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A LARGE-AREA COLD-CATHODE GRID-CONTROLLED ELECTRON GUN FOR ANTARES*

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Abstract

The CO_2 laser amplifiers used in the Antares inertial confinement fusion project require large-area radial beams of high-energy electrons to ionize the laser medium before the main discharge pulse is applied. We have designed a grid-controlled, cold-cathode electron gun with a cylindrical anode having a window area of $9.3m^2$. A full diameter, 1/4 length prototype of the Antares gun has been built and tested. The design details of the Antares electron gun will be presented as well as test results from the prototype. Techniques used for the prevention and control of emission and breakdown from the grid will also be discussed.

Introduction

The Antares laser fusion system at the Los Alamos Scientific Laboratory (LASL) is designed to deliver up to 100 kJ of energy to a target in a 1-ns pulse. A low energy, short pulse of CO_2 laser light is split into six beams, each of which is then amplified in a laser power amplifier.

The annular pumped volume of each power amplifier is ionized by a radial beam of high-energy electrons produced in a central electron gun. Details of other aspects of the power amplifier and the Antares project are given elsewhere in these proceedings.

The electron-gun design is governed by several constraints. First, the electrons must have sufficient energy to penetrate the electron-gun window and the gas volume of laser gas between the windows and the power amplifier anode. For the range of operating pressures being considered for Antares, electrons having energy between 400 and 550 keV are required.

The second requirement is that the electron gun deliver a beam having uniform current density between 50 and 100 mA/cm^2 and lasting for 5 µs. This current density produces the required impedance in the gas for the main discharge.

A third constraint is that the spacing between anode and cathode must be sufficient to prevent vacuum breakdown.

Antares Electron-Gun Design

The solution to these constraints chosen for Antares is a cold-cathode, grid-controlled electron gun having a cylindrical geometry as shown in Fig.1. The cathode consists of 48 blades of 12.7-µm-thick tantalum foil, each 0.76-m long, arranged in 12 rows of 4 blades, 1 blade opposite the center of each window. An alternate design being considered is a spark cathode designed by G. Loda of Systems, Science and Software (S^3) of Hayward, California.

The grid, consisting of an 80% transmitting stainless steel mesh, is self-biased by current flowing from the grid through a resistor to ground. The space charged limited current, I_K, for this geometry is given by:[1]

$$I_K = 14.68 \times 10^{-6} \left[V_K - (1 - T) I_K R_g\right]^{3/2} \ell r_g^{-1} \beta^{-2} \quad . \quad (1)$$

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1979	**N/A**	-

4. TITLE AND SUBTITLE	
A Large-Area Cold-Cathode Grid-Controlled Electron Gun For Antares	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, Los Alamos Scientific Laboratory Los Alamos, NM 87545**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

The C02 1 aser amp 1 ifiers used in the Antares inertial confinement fusion project require large-area radial beams of high-energy electrons to ionize the laser medium before the main discharge pulse is applied. We have designed a grid-controlled, cold-cathode electron gun with a cylindrical anode having a window area of 9.3m2â¢ A full diameter, 1/4 length prototype of the Antares gun has been built and tested. The design details of the Antares electron gun will be presented as well as test results from the prototype. Techniques used for the prevention and contra 1 of emission and breakdown from the grid will also be discussed.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

where

V_K is the cathode voltage
T is the grid transparency
R_g is the grid resistance
ℓ is the length of the cathode
r_g is the radius of the grid

and β is a function of r_g/r_c, with r_c the cathode radius.

There are 48 windows in each electron gun, each 0.76 m x 0.25 m in size. Each window consists of a hibachi support structure covered by a window of 0.050-mm-thick titanium foil glued to a 0.9-mm-thick stainless steel rip-stop grid. The grid prevents damage to the interior of the electron gun in case of window failure by limiting the size of the rupture and thus the rate of rise of the internal pressure.

There are several advantages of the grid-controlled electron gun over the simpler diode geometry. First, the gun current can be controlled independently of the gun voltage and cathode-anode spacing. A diode electron gun meeting the Antares requirements would either be uneconomically large or would produce considerably more current than desired for ionizing the gas. Higher currents lead to shortened cathode and window lifetimes. The lower current of the grid-controlled gun also reduces the size of the high-voltage pulser required and reduces magnetic effects on the electron beam.

A second advantage is the current stabilization produced by the self-biased grid. This stabilizing effect certainly occurs for an ideal grid which does not show secondary emission. But it is also true that as long as the number of secondary electrons emitted from the grid surface for each primary incident is less than 1.0 the grid acts to stabilize the gun.

Prototype Results

In order to evaluate many aspects of the Antares design, a prototype power amplifier was constructed. Design details and initial measurements whch confirmed the Antares design concept have been reported by Leland.[2] After those tests were completed, it was decided to make a series of measurements to more fully characterize the electron gun.

One problem which was addressed is the control of vacuum breakdown. In the measurements reported by Leland[2] the cathode was shorted by a crowbar gap after 3 μs. Even under these conditions, occasional cases of runaway cathode current were observed. During the period of these measurements, the silicon-based diffusion pump oil (Dow Corning 704) was deliberately allowed to backstream into the electron gun in order to suppress secondary emission from the grid. In this case the operation of the electron gun was in general agreement with the predictions of the space charge equation.

One of the goals of the present investigation was to eliminate the crowbar gap, thus simplifying the electron-gun pulser and improving its reliability. The electron gun must thus be capable of holding off the high voltage for a longer period of time without breakdown.

At the beginning of the present set of measurements the diffusion pump was drained, cleaned and refilled with a carbon-based pump oil (Convoil 20). Once again, the pump oil was allowed to backstream into the electron gun. Two results were observed after this change. First, both the frequency and severity of breakdown increased. Upon later disassembly of the gun, several burn spots were seen on the cathode, grid, and anode. The second result was observation of anomalous grid current measurements, though the cathode current agreed with that predicted by Eq. (1).

We next disassembled the gun, carefully cleaned each part with solvent, and reassembled it, taking care to maintain cleanliness. The vacuum system was operated with a liquid N_2 cold trap and a larger backing pump to prevent oil backstreaming. Other changes included the addition of corona rings to the cathode assembly to shield areas of unwanted field enhancement.

The most significant improvement made by this investigation has been the development of a grid conditioning technique consisting of first shorting the grid to the cathode and then pulsing the grid using the electron-gun pulser. The series begins at low voltage (<-300kV) and increases in 50-kV steps until oscilloscope traces show an increase of grid emission. The voltage is then reduced until the excess emission ceases and the gun is operated for 5 to 10 shots. The gun voltage is then increased 15-20 kV and the gun is operated until there is no excess emission for 5 to 10 shots. This process is repeated until a voltage is reached at which less than half of the shots show no increase of emission. In the prototype power amplifier this voltage is usually between -500 and -600 kV, which is above the working voltage of the grid. The short is then removed and the gun is ready for operation.

The result of the cleaning, improved vacuum, and grid conditioning is a greatly reduced probability of breakdown. We occasionally see an increase in cathode current, but it almost always returns to normal after a few microseconds indicating that the grid is retaining control. Those pulses showing enhanced grid emission, usually do so only after approx. 4 μs and thus, since the laser energy extraction occurs before this time, have no effect on the operation of the power amplifier.

A second result is an increase of cathode current over that predicted by Eq. (1). This effect can be, at least partially, explained by an observed increase in grid emission. This effect was not seen by Leland[2] and is possibly a result of the loss of inhibiting properties provided by the silicon pump oil which was used for his measurements.

Figure 2 shows the measured and calculated gun impedance as a function of time during one shot. Two calculated impedances are shown, one assuming the grid transparency is the geometrical value of 80% and the other using the measured transparency, $T = 1 - I_{grid}/I_K$. At present, we do not have a satisfactory explanation for the discrepancy; however, it does not have any adverse effect on the operation of the electron gun.

In order to achieve uniform pumping in the laser gas the intensity of the electron beam should be independent of position on the window. Using rectangular Faraday cups of size 3.8 cm x 25.4 cm we have measured the current density at several points on the window and found that at the edge it decreases to not less than 80% of the center value.

Discussion

Several results have come from the prototype study which will be applied to the Antares electron gun. Since the probability of excess emission and breakdown depends on the emitter area, these problems can be expected to be worse in Antares. Thus, the grid conditioning technique and our improved understanding of the role of the grid in controlling breakdown is significant. Other prototype results give us confidence that the requirements for the Antares electron gun can be met by the present design.

References

1. I. Langmuir and K. Blodgett, "Currents Limited by Space Charge Between Coaxial Cylinders," Phys. Rev., Vol. 22, pp. 347-356, 1923.
2. W. T. Leland, et al, "Antares Prototype Power Amplifier -- Final Report," Los Alamos Scientific Laboratory Report LA-7186, 1978.

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*Work performed under the auspices of the U.S. Department of Energy

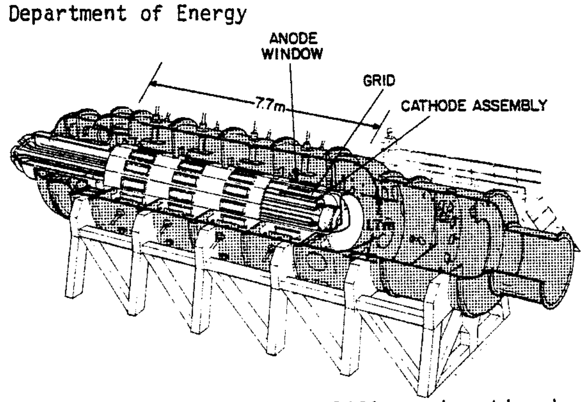

Fig. 1. Antares power amplifier schematic showing electron-gun part.

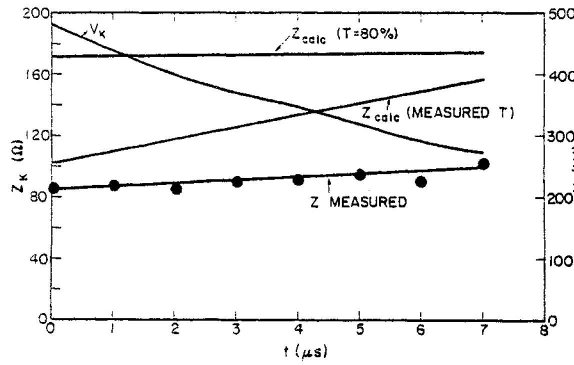

Fig. 2. Measured and calculated impedance and measured cathode voltage of the prototype electron gun with 800-ohm grid resistor as a function of time for a single shot.