RELATIVISTIC FIELD EMISSION DIODES IN FREE ELECTRON RAMAN LASERS

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ABSTRACT

Foil and foilless field emission diodes (current ~10kA, voltage ~1.5MeV) used in free electron Raman lasers are studied experimentally with the view of reducing the perpendicular temperature of the emitted beam. Removal of the outer portions of the beam leads to significant improvement in its quality.

Computer simulations[1,2] of relativistic electron beams generated by field emission diodes show that the quality of the beams do not meet the requirements[3] for efficient stimulated Raman scattering in present day, high current, free electron lasers.[4-9] In particular, one finds[1,2] that electrons emitted from cathode regions where the diode electric and magnetic fields are not parallel, introduce in the beam undesirable transverse energy (temperature). In this letter we describe an experimental study of electron beams produced by foil[10] and foilless[11] field emission diodes (current ~1-10kA, voltage ~1.5MeV) of the type illustrated in Fig. 1. We show that removal of the outer "hot" electrons by means of metal apertures leads to a significant improvement in the beam characteristics.

The experimental arrangement is illustrated in Fig. 1. The diode is energized by the Pulserad 110A Physics International accelerator (voltage 1.5MeV, current 20kA, pulse duration 30nsec). The ensuing beam propagates down an evacuated stainless steel drift tube 2cm ID and 70cm long, immersed in a uniform guiding magnetic field of ~10kG. After passage through the solenoid, the beam is allowed to expand in the fringing magnetic field and is collected on the drift tube walls. The field emission diodes illustrated in Fig. 1 are likewise situated in the uniform solenoidal magnetic field. They are comprised of a graphite cathode and a single accelerating anode. In the foil diode, the anode is a 0.5mil thick titanium foil stretched perpendicular to the axis; in the case of the foilless diode, the anode is a coaxial stainless steel cylinder. Provisions are made for inserting stainless steel limiting apertures of various radii in front of the diode structures. Measuring the drift tube current as a function of aperture size allows us to unfold the radial current density profile of the electron beam. We see from Fig. 2 that the foil diode produces a beam whose current density profile is peaked on axis, whereas the foilless diode produces an annular beam with the highest current density at a radius corresponding to the cathode radius. This is in qualitative agreement with the results of computer simulations.

Microwave radiation emenating from a conical horn antenna attached to the drift tube (see Fig. 1) is used as the beam diagnostic. The presence of the microwave radiation is attributed to a cyclotron[12,13] type of instability in the beam and is thus an indicator of transverse energy in the beam electrons (there is no pump in our experiments to drive stimulated Raman or Compton scattering). The detection apparatus[14] shown schematically in Fig. 1 consists of calibrated crystal diodes and a dispersive line capable of measuring the power and spectral characteristics of the radiation in the 26-40GHz frequency band. Typically, the radiation occurs at a frequency of 30GHz with a bandwidth of less than 3GHz. Its amplitude is strongly dependent on magnetic field and peaks at a field of 9kG. Power levels on the order of 1MW are detected, and these are comparable to the power levels attributed to Raman backscattering in earlier free electron laser experiments[7,8,9] which use a quasi-static magnetic "wiggler" pump. To assure ourselves that the radiation does originate in the uniform magnetic field region of the drifting electron beam, wire meshes transparent to the beam but highly reflective to the radiation, were placed in the drift tube. A mesh inserted at the diode end, as indicated in the figure, has almost no effect on the observed microwave power. But, moving the mesh to the far end of the uniform field region results in strong attenuation of the signal.

In order to study the microwave radiation from electrons emitted from different transverse locations on the cathode surface, limiting apertures of smaller and smaller radii were placed in front of the diode. In this way electrons carrying most of the transverse momentum in the beam can be removed incrementally. Figure 3 illustrates the dependence of the microwave power on aperture radius for both the foil and foilless diodes. The maximum power level for the unapertured beam corresponds to approximately 1MW. We see that the radiation drops by three orders of magnitude when the outer portion of the beam is masked off, even though there is still substantial current, more than 1kA, flowing in the drift tube. The decreased microwave emission is not simply the result of reducing the current flowing in the pipe since, for the large aperture sizes, reducing the current by a factor of three has little or no effect on the radiated power.

Another way to determine which portion of the beam is responsible for generating the microwave noise is to allow only electrons emitted near the cathode edge to propagate down the pipe. This is done by using limiting apertures with holes placed off the beam axis. The top of Fig. 4 shows the geometry of these apertures. We begin with a small aperture which passes only electrons emitted close to the axis. Then we move the aperture out to a radius close to the outer radius of the beam. We then add more apertures of the same size to allow a larger portion of the current from this outer annulus to enter the pipe. The results of using the off-center apertures with a foil diode are plotted in Fig. 4. Zero db on this scale corresponds to the peak power (~1MW) radiated by an unapertured beam. With the small aperture on center the microwave emission is decreased by about 25db with a drift tube current of 1.2kA. When the aperture is moved to the outer radius of the beam, the microwave power increases by two orders of magnitude even though the drift tube current has decreased by a factor of three. Adding more holes symmetrically about the beam axis increases the power and current approximately in proportion to the number of holes, until finally with six holes at the beam outer radius the microwave power has reached its maximum level even though less than one-third of the total beam current is allowed to enter the drift tube.

The above observations show that the intense microwave emission is generated primarily by electrons emitted at the outer radius of the cathode where cross-field flow adds transverse energy to the beam. We note, however, that the dramatic increase of microwave power with increasing aperture radius (Fig. 3) or with aperture position (Fig. 4) may be due in part to the fact that current flowing at larger radii may be more strongly coupled to an electromagnetic waveguide mode of the cylindrical drift tube. We also see that both the foil and foilless diodes used by us appear to be equally afflicted by transverse electron energy. Indeed, in a foil diode, additional transverse energy is added by electron scattering[15,16] in the foil. For example, we find that by changing from a 0.5mil to a 2.0mil thick titanium foil, the microwave noise power increases by an additional 2db, while the drift tube current decreases by approximately 10%.

In conclusion, then, intense electron beams produced in field emission diode configurations similar to those used in previous FEL experiments generate megawatt power levels of noise radiation in the absence of any pump wave. There is evidence that this radiation is generated by electrons emitted from portions of the cathode where the diode electric and magnetic fields are not parallel. It is possible to reduce the noise level and therefore the transverse energy in the beam by masking off current from these cathode regions.

ACKNOWLEDGMENTS

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CAPTIONS TO FIGURES

Fig. 1. Experimental setup. The diodes are to scale. The dashed lines are sketches of electric field lines.

Fig. 2. Measured radial current density distribution for the foil and foilless diodes of Fig. 1.

Fig. 3. Microwave radiation intensity as a function of radius for various apertures inserted in front of the diodes. The intensity is in db below 1MW. The frequency is 30 GHz, the bandwidth is <3GHz.

Fig. 4. Microwave radiation intensity as a function of the off-axis positions of various limiting apertures. The intensity is in db below 1MW. The frequency is 30GHz; the bandwidth is <3GHz.

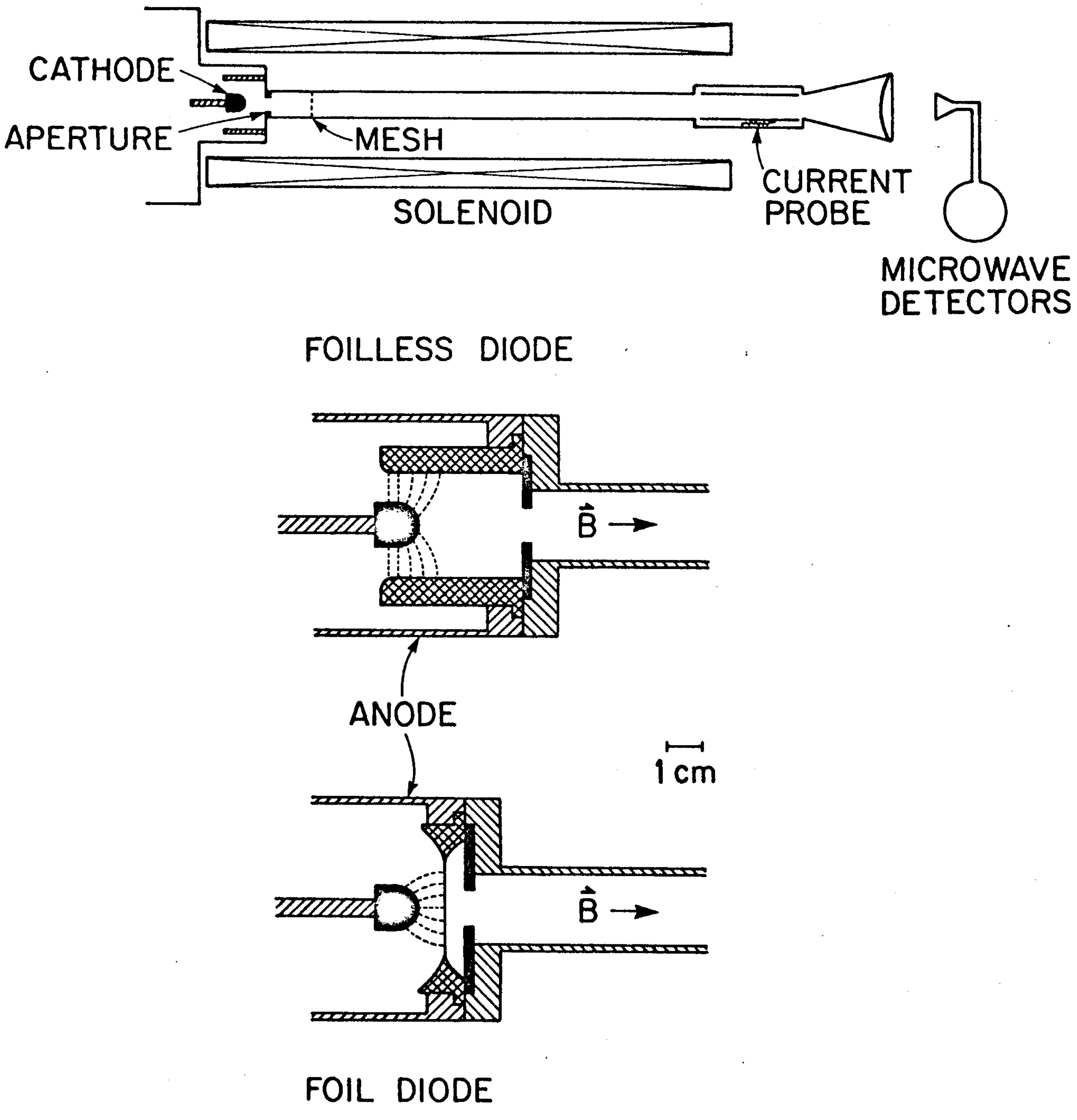

Fig. 1
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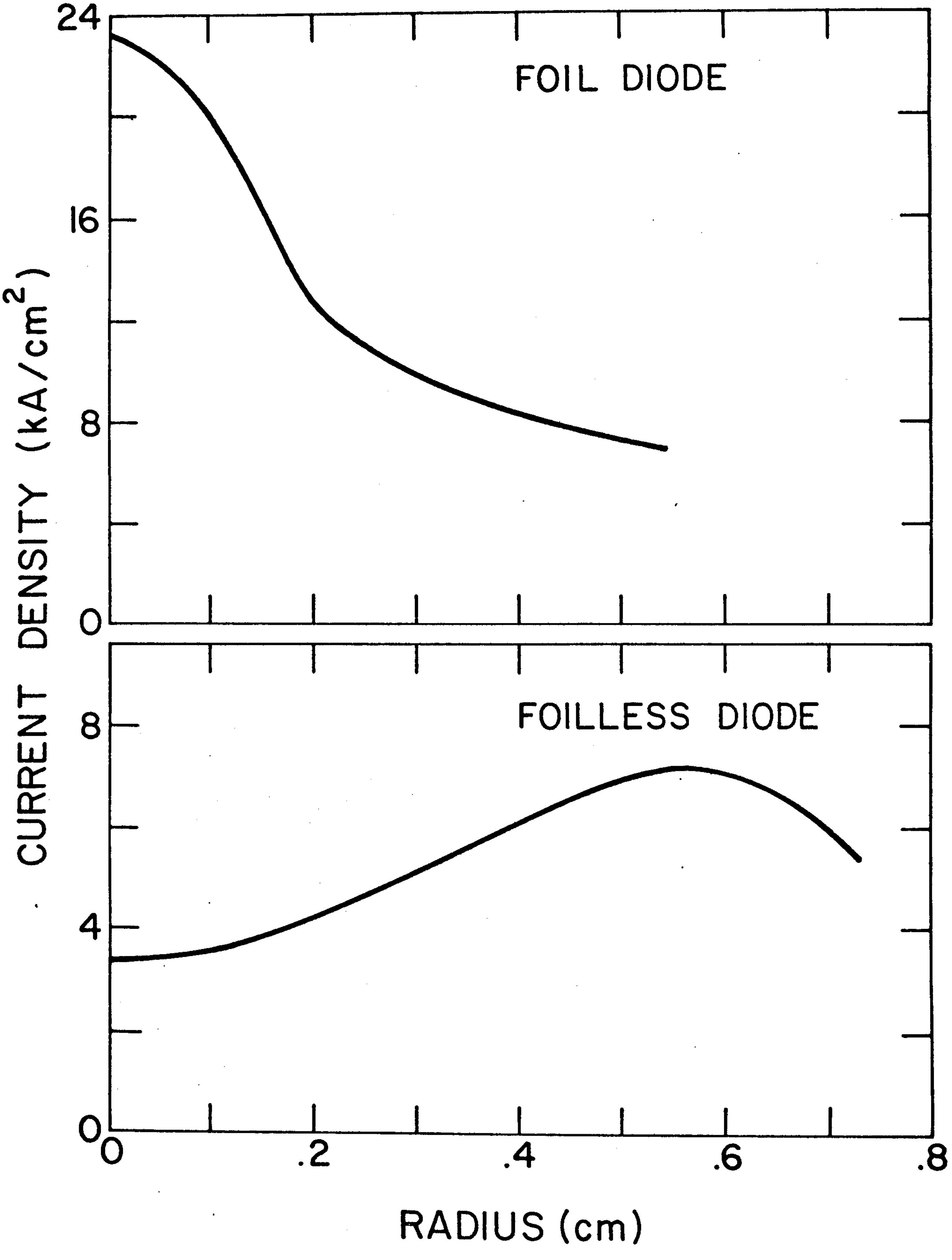

Fig. 2
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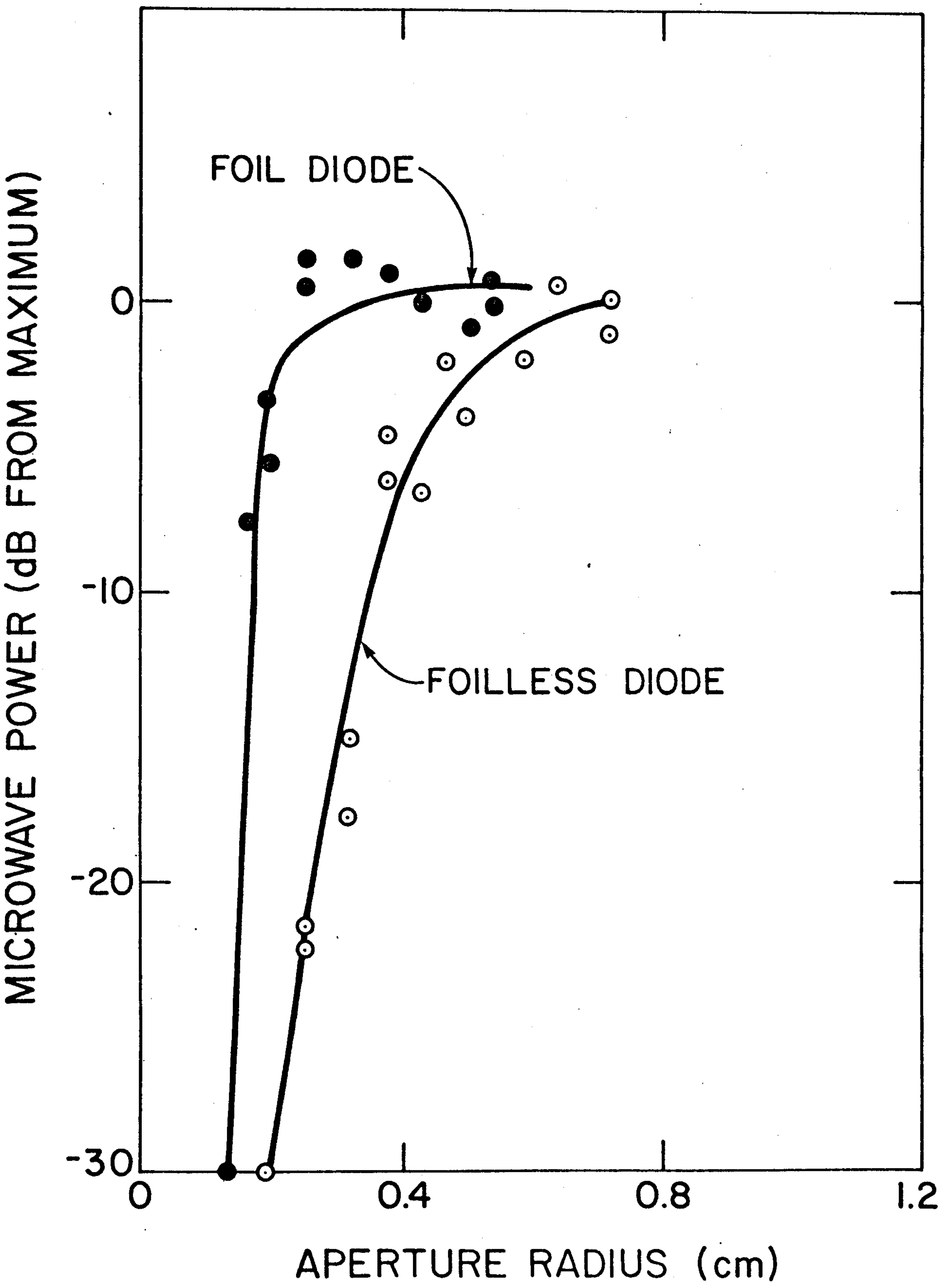

Fig. 3
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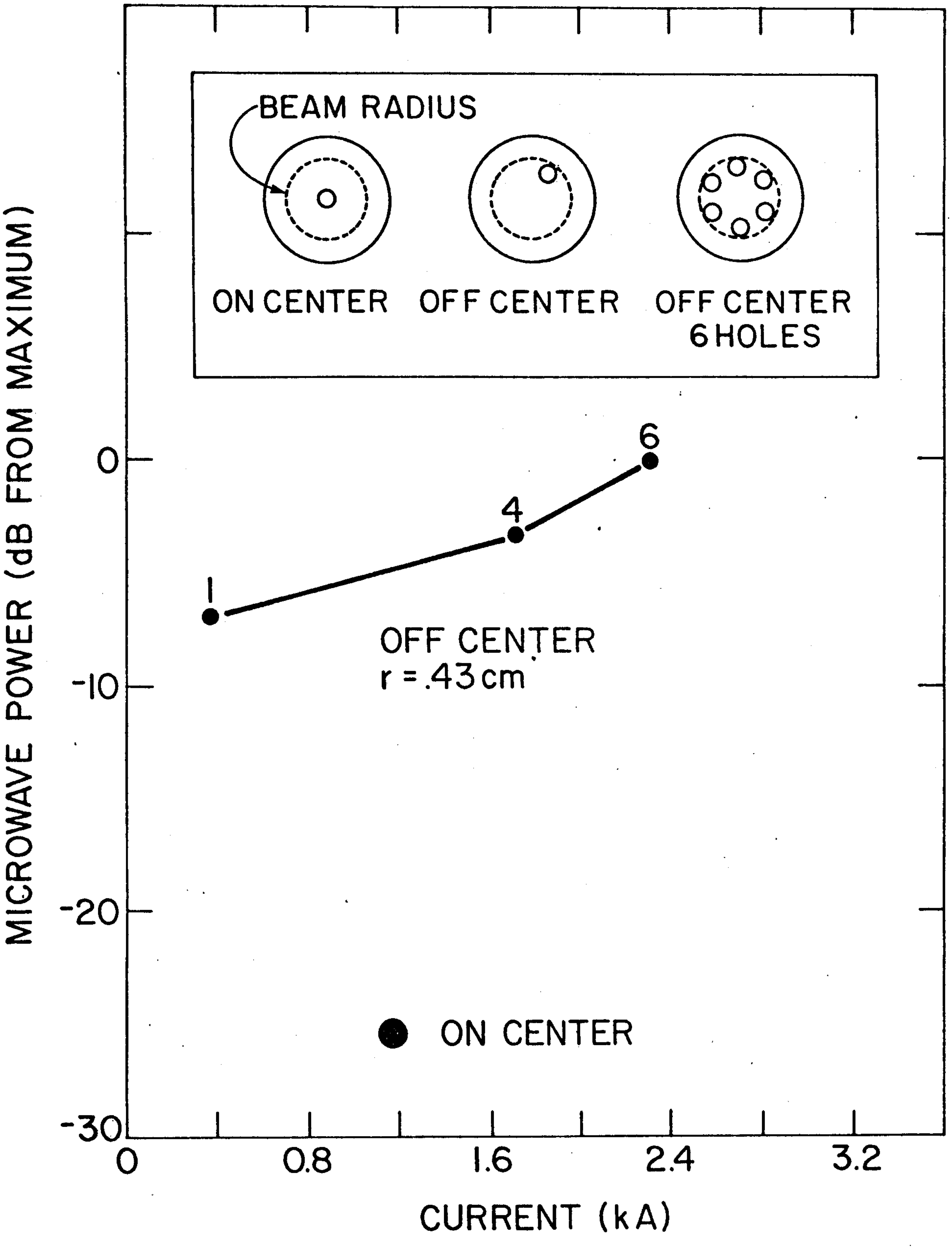

Fig. 4
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