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Quantum Yield Measurements of Photocathodes Illuminated by Pulsed Ultraviolet Laser Radiation

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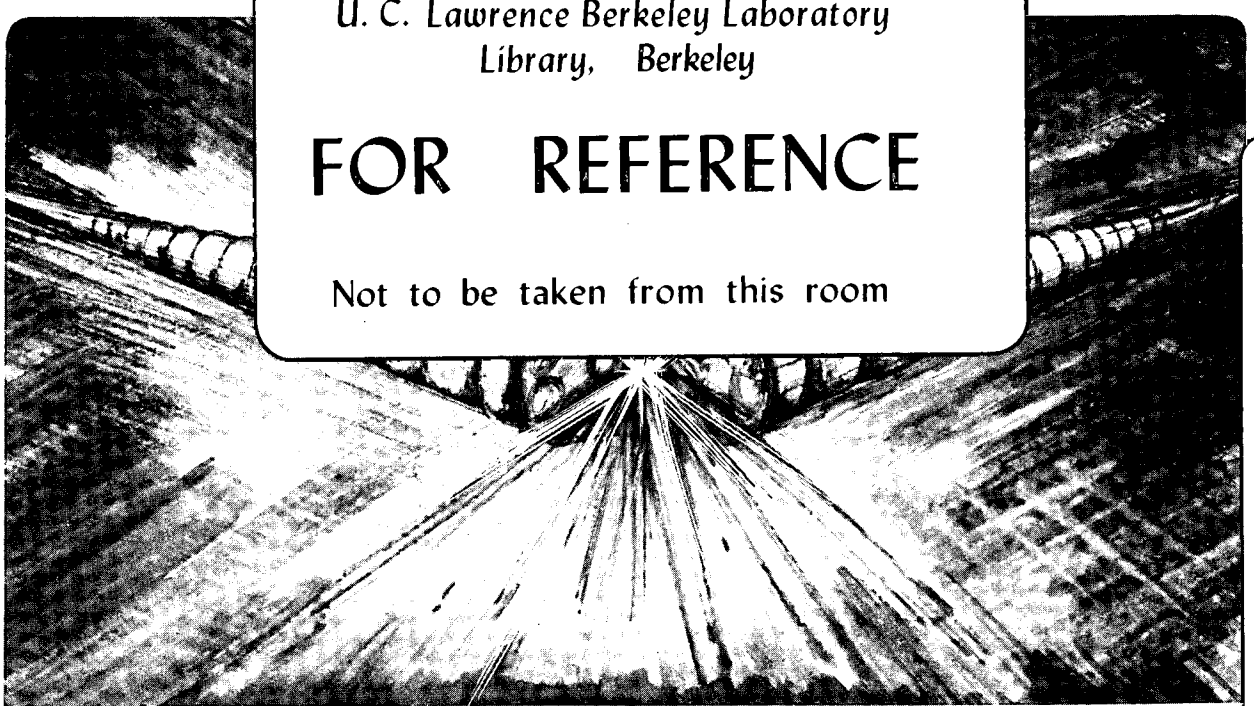

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Abstract

The electron quantum yields from polycrystalline lanthanum hexaboride and barium irradiated by near ultraviolet laser excitation have been determined. These measurements show that the quantum yields from these materials are dependent on the processing and previous history of the photocathode material. For lanthanum hexaboride, a yield of 7 x 10^{-6} with 337 nm irradiation has been achieved. For barium, a yield of 1 x 10^{-6} has been measured with excitation at 308 nm. These results are discussed and future plans are outlined.

I. INTRODUCTION

The use of cathodes as a source of electrons has become the subject of much recent research. Photocathodes have many characteristics which meet special requirements. Short pulselength sources of electrons have applications in many fields, including free-electron lasers, high energy accelerators, microwave generation, and ion source cathodes and starter cathodes. With photoemission, free electrons are produced on a picosecond (or less) timescale, and the production of the electrons follows the temporal characteristics of the exciting light. Combining the good temporal characteristics of photoemission with the short pulses available from lasers leads to the possibility of well-defined picosecond-long pulses from photocathodes. Other applications of photocathodes take advantage of their "clean" emission characteristics. Unlike thermionic sources which may deposit cathode material throughout the discharge chamber, a photocathode does not intrinsically degrade and liberate any materials which could contaminate a chamber or a process.

Unfortunately, the application of photocathodes is not always possible. One problem is the low quantum efficiency of most materials, requiring the use of high optical powers to get usable currents. Allied with this problem is the large work function of some materials, necessitating the use of radiation in the far ultraviolet. Finally, many of the most efficient materials used as photocathodes require very stringent environmental conditions, such as vacuum levels on the order of 10^{-8} -10^{-9} torr, in order to function. These problems have prevented the widespread use of photocathodes.

This paper describes preliminary work on two candidate photocathode materials, lanthanum hexaboride, LaB_6, and barium. These materials have low workfunctions and may be more "rugged" than many of their more conventional counterparts. Quantum yields for these materials are measured using near UV pulsed laser excitation, and the effects of preparation and treatment are studied.

II. EXPERIMENTAL APPARATUS

Several different experimental configurations are employed in the quantum yield measurements. A generic schematic is shown in Figure 1. A vacuum chamber/ion source chamber houses the photocathode holder. The cathode is at ground potential. The collection anode, a faraday cup biased at up to +2.2 kV is also located within

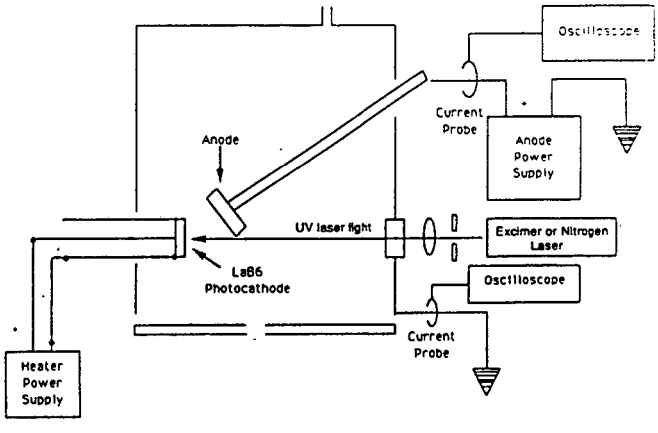

Fig. 1 Schematic diagram of quantum yield measurement apparatus shown here with a LaB_6 photocathode.

the chamber, approximately 5 cm from the photocathode surface. Laser radiation from a XeCl excimer laser operating at 308 nm or a nitrogen laser at 337 nm is used to stimulate photoemission. These lasers have pulsewidths of 30 ns and 10 ns, respectively. The laser beams are apertured using adjustable irises and directed into the chamber through quartz windows. The photo-induced current was detected using current transformers connected to either the anode/anode bias supply line or the cathode/ground line. This technique has a time resolution of 10 ns. This allows us to observe the pulselength of the photoelectrons and ensure we observe only photoemission current, rather than thermal emission current, which would last much longer than the laser pulse.

The disc-shaped polycrystalline LaB_6 photocathode is 19 mm in diameter. The LaB_6 is placed in a cathode holder that allowed an electric current to pass from the center of the disk to its outer edge[1]. By passing DC currents through the cathode, the LaB_6 could be heated resistively. The effects of this treatment on the quantum yield are discussed below.

The barium photocathode is prepared by melting, in an induction furnace and in an inert atmosphere, pieces of barium rod. The molten barium is contained in a shallow well in a copper disc 25 mm in diameter. The barium layer is about 4 mm thick. After cooling, the barium assembly is stored under paraffin oil. Just prior to installation in the experimental chamber, the surface of the barium is polished to remove any contamination. The photocathode is then rinsed with isopropyl alcohol and installed in the vacuum chamber, which is immediately pumped down.

The barium photocathode experiments are performed in a stainless steel high vacuum chamber equiped with a cryopump. This system could attain a vacuum of $\approx 5 \times 10^{-8}$ torr. The LaB_6 experiments are performed in a magnetic multicusp ion source. The base pressure of the chamber is 3×10^{-6}. Both the LaB_6 cathode and the anode are in the central, zero magnetic field volume of the source chamber.

III. RESULTS AND DISCUSSION

The experiments with LaB_6 were performed in an ion source chamber using nitrogen laser excitation at 337 nm. This set-up was chosen because one possible application, as mentioned in the introduction, is the use of a photocathode as a "starter" cathode for a pulsed discharge utilizing an RF drive system. Figure 2 shows some representative data obtained with this experimental configuration. This figure plots the peak photocurrent as a function of energy in the laser pulse. As can be seen from the figure, the current scales linearly with laser energy. This is indicative of photoemission. From this data, a quantum yield of 7×10^{-6} is calculated. This value lies in the range of yields

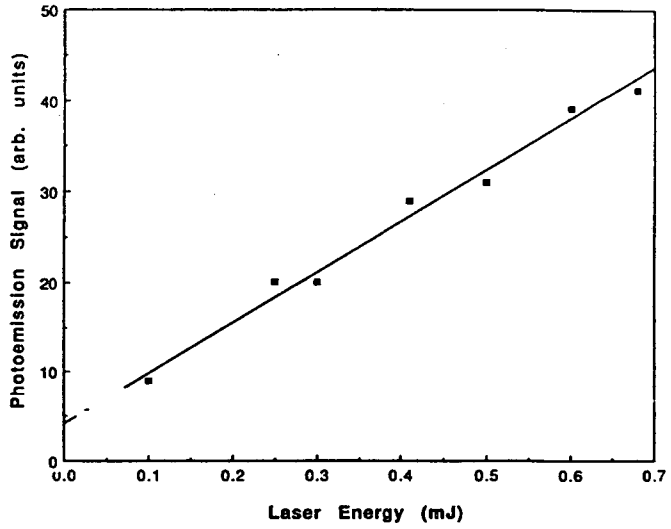

Fig. 2 LaB_6 photocurrent vs. N_2 laser energy. Linearity indicates photoemission is occuring.

previously reported[2,3], but is somewhat smaller than the value obtained by Lafferty[4].

To obtain this value, the LaB_6 was resistively heated. This heat treatment raises the temperature of the photocathode to approximately 600 K for 5 minutes. Prior to heating, no photocurrent could be observed, corresponding to a quantum yield of $< 10^{-8}$. Enhanced photoemission would last for hours. However if the heating was maintained too long, the photocurrent would

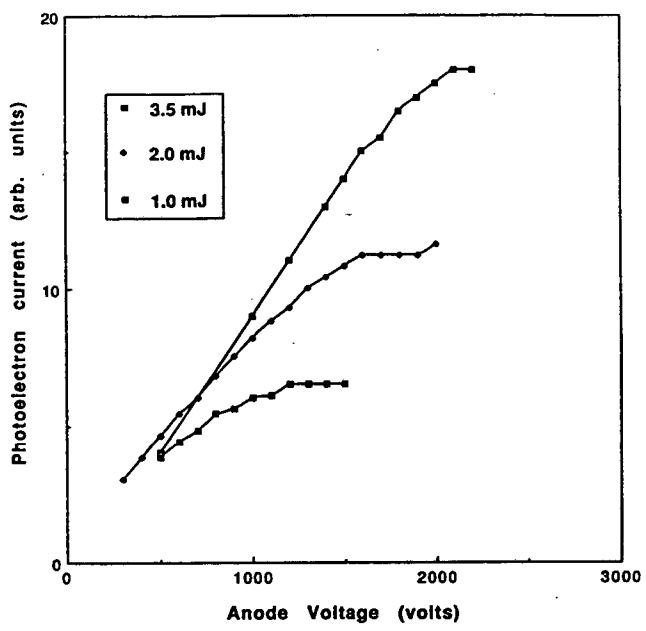

Fig. 3 Barium photocurrent vs. anode extraction voltage for 3 different laser energies. Variation of current with anode voltage indicates that the measurement is space-charge limited.

begin to decrease and would eventually disappear. It is possible that the initial heat treatment cleans away contamination that interferes with photoemission. However, too much heat may disrupt the crystal structure of the LaB_6 or alter the doping density of the lanthanum in the boron matrix. Lanthanum reportedly resides in interstices of a boron cage[4], and the photoelectric effect (both work function and quantum yield) may depend on the surface density or bonding of the lanthanum. Further experiments are being pursued to elucidate the mechanism of this effect.

Data for the barium photocathode was obtained using XeCl laser irradiation at 308 nm. Figure 3 shows the photocurrent collected at the anode as a function of the anode voltage for three different laser pulse energies. As can be seen, the current initially exhibits a dependence on the voltage before reaching an asymptotic value, something not predicted by photoemission theory. In addition, the voltage needed to reach this asymptotic value increases with increasing laser energy. These effects can be explained by assuming that at lower anode voltages or higher laser energies, the photocurrent collected is space charge limited. Increasing the extraction voltage or decreasing the photocurrent (by reducing the laser pulse energy) reduces the voltage necessary to collect all the photoelectrons. The three different pulse energies give approximately the same quantum efficiency, in this case 3×10^{-7}.

A quantum yield of 1×10^{-6} has been obtained for barium. However, the quantum efficiency of the barium

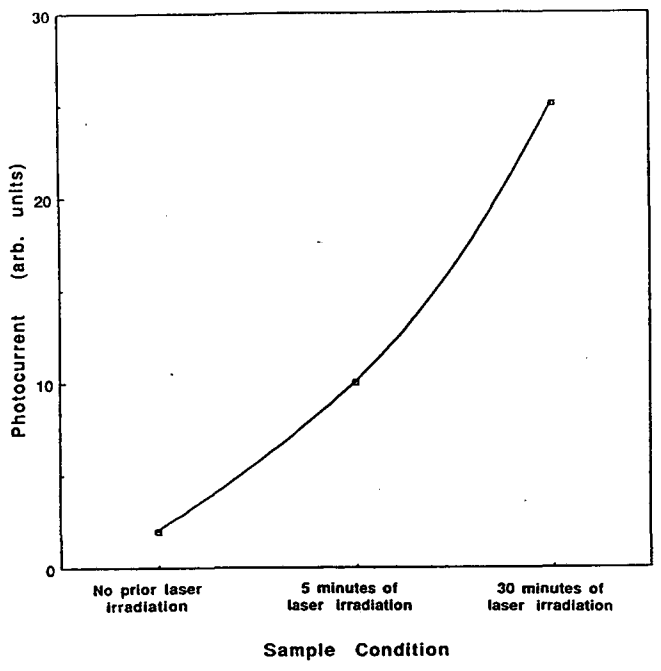

Fig. 4 Barium photocurrent as a function of laser treatment. Laser is 2 mJ/cm^2 while measuring the quantum yield and 30 mJ/cm^2 between measurements.

is also dependent on the treatment history of the barium. This is exemplified in Figure 4, which shows the quantum yield as a function of laser irradiation time. An untreated barium surface shows little photoactivity. However, after irradiation of the surface with 30 mJ/cm^2 of 308 nm light for 5 minutes, the quantum yield improves markedly. For reference, the laser fluence while measuring the quantum yield is limited to 6 mJ/cm^2 due to the space charge considerations mentioned above. Increasing the irradiation time to 30 minutes results in an increase of the quantum yield by more than a factor of 10 over the original value. The cause of this increase is not known. However, the area that is subjected to the high power irradiation is whiter, which more closely approaches the color of pure barium. It is possible that the intense laser irradiation causes either thermal desorption of contaminants from the surface, or causes plasma formation which also cleans the surface. More experiments are underway to determine the cause of the increased quantum yields.

SUMMARY

Preliminary experiments have been performed to measure the quantum yield of LaB_6 and barium under UV laser radiation. These experiments indicate that modest levels of photoemission can be obtained with UV laser excitation under environmental conditions which "poison" more efficient photocathode materials. Preparation and handling of the photocathodes has been shown to be crucial in obtaining improved performance. Experiments are continuing to determine procedures to further improve the quantum yield. Experiments will also be performed on single crystal LaB_6 as well as on other alkali earth metals.

ACKNOWLEDGEMENTS

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