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Cold Cathode Investigation

by

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COLD CATHODE INVESTIGATION

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ABSTRACT

This report describes experiments for the evaluation of a cold cathode electron gun. Different anode and cathode materials and configurations were tried. Small signal gains of 6.3%/cm were measured. It was found that the same small signal gains could be obtained with less energy deposition in the laser gas with the larger pre-ionizing currents from a cold cathode. Long-duration pulses were observed that were limited only by the electrical energy available in the Marx bank.

I. INTRODUCTION

Uniform excitation of large volumes of atmospheric or higher pressure laser media by electron-beam stabilized discharges have been demonstrated by many experiments. The earliest of these devices utilized hot filaments as the source of electrons.¹ More recent literature has described the work of several investigators using electron emission from a cold cathode.²⁻⁶ This investigation of cold cathode performance was to evaluate the advantages and shortcomings of a cold cathode electron gun.

The term cold cathode, as used in this report, refers to a cathode that does not require any additional power to become a source of electrons when subjected to a sufficiently high field. Many different cathode materials and configurations were demonstrated to work during these experiments. The only requirement found was for the electron-emitting surface to attain a field of approximately 10^7 V/cm. Most of the emitting surfaces used were 0.006-mm-thick tantalum. Foils made of stainless steel, titanium, gold, and nickel worked

equally well. A 0.013-mm foil of aluminum failed structurally by bending flat against the foil-holding structure. An emitting surface formed by soldering 200 needles together in a 20-mm-diameter bundle gave reproducible emission currents. A single needle was not usable in a repetitive mode: the end point rapidly eroded, became blunt, and eventually either stopped emitting or became erratic in its emission.

II. EXPERIMENTAL

These cold cathode experiments were performed in two different devices, a 0.4-m-long by 0.3-m-i.d. vacuum chamber, and a 1.4-m-long by 1-m-i.d. vacuum chamber. The smaller device was used to make small signal gain measurements, while the larger device was used during the long-duration pulse studies. All electron transmission was through a 0.020-mm titanium foil.

The small signal gain is a good measure of the usefulness of a CO₂ lasing medium. The small signal gain was measured over two different path lengths--one was 50-mm long and the other was 100-mm long.

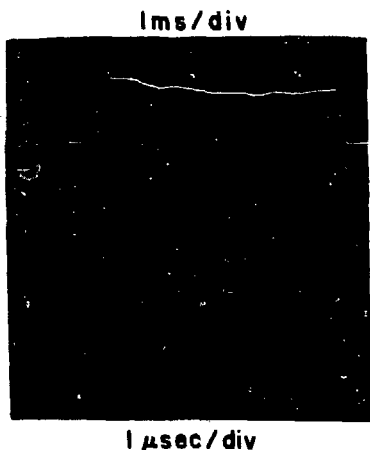


Fig. 1. Gain and current signals for typical experiment.

The path lengths were delineated by Lucite tubes inserted in the lasing medium. This known path length, coupled with a segmented anode,⁸ enables one to make accurate gain per unit length of active media measurements, as well as the energy deposition per unit volume. Short path lengths of active media were used to eliminate the problem of free oscillations that can occur in longer active paths.

Figure 1 shows the typical gain records obtained during a small signal gain experiment. This figure is a composite of

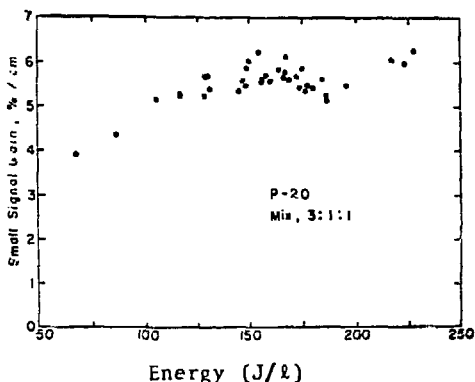


Fig. 2. Maximum small signal gain vs energy deposited in 3:1:1 mixture of He:N₂:CO₂, measured on P-20 line.

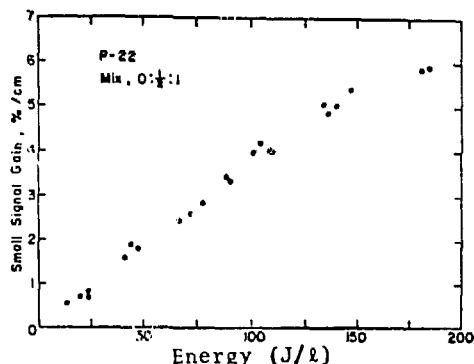


Fig. 3. Maximum small signal gain vs energy deposited in 1/2 : 1 mixture of N₂:CO₂, measured on P-22 line.

two oscillograms. The upper trace is the entire gain signal 20-mV/div and 1-μs/div; below it is the expanded gain signal at 10-mV/div and 1-μsec/div; the second from the bottom is the total lasing gas current at 4-kA/div and 1-μs/div; and the bottom trace is the current in a 50-cm² segment of the anode, 82-A/div and 1-μs/div. The laser gas for this experiment was a 3:1:1 mixture by volume of He:N₂:CO₂. The maximum small signal gain was a 5.6%/cm; this was achieved with an energy deposition of 170 J/liter.

Figures 2, 3, and 4 are plots for three different gas compositions of the measured maximum small signal gain vs the energy deposited in the gas. The laser gas

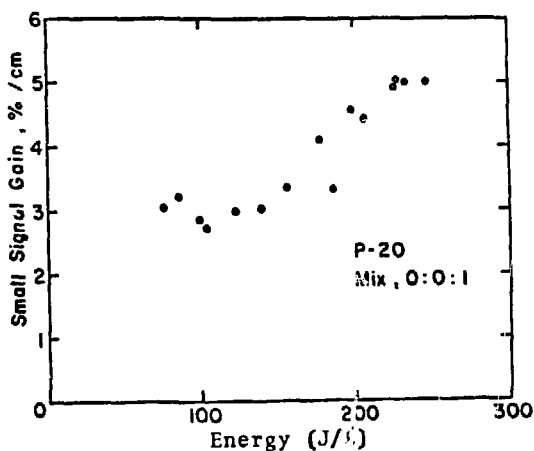


Fig. 4. Maximum small signal gain vs energy deposited in pure CO₂, measured on P-20 line.

pressure in all the small gain experiments was 585 torr.

The small signal gain data was obtained with a wide variation of input parameters -- the ionizing currents varied from 50-mA/cm² to 5-A/cm²; the ionizing current accelerating potential was varied from 120 kV to 170 kV; the current pulse lasted from 1/2 μ s to 4 μ s; and the field strengths in the laser gases were varied from 3.8 kV/cm to 6.5 kV/cm. These changes in parameters account for most of the scatter in the data. Note that the N₂/CO₂ data in Fig. 3 was measured on the P-22 line, while the data in Figs. 2 and 4 were measured on the P-20 line. Small signal gains on the P-22 line are about 10% less than those measured on the P-20 line.

Figure 5 shows an unexpected result of this cold cathode research. The dots are the 3:1:1 data shown previously in Fig. 2; the triangles are data taken at Los Alamos Scientific Laboratory using a hot filament device.⁸ Note that in addition to the higher small signal gains achieved, gains of the same value were attained with less energy deposition in the gas. This was achieved through higher electron gun currents and usually higher fields across the laser gas. The field strength in the laser

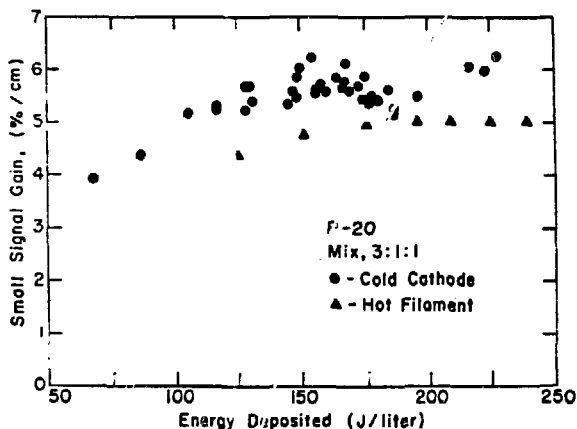


Fig. 5. Small signal gain vs energy deposition.

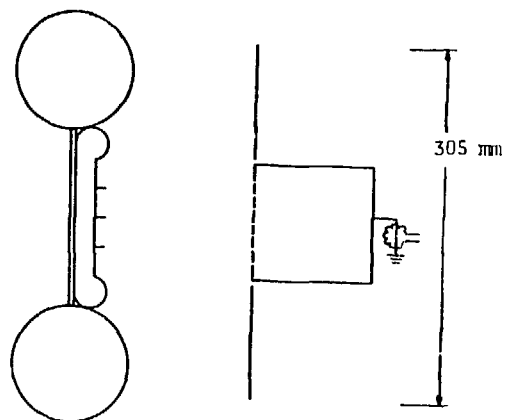


Fig. 6. Long pulse electrode configuration.

gas for the hot filament device was 5kV/cm, and the current pulse duration was 10 μ s. In all of the hot filament experiments, a maximum small signal gain was achieved before the end of the current pulse. In only three cold cathode experiments did the small signal gain reach a maximum before the end of the current pulse.

The large vacuum vessel previously mentioned was now utilized to investigate how long-duration pulses could be obtained. The larger vessel was used to minimize wall effects. Figure 6 shows an electrode configuration that produced long-duration pulses, pulses lasting as long as 14 μ s. The cathode was comprised of a 355-mm torus behind the foil support structure. The anode was a flat, circular plate 305 mm in diameter. The box represents a Faraday cup behind an 0.020-mm titanium foil. This arrangement was used to measure the transmitted current through the center 126 cm² of the anode.

Varying the number of foils in the cathode, the foil material and foil projection height had little effect on the gun-current amplitude or pulse duration. The anode surface had the greatest effect on the cold cathode performance in these experiments. Anodes of aluminum and one made by electroplating gold on brass produced higher currents and shorter duration pulses.



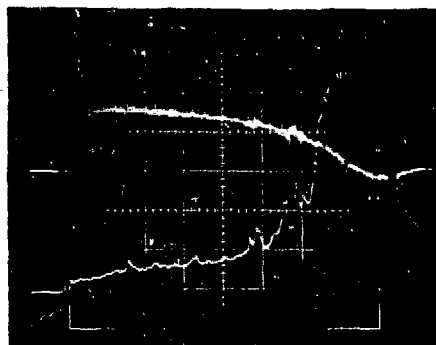
1 $\mu\text{sec}/\text{div}$

Fig. 7. Long-duration pulse; 120 kV; 5-cm electrode spacing; and 5000 A/div.

The gold plating was not adequate; and after about 10 pulses, all the gold in the center 100 cm^2 of the anode had been removed. The pulse duration and current amplitude then returned to those values obtained with a plain brass anode. This is in agreement with an observation during experiments on the small cold cathode device. The current pulse in the small device increased in duration from $2\text{ }\mu\text{s}$ to $4\text{ }\mu\text{s}$ when a Lucite isolation plate around the anode was replaced with a stainless steel plate.

Pulse durations of 8-10 μs were obtained routinely at electrode spacings of 5 to 25 cm in the larger cold cathode chamber. Figure 7 shows the gun voltage and total current as a function of time. The only limiting parameter in this experiment was the depletion of the energy stored in the Marx bank, which was comprised of five $0.7\text{-}\mu\text{F}$ capacitors rated at 50 kV each. This gave a system capability of $0.14\text{ }\mu\text{F}$ at 250 kV. From the ringing frequency after an arc, a system inductance of $1.6\text{ }\mu\text{H}$ was calculated.

Figure 8 shows a long-duration pulse terminated with an exponential current increase in the last portion of the pulse. Figure 9 is a composite of two oscillograms -- the upper trace is the voltage, the middle trace is the total gun current, and



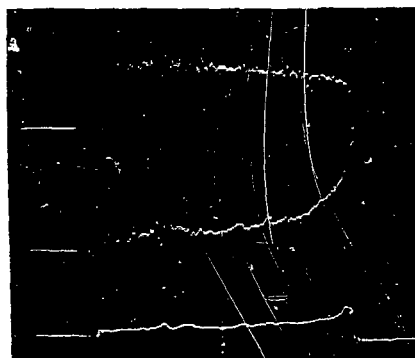
2 $\mu\text{sec}/\text{div}$

Fig. 8. Pulse termination by exponential current increase; 180 kV; and 15-cm electrode spacing.

the bottom trace is the current transmitted through a 0.020-mm titanium foil. Note how the transmitted current drops to zero when the electrode voltage drops below 90 kV.

The currents were measured with Pearson current transformers, which have a time response of less than $0.1\text{ }\mu\text{s}$. Voltage signals were obtained by measuring the current in a copper sulfate resistor connected externally between the cathode and anode of the electron gun.

Vacuum requirements for a cold cathode were found to be quite minimal. Satisfactory electron emission was observed in the



1 $\mu\text{sec}/\text{div}$

Fig. 9. Total and transmitted currents; 180 kV; and 10-cm electrode spacing.

vacuum regime of 3×10^{-4} to 6×10^{-7} torr.

Work by other investigators has shown that electron emission from a cold cathode starts from a field emission process.⁷ To provide the large currents during a pulse, a plasma then has to form around the emitting surface. This plasma is probably formed by ions falling back on the cathode. If the field-forming electrodes are of the proper form, the ions will all be constrained to fall back on the thin foil that provided the initial emission. The small electron gun was a good example of improper electrode configuration. From photographs of the discharge and pitting of the small cathode electrode, it was ascertained that the cathode was emitting in a 4- π geometry to all the inner surfaces.

III. CONCLUSIONS

The cold cathode gun has produced larger small signal gain with less energy deposition in the laser gases than has been achieved with hot filament devices. The use of cold cathodes in proposed large CO₂ amplifiers results in savings through simplicity of the cathode structure and no need for filament heating power. However, even with all the advantages, the cold cathode is not going to replace all the hot filament devices. Cold cathode has several disadvantages, such as (1) The nonrepeatability of current pulses, which is greatly dependent upon the device geometry; (2) The current pulse shape is not constant as a function of time; (3) Pulse durations of most cold cathode devices are still too short; (4) Due to the large currents and depletion of the charge on the capacitor, the electron energy can vary as a function

of time; and (5) The higher currents associated with cold cathodes place additional demands on the power supplies for a cold cathode amplifier device, specifically in terms of capacity and inductance. In spite of these shortcomings, cold cathode devices have demonstrated capabilities not attainable with hot filament machines.

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