Electron Emission from a (100) Tungsten Surface under Proton Bombardment*

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The yield of electrons from a clean (100) surface of tungsten under bombardment by protons at normal incidence is reported as a function of proton energy in the range 50 to 225 keV. The maximum value of the yield is 1.51 ± 0.03 electrons per incident proton at a proton energy of 125 keV. The yield from the (100) plane surface fell $(10\pm2)\%$ below the yield from a polycrystalline surface. This difference can be attributed to the higher work function of the (100) surface. The tungsten surface was cleaned by flash-heating a single-crystal tungsten ribbon to 2400°K in a vacuum chamber in which the total pressure was about 2×10^{-10} Torr. The yield was measured with the surface at room temperature, about 2 min after the surface was cleaned, while the time for a monolayer of residual gases to form on the surface was greater than 2 h.

INTRODUCTION

IN an earlier paper,[1] the electron yield from a polycrystalline tungsten surface under proton bombardment was reported. The results were analyzed according to a theory by Sternglass.[2] In the present experiment, similar measurements are reported for a tungsten single crystal oriented with the surface parallel to the (100) plane. The protons were directed onto the target at normal incidence. The beam current density was about 10^{-8} A/cm^2 so that the surface structure was not appreciably disrupted by the beam. The surface was freed of adsorbed gases by flash desorption[3] to a temperature of 2400°K.

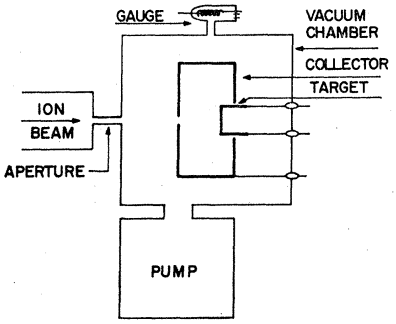

FIG. 1. Experimental arrangement.

EXPERIMENT

A schematic diagram of the apparatus is shown in Fig. 1. The apparatus, experimental procedure, vacuum techniques, and method of yield measurement were the same as those described in Ref. 1. A Cockcroft-Walton accelerator was used to provide the proton beam of variable energy. The vacuum chamber was baked and ion-pumped to a base pressure of about 1×10^{-10} Torr.

The currents to the collector and the target were measured separately. All of the secondary electrons released from the tungsten target by the protons reach the collector electrode when it is biased 300 V positive with respect to the target. This secondary current includes a small contribution (about 1%) due to fast protons reflected from the target. This component was measured separately by biasing the collector at 300 V negative. The reported values of γ (electrons emitted per incident proton) were determined by the ratio of the secondary current, corrected for reflected protons, to the current of protons incident on the target.

The target was a tungsten single crystal[4] of dimensions $0.2\times2\times6$ mm cut from an ingot with a spark cutter and oriented by the Bond technique[5] so that the normal to the surface was within 6 min of arc of the normal to the (100) plane. The crystal was ground with fine abrasive paper and electrolytically polished.

The crystal was spot-welded to two 0.002-in.-thick tungsten ribbons which were in turn mounted on molybdenum lugs leading to 0.10-in.-thick tungsten rods. A constant voltage of 3.0 V dc applied to the tungsten rods was sufficient to raise the temperature of the single crystal to about 2400°K in 0.2 sec. This temperature is sufficient to drive off oxides and other surface contaminants.[3] The crystal was first heated to 1500°K for 8 h at an oxygen pressure of 10^{-4} Torr to remove carbon contamination.[6] This oxygen exposure is about two orders of magnitude greater than that found sufficient to remove carbon contamination from the surface of a (110) tungsten crystal.[7]

The crystal was cleaned by repeated flashing to 2400°K in a residual gas pressure of about 2×10^{-10} Torr, with the proton beam on the target. The momentary rise in system pressure during desorption of surface gas was used to indicate the coverage of the surface by adsorbed gas. The observed pressure rise as a function of adsorption time was identical to that shown in Ref. 1. The gas desorbed increased with adsorption time up to

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[1] R. I. Ewing, Phys. Rev. **139**, A1840 (1965).
[2] E. J. Sternglass, Phys. Rev. **108**, 1 (1957).
[3] H. D. Hagstrum, J. Appl. Phys. **31**, 715 (1960).
[4] Kindly provided in finished form by Professor L. H. Germer, Cornell University.
[5] W. L. Bond, J. Sci. Instr. **38**, 63 (1961).
[6] J. A. Becker, E. J. Becker, and R. G. Barnes, J. Appl. Phys. **32**, 411 (1961).
[7] R. M. Stern, Appl. Phys. Letters **5**, 218 (1964).

2 h and then remained essentially constant, indicating that the surface became covered with a monolayer of adsorbed gas about 2 h after cleaning. The values of γ reported here were obtained about 2 min after cleaning the target so that they are representative of a "clean" surface with no more than a few percent of a monolayer coverage by adsorbed gas.

RESULTS

The measured values of the secondary electron emission coefficient $\gamma(100)$, in electrons emitted per incident proton, are listed in Table I, along with the previously reported γ for the polycrystalline surface. These data are plotted as a function of proton energy in Fig. 2. The experimental uncertainty associated with these values is $\pm 2\%$.

The ratio of the γ values obtained for the (100) surface and the polycrystalline surface are shown under $\gamma(100)/\gamma(\text{Poly})$ in Table I. This ratio varies between 0.88 and 0.92, which indicates that, within the experimental uncertainty, γ for the (100) surface is about 10% less than γ for the polycrystalline surface, independent of proton energy in the range studied.

DISCUSSION

Since $\gamma(100)$ is a constant fraction of $\gamma(\text{Poly})$, both quantities show the same dependence on proton energy. This observation is in accord with the Sternglass theory,[2] in which the energy dependence of γ is due to the variation with proton energy of the cross section per tungsten atom for electron production (ionization) and should be independent of crystallographic orientation. In this theory, the 10% difference between $\gamma(100)$ and $\gamma(\text{Poly})$ could be accounted for by differences in (1) the mechanism for transport of free electrons through the lattice to the surface and (2) the subsequent transmission of some of the electrons through the surface.

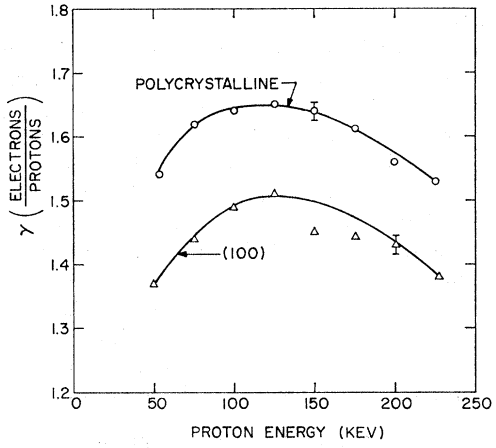

FIG. 2. Secondary emission ratio γ in electrons per proton, for a polycrystalline surface of tungsten and a (100) single-crystal surface, versus energy of bombarding protons.

TABLE I. The experimental values of γ for the (100) surface $\gamma(100)$ (electrons emitted per proton incident); the $\gamma(\text{Poly})$ reported by Ewing (Ref. 1); and the ratio of these two quantities for various energies of the incident protons.

Proton energy (keV)	$\gamma(100)$ (Present experiment)	$\gamma(\text{Poly})$[a]	$\gamma(100)/\gamma(\text{Poly})$
50	1.35	1.54	0.88
75	1.44	1.62	0.89
100	1.49	1.64	0.91
125	1.51	1.65	0.92
150	1.45	1.64	0.88
175	1.45	1.61	0.90
200	1.43	1.56	0.92
225	1.38	1.53	0.90

[a] Reference 1.

The fraction of electrons reaching the surface which are transmitted is given by[2]

$$T=1-[\Phi_D/(\bar{E}+\Phi_D)]^{1/2},$$

where Φ_D is the dipole surface potential, which is part of the electronic work function, $\bar{E}$ is the average energy of the emitted electrons, and T is the transmitted fraction. Assuming reasonable values[2] for these quantities ($\bar{E}=10$ eV, $\Phi_D=1$ V for the polycrystalline surface), a work function difference of 0.7 V between the polycrystalline and the (100) crystal surfaces is sufficient to account for the 10% difference in γ. This is just equal to the reported[8] difference in work function for these surfaces ($\phi_{\text{Poly}}=4.5$ eV, $\phi_{100}=5.2$ eV), so that the difference in electron transmission through the two surfaces of different work function could account for the observed difference in γ. However, due to the uncertainty in the assumed values of $\bar{E}$ and Φ_D, differences in the mechanism for transport of free electrons through the different lattices cannot be ruled out.

ACKNOWLEDGMENT

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[8] A. A. Holscher, J. Chem. Phys. **41**, 579 (1964).