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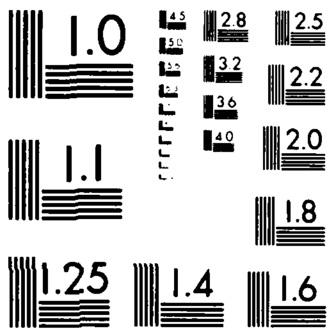
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IMPROVED ELECTRON EMISSION BY USE OF A CLOTH FIBER CATHODE

October 1984

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B. E. Simpkins
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Prepared for: Air Force Office of Scientific Research
Physics Directorate
Bolling Air Force Base
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and

Air Force Weapons Laboratory
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Intense electron beams are usually produced by applying a strong electric field (> 400 kV/cm) to the surface of a suitable material.[1,2] In a number of applications of intense, pulsed beams, such as Free Electron Lasers (FELs), microwave generation and collective ion acceleration, good uniformity is desirable. In addition, there are many applications such as laser pumping and microwave generation where it is useful to produce pulsed electron beams at relatively low potentials (20-50 kV) and high currents (.2-10 kA).

In this note we present data which demonstrates that cloth fiber cathodes can have superior properties as cold cathode emitters. The specific material we used is a 12/cm × 12/cm array of tufts, each composed of approximately 40, 75% rayon, 25% silk, 10-20 μm diameter, 1 mm long fibers. Each fiber is oriented approximately perpendicular to the cloth substrate. The substrate is, in turn, attached to a stainless steel base using a thin layer of epoxy. This material is easily obtained at any cloth store at a nominal cost.

We first tested this type of cathode in a low voltage microwave generator of the virtual cathode/reflexing electron type (Vircator).[3] Although the voltage was relatively low, (approximately 40 kV matched), high current densities (200 A/cm^2) were still required for efficient microwave generation. From Child-Langmuir space-charge limiting current considerations, these values imply an anode-cathode gap of approximately .3 cm. We investigated several other types of cathodes, including smooth carbon cathodes and carbon fiber tuft cathodes.[4] The cloth fiber cathodes were found to have much superior turn-on times and uniformity. Smooth carbon cathodes tested did not emit uniformly at any time before the anode-cathode gap actually shorted due to plasma effects. A comparison of cathode performance indicated that for a pulse with a 30 ns voltage rise time, the carbon tuft cathode had a 60 ns risetime, while the cloth fiber cathode had a 30 ns rise. Clearly, cathode performance was superior for the cloth both in terms of turn-on time and gap closure. In fact, gap closure velocities of less than 1 cm/μsec (as opposed to the usual 2-3 cm/μsec) have been observed for small (0-5 mm) gaps, using the cloth cathodes. Voltage and current signals for a 5 mm A-K gap are shown in Fig. 1. The effective gap spacing ($V^{3/4}/I^{1/2}$) and impedance are shown as a function of time in Fig. 2.

The uniformity of electron emission was investigated at low voltage (approximately 30 kV) where it is expected to be poor. We found that the current density was uniform to ±10% over the central portion of a 2 cm diameter cathode, with better than ±10% reproducibility. Enhanced currents were observed due to field enhancements at the cathode edges. The global reproducibility is excellent as shown in the 50 shot overlay of Fig. 3.

A 40,000 shot, 6 Hz lifetime run was made at 30 kV, 3 mm gap spacing, and with a 1.27 cm diameter rounded cathode. Data from t = 3 minutes (shot 1100) and t = 45 minutes (shot 17,000) is shown in Fig. 3. A slight increase in current and decrease in reproducibility is noted in the second trace, but, in general, the performance of the cathode is about the same. Clearly the cathode is emitting no less current after 18,000 shots than after 1100 shots.

Measurements made by Lawrence Livermore National Laboratory on a cathode made with material we supplied, indicated an increase of at least a factor of 7 in beam brightness with a cloth cathode when compared to a carbon tuft cathode.[5] This results because of the improvements in uniformity which we observed.

We believe that the improved properties of cloth fiber cathodes occur due to both the large number of field enhancement points on the fibers, and the non-conducting nature of the material. Because the fibers are initially non-conducting (they were also found to be non-conducting after 40,000 shots), surface flashover along the fibers must play a role in cathode plasma production. Charge builds up on the end of each fiber, and this gives rise to a breakdown process which is ballasted because the individual fibers and fiber tufts are separated.

Other effects may contribute to the slow gap closure velocity. For extremely small gaps (< 2 mm), the effective emission surface appears, based on measured current and voltage, to be below the top of the cloth fibers. Plasma produced by surface flashover below the surface of the material will approach temperature equilibrium with the fibers, resulting in temperatures much lower than the 1-2 eV typical of cathode plasmas.

Use of this material was essential in achieving pulsed microwave generation with our low voltage accelerator, and we suggest that it will find utility in a variety of electron beam experiments.

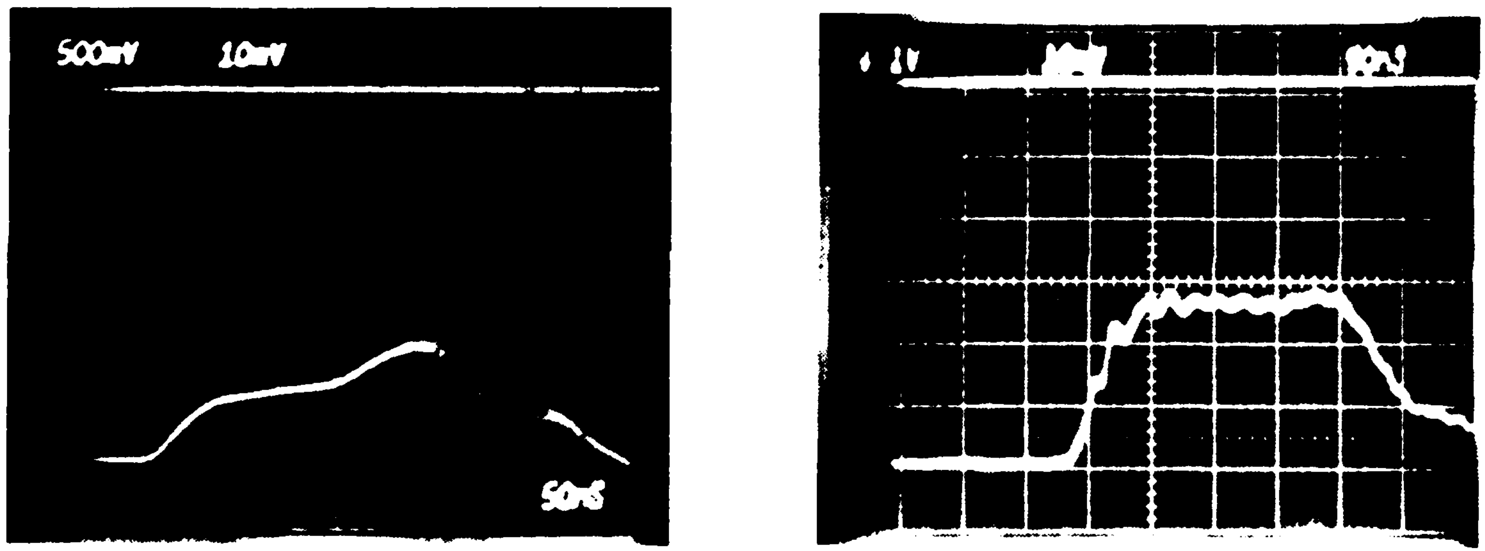


Figure 1. a) Diode current (690 A peak) and b) diode voltage (35 kV peak) for a .5 cm A-K gap, .9 cm radius cathode diode.

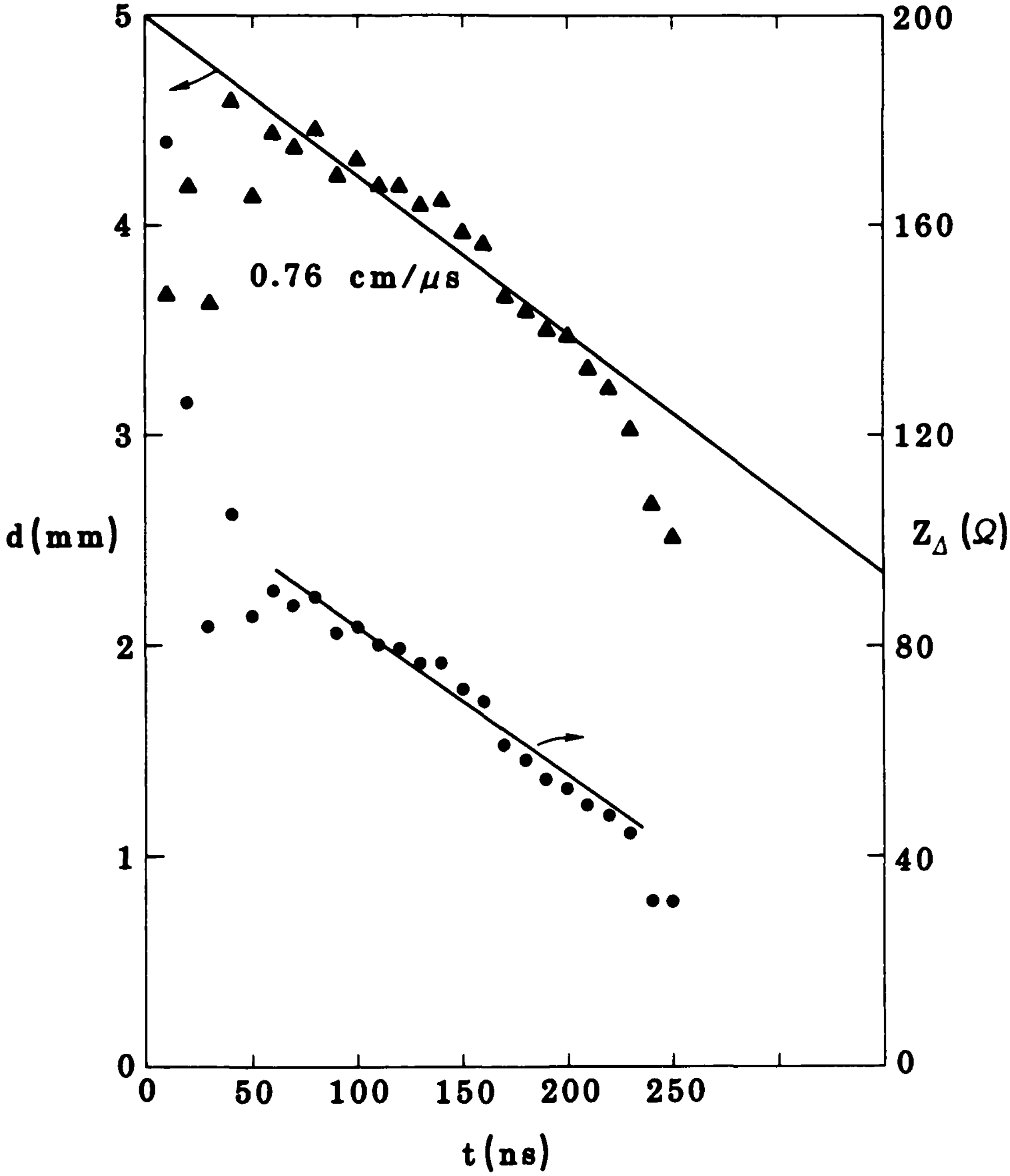
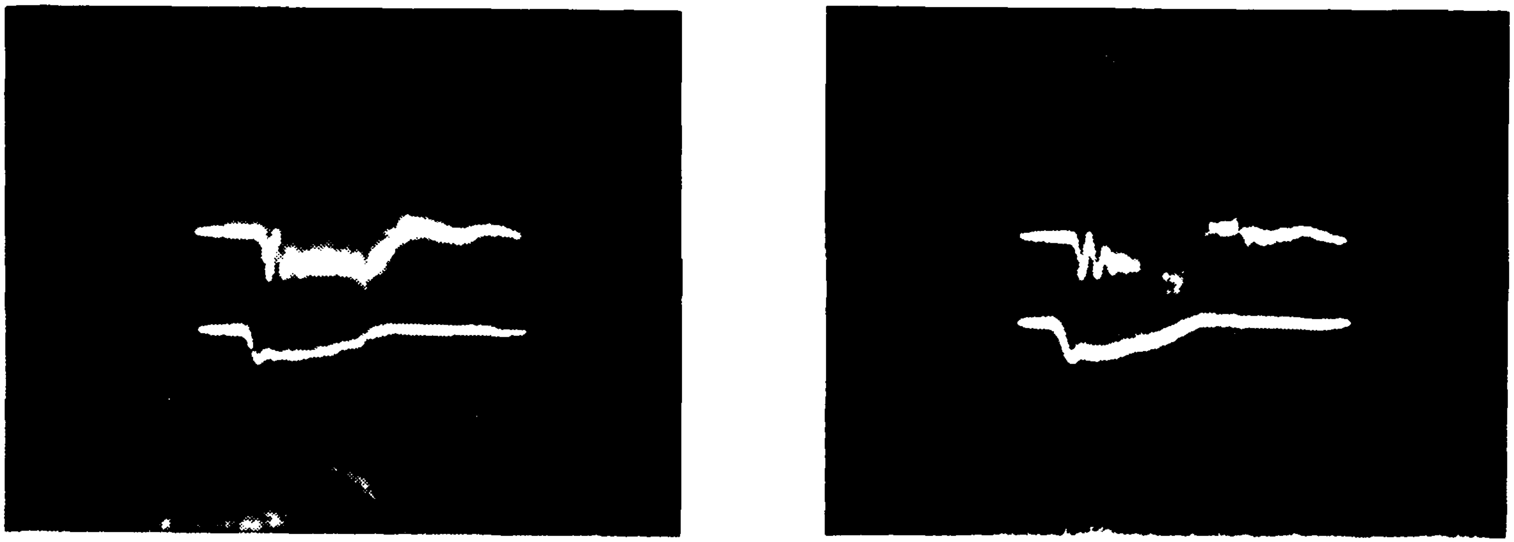


Figure 2. Effective anode-cathode gap and diode impedance for the data of Fig. 1.



3(a) 3(b)

Figure 3. a) 50 shot overlay of current (upper, max 200 A) and voltage (lower, max 22 kV) for shot number 1100. b) same as above for shot 17,000.

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