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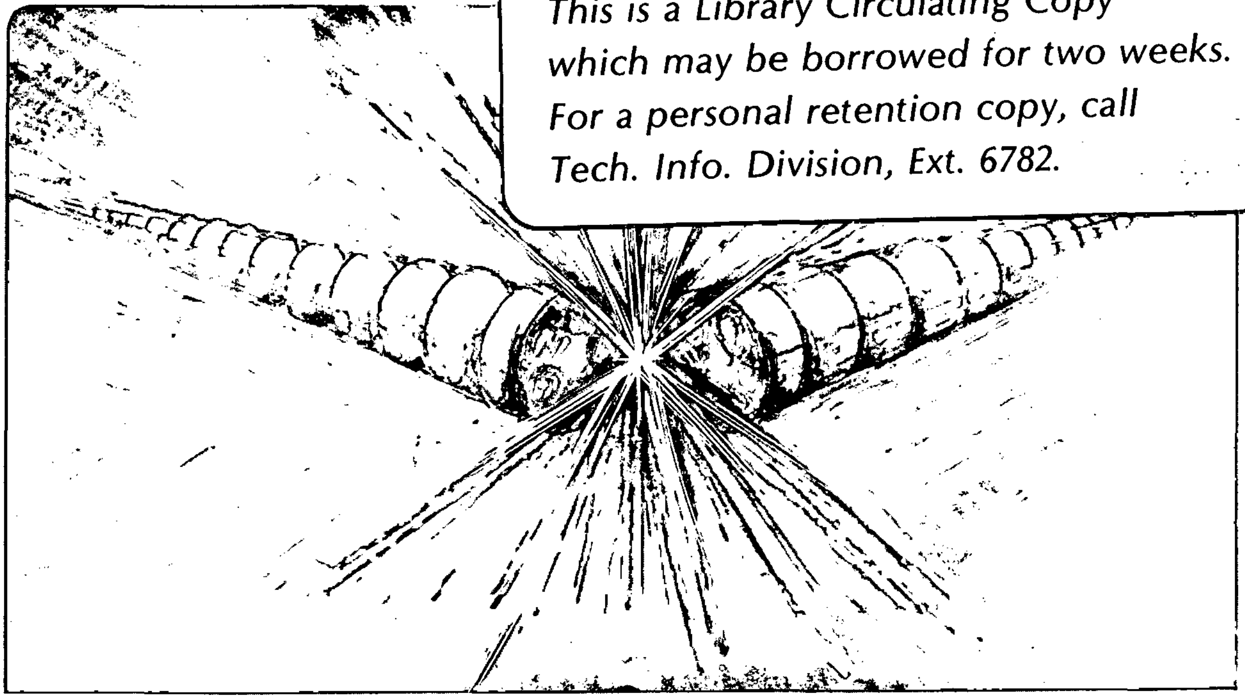

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DISCLAIMER

Photoelectric Work Function Measurement of a Cesiated Metal Surface and Its Correlation with the Surface-Produced H- Ion Flux*

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ABSTRACT

For application in plasma heating, fueling, and current drive of magnetic fusion devices, high current negative deuterium ion sources for intense neutral beam injectors are being developed using efficient production of negative hydrogen isotope ions on low work function metal surfaces imbedded in hydrogen plasmas. In order to investigate the correlation between work function and negative hydrogen ion production, photoelectron emission from a cesiated metal surface, which is immersed in a hydrogen plama with an electron density less than 5 x 10^{10}/cc, was measured in the photon energy range of 1.3 to 4.1 eV. The work function determination was based on Fowler's analysis, and at the optimum coverage a work function of less than 1.5 eV was observed for a Cs-Cu surface. Measured values of work functions for different Cs coverages were compared to the negative hydrogen currents produced at the metal surface in the discharge; the surface production of negative hydrogen ion current is monotonically increasing with decreasing work functon.

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Introduction

The enhancement of H^- ion production in a hydrogen discharge with an admixture of Cs was first reported by Belchenko, Dimov and Dudnikov[1] who found two peaks in the energy spectrum of the resulting H^- ion beam. The peaks corresponded to the extraction potential only, and the extraction potential plus the cathode potential of their magnetron ion source. The latter peak in the H^- ion beam energy spectrum indicated that H^- ions were being produced at the surface of the cathode. These H^- ions were thought to be produced either by backscattering of positive hydrogen ions or desorption of hydrogen atoms resident on the surface. Since then, H^- ion production on the cathode surface in a cesiated hydrogen discharge has been employed in several types of H^- ion sources.[2,3] In these sources introduction of alkali metals into the discharge increases the total H^- ion current by several orders of magnitude; this enhanced H^- production is thought to result from a lower work function produced by the alkali-metal coverage of the cathode surface.

The work function dependence of H^- ion production from surfaces was experimentally investigated by Schneider[4], who measured H^- yield from back scattering of energetic hydrogen ion beams, and by Yu[5], who studied H^- desorption from a surface irradiated by a Ne^+ beam. In these measurements the maximum yield of H^- ions was observed near the minimum of the measured work function.

Attempts have been made to theoretically explain how the efficiency of H^- ion surface production depends on the work function. From the simple potential diagram for the H^- ion electron affinity and surface potential barrier, Kishinevskiy[6] calculated the H^- ion survival probability as related to the work function and H^- ion escape velocity. He showed that the H^- ion survival probability became larger as the work function was reduced. This enhancement of the survival probability by lower work function was shown to be more pronounced at low velocities for the H^- ions escaping from the surface. However, Hiskes, Karo and Gardner[7] showed that the probabilities for H^- formation and survival were not only dependent upon the work functions but were also highly dependent upon the details of the potential profile near the surface, and that the surface production of H^- ions could not be expressed in a simple analytic form.

In these theoretical studies, the surface was assumed to be pure Cs on a clean substrate. Also, experiments which measured H^- ion yield by back scattering and sputtering employed careful surface conditioning and ultra high vacuum systems. A surface in a cesiated hydrogen discharge may be affected by impurities present in the plasma, as well as by energetic hydrogen and cesium ions and neutrals. Therefore, the work function of a surface in a discharge may be different from that in a cleaner environment. At the same time, it is likely that plasma particles sputter Cs from the surface sufficiently to prevent a thick coverage. To investigate the dependence of H^- production on the work function in H^- ion sources, in situ measurements of the work function in a discharge, correlated with the H^- yield from the surface, are necessary.

In this report we show that the work function of a cesium covered metal surface in the presence of a discharge can be determined with reasonable accuracy by measuring the photoelectron emission current from the surface. Derived values of the work function in a cesiated hydrogen discharge are compared to measured H^- ion currents to show how the H^- ion current increases as the work function decreases. Finally, we briefly discuss the measured energy spectrum of surface produced H^- ion beams.

Apparatus

The diagram for the experiment is schematically shown in Fig. 1 Because of its quiescence, a magnetic line cusp geometry[8] was employed to contain the plasma produced with an arc discharge. An 18-cm-long, 15-cm-diameter stainless steel chamber was surrounded by six columns of samariun-cobalt magnets to produce the magnetic field of approximately 1.9 kG at the wall.

The end face of a water cooled 1.1 cm diameter copper rod inserted into the chamber and biased to a negative potential with respect to the discharge was used as the H^- ion production surface. Surface produced H^- ions were accelerated across the plasma sheath and traveled across 10 cm of plasma before they were extracted toward the entrance slit of a compact 90° mass analyzer.

This extraction section was shielded by 3.3 cm diameter, 0.6 cm thick soft iron to reduce the residual field. The maximum magnetic field experienced by the H^- ions was less than 5 G near the target. The field reduced rapidly to less than 1 G before the beam exit.

A set of interference filters was used to produce 10 nm-band-width mono chromatic light from a Xe arc lamp. The light was collimated onto the target with an incident angle of 60° normal to the surface. A rotating blade light chopper was used to modulate the light beam. It also provided a reference signal to a phase sensitive amplifier which was used to measure the photoelectron current from the target. The photoelectron current was measured with a transformer which also was part of a band pass filter for the signal.

Experimental Procedure

Plasma was created by a hot cathode discharge which used the chamber wall for the anode. The cathode consisted of from 1 to 4 0.05-cm-diameter tungsten filaments biased at -80 V with respect to the chamber wall-anode. The neutral hydrogen pressure was normally kept at 1 m Torr, which resulted in an electron density of about $4 \times 10^{10}/\mathrm{cm}^3$ for 1 ampere of discharge current. Cs was directly introduced into the discharge either by a Cs oven or SAES getters. For longer operation of a cesiated hydrogen discharge, the Cs oven power was controlled so that the H^- current detected by the mass analyzer could be kept constant. For normal discharge conditions, the temperature of the target was less than 20°C.

The photoelectron current was discriminated from the plasma noise by means of a lock-in-amplifier. The power spectrum of incident light was monitored by a spectrally neutral pyroelectric detector and a grating monochromator. Total light beam power was measured by another pyroelectric detector during photoelectron current measurements. Typical power of the incident monochromatic light beam was approximately 10 mW after passing through all of the collimation.

The determination of the work function from the photoelectron emission measurement was based on the Fowler's analysis[9]. We define the quantum yield, Y = (Photoelectron current)/(photons-sec) and we employ the relationship

$$Y \propto (h\nu - \phi)^2 \qquad h\nu > \phi .$$

where $h\nu$ is the energy of the incident photons and ϕ is the work function of the surface. The intercept of $Y(h\nu)$ vs $h\nu$ was used to determine ϕ. We have assumed that the absorptivity of the surface for equilibrium Cs coverage is nearly constant in the region where the photon energy and quantum yield follow Fowler's curve.

Figure 2 shows a typical plot of quantum yield as a function of photon energy. For the lowest work functions measured, the quantum yield fell off so rapidly with each filter change to longer wave-length that not many points in the linear region could be measured. This together with increasing plasma noise level at high Cs concentration in the discharge, made work function measurements difficult when the work function was low.

The noise amplitude measured on the target was typically 0.4% of the saturated ion current for a pure H_2 discharge. The frequency spectrum of the noise was broad and relatively flat from 0 to 500 kHz. For a chopping frequency of 1 kHz, 10 nA of photoelectron current could be detected with 1 μA current noise. The output of the Lock-in-amplifier under these conditions fluctuated about 20% with a setting of 300 ms for the output time constant. Further increase of the signal integration time would reduce the level of this fluctuation, but the slow drift of conditions in the discharge required fairly rapid measurements so that the whole curve could be acquired in less than 90 seconds.

Results and Discussion

(1) Work function measurements in Cesiated Hydrogen Discharge

Not many results were obtained for work functions less than 1.6 eV due to experimental difficulties. The lowest work function so far measured for the present experimental system is 1.38 eV. This value is lower than that reported for optimum coverage of Cs on Cu.[10] There are several possible explanations for this low value of work function. 1) It has been reported the H^- ion survival probability became larger as the work function was reduced. This enhancement of the survival probability by lower work function was shown to be more pronounced at low velocities for the H^- ions escaping from the surface. However, Hiskes and Karo[7] showed that the probabilities for H^- formation and survival were not only dependent upon the work functions but were also highly dependent upon the details of the potential profile near the surface, and that the surface production of H^- ions could not be expressed in a simple analytic form.

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In this report we show that the work function of a cesium covered metal surface in the presence of a discharge can be determined with reasonable accuracy by measuring the photoelectron emission current from the surface. Derived values of the work function in a cesiated hydrogen discharge are compared to measured H^- ion currents to show how the H^- ion current increases as the work function decreases. Finally, we briefly discuss the measured energy spectrum of surface produced H^- ion beams.

power was kept constant and the H^- ion current was normalized to the apparent ion saturaton current at the target. (No account was taken for the effect of secondary electron emission due to ion bombardment in the measurement of the saturated ion current.)

Figure 3 shows the ratio of H^- ion current to saturated ion current on the target for several different values of work function. The target was biased at -100 V. Typical electron density during the entire measurement was approximately $6 \times 10^9/cm^3$. This particular result was reproduced on two different occasions to better than 15%.

Although larger H^- yields were observed for greater Cs oven power, we were unable to measure the corresponding work function because of high plasma noise. Qualitatively, we have found that for a plasma where the Cs^+ ion flux is more than 30% of the total positive ion flux, as the Cs^+ level increases, the work function increases and the H^- ion current decreases. A work function of 1.86 eV was recorded at the highest concentration of Cs in the discharge.

(3) H^- ion energy spectrum

The H^- energy spectrum was studied using the momentum analyzer which was calibrated with H^- ions sputtered from the target by Cs^+ bombardment. In Fig. 4, two typical H^- ion spectra are shown; (a) for pure H_2 discharge and (b) near the optimum Cs concentration, for H^- production. When the result (a) was recorded, no photoelectron current could be seen for the direct light beam out of the lamp, which has a maximum photon energy of 4.65 eV. We observed a relatively large photoelectron current for $h\nu = 1.46$ eV for the condition of (b). For the low work function, case (b), most of the H^- ions have energy close to the target potential as shown by the sharp peak at 100% of the target bias. Figure 4(a) shows a broad energy spread of up to 200% of the target potential. The three peaks represent H^- ions formed by back scattering nuclei from H^+, H_2^+ and H_3^+ accelerated across the sheath. To investigate the effect of sputtering by heavy ions, as may occur with Cs in the discharge, Xe gas was introduced to simulate Cs^+ sputtering without changing the target work function. In comparison with the spectrum shown in Fig. 4(a), except for a decrease of total H^- ion current, no appreciable change of the energy spectrum shape was observed. Thus for the high work function case, little H^- is formed by sputtering. Though we are not certain about the mechanism that forms the low energy hydrogen flux from the surface of Fig. 4(b), the efficiency of converting this flux to H^- ions is greatly increased by the presence of the discharge which is probably attributable to a decrease of the work functions.

Conclusions

The work function of a Cs-Cu surface was measured in the presence of cesiated discharges using the photoelectric effect. The work function minimum was lower than previously measured without the presence of a discharge. This suggests that H^- ions are in fact enhanced by a low work function surface in actual surface-plasma H^- ion sources. Simultaneous measurement of the work function and H^- ion flux, together with the H^- spectrum, indicate that lower work function surfaces do enhance the production of low energy H^- ions.

Acknowledgments

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Figure Captions

Figure 1	Schematic diagram of the experiment to measure the work function of metals immersed in a plasma.
Figure 2	Typical graph of the square-root of the quantum yield as a function of the photon energy. This result was obtained in the presence of a plasma with $n_e = 4 \times 10^9/\mathrm{cm}^3$.
Figure 3	The dependence of (H^- ion current)/(ion saturation current) upon the work function of the target. H_2 pressure, 1 mTorr; discharge power, 10 watts.
Figure 4(a)	Energy spectrum of surface produced H^- ions without Cs in the discharge. Target potential, 350 V; discharge power, 250 watts; and H_2 pressure, 1 m Torr.
Figure 4(b)	Energy spectrum of surface produced H^- ions with Cs concentration near the optimum for production of ions in the beam. Target potential, discharge power and H_2 pressure the same as Fig. 4(a).

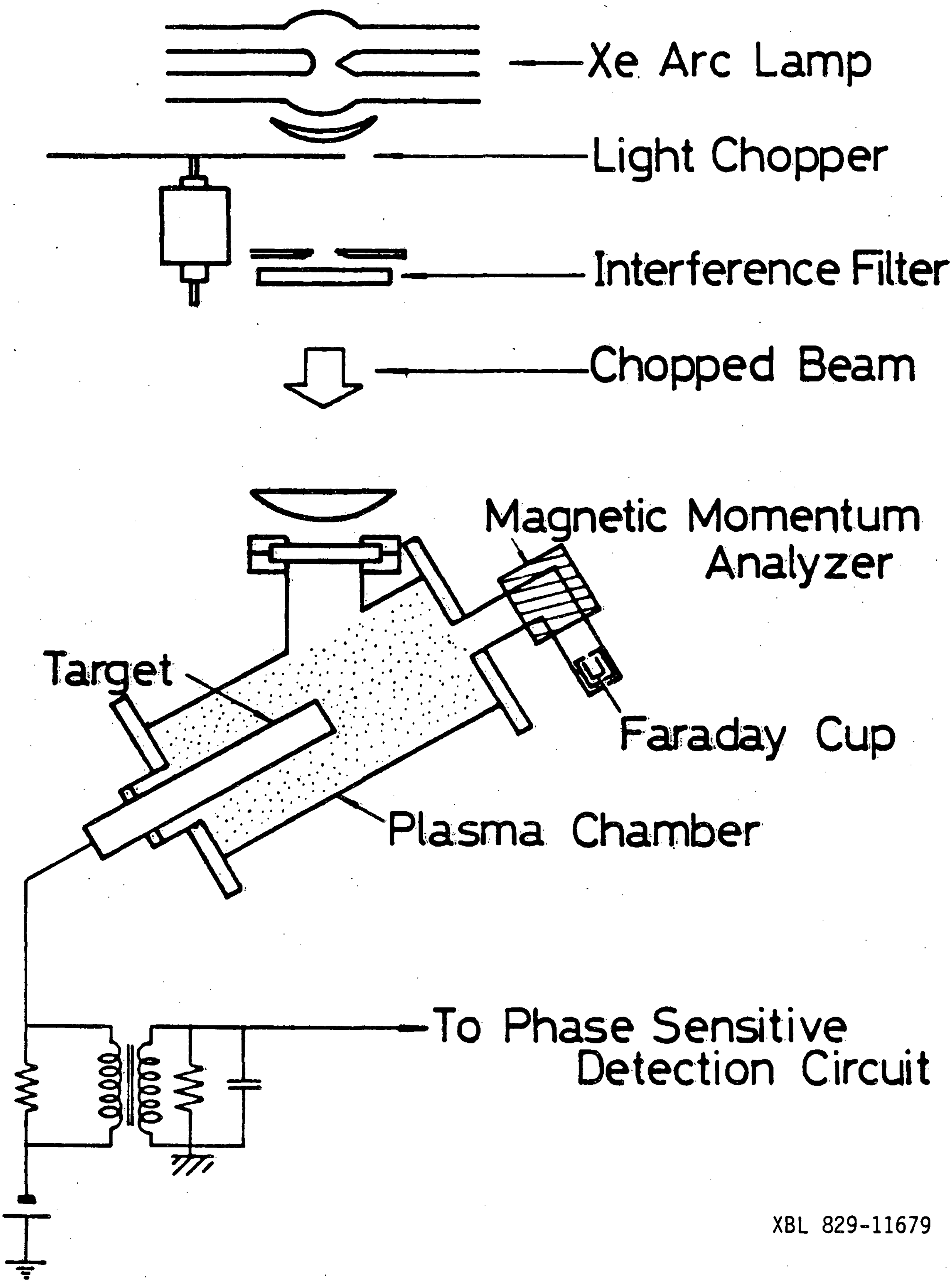
Xe Arc Lamp
Light Chopper
Interference Filter
Chopped Beam
Magnetic Momentum Analyzer
Target
Faraday Cup
Plasma Chamber
To Phase Sensitive Detection Circuit
XBL 829-11679

Figure 1

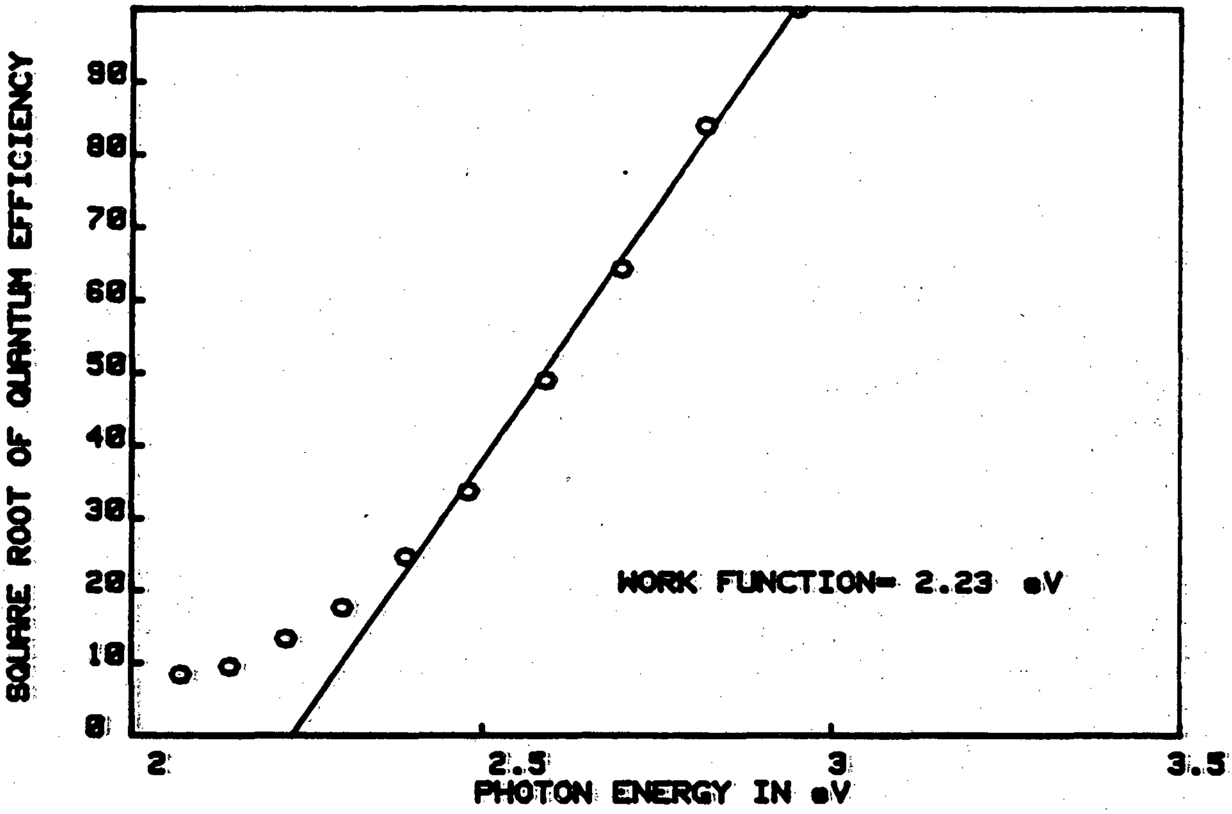

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Figure 2

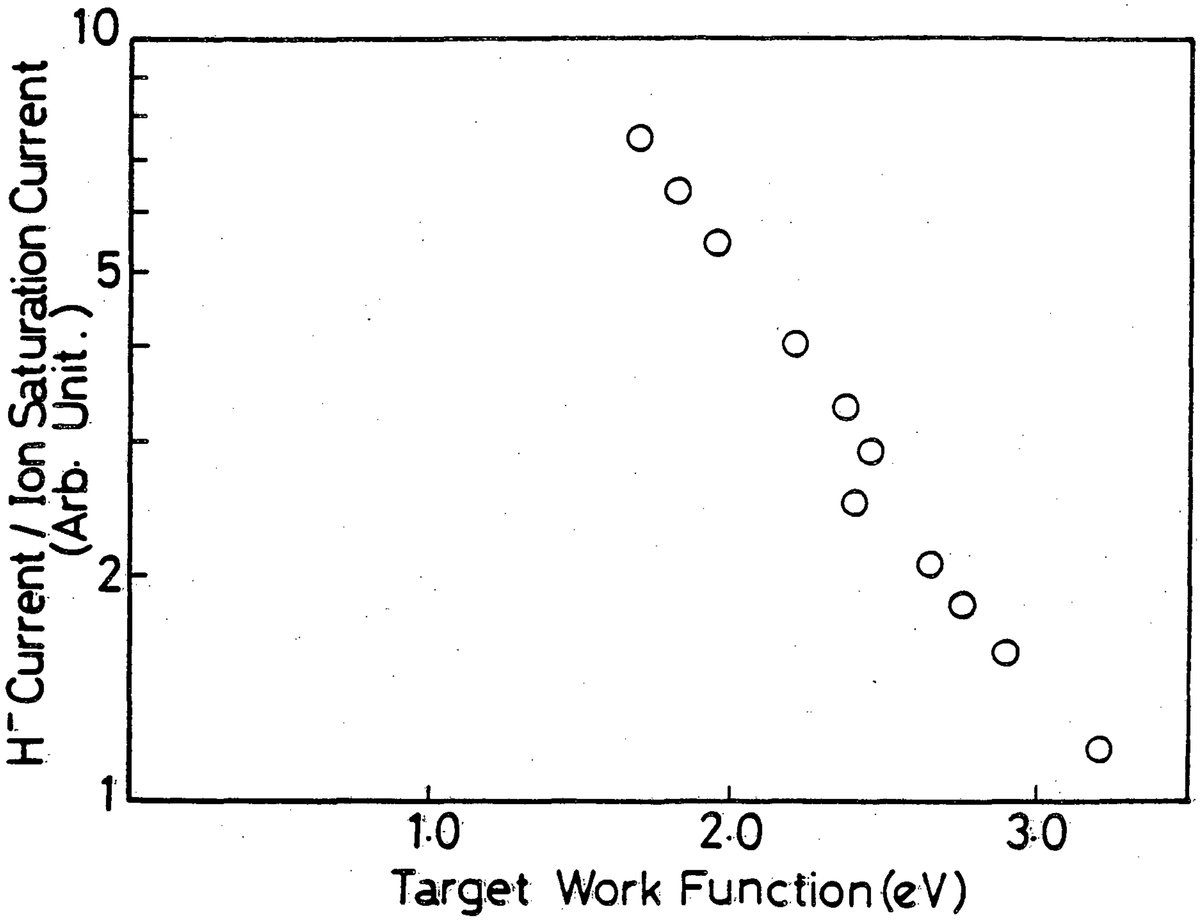

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Figure 3

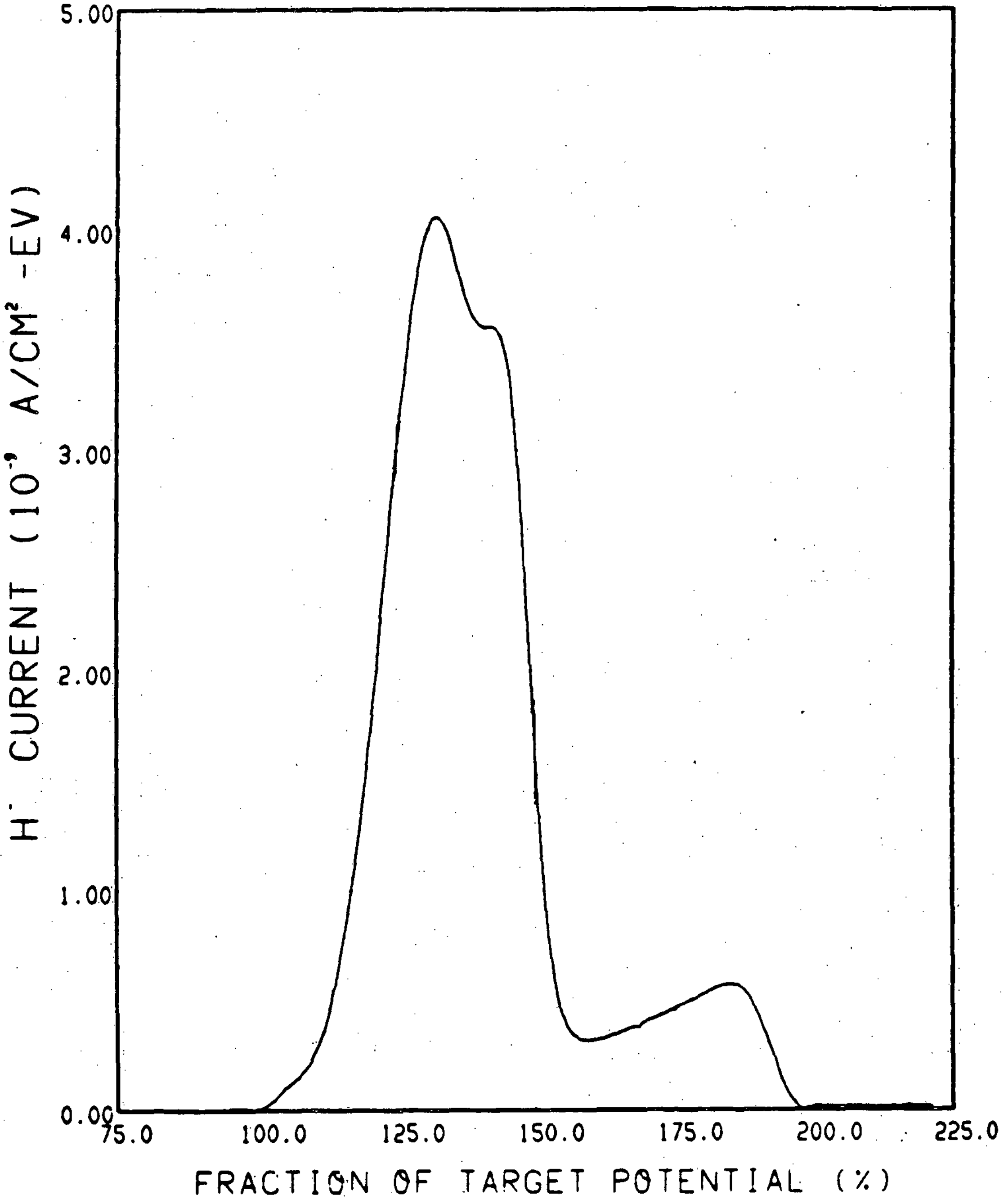

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Figure 4(a)

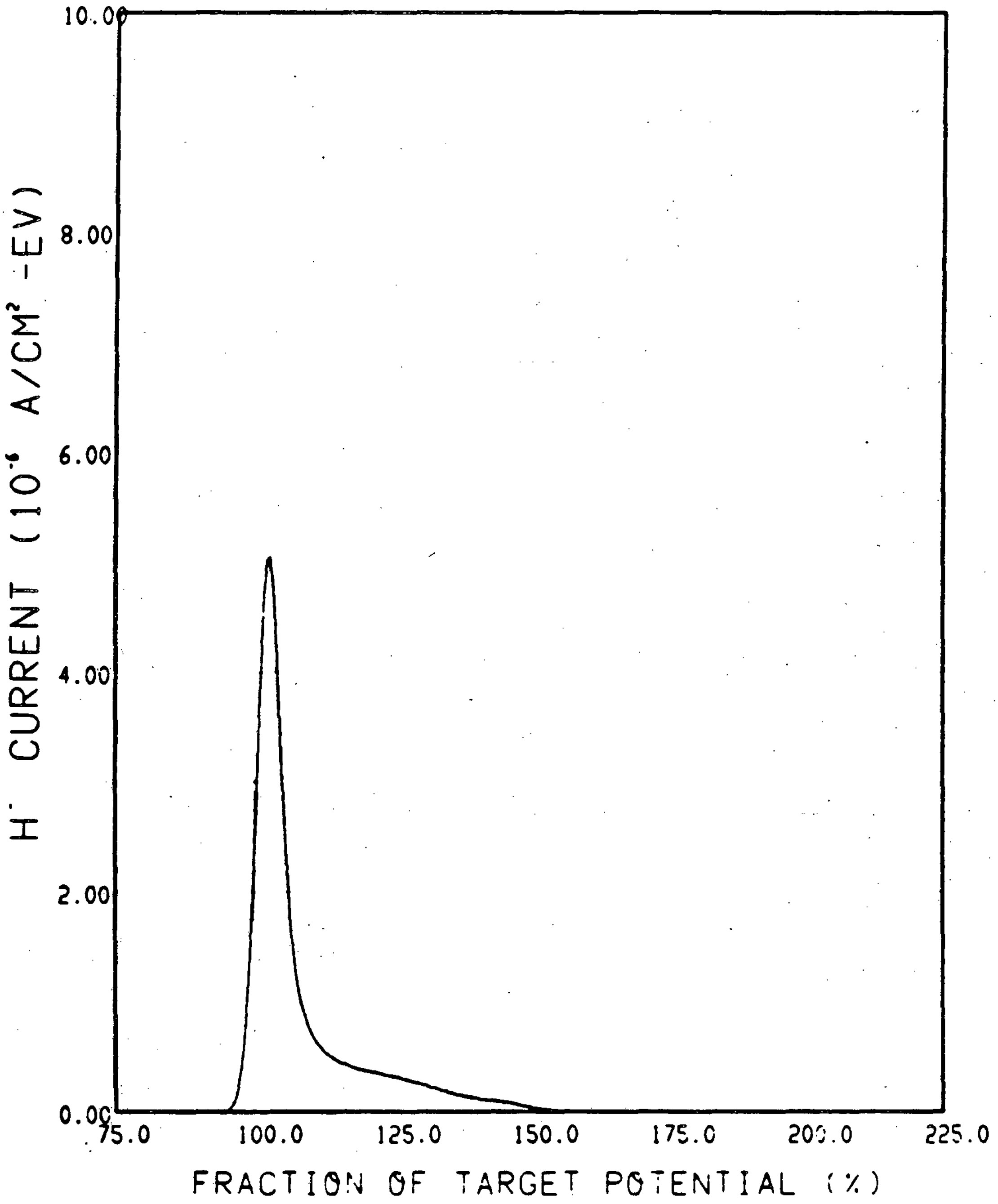

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Figure 4(b)

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