PFC/CP-85-7

CONF-850956--12

DE86 001112

Beam Brightness From a Relativistic, Field-Emission Diode With a Velvet Covered Cathode

Bekefi, G., Shefer, R.E., and Tasker, S.C.

August 1985

Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139 USA

This work was supported by the Lawrence Livermore National Laboratory Subcontract 6264005, the Air Force Office of Scientific Research Grant AFOSR-84-0026, and by the National Science Foundation Grant ECS-8213485.

Paper presented at: Seventh International Free Electron Laser Conference, September 8-13, 1985, Tahoe City, California

BEAM BRIGHTNESS FROM A RELATIVISTIC, FIELD-EMISSION DIODE WITH A VELVET COVERED-CATHODE*

G. BEKEFI, R.E. SHEFER,[†] and S.C. TASKER

Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Abstract

The beam emittance and brightness from a mildly relativistic (200-400 kV) high current density (0.5-3.5kA/cm^2) planar, field emission diode provided with a velvet covered cathode have been studied experimentally as a function of the applied electric field (100-600kV/cm). Transverse beam spreading has been measured using a conventional pinhole arrangement followed by a fluorescent screen and open shutter camera. Good turn-on, and a high normalized beam brightness ($B_n \simeq 300$kA/cm^2-rad^2) have been observed. The results are compared with those obtained with a graphite cathode.

*This work is supported by the Lawrence Livermore National Laboratory, the Air Force Office of Scientific Research and by the National Science Foundation.

[†]Present address: Science Research Laboratory, Inc., 15 Ward St., Somerville, Massachusetts 02143.

1. Introduction

Relativistic electron beams with high current densities and low temperatures are a prerequisite for the successful operation of various devices including accelerators and free electron lasers (FEL's) and other sources of coherent radiation employing electron beams. If high radiation powers are also a requirement, high currents in addition to high current densities are necessary.

Beam brightness is a useful measure of beam quality. For example, the gain of a free electron laser operating in the low gain Compton regime is directly proportional to beam brightness. In an earlier paper [1] we have shown that high beam brightness can be achieved from an electrostatically focused, multistage field emission electron gun which produces a 1.1kA, 2.0 MV electron beam with a normalized emittance of 38×10^{-3}(π cm-rad) and a normalized brightness of 74kA/cm^{2}rad^2. The good beam characteristics are due in part to the choice of appropriate cathode material (reactor grade graphite) and in part to the large electric field ($\sim$650kV/cm) applied between the cathode and the first accelerating anode. Lower fields and other cathode materials tested produce a poorer electron beam [1].

Until our acquaintance with velvet cathodes [2], previous studies have shown that reactor-grade graphite surpasses many other materials [1]. Pressent tests indicate that, while reactor graphite approaches the performace of velvet at high applied electric fields ($E\gtrsim500$kV/cm), it does less well at low E ($\lesssim200$kV/cm). In this range this manifests itself as poor shot-to-shot reproducibility, low currents, and a larger beam emittance (as was also noted in Ref. [1]). In section 2 of this paper we describe the experimental arrangement and we summarize the results. In section 3 we discuss the observations and compare them with previous studies.

2. Experimental Results

The experimental setup is shown in Fig. 1. The Nereus accelerator (100-500kV; 50kA; 30ns) is used to energize a parallel plate diode with a variable (0.6-2cm) anode-cathode gap d. The electric field E applied to the cathode is varied by changing d.

The cathode plate is a thick aluminum disk with a cylindrical hole in the center, allowing the insertion of a plug of emitting material. The entire surface of the cathode, with the exception of the emitting area, is anodized [1] to minimize undesired emission. The hard aluminum oxide (anodized) coating has a thickness of 0.05mm.

The diode voltage is measured with a voltage divider and the total current I with a Rogowski coil placed around the shank leading to the Nereus accelerator. The average current density J is obtained from the measured value of I and from the known area of the emitting surface ($12.6cm^2$). A more accurate determination of J is obtained by placing a current viewing resistor behind the anode plate pierced with four pinholes each 0.10cm in diameter. Figure 2 shows the current density and diode impedance as a function of the applied electric field E, defined as the accelerator voltage V/anode-cathode gap distance d. The current density exceeds that predicted by Child-Langmuir electron flow, in agreement with earlier studies [3]. We note that over the range of d values used ($0.6<d<2cm$), V remains nearly constant.

The emittance is measured [1,4,5] by allowing the electron beam to impinge on an array of 9 pinhole apertures in a 0.0381cm thick stainless steel disc. The apertures, each 0.0254cm in diameter are separated by a distance of 1.27cm in a 3×3 square pattern. The transmitted beamlets are then allowed to traverse a field free region 5cm in length before they strike a thin (0.4 mm) aluminum target which is coated on the downstream side with ZnS scintillator (see Fig. 1). An open shutter camera photographs the scintillating screen.

Figure 3 shows how the spreading angle $\delta\theta$ (see Fig. 1), the normalized emittance ε_n and normalized brightness B_n vary with the applied electric field E. Here $\delta\theta$ is the corrected [6] half width at half maximum of the intensity profile of the center spot on the photographic film. The normalized emittance $\varepsilon_n = \beta\gamma A/\pi$ is calculated using the phase space area A occupied by 90% of the beam electrons, as discussed in Ref. [1]; and the normalized brightness is defined [1] as $B_n = I/\pi^2\varepsilon_n^2$. In the units used here the empirical Lawson-Penner condition, which may be used for purposes of comparison, gives a brightness of 1.1kA/cm^2-rad^2.

In Fig. 3 we also compare $\delta\theta$ and ε_n from a cathode covered with velvet composed of predominantly synthetic fiber (low conductivity material), with $\delta\theta$ and ε_n for a cathode covered with pure cotton velvet (higher conductivity material). We see that the latter produces a somewhat lower emittance beam.

The same measurements as those made on velvet cathodes shown in Figs. 2 and 3 were also carried out on cathodes made from reactor grade graphite. The results are illustrated in Figs. 4 and 5. We see that at low applied electric fields, the current density is low and the scatter in the measurements of $\delta\theta$ (and ε_n) is larger than for velvet cathodes. When $E \sim 150$kV/cm, one finds (data not shown) that $\delta\theta$ increases by a factor of two to three (see also Ref. [1]).

3. Discussion

We have investigated the emittance and brightness of a planar, field emission diode operating at high current densities. Use of velvet as the cathode emitting surface gives good performance over the entire range of applied electric fields studied ($100 \leq E \leq 575$kV/cm). The good qualities are exemplified by good shot-to-shot reproducibility of the current, voltage, and $\delta\theta$ even at low applied electric fields. A high beam brightness is achieved. There appears to be little difference between the performance of synthetic velvet and cotton velvet, although cotton velvet exhibits a slightly lower emittance. The performance of reactor grade graphite cathodes is poor at low applied electric fields ($\sim$100-200kV/cm), but approaches the performance of velvet cathodes at high electric fields ($E \sim 500$kV/cm).

Figure 6 compares the beam brightness from our planar diode (the solid and dashed lines) with other systems. The present data shown by lines and the data shown by solid dots refer to electron guns subjected to zero or very weak axial magnetic fields. The squares refer to immersed guns in which the entire assembly including the cathode are subjected to very strong guide fields ranging from 5 to 90kG. We see from Fig. 6 that, contrary to earlier belief [7], nonimmersed guns do as well, if not better, than immersed guns.

The fact that B_n of Figs. 3 and 6 increases approximately linearly with J reflects the fact that the normalized emittance is but weakly dependent on J, a fact which has been pointed out in Ref. [7] in regard to magnetic field immersed guns. It is noteworthy that similar behavior also occurs for the case of field-free guns, as is attested by the present experiments.

References

[1] D.A. Kirkpatrick, R.E. Shefer, and G. Bekefi, J. Appl. Phys. 57, 5013 (1985).

[2] R.J. Adler, G.F. Kiuttu, B.E. Simpkins, D.J. Sullivan, and D.E. Voss, Mission Research Corporation, Albuquerque, New Mexico, Report No. AMRC-N-275 (1984).

[3] D.W. Swain, S.A. Goldstein, L.P. Mix, J.G. Kelly, and G.R. Hadley, J. Appl. Phys. 48, 1085 (1977).

[4] C. Lejeune and J. Aubert, in Applied Charged Particle Optics, edited by A. Septier (Academic, New York, 1980), Part A, pp. 159-259.

[5] B. Kulke and R. Kihara, Lawrence Livermore National Laboratory Preprint No. UCRL-82533 (1979); J.G. Kelly and L.P. Bradley, Sandia National Laboratory Report No. SC-RR-720058 (1972).

[6] The correction is for electron "lensing" that occurs in the pinhole apertures caused by curvature of the equipotential lines in the apertures (see G.R. Brewer in "Focusing of Charged Particles", A. Septier, editor (Academic Press 1967, p. 35)). The correction does not exceed 10% of the measured $\delta\theta$. In addition to the spreading angle $\delta\theta$, we have also measured the mean deflection angle θ (see Fig. 1). We find that there is a slight pinching within the diode, $\theta \simeq -5°$.

[7] C.W. Roberson, to be published in IEEE J. Quantum Electronics Special Issue on Free Electron Lasers; also, Proc. Soc. Photo-Opt. Int. Eng. 453, 320 (1983).

[8] A. Sessler and D. Prosnitz, Lawrence Livermore National Laboratory ELF

Note No. 114P (1984).

[9] M.L. Sloan and H.A. Davis, Phys. Fluids 25, 2337 (1982).

[10] R.H. Jackson, S.H. Gold, R.K. Parker, H.P. Freund, P.C. Efthimion, V.L. Granatstein, M. Herndon, A.K. Kinkead, and J.E. Kosakowski, IEEE J. *Quantum Electron.* QE-19, 346 (1983).

[11] R.L. Sheffield, M.D. Montgomery, J.V. Parker, K.B. Riepe, and S. Singer, J. Appl. Phys. 53, 5408 (1982).

Figure Captions

Fig. 1. Schematic drawing of the emittance test stand.

Fig. 2. Current density and diode impedance as a function of the applied electric field for velvet cathodes. The lines represent the best-fit curves.

Fig. 3. Spreading angle $\delta\theta$, normalized emittance ε_n, and normalized brightness B_n as a function of applied electric field. ● ● synthetic velvet; ■ ■ cotton velvet. The lines are the best-fit curves.

Fig. 4. Current density and diode impedance as a function electric field for a reactor grade graphite cathode. The lines are the best fit curves.

Fig. 5. Spreading angle $\delta\theta$, ε_n and B_n as a function of applied electric field for a reactor grade graphite cathode. The lines are the best fit curves.

Fig. 6. Comparison of beam brightness of various systems as a function of current density. Squares refer to magnetic field-immersed guns for ARA [9]; NRL [10]; LANL [11]. The lines labelled MIT refer to the present experiment and solid dots refer to MIT [1] and LLNL [8], all which represent nonimmersed guns. The MIT [1] point is referred to the current density at the cathode. The solid line is for synthetic velvet; the dashed line for reactor graphite.

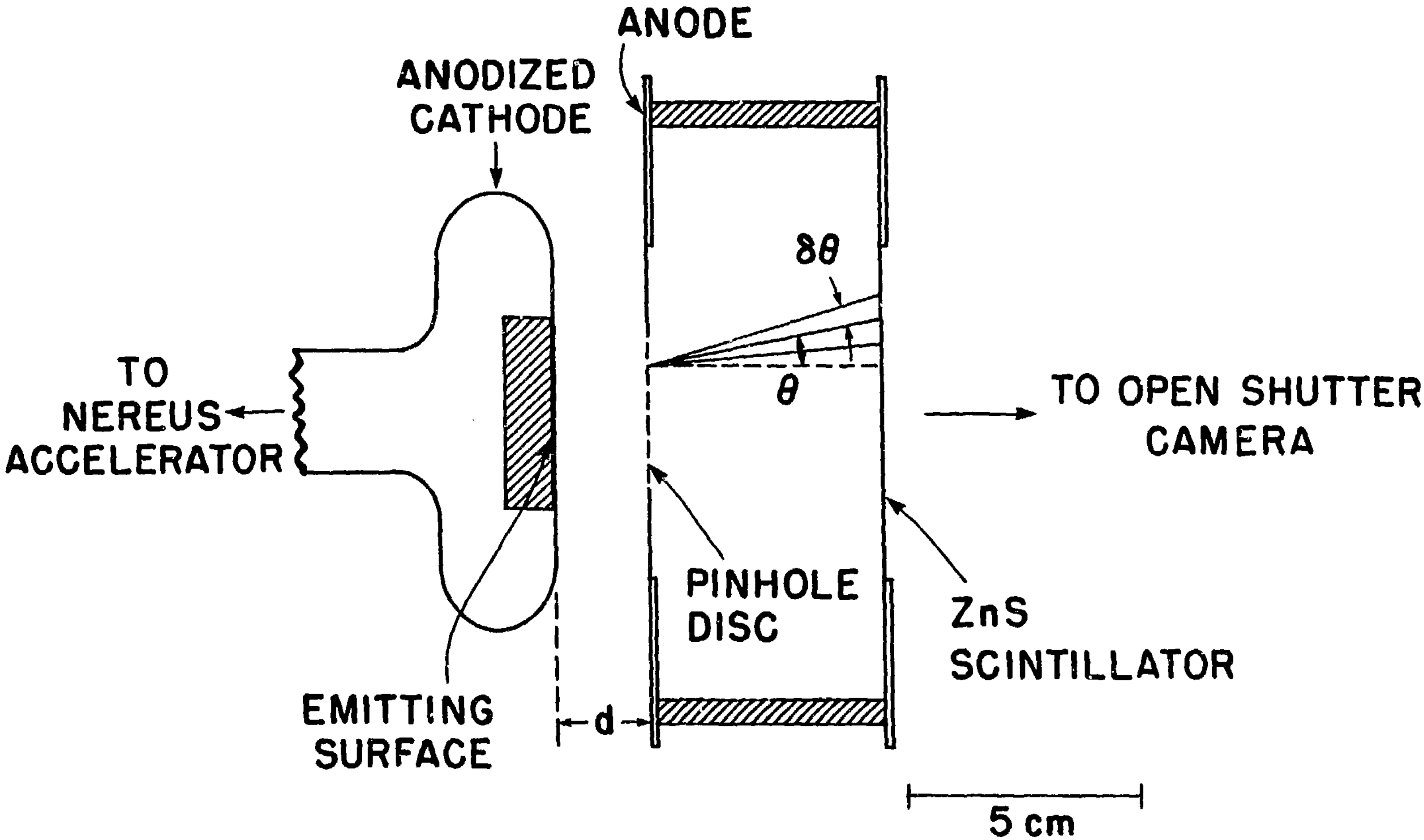

Fig. 1
Bekefi, Shefer, Tasker

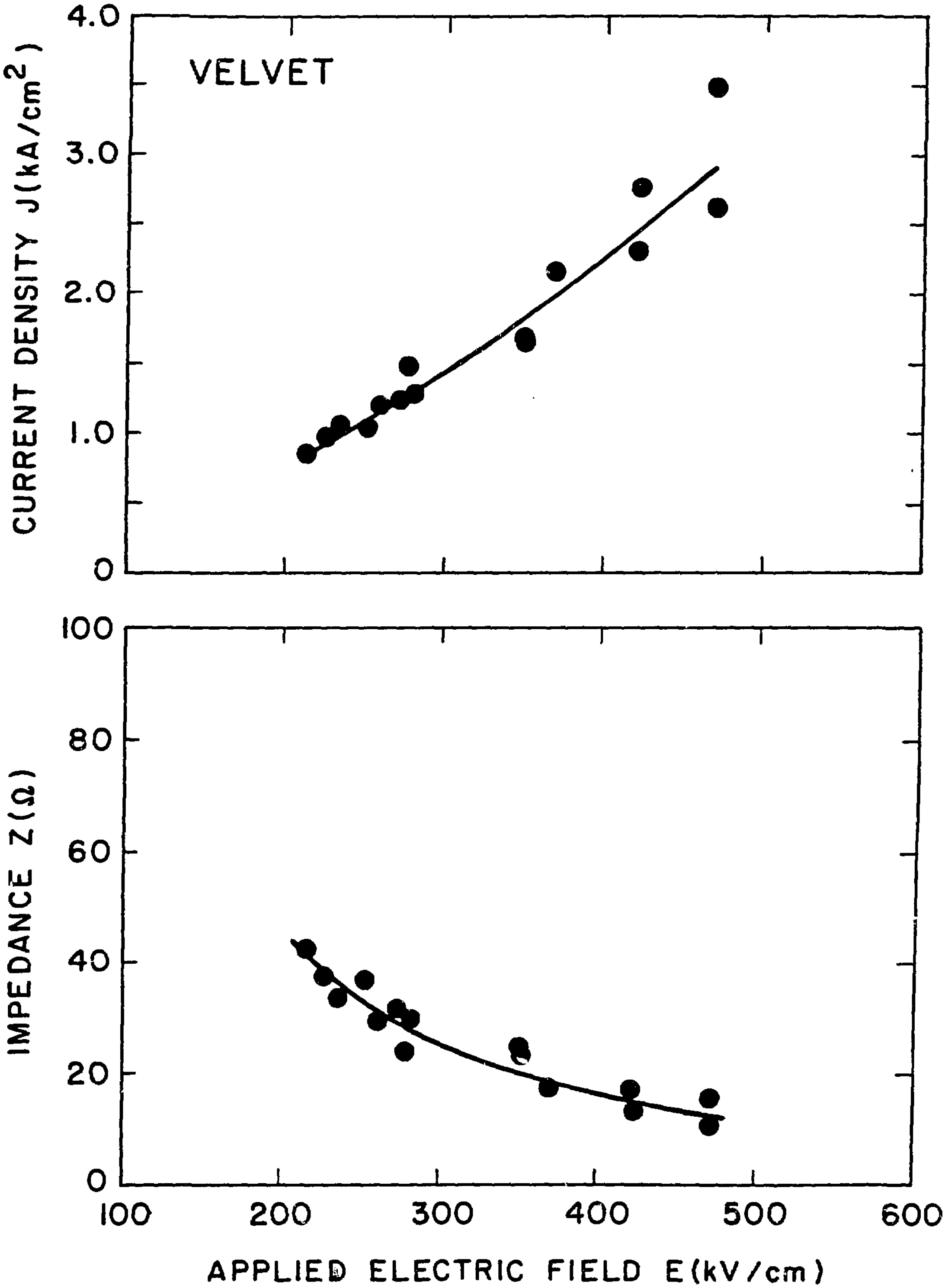

Fig. 2
Bekefi, Shefer, Tasker

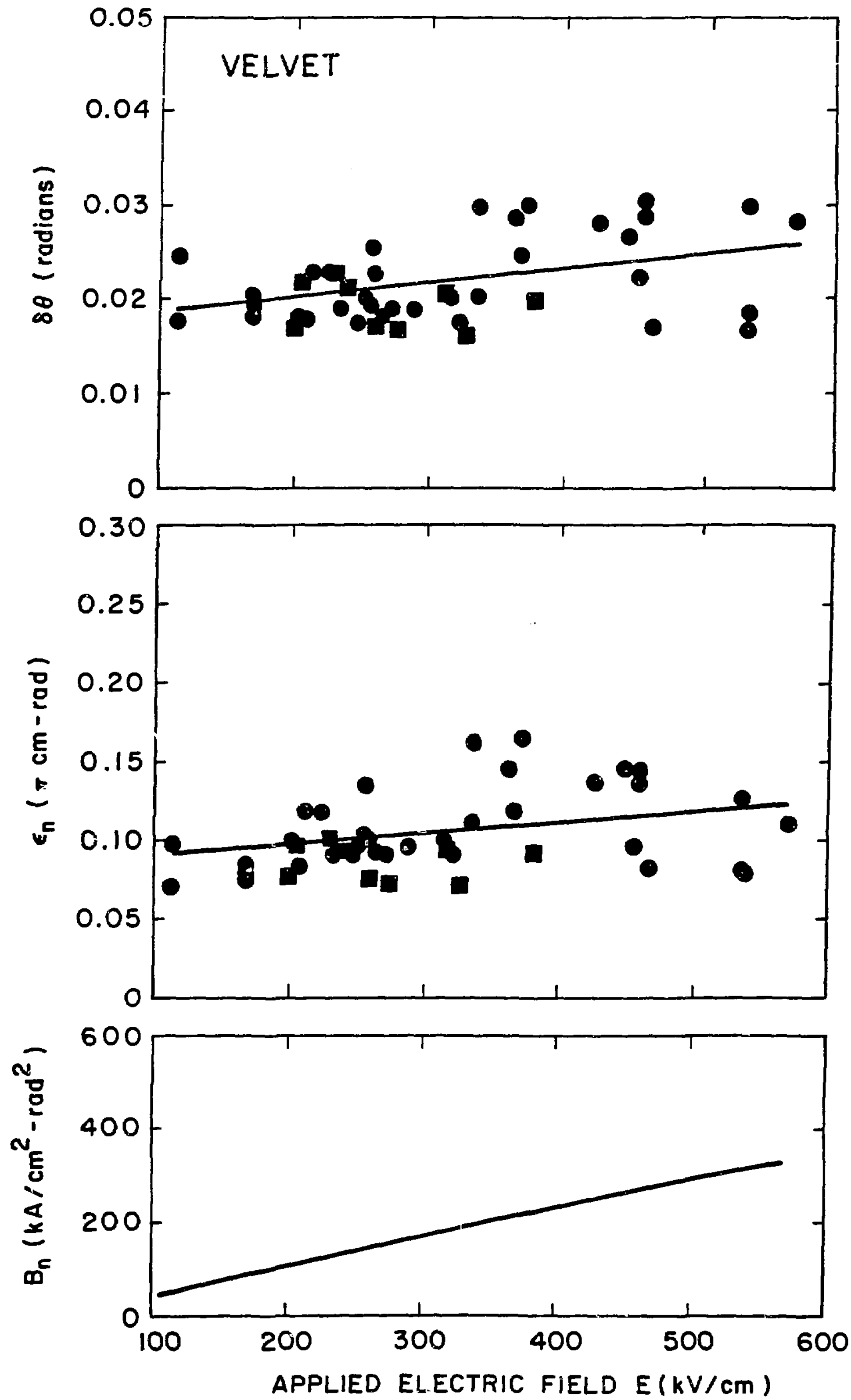

Fig. 3
Bekefi, Shefer, Tasker

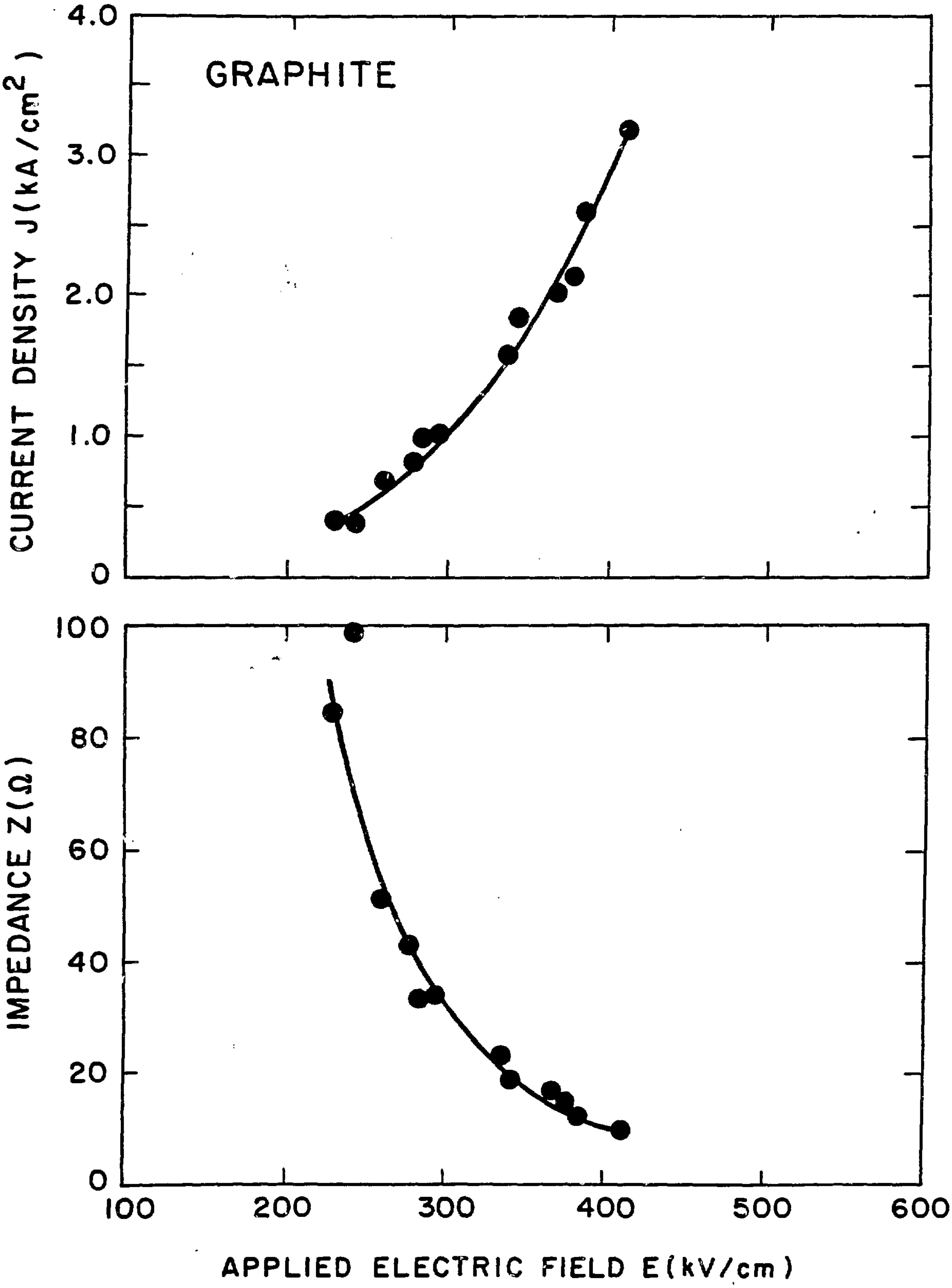

Fig. 4
Bekefi, Shefer, Tasker

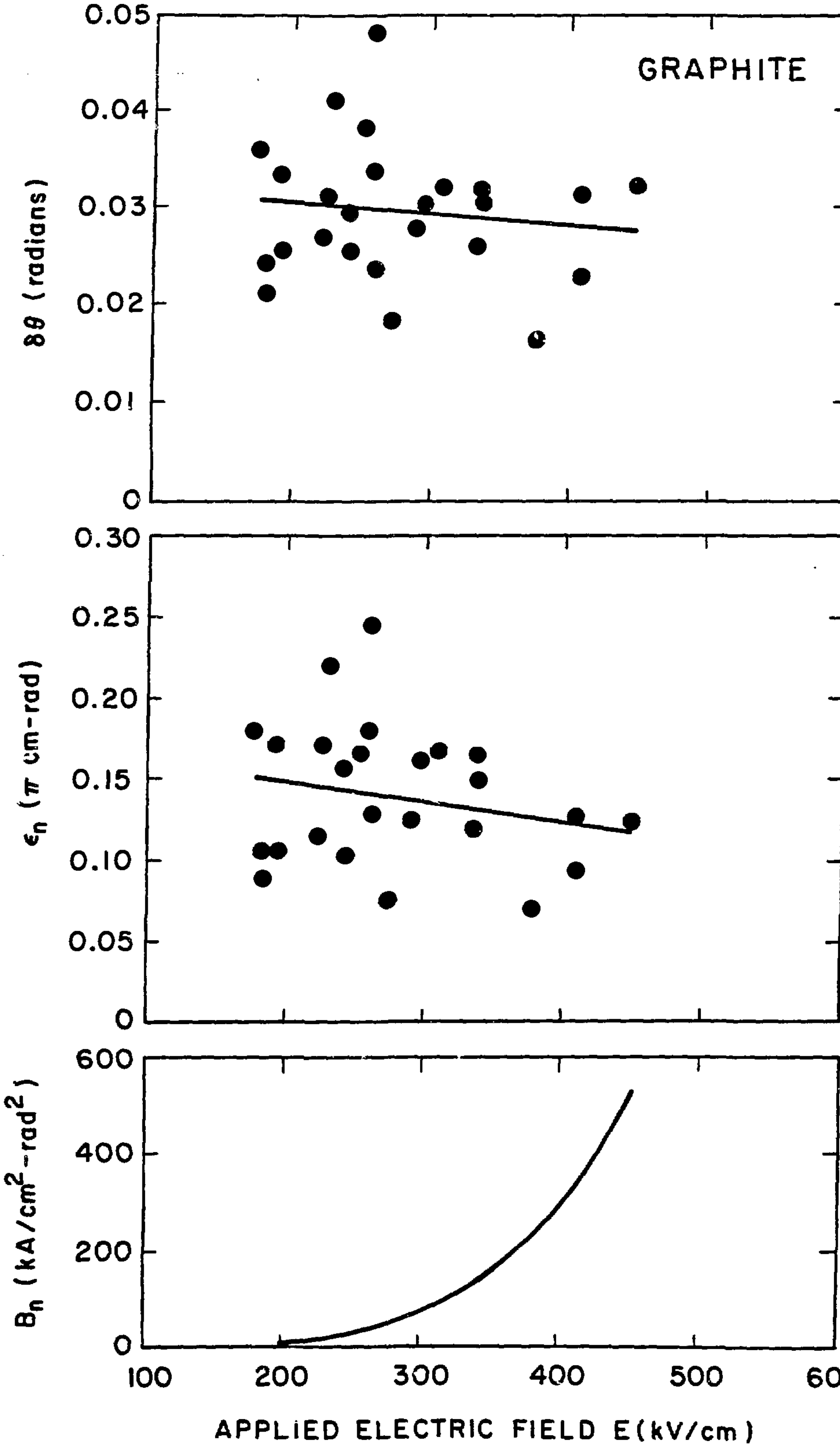

Fig. 5
Bekefi, Shefer, Tasker

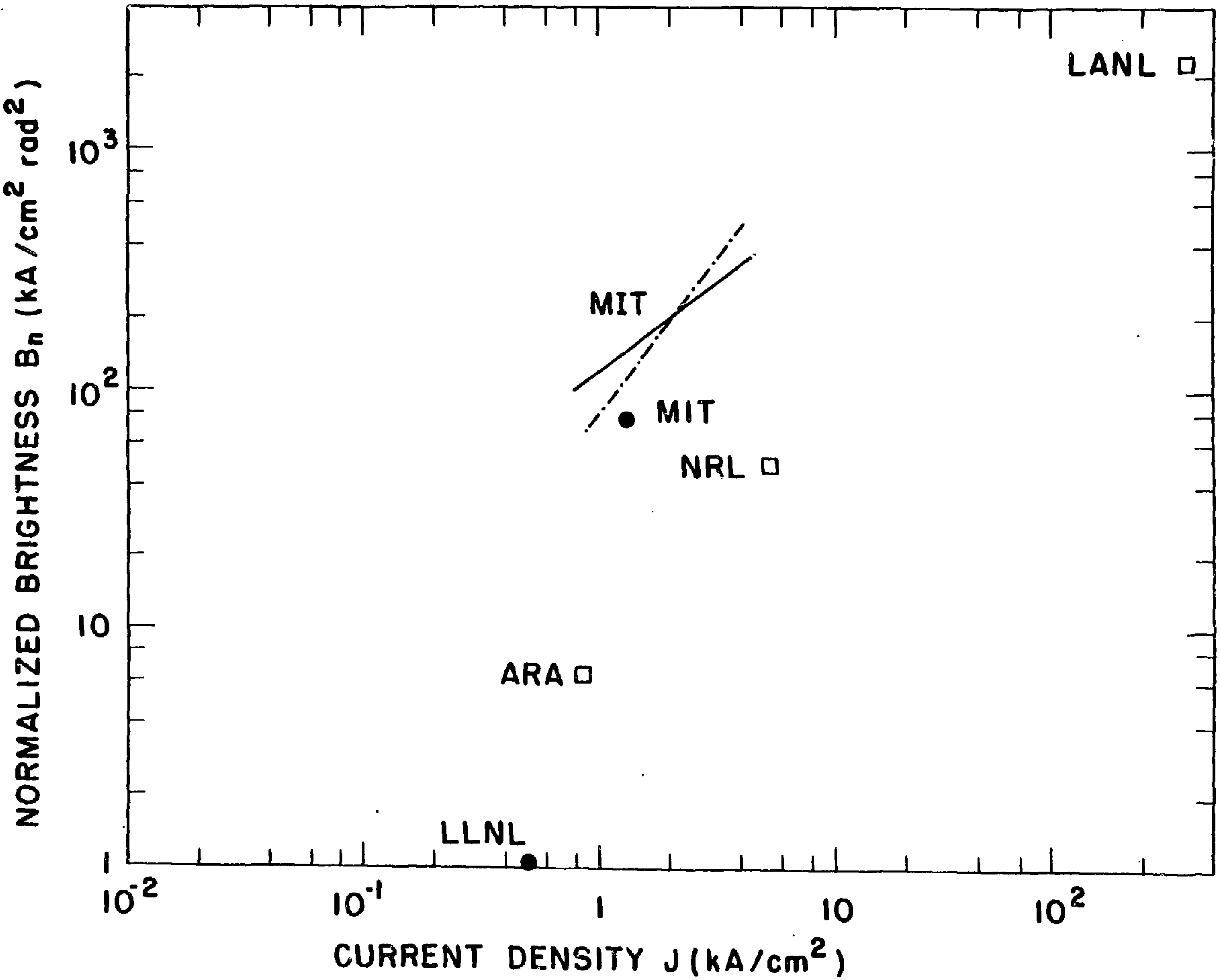

Fig. 6
Bekefi, Shefer, Tasker