FINAL REPORT

LASER-ACTIVATED ELECTRICAL SWITCHING CHARACTERISTICS OF HIGH-CURRENT, LOW-LOSS THERMIONIC DIODES

Thermo Electron CORPORATION

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LASER-ACTIVATED ELECTRICAL SWITCHING CHARACTERISTICS OF HIGH-CURRENT, LOW-LOSS THERMIONIC DIODES

For the Contract Period
February 1979 - September 1982

Prepared by

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ABSTRACT

This final report summarizes the research from February 1979 to September 1982 conducted under Contract N00014-79-C-0131, on experimentally investigating laser-activated electrical switching of and electron beam formation from cesium coated thermionic and photoemissive surfaces. Two areas were investigated. The first dealt with thermionic emission of electrons from pulse laser heated cesiated surfaces. High power irradiation of cesium-coated metallic targets has generated very dense electron beams. Partially space-charge-limited currents of 2500 A and current densities of 3900 A/cm^2 from 9-mm diameter tungsten-rhenium targets have been measured when irradiated by unfocussed 50-MW, 20-ns pulses from a Nd:glass Q-switched laser. Current growth rates of 10^9 A/s were observed. A high-voltage (180 kV) facility was constructed to overcome space charge effects and measure beam quality. Preliminary evaluation of the spatial distribution of the electron beam indicated improved emittance, or lower energy spread, with laser activation.

The second area of research focussed on CW laser stimulation of cesiated photoemitters. Using an argon-ion laser irradiating wavelength of 488 nm, 2.5 mA of current, at a current density of 80 mA/cm^2, was drawn. With 10% decay this current level was held for 70 hours. Full initial photosensitivity was recovered by adding cesium to the cathode surface at the completion of the test. The nominal electron energy spread was measured to be 0.30 eV.

1. INTRODUCTION

This final report summarizes the work that was done during the period from February 1, 1979 through September 30, 1982, on experimentally investigating laser-activated switching of- and electrom beam formation from cesium coated thermionic and photoemissive surfaces, under Contract No. N00014-79-C-0131.

The program was initially intended to research thermionic devices as high-power electrical switches triggered by laser-induced photoionization of interelectrode cesium atoms.[1] Laser-driven cesiated thermionic switches are thyratrons in nature. However, several important differences exist between these laser devices and conventional thyratrons. First, laser switches rely on radiation as the triggering source rather than on a conventional third electrode. Second, laser switches use the radiative pulse as a heat source for the cathode so no "thermionic" warmup is necessary. Finally, a cesiated laser switch operates at a much lower pressure than does a conventional thyratron. Consequently, higher standoff voltages and higher operating frequencies should be possible.

In October 1979, it was observed that very large currents would flow through the cesiated diode when the pulsed laser was fired directly onto the cathode. It was postulated that a low work function surface, which was suddenly radiation heated by a laser pulse to high temperature, would emit a high-density burst of electrons. Subsequently, the program was divided into two research paths: high-power laser-induced switching in cesium vapor, and high density electron beam generation from cesiated surfaces.

In high-power switching, we examined the effects of cesium and mixtures of cesium with inert gases on the amplitude of the self-breakdown voltage, and on the generated peak current, its rise time, and its delay time. Also investigated were cathode temperature laser-power and laser-beam characteristics on these switching parameters. A Mini-Marx high-voltage generator was purchased to overcome space charge problems created by emission of multi kilo ampere per square centimeter electron densities. For the production of intense electron beams, a diagnostic chamber was designed in which the high-density electrons created by laser radiation could be characterized. Of specific interest was the quality, or energy spread (emittance), of such electron beams. This spread was expected to be low because of the thermionic nature of the electron source. Preliminary tests have supported this characteristic.

In October 1981, the program was extended to the fabrication and investigation of electron emission from semitransparent Cs_3Sb photocathodes under back illumination by laser light. By tailoring the wavelength appropriately close to the photoemissive threshold, very monochromatic beams of electrons can be generated. Indeed, the full-width, half-maximum of the energy distribution was measured to be as low as 0.1 eV when photoexcitation was achieved with a He-Ne laser operating at 632.8 nm. With an argon-ion laser at 488 nm back illuminating a water-cooled Cs_3Sb photocathode, currents up to 2.5 mA (80 mA/cm^2) were emitted which remained constant to within 10% of their peak value for 70 hours. The initial maximum sensitivity of the photocathode could then be recaptured by adding some cesium, in situ, to the surface of the photocathode.

2. PROGRAM ACCOMPLISHMENTS

2.1 Thermionic High Current Switching and Electron Beam Generation

Laser-activated spark gaps have been studied extensively for the past 15 years. The theory of laser-activated spark gap switching is now well understood. Some of the desirable features of these devices are their short jitter and closing times, the ability to electrically uncouple the laser trigger from the switching gap, and the ease with which this technique can be adapted to multigap operations. A 1978 review article[2] summarized the research in this field. In contrast to the emphasis on spark gap switching, little attention has been directed toward the use of laser triggers in other types of switches.

Electrically triggered thermionic switches have been examined as a means of converting direct current into alternating current.[3-5] The advantage of thermionic devices in this application is that they characteristically operate with low voltage loss. By replacing the switch's triggering electrode with a laser ignition system, thermionic devices should provide low loss and rapid switching of high currents. There are a number of ways to implement such a laser-triggering system.

In the first way, a low pressure interelectrode cesium vapor was ionized by multiphoton absorption of Nd:glass laser radiation. With a laser output of 50 MW in a 20 ns pulse, an emitter temperature of 440 K, a cesium pressure of 7 x 10^{-3}

torr, and an applied voltage of 2 kV, a peak current of 180 A was observed. The test equipment is shown in Figure 1. Since the mean free path of electrons at such pressures is about 1 to 2 mm, which is larger than the focal spot dimension, multiphoton ionization provided all the electrons, at least in the initial stages of the vapor breakdown.

In the second way, the laser light was incident on the cathode surface, rather than being concentrated into a small area within the interelectrode space. Much larger currents were thus generated by thermionic emission from the electrode. Such high-density electron beams were then transported to the anode by cesium ions created through inelastic collisions between target emitted electrons and cesium atoms. Peak currents of 2500 A from 9-mm-diameter laser beams, for current densities of 3900 A/cm^2, were observed. With approximately 3/4-kV potential across the electrodes and 10^{-4} torr pressure of cesium, these currents were thought to be partially space charge limited. Furthermore, the ambipolar diffusion of electrons and ions from the target to the anode elongated the 20-ns pulse of electron emission to 1 to 2 μs in accordance with the ion transit time. Consequently, the observed peak electron current was probably somewhat depressed with respect to that actually emitted from the target's surface.

Because space charge and ambipolar effects mask the electron emission processes and the temporal pulse shape, the facilities were modified to allow beam transport under vacuum conditions. An electron beam diagnostic chamber, shown in

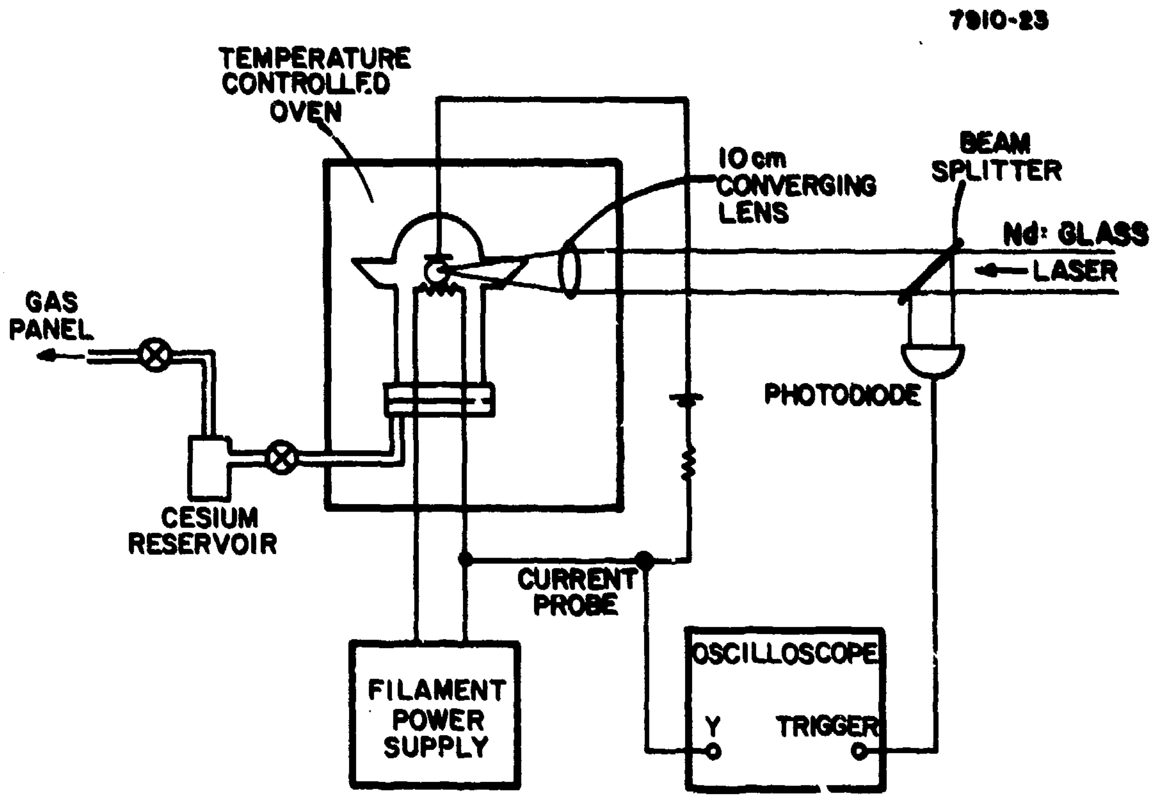


Figure 1. Schematic Representation of the Four-Window, Glass-Enveloped Diode Mounted Inside the Oven

Figure 2, contained a tungsten target emitter, which was coated with a thin layer of cesium by resistance heating a cesium chromate channel. The system operating at a pressure of 10^{-7} torr or lower required a high voltage to transport the electron flow. For this purpose a six-stage Mini-Marx generator provided a maximum open circuit voltage across the electrodes, spaced approximately one cm apart, of 180 kV. With this high voltage discharge coupled to the laser pulse, via a delay generator and an electro-optic Q-switch, the necessary space-charge-free transport of several hundred amperes of laser-induced, thermionically emitted electrons was possible. Beam quality (emittance), or the electron energy spread, was measured in the field-free region downstream of the annular anode by an array of ten Faraday cups.

With the Faraday cup array positioned 10 cm downstream of the annular anode, some initial measurements of the near-axial component of the electron beam passing through this electrode were made. Simultaneously, current-measuring coils determined the total electron flux passing from the cathode to the anode, and the portion of the flux passing through the hole in the anode.

At these high voltages, self-induced field emission occurred. Such emission generated "hot" (high thermal velocity) electrons, thereby obscuring the laser-induced thermionically produced "cold" electrons. Reduction of field emission effects is necessary, but could not be accomplished prior to program termination. The experiments during the final

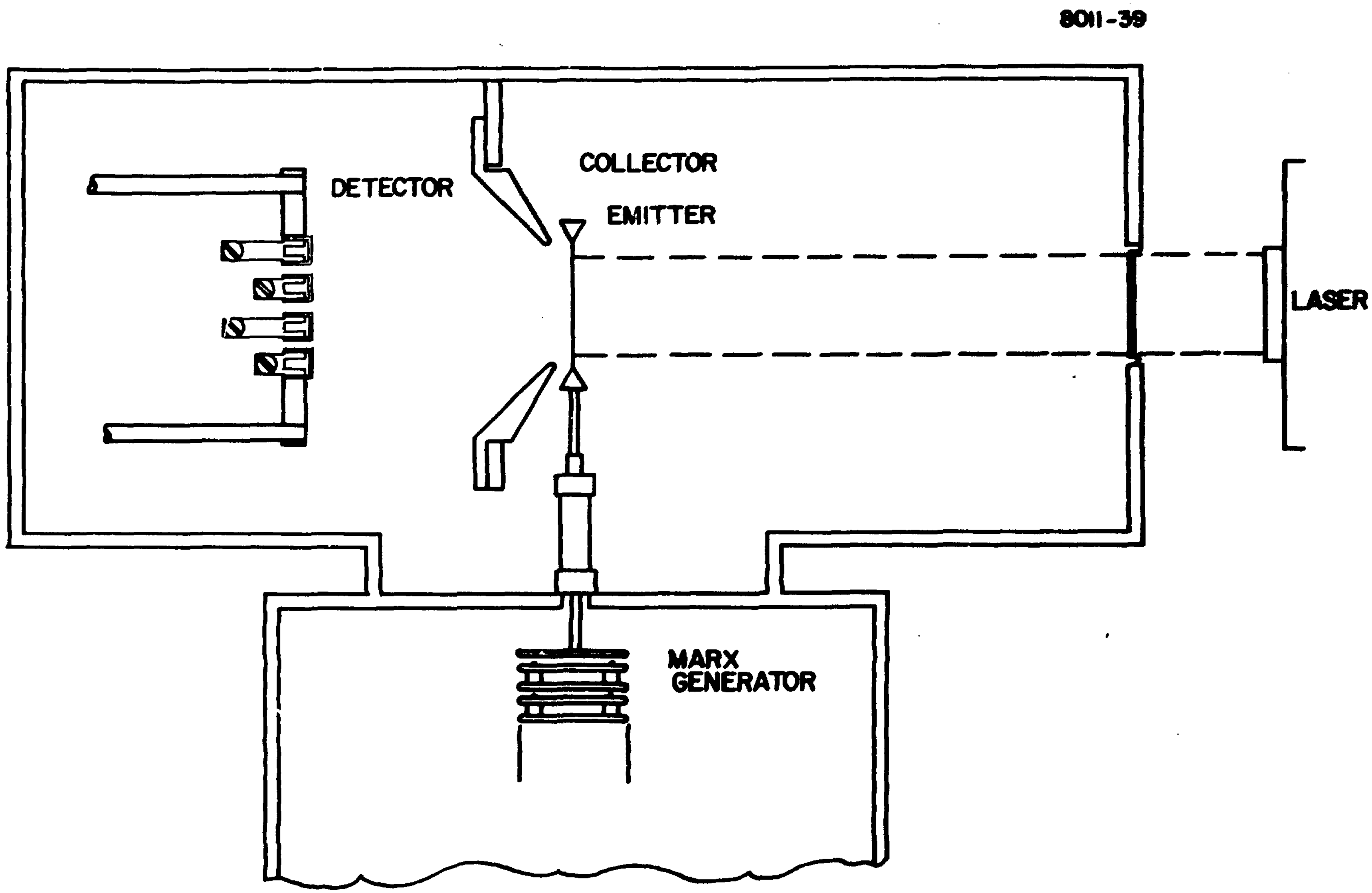
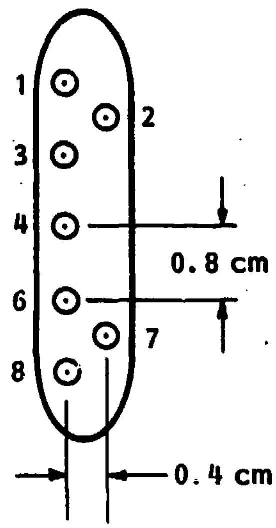


Figure 2. Schematic of Internal Components of Electron Beam Diagnostic Chamber

months were, therefore, used to evaluate the role of laser-activation on modifying the field emission processes. Consequently, when the Marx generator was fired, tests were conducted with and without simultaneous Nd:glass laser pulse irradiation of the tungsten cathode surface, which was either bare or coated with cesium. Although the total diode current and that portion passing through the anode was observed to remain the same and, therefore, did not depend on whether the discharge was self-induced field emission or a laser-induced thermionic emission, the near-axial electron beam flowing through the anode, as measured by the downstream Faraday cups, did vary (Figure 3).

Each entry in the table in Figure 3 is the average of five runs. Laser activation of the bare tungsten cathode surface was seen to enhance the magnitude of the electron beam with respect to that observed from self-breakdown alone. This increase in electron emission is thought to be caused by some residual surface impurities which lower the surface work function. The current distribution (Figure 4) indicated that the beam is moderately annular, a likely result of the nonuniform accelerating field in the central region of the anode caused by the large (approximately 2.5 cm) hole in this electrode.

Upon cesiating the cathode, the beam was observed to fill out, with a significent rise in its central current density (Faraday cup Nos. 3, 4, and 6) and a corresponding drop at points removed from the axis (Figure 3). These larger axial currents are expected for a "colder" (low transverse energy)



Faraday Cup Arrays

	#1	#2	#3	#4	#6	#7	#8
Vacuum Breakdown on Clean Surface	26	42	46	33	20	54	63
Laser-Activated Discharge on Clean Surface	67	125	59	59	42	83	125
Laser-Activated Discharge on Cesiated Surface	42	83	83	76	59	83	83

Figure 3. Faraday cup array current signals at various experimental conditions. Numbers in the table are in units of A/cm². All numbers are averaged over five runs.

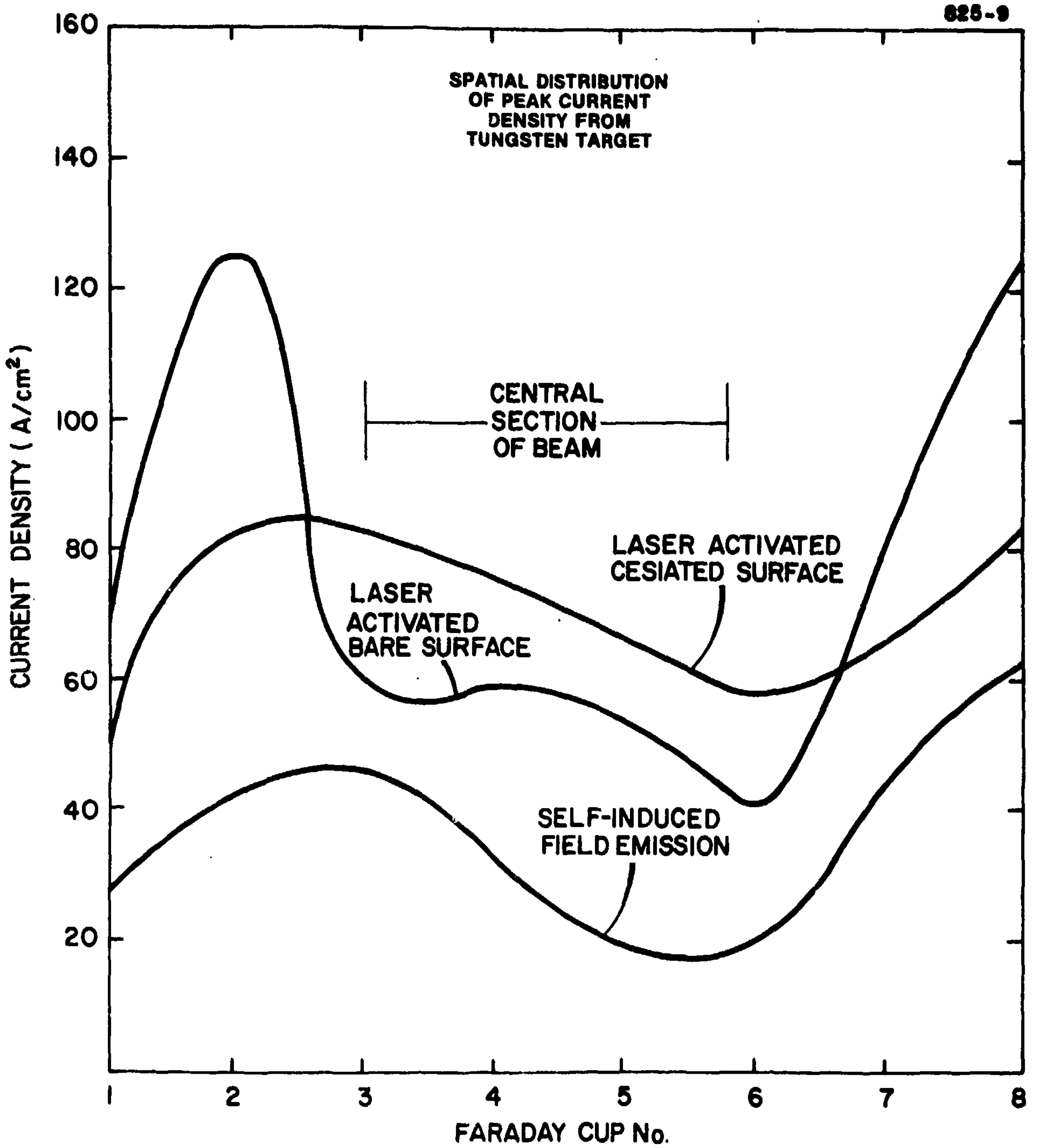


Figure 4. Spatial Distribution of Peak Current Density from Tungsten Target

beam generated thermionically from the laser-heated cesiated target. Consequently, the number of "cold" electrons emitted by laser heating of the surface is sufficient in a mix with the "hot" field-emitted electrons, to produce experimentally observable cooling of the beam. However, the actual energy exchange between these hot and cold groups of electrons is complicated by the space charge which limits the total current flowing through the anode hole.

Although, quantitatively, field emission and space charge effects may obscure measurement of the characteristics of the laser-induced cold electrons emitted at the target surface, qualitatively, these experiments appeared to confirm that substantial quantities of cold, low emittance (high quality) electrons were, in fact, formed in this manner. Higher voltage acceleration and a reduction in field emission would be expected to greatly enhance the cold electron beam formation by laser surface heating.

2.2 Photoemissive Electron Beam Generation

Whereas laser-induced thermionically emitted electrons have energy spreads determined by the surface temperature and, therefore, have some dependence on the intensity of electron emission, energy spread and intensity can essentially be decoupled with laser-induced photoemission of electrons. Pulsed laser-induced photoemission at Stanford University's SLAC facility using a frequency doubled 80-kW Nd:YAG laser and a cesium-coated GaAs surface have yielded peak currents of 60 A and current densities of 180 A/cm^2.[6] Pulsed ruby laser activation of multialkali surfaces at Thermo Electron have generated peak current densities of 30 A/cm^2. In CW operation, lower values f 1 to 100 mA/cm^2 are expected. Stable output of up to 2.5 mA for a current density of 80 mA/cm^2 were, in fact, achieved from a semitransparent Cs_3Sb surface back illuminated by an argon ion laser operating at 488 nm.

These tests were, however, conducted over a maximum period of only 70 hours, at which time the emission had decayed about 10% (Figure 5). Degradation in performance was caused by excessive surface temperature rise due to laser heating. Experience has shown that photoemission dramatically decreases when the surface temperature rises above 40°C. Water cooling of the photocathodes was employed to lower the surface temperature in these tests. To combat high electrical resistance effects, the thickness of the metal film underneath the photocathode was made sufficiently thick to allow good electrical conductivity, yet not so thick so as to appreciably limit light transmission. The illuminated area of the photocathode was 3.1 x 10^{-2} cm^2 in all three cases.

After completing the experiment, the full initial photosensitivity was recovered by simply adding cesium to the surface. Therefore, the decay was due solely to cesium desorption, rather than caused by chemical modification of the cesium antimonide by environmental impurities or ion bombardment of the surface.

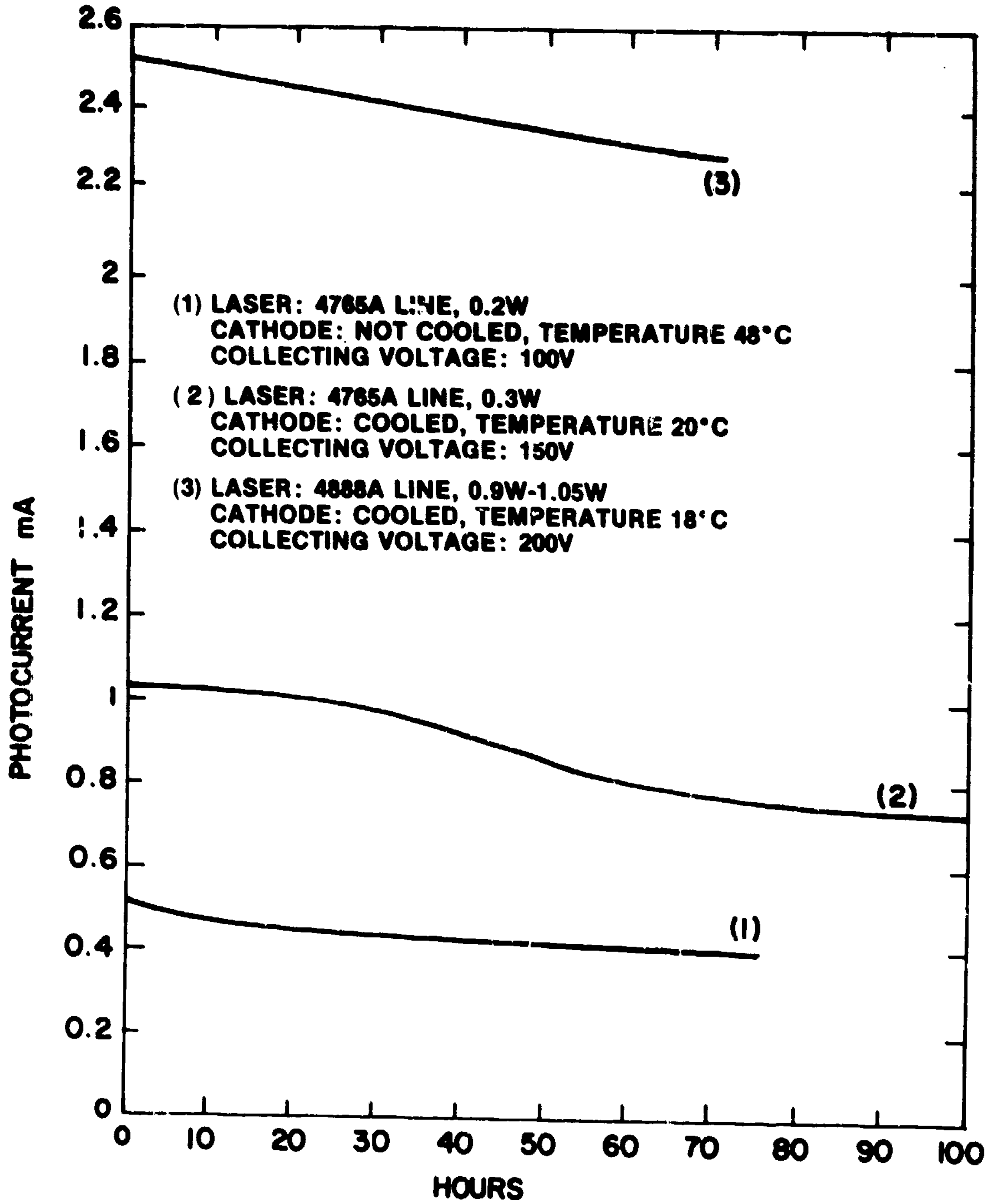


Figure 5. Laser-Activated High Current Photoemission Life Tests

A significant effort was devoted towards accurately measuring the electron energy spread of semitransparent Cs_3Sb photocathodes back illuminated by the argon ion laser beam. Cs_3Sb was chosen for the photoemissive surface because of its ease of fabrication and its sensitivity to the argon ion laser wavelength. The semitransparent configuration was selected because of its adaptability to electron beam lithography systems, the major identified application of this photoemissive electron source technology.

Photocathodes were constructed on a quartz or sapphire substrate with a thin, semitransparent (40-50 percent) electrically conductive chromium coating. Layers of antimony and cesium on this coating provided the photoemissive surface. A variety of energy analyzers were designed and tested with poor results. Charged insulators, spatially varying contact potentials, and directional effects of the emitted electrons all contributed to erroneous measurements.

In overcoming these various problems, a device was eventually developed (Figure 6) which provided accurate energy discrimination. Differential measurements of the photoemitted current detected by the Faraday cup were obtained directly with a lock-in amplifier. This differential is proportional to the number density of electrons at each level of energy. The full width of the curve at half-maximum intensity is, therefore, an accurate reflection of the nominal energy spread of electrons emitted from the photocathode.

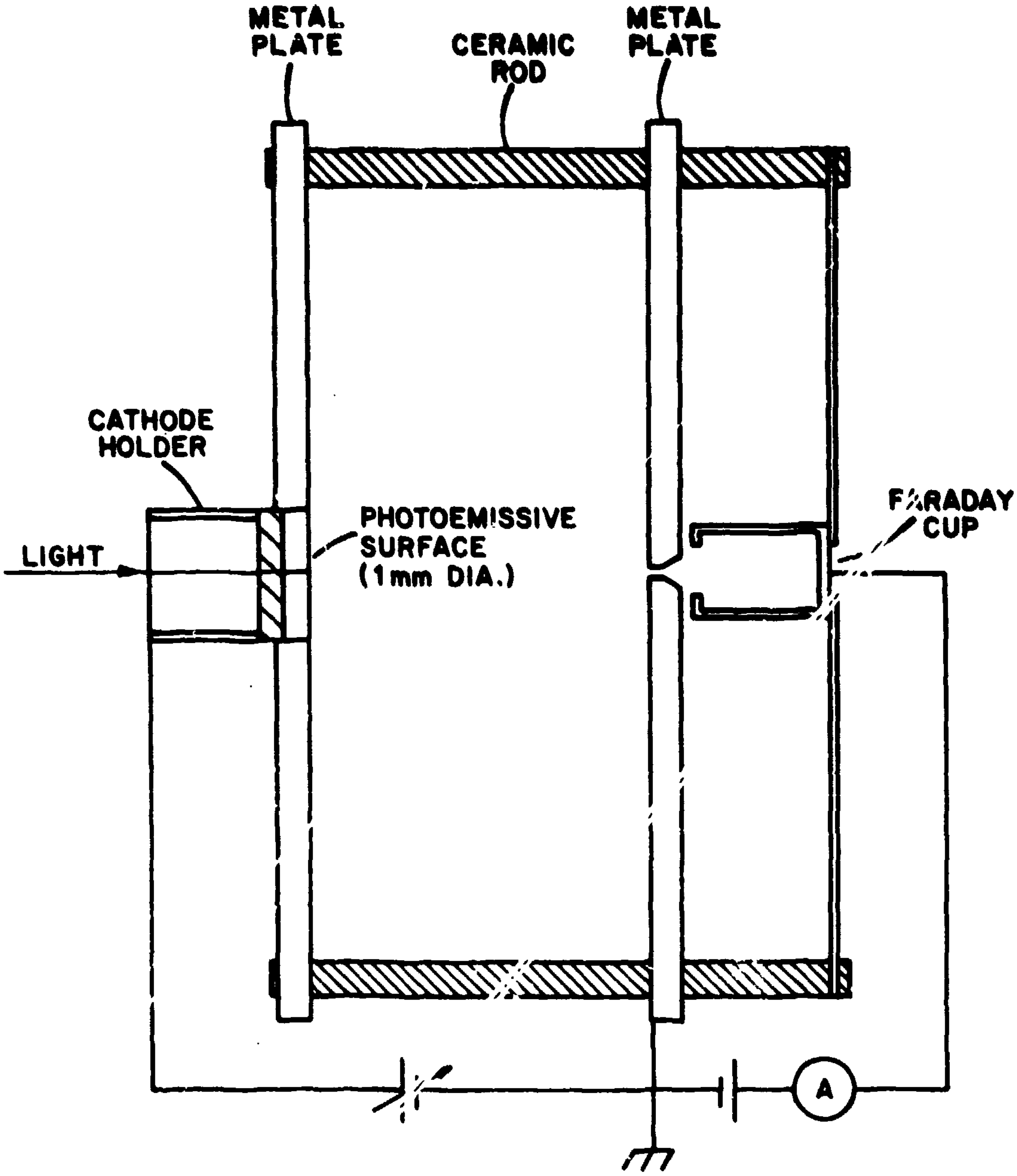


Figure 6 Photoemitted Electron Energy Analyzer

The results for three different argon ion laser spectral lines (457.9, 488.0, and 514.5 nm) are shown in Figure 7. Corresponding energy spreads are 0.33, 0.30 and 0.25 eV. As expected, the longer wavelength laser lines reduce the energy spread because electron emission occurs closer to the photoemessive threshold of the Cs_3Sb surface. An even smaller spread (0.175 eV) was measured with He-Ne laser (632.8 nm) activation of the surface (Figure 8).

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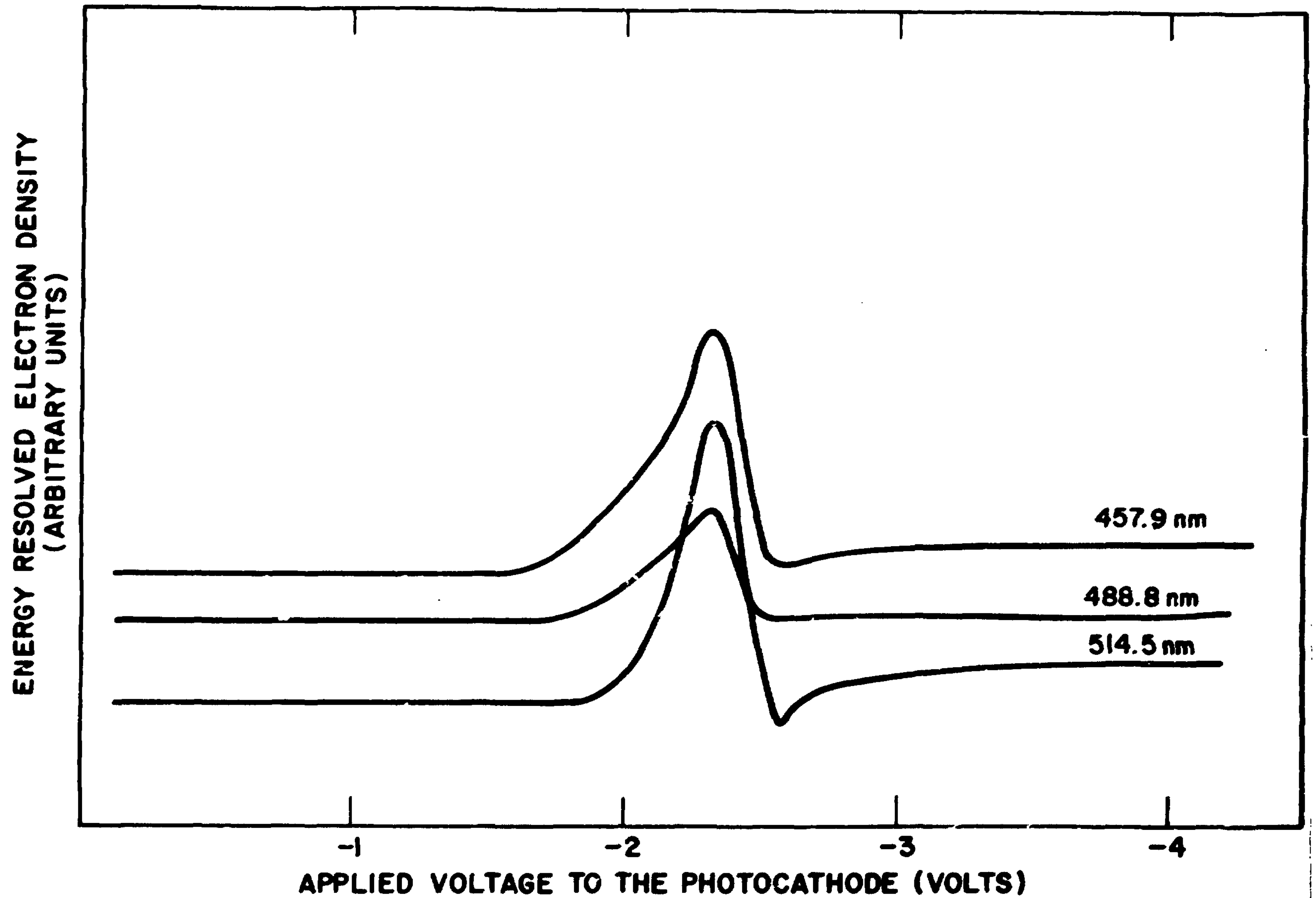

Figure 7. Photoemitted Electron Energy Spread at Ar^+ Laser Lines

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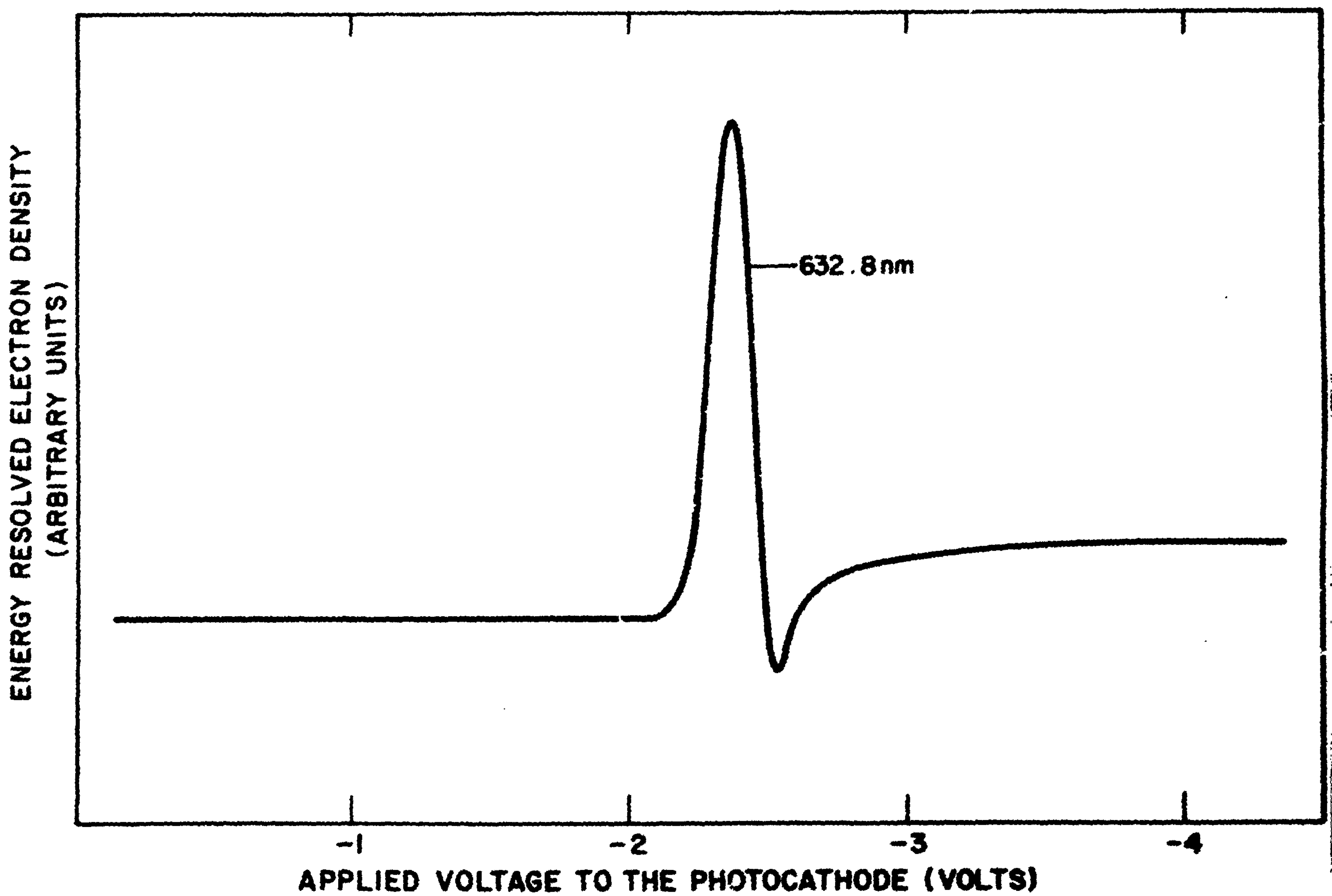

Figure 8. Photoemitted Electron Energy Spread at He-Ne Laser Line

3. CONCLUSIONS

The program was initially intended, in 1979, to research cesiated thermionic devices for laser-activated high-power electrical switching, but was focussed during much of its life on generating high-current density, good quality electron beams. Both laser-induced thermionic and photoemissive electron beam formation were explored. The former provided pulsed current densities up to 4 kA/cm^2, with apparently improved emittances, and has application to microwave generation, free electron lasers, and beam weaponry. It may also have some application to the production and study of localized electromagnetic pulses (EMP). In the latter, CW current densities up to 80 mA/cm^2 were attained with 0.30 eV electron energy spreads. These sources presage a significant improvement of feature resolution and chip throughput in electron beam lithography systems being developed for the production of very high-speed integrated circuits. More details on this program can be obtained by referring to the two annual reports.[7,8]

4. RECOMMENDATIONS

Although the potential of generating intense, high-quality pulsed (thermionic) and continuous (photoemissive) beams by laser-activating cesiated surfaces was demonstrated during the course of the program, the work was, unfortunately, terminated before additional important information was obtained. Specifically, high-power pulsed experiments need to be performed on cesium-coated refractory metals positioned in vacuum chambers, and configured to minimize field emission. The characteristics of these beams should be analyzed temporally and spatially by Faraday cup arrays, such as those used in this program. In this way, precise quantitative measurements of beam emittance can be made, and compared to those associated with field emission and plasma emitting sources. Perveance measurements in such experiments would identify to what extent ions are created from the cesium, and whether closure problems exist.

Improved photoemissive sources should continue to be developed. Specifically, better cooled cathodes will limit the laser-aggravated cesium evaporation, thereby lengthening operating times. Replacement of the Cs_3Sb by negative electron affinity photoemissive semiconductors should dramatically reduce the electron energy spreads even further, and allow use of rapidly current modulable injection lasers to activate these sources.

A continuing effort in both these areas should pay off in the development of superior electron sources for filling future DOD needs in weaponry, communications, and electronics.

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