SYSTEMS, SCIENCE AND SOFTWARE
SAN FRANCISCO DIVISION

DOE/DP/01597-1

MASTER

DEVELOPMENT OF SPARK CATHODE
E-GUNS

FINAL REPORT - PHASE I
July 1978 - October 1978

G. Loda
R. Lindstrand

January 1979

WORK PERFORMED UNDER CONTRACT
DE-AC08-78DP01597

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent, the United States Department of Energy, nor any Federal employees, nor any of their contractors, subcontractors or their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Reference to a company or product name does not imply approval or recommendation of the product by Systems, Science and Software or the U.S. Department of Energy to the exclusion of others that may be available.

Printed in the United States of America
Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy \$4.00
Microfiche \$3.00

Price of the printed copy is determined by the number of pages in the report. Since prices are revised periodically, contact the Contracting Officer for current prices.

SYSTEMS, SCIENCE AND SOFTWARE
SAN FRANCISCO DIVISION

DOE/DP/01597-1

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**DEVELOPMENT OF SPARK CATHODE
E-GUNS**

FINAL REPORT - PHASE I
July 1978 - October 1978

G. Loda
R. Lindstrand

January 1979

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *EB*

WORK PERFORMED UNDER CONTRACT
DE-AC08-78DP01597

12 sided spark cathode assembly

ABSTRACT

A 12 sided spark cathode is designed and constructed to replace the bladed, cold cathode structure in the electron gun of the Los Alamos Scientific Laboratory Antares prototype power amplifier. Design work includes computer modeling and full scale low voltage modeling. Life testing to 100,000 pulses is documented. The spark cathode offers precise control of emission site location and a high reliability.

TABLE OF CONTENTS

Introduction	1
Technical Discussion	5

LIST OF ILLUSTRATIONS

- Figure 1 A transverse section of the Antares prototype amplifier
- Figure 2 Surface flashover characteristic in vacuum
- Figure 3 Schematic representation of the capacitively isolated multiple spark source cathode
- Figure 4 Spark cathode design
- Figure 5 Alternative spark cathode design
- Figure 6 Equipotential mapping - electrode fixed at grid voltage
- Figure 7 Equipotential mapping - electrode fixed at cathode voltage
- Figure 8 Electrolytic test tank

INTRODUCTION

This report covers the first phase of a two phase program entitled "Development of Spark Cathode Electron Guns for the CO₂ Laser Fusion Program" (SSS-P-78-84100-85). The requirements leading to the need for such a development are briefly reviewed, followed by a technical discussion of the first phase efforts.

With carbon dioxide laser systems becoming larger and more complex due to the continuing sophistication of laser fusion studies, the need for reliable component operation increases. A large stride forward was accomplished three years ago with the replacement of the hot cathode electron gun with a cold cathode unit. However, even the routine maintenance of a single electron gun unit, such as used in the Los Alamos Scientific Laboratory (LASL) Antares laser power amplifiers, will likely require a two day turn-around penalty.

The projected lifetime for the Antares system is 10,000 shots, but experiences from devices at LASL and elsewhere demonstrate a deterioration in beam uniformity by the 1000 shot level. The beam uniformity of these large area electron guns depend upon:

- The generation of a significant number of well distributed electron emission sites.
- The electron "optics" - electric and magnetic field configuration.
- The condition of the emitting surfaces.

Blade cathodes feature somewhat random site generation and a decrease in site density with use. As the cathode blades "age", the changes in the microstructure of the emission edge degrade their performance, resulting in the necessity of periodic blade replacement.

The requirement for long lifetime and beam uniformity is one of reproducibility. If this requirement can be satisfied, the need for routine maintenance of the LASL electron guns no longer involves the cathode structure and reduces to insuring the vacuum integrity of the electron beam transmission windows.

In addition to reproducibility considerations, the Antares laser project staff expressed an interest in expanding the possible range of electron gun operating voltages from 450-500 kV to 300-500 kV. This interest was generated as a means of improving the laser gain uniformity for the particular pumping volume geometry utilized in the Antares power amplifiers. The intention was to extend the voltage range without modifying the mechanical structure of the gun, i.e., by merely changing the energy storage system parameters. Operation of a 500 kV designed blade cathode at only 300 kV intensifies the previously mentioned problems in achieving lifetime, repeatability and beam uniformity.

To achieve the desired cathode performance characteristics the San Francisco Division of Systems, Science and Software (S-Cubed) designed and constructed a spark cathode assembly suitable for test and evaluation in the Antares prototype power amplifier electron gun. Figure 1 is a transverse section of the prototype power amplifier including the cathode, a 12 section cylindrical assembly, approximately 75 cm in diameter by 1.3 m in length.

Following computer design calculations and low voltage modeling, S-Cubed built a 12 sided spark cathode configuration for use in the LASL prototype. The assembly was received at LASL in October, 1978. The frontispiece shows the spark cathode assembly just prior to shipment.

A life test was performed on a small section of the large spark cathode array at S-Cubed to determine the projected reliability of the specific design. After being subjected to 10,000 pulses, the design point for Antares, no discernible deterioration had occurred. The cathode section was then returned to life testing to obtain a 100,000 shot history. Again, no significant deterioration in performance occurred.

Figure 1 A transverse section of the Antares prototype amplifier

S-Cubed has thus developed what appears to be a cathode assembly which gives precise control of emission site location for beam uniformity and which has a lifetime far in excess of present laser fusion program requirements.

TECHNICAL DISCUSSION

The ultimate success of a cold cathode for electron gun operation lies in its ability to generate specific electron emission site locations and to protect these sites from degradation in use. Blade cathodes require an electric field near a sharp edge in a vacuum to create the plasma source for electrons. This plasma production is the first phase of the vacuum breakdown process. The voltage supplied to the cathode and the electrode spacing are generally determined by the specific beam parameters required, rather than to create optimum conditions for emission site initiation.

In contrast to this, spark cathodes utilize a breakdown plasma along insulated surfaces at the cathode as a source of electrons. With proper design of the electrodes and the surface spacing, breakdown can be readily achieved at voltages small compared to the total cathode voltage. Figure 2 details the voltages necessary for breakdown to occur on surfaces for small gaps. The cathode structure takes the form of an array of electrically isolated (floating) electrodes distributed on a surface which includes a cathode frame. As voltage is applied to the cathode frame, capacitive coupling between each floating electrode and the anode causes a voltage differential to occur between the electrode and the cathode frame (Figure 3). When the surface flashover potential is exceeded, breakdown occurs and the associated plasma is the source for further cold cathode emission. The occurrence of sparks between the cathode and the floating electrodes does not destroy the voltage differential established by the unsparked electrodes. Eventually all electrodes will spark, leading to precise geometric control of emission site density.

Figure 2 Surface flashover characteristic in vacuum

Figure 3 Schematic representation of the capacitively isolated multiple spark source cathode

Two specific spark cathode designs were constructed for the Antares prototype power amplifier. The first has 5 cm x 7.5 cm floating electrodes spaced between frame rails at cathode potential. Figure 4, is a photograph of a section of the cathode assembly. The gap where the spark is created is approximately 0.7 mm and the sites are distributed at a linear density of 20 per meter. The cathode is constructed by etching a copper-clad printed circuit board. The insulating material is G-30 fiberboard.

An alternative cathode design is shown in Figure 5. The "buttons" in the photo are tied to the cathode potential. The primary difference between the two designs lies in the electric field configurations surrounding the floating electrodes. The alternative design should provide additional defocussing of the electron beam for improved beam uniformity. One such cathode section was supplied to LASL for comparative evaluation.

For design of the spark cathodes, it was necessary to determine the potential difference generated between the cathode and the floating electrodes. This has been accomplished by determining the relative capacitance values between the electrode and anode (grid), and between the electrode and the cathode. The magnitude of the capacitances was obtained by solving pairs of Laplace's equations for two cases:

1. The floating electrode fixed at ground (or grid) voltage.
2. The floating electrode fixed at cathode voltage.

Figures 6 and 7, respectively, show the equipotential mapping created from the computer generated solution for the Antares geometry. Integrating the normal electric field yielded the charge on the electrode for the two cases. The capacitances were proportional to the charges at fixed voltages. Knowing the capacitances, the floating potential was calculated directly. The method may be summarized as follows:

Figure 4 Spark cathode design

Figure 5 Alternative spark cathode design

Figure 6 Equipotential mapping - electrode fixed at grid voltage

Figure 7 Equipotential mapping - electrode fixed at cathode voltage

a) Equivalent Circuit for the Electrostatic Problem

b) Determination of Relative Capacitances

Case 1 - Electrode fixed at ground voltage

$$C_1 = Q_1 / \Delta V_1$$

Obtain Q_1 from integration of the normal electric field

Case 2 - Electrode fixed at cathode voltage

$$C_2 = Q_2 / \Delta V_2$$

Obtain Q_2 from integration of the normal electric field

c) To find the floating potential then

$$C_1(V_f) + C_2(V_f - 1) = Q_{\text{total}} = 0$$

$$V_f = \frac{C_2}{C_1 + C_2}$$

The Antares electron gun uses a control grid referenced to ground through a resistor. During the turn-on phase, this grid capacitively divides between cathode and ground potential and acts as the effective anode shown in the calculations. The calculations predict the floating electrode will attain 78% of the cathode to grid voltage, establishing a flashover condition before the cathode reaches 20 kV.

An experiment was performed as an alternative means of determining the floating potential. A full scale Antares prototype cathode mock-up with a representative grid structure was immersed in an electrolytic solution. Alternating current voltages between 10 volts and 75 volts were applied to the cathode with the grid grounded. Voltage on a single floating electrode was monitored both with an oscilloscope and a digital voltmeter. In all cases, the floating potential achieved ~20% differential to the cathode voltage. Measurements were also made with all the floating electrodes shorted to the cathode, save one. This approximated the condition of all but one electrode sparked. Results indicate an 11% voltage differential still existed, sufficient to create flashover. These results agreed well with the previous calculations. The experimental set-up is shown in Figure 8.

A life test was performed at S-Cubed on a partial section of the spark cathode designed for LASL. Two emission sites were subjected to 10,000 shots of 100 kV, 10 amps emission current per site, and ~3 μ sec duration pulses. These parameters reflected the cathode to grid operating conditions to be encountered in the Antares system. Inspection of the spark cathode and monitoring of current and voltage waveforms revealed no deterioration of the electrodes. Life testing was continued to 100,000 shots, 10 times the design lifetime for Antares. Cathode performance continued to be reliable and highly reproducible. Consequently, spark cathode lifetimes for LASL fusion lasers should exceed system requirements.

Figure 8 Electrolytic test tank

Distribution List

- 5 Lt. Col. Ernie D. Brauschweig, USAF
CO₂ Program Manager
Office of Laser Fusion, C-404
U.S. Department of Energy
Washington, D.C. 20545
- 4 Mr. Rex Purcell
Contract Management Division
U.S. Department of Energy
Nevada Operations Office
P. O. Box 14100
Las Vegas, NV 89114
- 2 DOE Technical Information Center
P. O. Box 62
Oak Ridge, Tennessee 37830