IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

LASER GENERATION AND TRANSPORT OF A RELATIVISTIC ELECTRON BEAM*

S. L. Shope, C. A. Frost, G. T. Leifeste, C. E. Crist, P. D. Kiekel, and J. W. Poukey

Sandia National Laboratories
Albuquerque, New Mexico 87185

and

B. B. Godfrey

Mission Research Corporation
Albuquerque, NM 87106

Abstract

A foilless diode usually requires an externally applied magnetic field to control expansion and transport of a relativistic electron beam. A new foilless diode has been developed that does not require an external magnetic field. A low pressure organic gas is introduced into the diode and the transport region. A UV laser beam is injected through the transport region and is terminated at the cathode. The laser photoionizes the low pressure gas forming an ionized channel that captures the electron beam near the cathode. The electron beam is focused and guided by electrostatic attraction to the ionized channel. A 1.5-MeV, 20-kA electron beam has been generated and transported 1 m using this technique. The laser was replaced by an 800-V, 250-ma, low-energy electron beam which was used to guide the relativistic electron beam 4 m through a 90° bend.

*Work supported by U. S. Dept. of Energy under Contract #DE-AC04-76-DP00789 and the U. S. Army Ballistic Research Laboratory.

Introduction

When an electron beam is injected into a preionized channel, the beam space charge ejects plasma electrons leaving an ion core, and the beam electrons are electrostatically attracted to the ion channel. Electrostatic guiding has been used for the transport of relativistic beams.[1,2,3] Recently, this technique has been used to guide a beam through the ATA without the use of magnetic guide fields.[4]

If the channel radius, r_c is less than the beam radius, r_b, the resulting potential is anharmonic, which gives phase-mix damping of transverse beam motion. In the cold beam approximation charge neutralization, $f_e = \gamma^{-2}$, is required to achieve radial force balance. Here, $f_e = n_c r_c^2 / n_b r_b^2$, γ is the Lorentz factor, and n_c and n_b are the ion and beam number density. If $f_e > 1$, plasma electrons remain in the channel and cause an on-axis return current, which can destablize the electron beam.

In previous experiments, the beam was generated in a conventional diode using foils[3] or a magnetic field to transport the beam to the ionized channel.[4] In our experiment, the preionized channel was extended into the foilless diode region and used to directly generate an electron beam. When the accelerator is pulsed, a potential is developed over the first few centimeters nearest the cathode, enabling a beam to form and accelerate into the neutral region of the channel. The beam is focused and guided by the channel in the diode region without the use of an externally applied magnetic field. This technique provides phase-mix damping in the diode region.

Experiment

The experiments were performed using a 10 Ω, 50 ns accelerator. Figure 1 is a schematic of the experiment. The diode consisted of a bullet-shaped graphite cathode 1.0-cm in diameter. The anode was a 0.6-cm-thick graphite plate with a 2-cm diameter aperture.

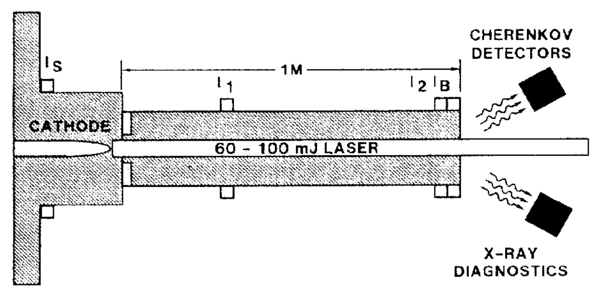

Figure 1: Schematic of laser diode and transport experiment.

A 1-cm diameter ionized channel was formed by 2-step photoionization of diethylaniline (DEA) with a 100-mJ, 266-nm, 10-ns laser (4th harmonic Nd:YAG). A steady flow of DEA, 0.2 to 1.0 mTorr, was maintained in the transport region. The diode region was differentially pumped to a slightly lower pressure, 0.1 to 0.5 mTorr, to prevent diode shorting. The DEA pressure was measured with ionization gauges that had been calibrated against a Baratron capacitive gauge. The DEA was ionized with the laser 100 ns before the voltage was applied to the diode.

A Rogowski coil measured the cathode shank current. Rogowski coils also measured the injected net current and the transported net current. The transported current was also measured with an inductive type fast beam current monitor, which could be used for measuring off-axis displacement.

A quartz window was used to transmit the laser pulse into the chamber. When the beam struck the quartz window, it produced Cherenkov radiation and x-rays. The Cherenkov radiation was diagnosed with open shutter photographs and a photodiode. The x-rays were diagnosed with a pinhole camera and a PIN diode.

The laser foilless diode has been used to generate a 1-MeV, 14-kA, 50-ns beam with dI/dt exceeding 2 kA/ns, which was transported 1 m. Figure 2 shows the injected and transported current waveforms. The close agreement between the injected and transported current indicate efficient beam transport. There was a small amount of beam-front erosion and some loss of current from the end of the

0018-9499/85/1000-3092$01.00© 1985 IEEE

pulse because of beam energy sweep during the pulse rise and fall times. The difference in the net current and beam current monitors indicates there was some plasma current flowing at late time. The beam current waveform agreed with the Cherenkov radiation waveform, Fig. 3. Depth of damage in a Lucite witness plate was consistent with a 1-MeV electron beam. The x-ray pinhole radiographs and photographs of the Cherenkov light indicate a transported beam radius of < 0.5 cm. Increasing the diode voltage to 1.5 MeV resulted in generation and propagation of a 22-kA, 3-kA/ns electron beam, suggesting that this technique may scale to currents greater than 50 kA for a 4-MeV injector.

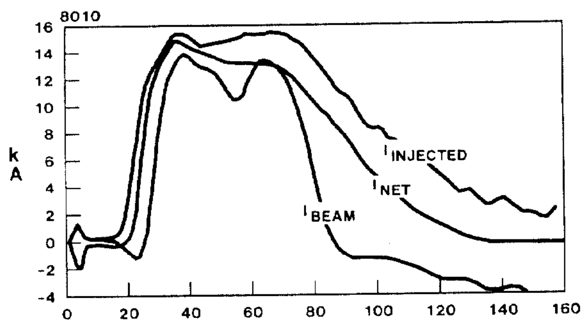

Figure 2. Current transport showing the injected net current and the transported net and beam current of a 1-MeV beam in .3 mTorr of DEA.

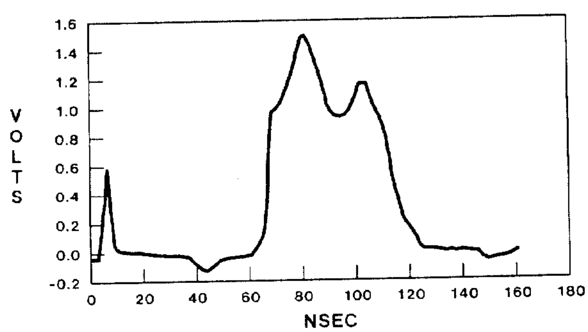

Figure 3: Cherenkov photodiode output. The fast risetime is due to the 300 KeV threshold

Numerical Simulations

Simulations of the laser foilless diode were performed with the 2-D MAGIC code.[5] The ionized channel was represented by an initially cold, uniform, neutral collection of electrons and ions placed on the calculational mesh at t = 0 in a quiet start. All simulations used an applied voltage of 1 MeV. The results for $n_c = 0$ is shown in Fig.4. The shank electrons all hit the anode plate, and the electrons from the front face of the cathode expand radially because of space charge repulsion.

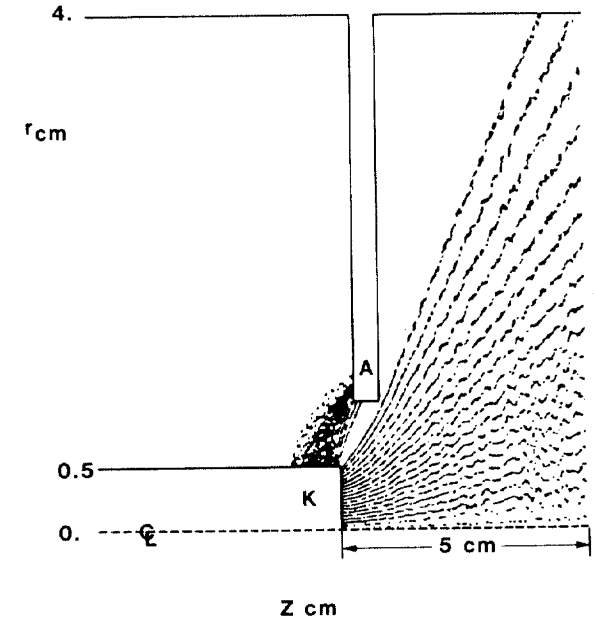

Figure 4: Electron map from MAGIC simulation at t = 3.2 ns for a 1-MeV diode with $n_c = 0$. Total current was 18 kA, with 3 kA transported on axis.

Figure 5 shows the result of using a weak channel, $n_c = 8 \times 10^{11}$ cm^{-3}. The beam is partially focused with 5 kA on axis. Electrons emitted near the outer radius still expand radially.

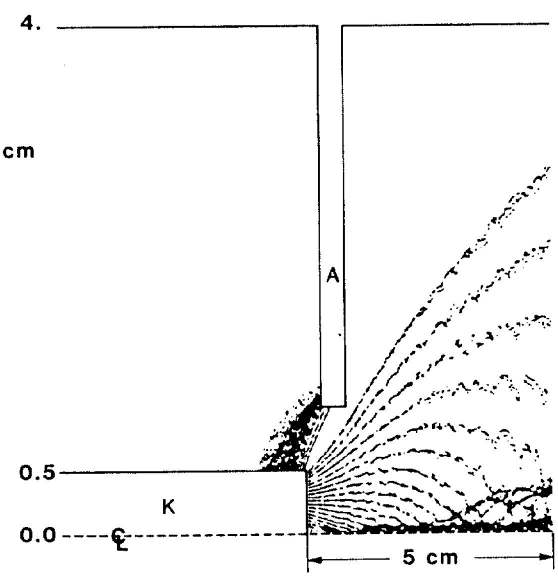

Figure 5. Electron map from MAGIC simulation at t = 2.4 ns for a 1- MeV diode with $n_c = 8 \times 10^{11}$ cm^{-3}. Total current was 19 kA, with 5 kA transported on axis.

Figure 6 shows the result of using a strong channel, $n_c = 8 \times 10^{12}$ cm^{-3}. The beam and some shank electrons are focused and guided by the channel. The strong channel simulation generates a 1.2-cm diameter, 15-kA beam which is in good agreement with the measured 1-cm diameter, 14-kA beam, Fig. 2.

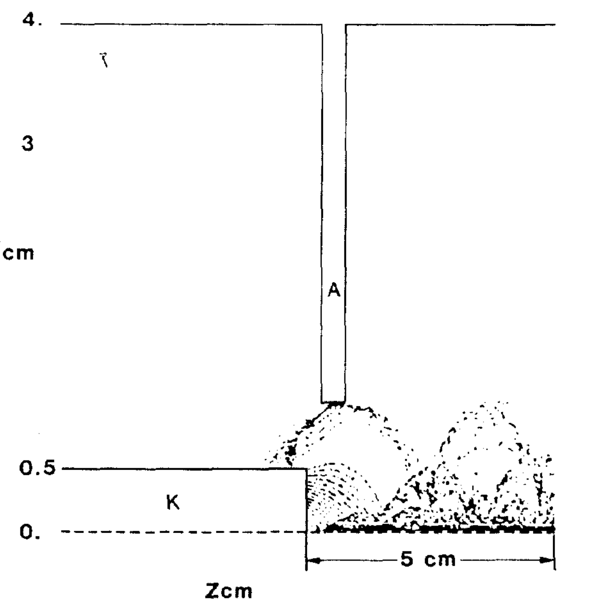

Figure 6: Electron map from MAGIC simulation at t = 2 ns for a 1-MeV diode with $n_c = 8 \times 10^{12}$, cm^{-3}. Total current was 21 kA with 15 kA transported on axis.

The results of the simulations indicate a steady voltage drop over the first one or two centimeters near the cathode, enabling a beam to be accelerated. Compared with the applied-B case, the laser diode formed beam has increased perpendicular velocity, $V_\perp$. However, the increase in $V_\perp$ is not as great as with an anode foil.

Electron Gun

The laser was recently replaced by a low-energy electron gun (800 V and 250 ma produced by a hot tungsten filament). The low-energy electron beam was used to form an ionized channel in 1 mTorr of argon. A 100-Gauss magnetic field was used to guide the low-energy electron beam through the transport region to the cathode. This technique has been used to generate and transport a 1-MeV, 18-kA, 1.5-cm diameter IREB through a 90° bend. Figure 7 shows the experimental setup and Fig. 8 the current waveforms. The result is about 90% transport efficiency

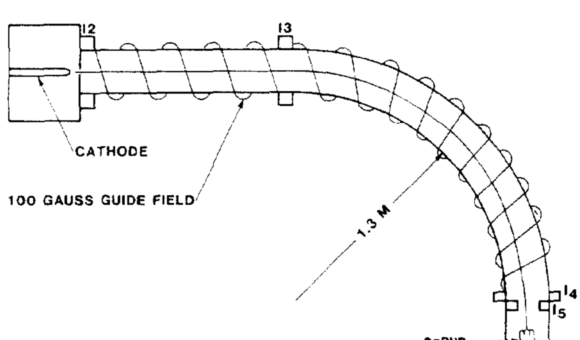

Figure 7: Schematic of 90° bending experiment.

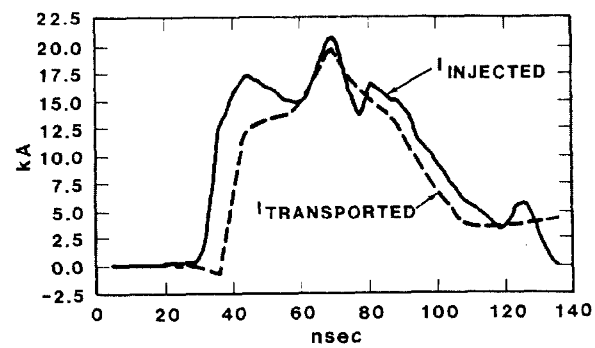

Figure 8: Current transport efficiency around a 90° bend of a 1-MeV beam in 1 mTorr of agron.

Summary

Successful generation and transport of a relativistic electron beam using an ionized channel has been demonstrated. Particle simulations are in good agreement with experimental data. The primary advantage of the channel technique is the elimination of the magnetic guide field used in conventional systems.

Acknowledgments

The authors would like to thank R. B. Miller and C. A. Ekdahl for their technical assistance. We would especially like to thank J. Leija, and D. A. Johnson for their experimental assistance.

References

[1] D. S. Prono, et. al., Phy. Rev. Let. 51, 723 (1983)

[2] W. K. Martin, et. al., Phy Rev. Let. 54, 685 (1985)

[3] C. A. Frost, et. al., "Laser IFR Guiding With a Low γ Beam," unpublished

[4] D. S. Prono, Proc. of the 1985 Part. Accel. Conf., Paper N3, to be published in IEEE Trans. on Nuc. Sci. (Oct. 1985)

[5] B. Goplen, et. al., MRC Report "MRC/WDC-R-068," Sept. 1983