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ELECTRON EMISSION FROM TUNGSTEN
UNDER PROTON BOMBARDMENT:
EFFECT OF NITROGEN ADSORPTION

Ronald I. Ewing

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

SANDIA CORPORATION

PRIME CONTRACTOR TO THE U.S. ATOMIC ENERGY COMMISSION

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ABSTRACT

The yield of electrons emitted from polycrystalline tungsten under bombardment by 100 keV protons is found to depend upon the coverage of the surface by adsorbed nitrogen gas. The tungsten surface was cleaned by the flash filament method and the yield measured as nitrogen gas adsorbed on the surface to a coverage of about 1.1 layers. The monolayer coverage time was varied from 9.0 minutes to 1.3 minutes by controlling the pressure of the nitrogen gas in the system. The yield increased with increasing surface coverage to about one monolayer, at which the increase over the value for a clean surface was 3.5 percent. Further adsorption of nitrogen caused the yield to decrease even below the clean surface value.

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ELECTRON EMISSION FROM TUNGSTEN UNDER PROTON BOMBARDMENT: EFFECT OF NITROGEN ADSORPTION

Introduction

This work is part of a comprehensive experimental study of electron emission from clean metal surfaces under ion bombardment. In this study a polycrystalline tungsten ribbon is bombarded with 100 keV protons. The quantity measured is the total yield of secondary electrons per incident proton, and the parameter that is varied is the coverage of the tungsten surface by adsorbed nitrogen, from an initially clean tungsten surface to about one atomic layer of nitrogen. The rate at which nitrogen is adsorbed is also varied. On the average, more than one electron is emitted per incident proton. A few percent of the incident protons are reflected, or scattered more than 90 degrees. Some surface atoms are removed by sputtering, but the yield for this process is several orders of magnitude less than the electron yield. The phenomenon of electron emission is quite surface-sensitive, and only by careful specification of the surface condition and, hopefully, identification of the first layer of atoms can meaningful results be obtained. In this case, the surface was cleaned by the flash filament technique, in which the temperature of the surface is rapidly raised high enough to drive off all adsorbed surface contaminants, leaving an atomically clean surface. As the temperature is lowered, the gas surrounding the surface begins to adsorb on it at a rate depending upon the pressure of the gas and the probability that an impinging molecule will remain on the surface.

Experiment

The essential elements of the experiment are shown in Figure 1. The proton beam is obtained from a 250 kilovolt Cockcroft-Walton accelerator. The entrance aperture limits the exchange of gas between the accelerator and the experimental chamber, so that the pressure in the experimental chamber can be maintained below 10^{-10} torr, while the accelerator operates at 10^{-6} torr. Purified gases are admitted to the chamber through a mechanical leak. The target is a polycrystalline tungsten ribbon of dimensions $1 \times 3/16 \times 0.001$ inches supported by molybdenum lugs mounted on 0.1 inch diameter tungsten rods. The electrons released when the beam strikes the target are attracted to the cylindrical collector which surrounds the target and which is biased 300 volts positive with respect to it. The currents to the target and to the collector are measured and the yield calculated from

$$\gamma = \frac{I_c}{I_T - I_c}$$

where γ is the yield in electrons per incident proton, and I_c and I_T are the magnitudes of the currents to the collector and target, respectively. The pressure of gases in the system is measured by a modified Bayard-Albert ionization gauge.

Recent experiments have shown that tungsten surfaces cleaned by flash-heating may be contaminated by carbon atoms which have diffused to the surface, and that the carbon may be removed by heating the ribbon in an oxygen atmosphere. The results reported here were obtained after heating each ribbon to 2000°K for 8 hours in oxygen at a pressure of 10^{-4} torr. The vacuum system was then pumped down to a residual gas pressure of about 10^{-10} torr. Nitrogen was then admitted and adjusted to the desired pressure for the experiment, about two orders of magnitude higher than the residual pressure.

The flash-off of adsorbed gas was accomplished by applying a constant voltage (about 6 volts DC) to the terminals of the ribbon. A typical desorption profile is shown in Figure 2. The voltage is applied at $t = 0$ and turned off after 0.3 second. The solid line is the pressure in the system indicated by the ion gauge. The dashed curve shows the target temperature as inferred from the instantaneous current through the ribbon. As the temperature of the ribbon rises, the surface contaminants are driven off and the pressure rises, then decreases as the gas is pumped out of the system. The maximum temperature, 2400°K , is maintained until most of the desorbed gas is pumped out, to avoid re-adsorption. The amount of gas driven off by the flash is determined by the surface coverage. The maximum pressure rise is proportional to the amount of gas driven off and is, therefore, a relative measure of the surface coverage, provided the nature of the surface contaminants does not change with time. The maximum pressure rise is plotted in Figure 3 as a function of adsorption time, the time between cleaning flashes while the ribbon is cool and nitrogen is being adsorbed. The surface coverage begins to saturate at about 9 minutes of adsorption time. This saturation time, sometimes called the monolayer formation time, was varied from 1.3 minutes to 9 minutes by varying the pressure of nitrogen in the chamber. At the residual pressure, about 10^{-10} torr, the monolayer time was greater than 3 hours. The target was flashed several times in nitrogen and γ was measured as a function of time after cleaning.

Results

The variation of γ as nitrogen is adsorbed on the tungsten surface is shown in Figure 4. The unit of the adsorption time scale is one monolayer time. Data was taken at several nitrogen pressures to vary the monolayer time. The γ scale is greatly truncated to emphasize the variation. Results were obtained for three ribbons at four nitrogen pressures, with each

run repeated three times. All of the 36 runs fell within the ± 1 percent error limits shown. The curve is the smoothed average of all runs. Protons scattered back to the collector by the tungsten ribbon were measured by applying a negative bias to the collector. The fraction of protons reflected from the target surface did not vary with adsorption time. The maximum rise in electron yield of 3.5 percent occurs at about one monolayer time. Further adsorption causes the yield to decrease, even below the clean surface value. Although the time scale is shown to five monolayer times, this does not mean that five layers of nitrogen are present, since the amount of nitrogen adsorbed saturates rapidly around one monolayer. The surface coverage at five monolayer times is no more than 1.1 layers of nitrogen.

Conclusion

The yield of electrons from polycrystalline tungsten bombarded with 100-keV protons is found to increase over the clean surface value with increasing coverage of the surface by nitrogen up to one layer coverage. Further slight increase in nitrogen coverage to about 1.1 layers strongly decreases the yield.

A theory of ion-electron emission due to Sternglass indicates that the emission of electrons freed in the metal is controlled by their transmission through a surface potential barrier determined by the dipole contribution to the work function caused by the topmost layer of atoms. In this view, these results indicate that nitrogen adsorption on tungsten up to one layer decreases the work function, and further adsorption increases it.

Figure 1. Experimental Arrangement

Figure 2. Desorption Profile. (System pressure and target temperature during flash-off of surface gases)

Figure 3. Relative Surface Coverage Versus Time of Adsorption of Nitrogen. (Nitrogen pressure about 5×10^{-9} torr)

Figure 4. Variation of the Electron Yield with Time as Nitrogen is Adsorbed on the Initially Clean Target. (The unit of time is one monolayer formation time. The solid curve is the smoothed average of 36 experimental runs, all of