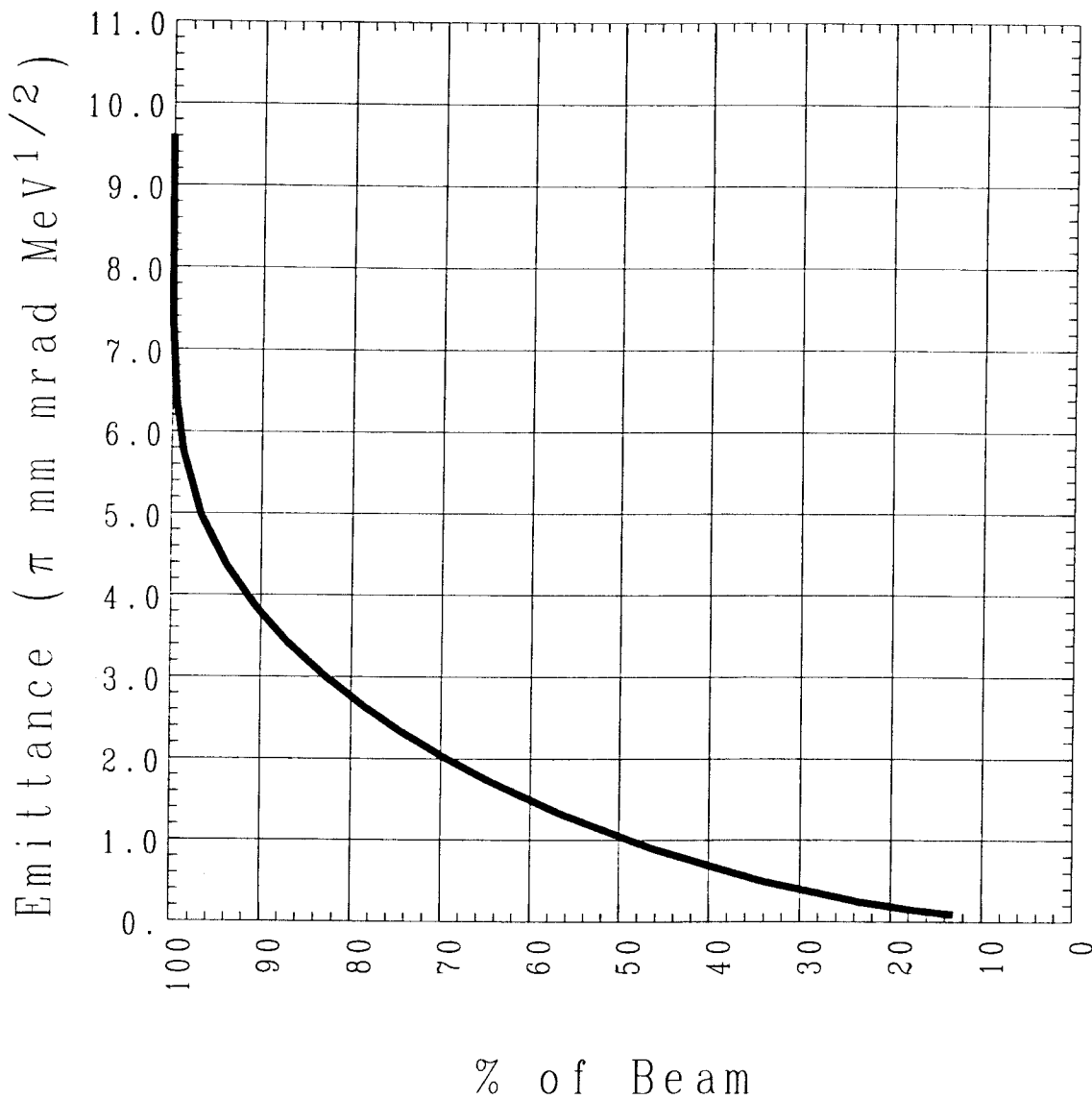


Figure 3.

Brightness Contours

2.97 mm Aperture 2.0 kV Cathode

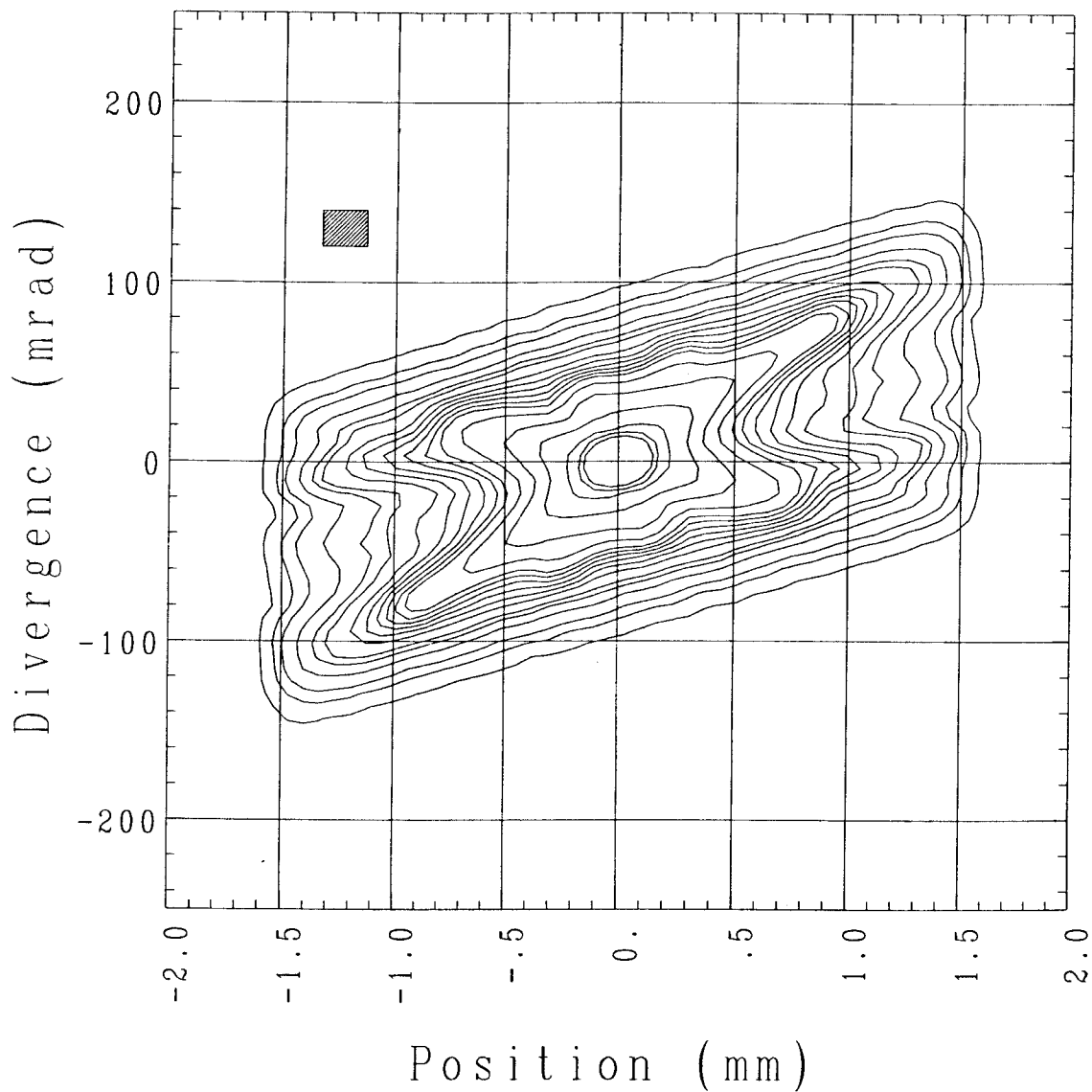


Figure 4.

Emittance vs. Cathode Voltage

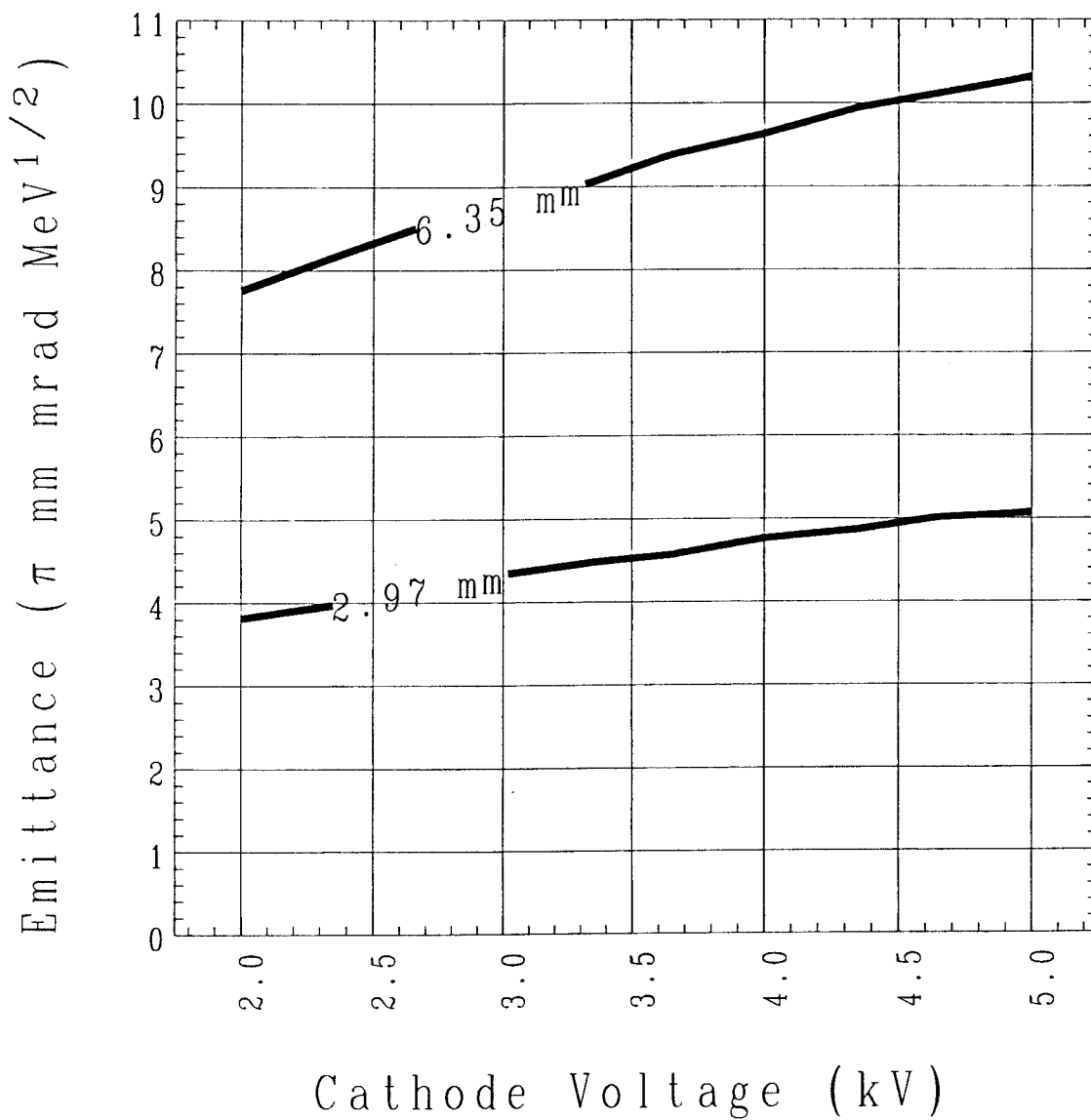


Figure 5.

Current vs. Cathode Voltage

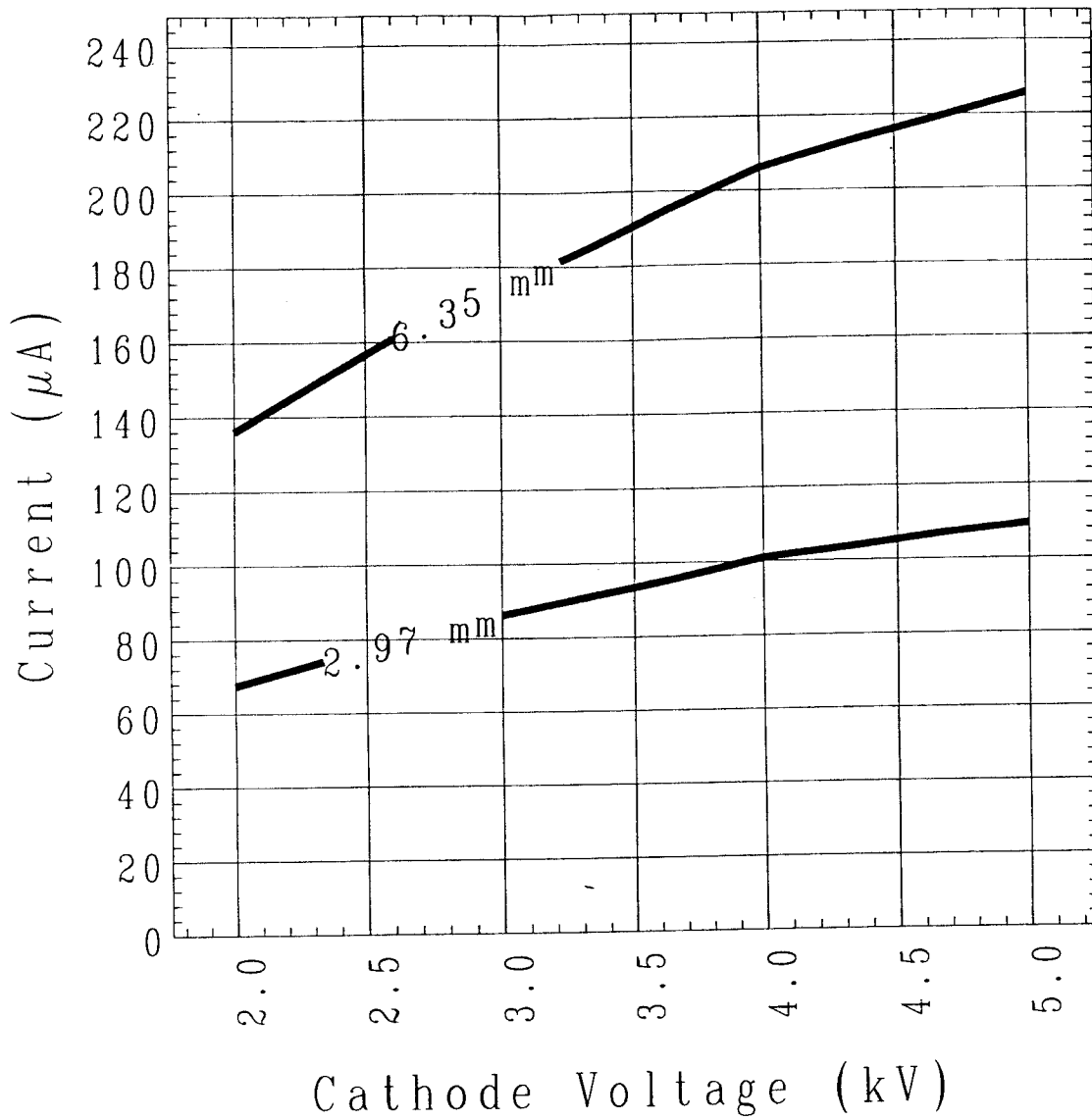


Figure 6.

Brightness vs. Cathode Voltage

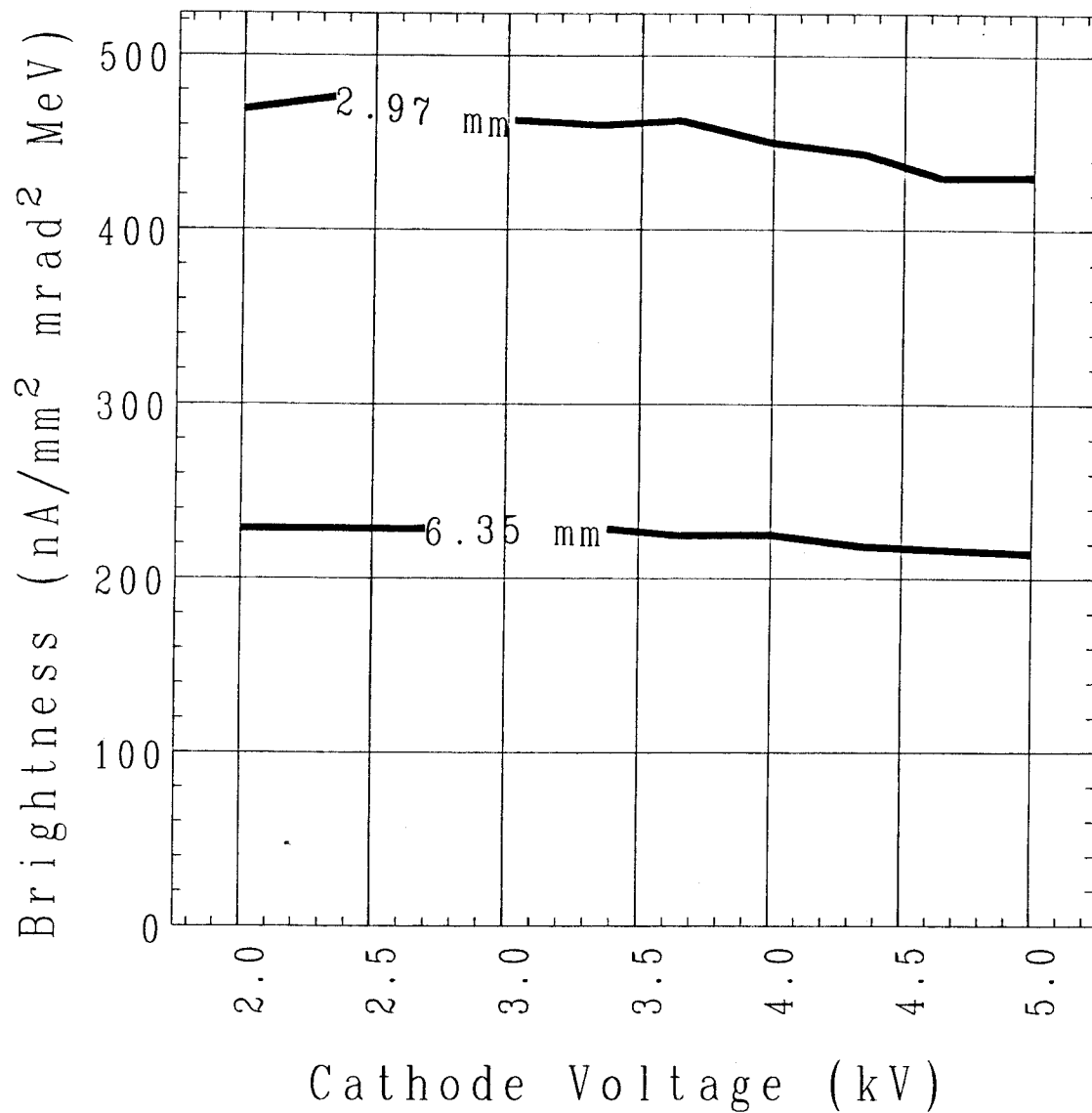


Figure 7.

90% Emittance vs. Diameter

5.00 kV Sputter Cathode

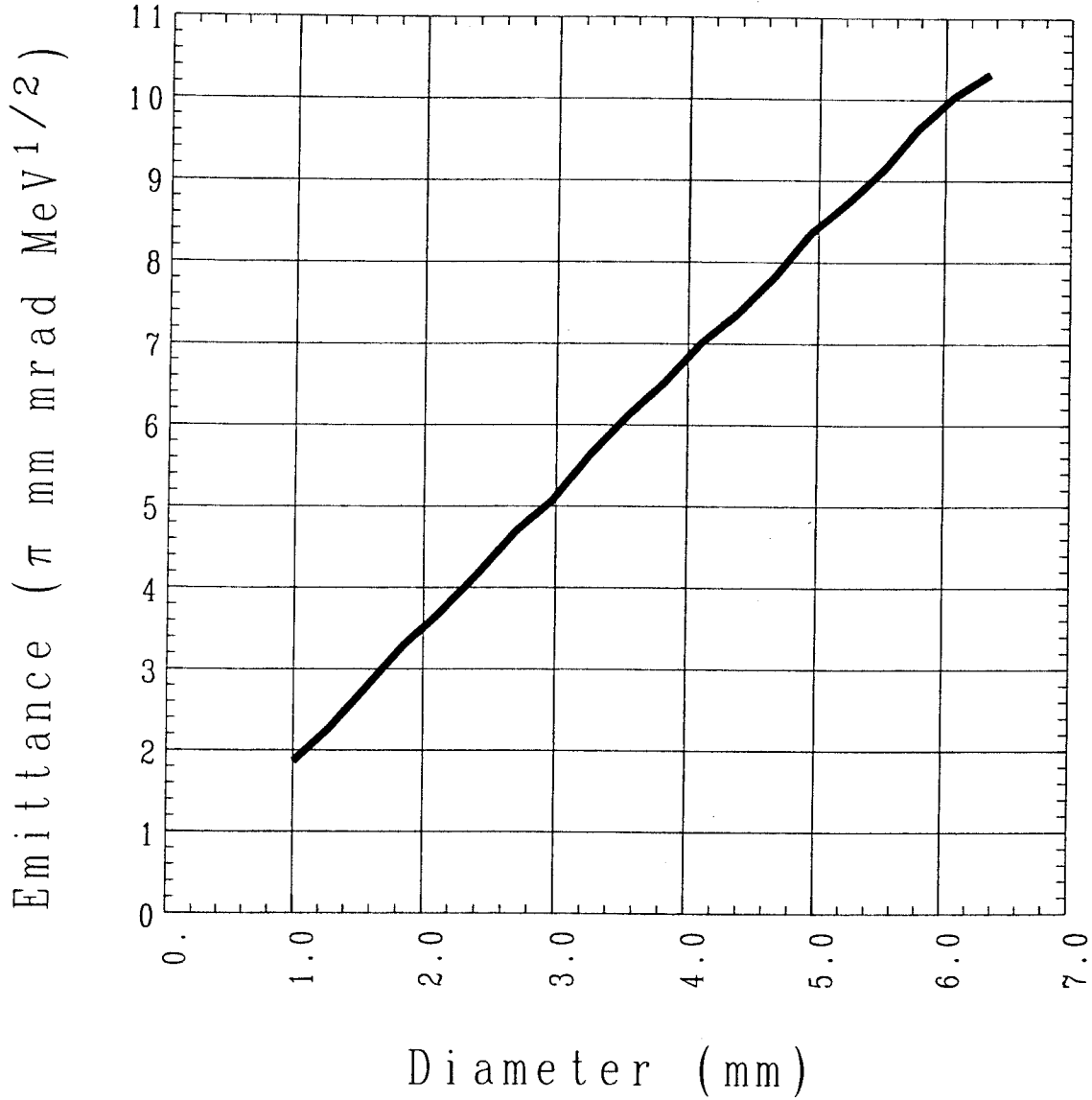


Figure 8.

90% Brightness vs. Diameter

5.00 kV Sputter Cathode

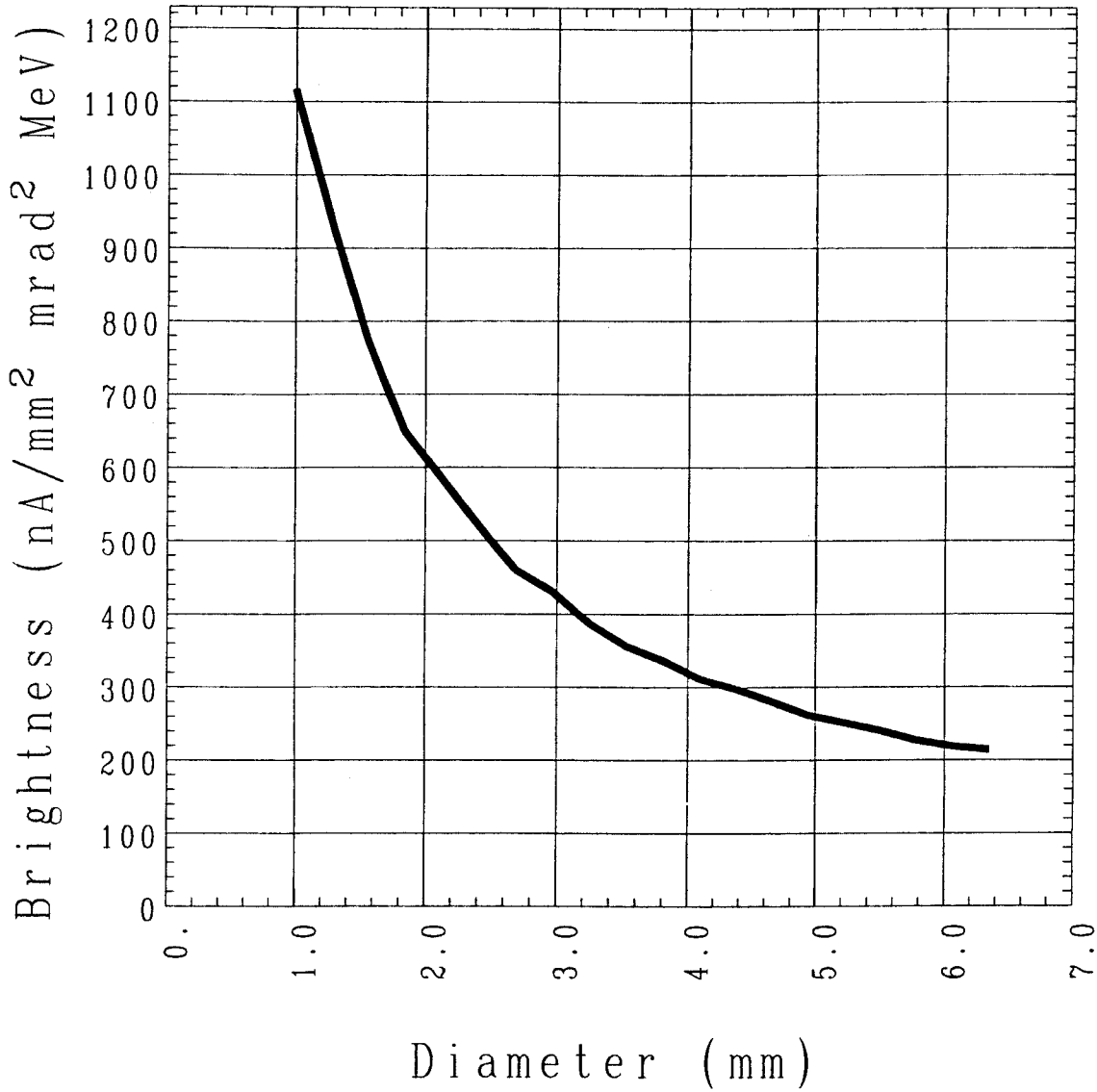


Figure 9.