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### Journal

Review of scientific instruments, 61(1)

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### Publication Date

2017-12-04



# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## Accelerator & Fusion Research Division

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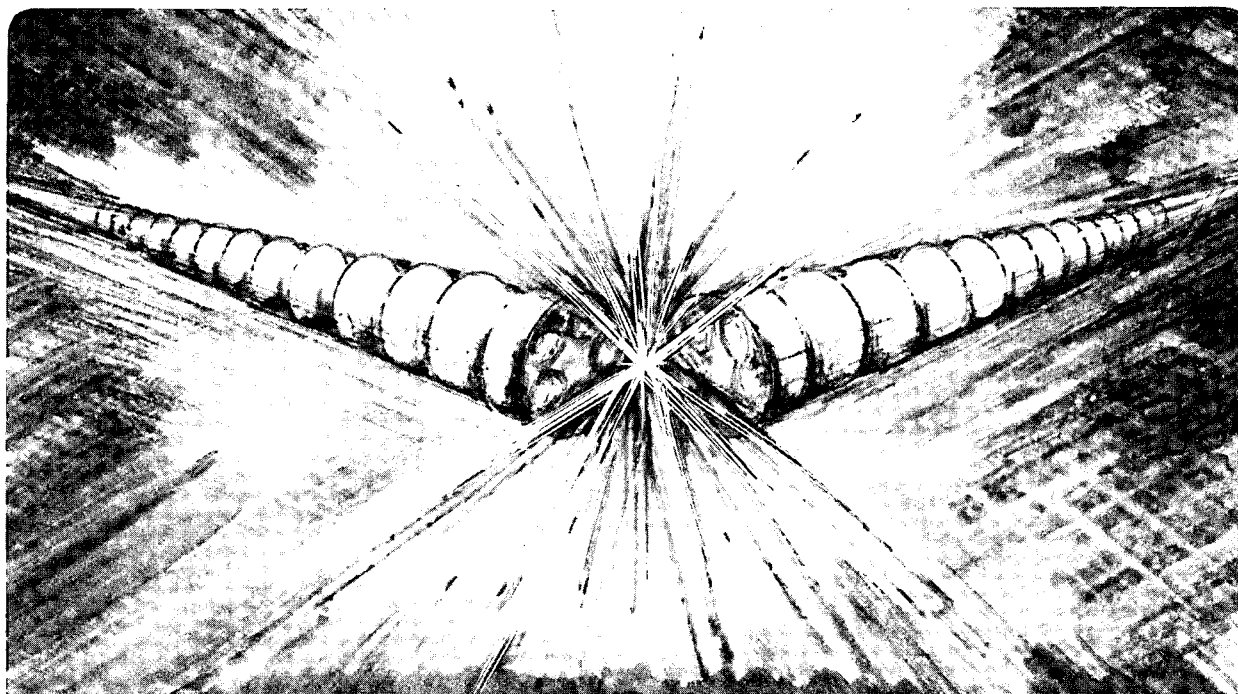
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Presented at the International Conference on Ion Sources,  
Berkeley, CA, July 10-14, 1989, and to be published in the  
Review of Scientific Instruments

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June 1989



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NANOSECOND LENGTH ELECTRON PULSES FROM A LASER-EXCITED  
PHOTOCATHODE

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This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

# Nanosecond Length Electron Pulses from a Laser-Excited Photocathode

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## ABSTRACT

A photocathode made from polycrystalline lanthanum hexaboride ( $\text{LaB}_6$ ) has produced nanosecond length electron pulses when excited by an excimer laser at 308nm. Peak currents in excess of 1A have been observed, with quantum yields of  $4 \times 10^{-5}$  being measured. A method for extracting the electrons from an emission-limited cathode, plasma extraction, has been demonstrated. This technique uses a low power continuous discharge to provide the electric field needed to extract the photoelectrons. This technique may be useful in producing high repetition rate short pulse ion sources.

## I. Introduction

Short pulse sources of electrons have applications in many fields. They range from high energy particle accelerators, free electron lasers, high power microwave generators, and ion sources. Much recent work has focussed on the use of the photoelectric effect to produce these short pulses<sup>1,2</sup>. With photoemission, the electron burst will have a temporal behaviour similar to that of the exciting light. By using short pulse length laser excitation, picosecond pulses of electrons have been produced<sup>3</sup>.

The application of laser-excited photocathodes to ion sources has several unique requirements. In addition to the requisite good electron yield and short pulse capability, if the photocathode is placed within the ion generating chamber, it must operate under conditions of only modest or partial vacuum. In addition, the photocathode may be exposed to the ions created in the source. Finally, if large electron yields are realized, the peak current from the photocathode may be limited by space-charge effects. Although extraction with high voltage grids is possible, it would be preferable to avoid the use of very high voltage supplies or complicated accelerator structures while still providing a large space charge limit and minimal temporal distortion.

In this paper, we report a new configuration for a laser-excited, nanosecond pulse width electron source suitable for use in ion sources. A new method for collecting the photoelectrons, plasma extraction, is demonstrated. This technique, which

employs the cathode sheath potential of a low density plasma to extract the photoelectrons from an emission-limited cathode, is shown to be effective in producing nanosecond pulses of electrons with peak currents in excess of 1A.

## II. Experimental

The experimental apparatus is shown schematically in Figure 1. The disk shaped polycrystalline LaB<sub>6</sub> photocathode was 19 mm in diameter. The LaB<sub>6</sub> was placed in a cathode holder<sup>4</sup> which allowed an electric current to pass from the center of the disk to its outer edge. This steady-state current,  $\leq 10$  V and  $\leq 500$  A, was used to heat the cathode resistively. The "heater" power supply and the cathode itself could be biased using a 400 V, 5 A DC power supply when operating the experiment with plasma extraction. This "discharge" power supply provided the current to maintain the continuous discharge.

The cathode holder was placed in a multicusp ion source<sup>5</sup>. This chamber was cylindrical, 25 cm in diameter and 30 cm long and was made of aluminum. The cathode holder was inserted through a vacuum port, with the cathode at the center of the chamber. One end of the cylinder was capped with a copper flange, while the other end was closed off by an acrylic flange with a copper insert. This flange provided electrical isolation between the chamber and ground. The entire assembly was mounted on a vacuum system and evacuated through a 2 mm

diameter orifice in the copper insert. The base pressure in the source was  $5 \times 10^{-5}$  torr.

The source of optical excitation was a XeCl excimer laser. This laser emits 308 nm radiation in a double-humped pulse with a combined 50 ns width. The beam was sent through an iris and attenuated so that  $\leq 30$  mJ were directed to the photocathode. The beam diameter, typically 6mm, was controlled by the iris and a lens placed after the beam steering optics. The beam entered the chamber through a quartz window and was incident on the photocathode surface at a  $45^\circ$  angle.

The electrons liberated by the photoemission process were extracted from the surface by two methods, high voltage extraction under vacuum, and plasma extraction in the presence of a low power dc discharge. For high voltage vacuum extraction, a graphite anode was placed 1.5 cm away from the photocathode and biased at up to +3 kV in order to collect the photoelectrons from the cathode. In this configuration, the discharge power supply was removed from the circuit and one leg of the heater supply was grounded. For plasma extraction, the graphite anode was retracted. Instead, the walls of the chamber served as the anode, with the current being measured between them and ground. For the experiments described here, a hydrogen plasma was employed with  $H_2$  filling pressures between 4 and 30 mtorr.



### III. Results and Discussion

Figure 2 displays the temporal evolution of the photocurrent measured by high voltage vacuum extraction and by plasma extraction. For comparison, figure 2 also shows the temporal evolution of the exciting laser pulse. As can be seen, the emitted photocurrent has a pulsewidth comparable to the laser pulse. This indicates that the bulk of the electrons are produced via photoemission. The slight lengthening of the electron pulses can be attributed to transit time spreading of the electrons.

The quantum yield of the LaB<sub>6</sub> was measured in vacuum and also with plasma. Figure 3 shows the results of measurements in vacuum as a function of photocathode temperature. As can be seen, the emitted current increases as a function of photocathode temperature. The peak quantum yield (QY) obtained from these experiments is  $6 \times 10^{-6}$  electrons/incident photon at 1475 K. With plasma extraction, QY's up to  $4 \times 10^{-5}$  at 1600 K were measured. No emission, corresponding to a QY of  $< 10^{-8}$ , was observed at room temperature in vacuum. However, upon return to room temperature following heating, a period of enhanced photoemission sometimes ensued. The QY slowly decreased during this period; the enhancement lasted for seconds to minutes, much longer than the thermal equilibration time of the LaB<sub>6</sub>.

Previous experiments with uv excitation of LaB<sub>6</sub> have been performed by Lafferty<sup>6</sup>, Oettinger<sup>7</sup>, and Bergeret<sup>8</sup> *et al.* These authors studied photoemission *in vacuo* at room temperature with

various excitation wavelengths. The Q.Y. reported here for high voltage extraction lies between the  $2 \times 10^{-4}$  and  $1.3 \times 10^{-6}$  QY's reported by Lafferty and Oettinger, respectively. Bergeret *et al* reported QY's up to  $10^{-3}$ , but with strong focussing of the light which damaged the LaB<sub>6</sub>; those results will not be discussed further. The present work demonstrates an increasing yield at higher temperature. The variation in quantum yield does not appear to be fundamentally related to the photocathode temperature, however, as enhancements to the quantum yield in vacuum were often noted for some time after the temperature was reduced. A more plausible explanation is that high temperatures and plasma bombardment tend to free the surface of contamination or may assist the lanthanum in diffusing to the surface, providing a continuous refreshment of the emitting layer. In both Lafferty's and Oettinger's experiments, the LaB<sub>6</sub> was treated at high temperature and stored in vacuum at  $<10^{-5}$  torr.

The space charge limited current density which can be extracted from the photocathode is given by<sup>9</sup>

$$j(A/cm^2) = 2.33 \times 10^{-6} E^{\frac{3}{2}} d^{-2} \quad (1)$$

where E is the cathode-anode potential difference in volts and d is the cathode-anode distance in cm. For high voltage extraction in vacuum, E = 3000 V, d = 1.5 cm, yielding  $j_{\max}(\text{vacuum}) \sim 0.2 \text{ A/cm}^2$ . In the presence of a plasma, eq. (1) is still valid, however, E is now the discharge voltage,  $\sim 200 \text{ V}$ , and d is  $\lambda_s$ , the width of the plasma

sheath, e.g., the width of the boundary layer between the cathode and the bulk plasma.  $\lambda_s$  given by  $\lambda_s^2 \sim \lambda_D^2 (V/k_B T_e)$  where  $V$  is the discharge voltage,  $\lambda_D$  is the Debye length, and  $k_B T_e$  is the electron temperature in eV.<sup>10</sup> For  $k_B T_e \sim 1$  eV,  $\lambda_D \sim 8 \times 10^{-3}$  cm, and  $V = 200$  V,  $\lambda_s \sim 10^{-1}$  cm. The space charge limited current for plasma extraction is thus  $j_{\max}(\text{plasma}) = 0.4$  A/cm<sup>2</sup>. This calculation is subject to the uncertainty in the exact value of  $\lambda_s$ , and assumes no gradients in  $n_e$  and  $T_e$  but it illustrates the fact that the plasma can effectively extract electrons from the photocathode.

While using plasma extraction, the photocurrent was measured as a function of various discharge parameters. Although no large variation in the current was observed for changes in the H<sub>2</sub> pressure, a dependence upon the discharge voltage was observed. Figure 4 shows this dependence for several incident laser energies. As can be seen, at lower discharge voltages the signal increases with applied voltage, until an asymptotic value is reached. Two observations can be made: (1) the QY at high discharge voltage is about the same,  $3 \times 10^{-5}$  for all energies (2) the threshold voltage required to reach the asymptotic value increases with increasing laser energy, ranging from 50 V for 0.2 mJ to 250 V for 2.5 mJ.

The voltage dependence of the photocurrent qualitatively agrees with prediction. Below the threshold voltage the current is space-charge limited and not all the electrons are collected. Increasing the voltage leads to extraction of more of the photoelectrons thereby increasing the measured current until the

extraction is no longer space charge limited. This occurs at the threshold voltage. With increased laser energy, more photoelectrons are available, and the threshold voltage should increase.

The use of a plasma to extract electrons from the photocathode allows shorts bursts of electrons to be produced and introduced into the plasma. As long as the laser fluence is kept below the threshold for thermionic emission, the electron pulse width will be comparable to the pulse width of the laser excitation source. Once in the plasma, these electrons will participate in the chemical and physical processes occurring in the plasma. Although the photocurrents reported here,  $\leq 1A$ , are modest, the laser energies employed,  $\leq 30$  mj, are also small. In excess of 500 mJ at 308 nm is available from commercial excimer lasers. With sufficiently large photocathode surfaces, peak currents  $>100$  amps should be obtainable. In addition, illumination with other wavelengths with larger Q.Y's is possible. These larger quantum yields may lead to even higher peak currents. Finally, high repetition rate excimer lasers are also available, with some models operating at 1 KHz. This would allow the development of high repetition rate, short pulse length ion sources. Experiments are currently underway to measure the ions produced by these photoelectrons.

#### IV. Acknowledgements

We would like to thank D. Moussa and S. Wilde for their technical assistance. This work is supported by the Director's Exploratory R&D Fund of Lawrence Berkeley Laboratory under DOE Contract No. DE-AC03-76SF00098.

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## FIGURE CAPTIONS

- Figure 1. Schematic diagram of experimental apparatus, showing equipment used for both high voltage extraction and plasma extraction of the photoelectrons.
- Figure 2. Temporal response of a) high voltage extracted electrons; b) plasma extracted electrons; and c) excimer laser pulse.
- Figure 3. Temperature dependence of the quantum yield obtained using high voltage extraction. Extracter voltage was 3 kV or higher and laser fluence was 0.9 mJ/cm<sup>2</sup>.
- Figure 4. Peak photocurrent obtained using plasma extraction vs. the discharge voltage. Curves are shown for 4 laser energies. Asymptotic quantum yields for all of the energies is  $\sim 3 \times 10^{-5}$ .



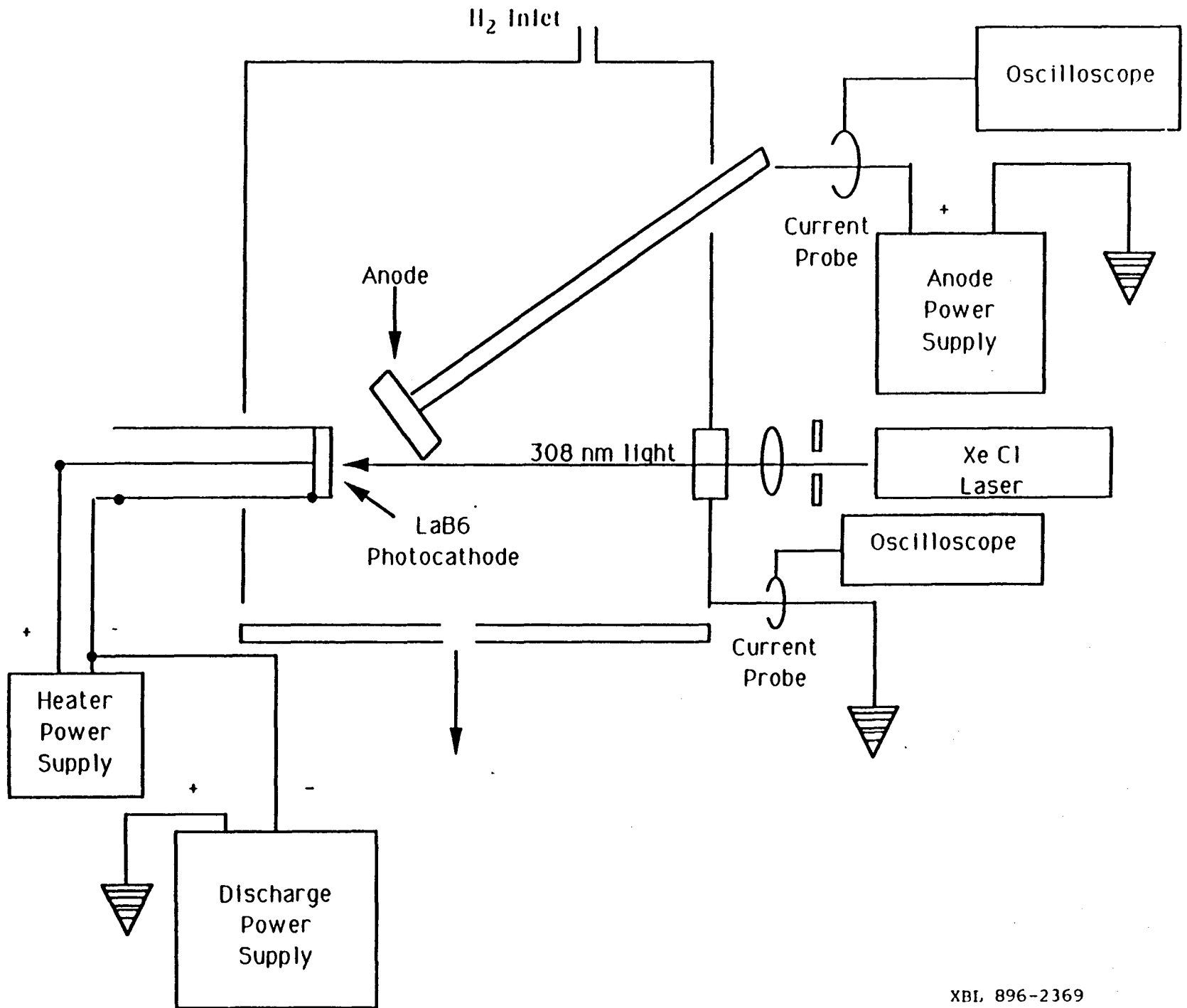
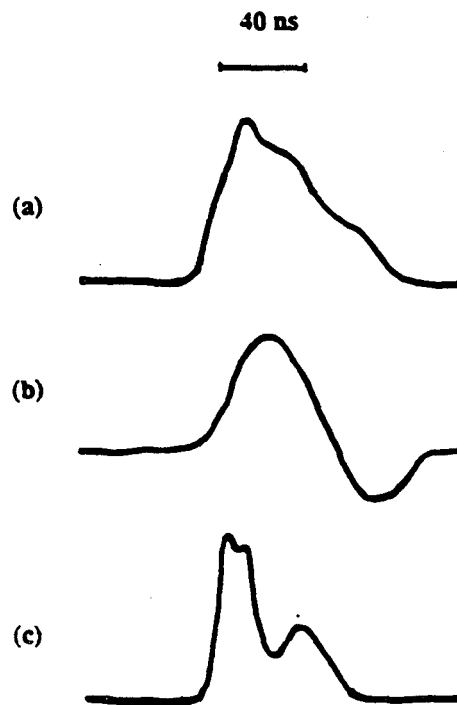
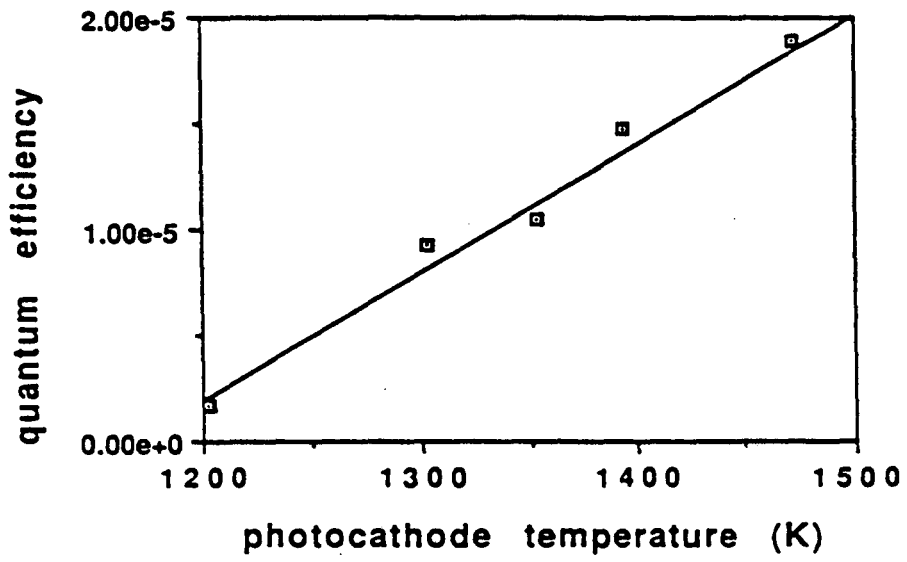


Figure 1



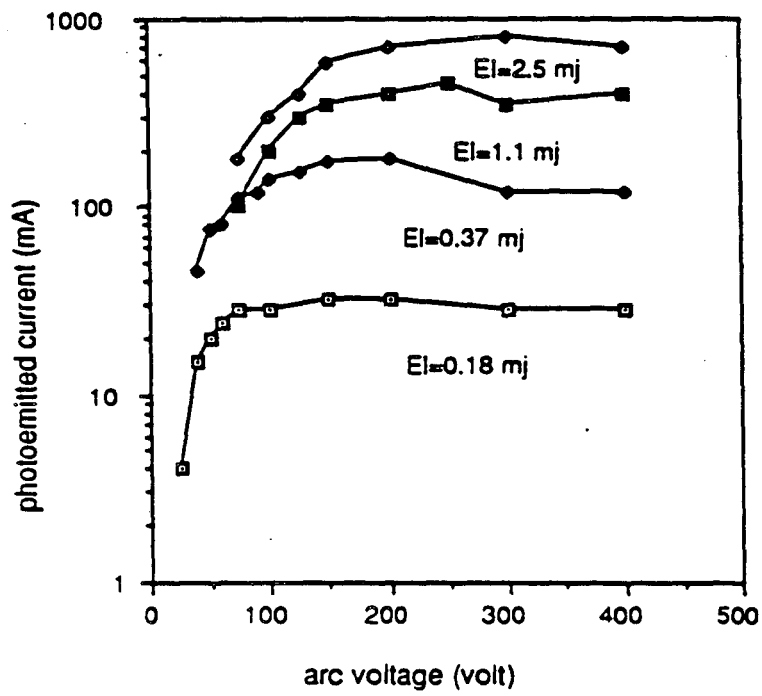
XBL 896-2370

Figure 2



XBL 896-2371

Figure 3



XBL 896-2372

Figure 4

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