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LOW ENERGY SPUTTERING OF COBALT BY CESIUM IONS*

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ABSTRACT

An experimental facility to investigate low energy (<500 eV) sputtering of metal surfaces with ions produced by an ion gun is described. Results are reported on the sputtering yield of cobalt by cesium ions in the 100 to 500 eV energy range at a pressure of 1×10^{-6} Torr. The target was electroplated on a copper substrate. The sputtered atoms were collected on a cobalt foil surrounding the target. ^{57}Co was used as a tracer to determine the sputtering yield.

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1. Introduction

Electron bombardment ion engines are required to have operational lifetimes of up to 15,000 hours at 2 A beam current for successful completion of many proposed space missions [1]. From the mission profile life tests, it was observed that the major life-limiting mechanism is the formation of flakes of sputtered material which might be of sufficient size to cause electrical shorts or arcing in the discharge chamber [2]. The internal surfaces of the discharge chamber where the erosion is most severe are subjected to bombardment by ions having energies less than 100 eV, assuming that up to triply charged ions exist in the plasma potential of 32 V within the discharge chamber where the ions are generated. However, the data on yields from low energy sputtering are sparse and there are uncertainties due to difficulty in detecting the extremely low sputtering yields [3-5]. In view of the scarcity of sputtering yield data at low energies, a systematic experimental study is being undertaken using a radioactive tracer technique. In the present study cesium ions having well-defined ion energies impinge on a cobalt target mixed with a small amount of cobalt-57. Cobalt is chosen as the target material for initial studies because its tracer, cobalt-57, has a relatively long half-life of 270 days and decays predominantly by emitting low-energy (122 KeV) gamma rays. Since the total sputtering yield at low incident ion energies is expected to be very small even after a prolonged exposure, the radioactive tracer technique appears to be quite useful. The sputtering yield data reported are taken at a pressure of 1×10^{-6} Torr with energy of the cesium ions varying from 100 to 500 eV.

2. Experimental Design and Procedure

The vacuum chamber is 10 cm in diameter, 22.5 cm long and has six ports. The ion gun enters from the left through a 150 mm CF port. The target assembly is introduced from the right port by a linear motion feedthrough which is connected to the vacuum chamber through a 150 mm CF adapting nipple. The ionization gauge is mounted on another 70 mm CF port. A viewport is attached through a 115 mm port on the top and there is also a provision to introduce a SIMS probe through an auxiliary 70 mm CF port which is at a 45° angle.

a) Vacuum system:

Before any successful sputtering can be undertaken, the surface should be made as free of adsorbed layers of gases as possible. This can be achieved by baking and maintaining a very high vacuum in the system. A turbomolecular pump of 170 ls^{-1} pumping speed is used to maintain the vacuum. All the flanges used in the chamber are metal gaskets sealed to have minimal outgassing and diffusion rates. A hot cathode ionization gauge with its digital readout controller is used to monitor the pressure level inside the vacuum chamber.

b) Ion Gun:

It is desirable that the ion beam impinges on the target in a small area with a high current density. However, space charge in the ion beam represents the fundamental limit on the ion current density. Hence, the lower the kinetic energy of the beam, the lower is the maximum current density that can be generated. The ion gun used in the present setup is procured from Kimball Physics Inc. and is capable of producing low-energy ion beam at well defined energies for both Cesium and noble gases. This will enable us to cross check the sputtering yield data using a variety of ions.

c) Target and collector assembly:

The target and collector assembly is shown in Fig. 1. At the end of the linear motion feedthrough is the holding rod with a tapped hole at the end. The target is cobalt (99.9% and 0.1% ^{57}Co) electroplated on the tip of a 4.8 mm diameter copper specimen. The edge of the copper specimen on which the cobalt is electroplated is at an angle of 45°, so the surface of the target is elliptical in shape with an area of 25.8 mm^2. The surface density of cobalt is approximately 50 $\mu g / cm^2$, which resulted in an activity of the target of 110 μCi. The other end of the specimen, which is threaded, is attached to the holding rod. The copper specimen is completely surrounded by a 19 mm diameter hollow cylinder, the inside of which is lined with a 0.05 mm thick cobalt foil. The distance between the target and the ion gun was optimized for maximum sputtering yield after conducting several initial runs under similar experimental conditions. The operating distance was found to be about 19 mm (Fig. 2).

The vacuum chamber is pumped down to a pressure of 1 x 10^{-6} Torr. The ions are extracted and accelerated to the desired energy by setting corresponding grid voltages. The beam current is then measured with a Faraday cup which is pneumatically operated to intercept the beam. The ion beam impinges on the target at a 45° angle. The target is exposed to the ion beam for a period ranging from 5 to 20 minutes depending on the beam energy level. The experiments were run for beam energies of 100, 200, 300, 400 and 500 eV for both focused and unfocused ion beams. The focused ion beam diameter is about 1 mm whereas the unfocused beam diameter is about 3 mm. The ion beam current ranged from 0.45 microampere at 100 eV to 1.15 microampere at 500 eV. After bombarding the target with cesium ions, the cobalt foil is removed from the vacuum chamber and taken to a multichannel analyzer for counting the gamma rays emitted by the disintegrating ^{57}Co atoms deposited on the foil. The analyzer is set so that only photoelectric peak is counted. A standard ^{57}Co source of 0.115 μCi is used to determine the efficiency of the counter. The amount of radioactive atoms in the sputtered material is then a measure of the total sputtering yield.

3. Sputtering Yield Measurement

Let N be the number of total atoms counted under the photoelectric peak in time t_c. Then the total number of radioactive atoms N_R on the cobalt foil is given by

$$N_R = N / (tc\, \lambda \eta)$$

where λ is the disintegration constant of ^{57}Co and η the efficiency of the counter. The percentage of radioactive atoms on the target, γ, decreases with time and is determined by

$$\gamma = \gamma_o\, e^{-\lambda T}$$

where γ_o is the percentage of radioactive atoms on the target at the time of electroplating, and T is the elapsed time between electroplating the sample and the day the data were taken. Assuming that all the sputtered atoms are deposited on cobalt foil, the sputtering yield S is given by

$$S = (N_R q) / (\gamma I t_e)$$

where q is the charge of an ion, I the ion beam current and t_e the beam exposure time of the target.

4. Results and Discussion

The sputtering yields of cobalt by cesium ions at 100, 200, 300, 400, and 500 eV are presented in Fig. 3 for both focused and unfocused ion beams. For comparison, the sputtering yield of cobalt by mercury ions reported by Wehner is also presented, although the experiments were performed under different conditions [3]. The sputtering yield values obtained by Wehner are 2 to 5 times higher than those obtained from our experiments with focused beams.

The discrepancy in the sputtering yield values can be traced to the vacuum chamber pressure and the ion current densities at which these data were taken. Wehner's experiments were performed with the target immersed in a low-pressure mercury plasma discharge at about 1×10^{-6} Torr and 5 mA/cm^2 ion current density. The highest current density obtained in our experiments was 0.15 mA/cm^2. At 0.15 mA/cm^2 a surface atom of the target receives about 30 impacts per minute form the incident ions whereas the residual gas molecules at 1×10^{-6} Torr will impinge about 10 times on the surface atoms during the same period [6]. Thus, the surface of the target will have an appreciable amount of adsorbed gases which inhibit the sputtering process significantly.

The effect of ion current density on the sputtering yield can be clearly seen in Table 1, where the ratios of the sputtering yields for the focused and the unfocused beams at various ion energies are listed. At all ion energies the sputtering yields of unfocused beams are lower by factors of 10 to 14. The focused and the unfocused ion beam densities differ by about the same values. It is obvious that a very high vacuum is required to minimize the effect of the residual gas on the sputtering yields at low ion current densities. In view of this, our vacuum system is being upgraded to a pressure of 10^{-8} Torr. Currently, we are in the process of obtaining data for sputtering yield of cobalt bombarded by low energy argon ions.

The amounts of material sputtered at ion energies down to 50 eV are within the detection limits using the 110 μCi target. A higher activity target would enable us to measure sputtering yields below 100 eV.

Table 1.
Ratio of the Sputtering Yields for the Focused and the Unfocused Ion Beams.

ION ENERGY (eV)	RATIO
100	10.4
200	10.0
300	13.7
400	11.9
500	11.1

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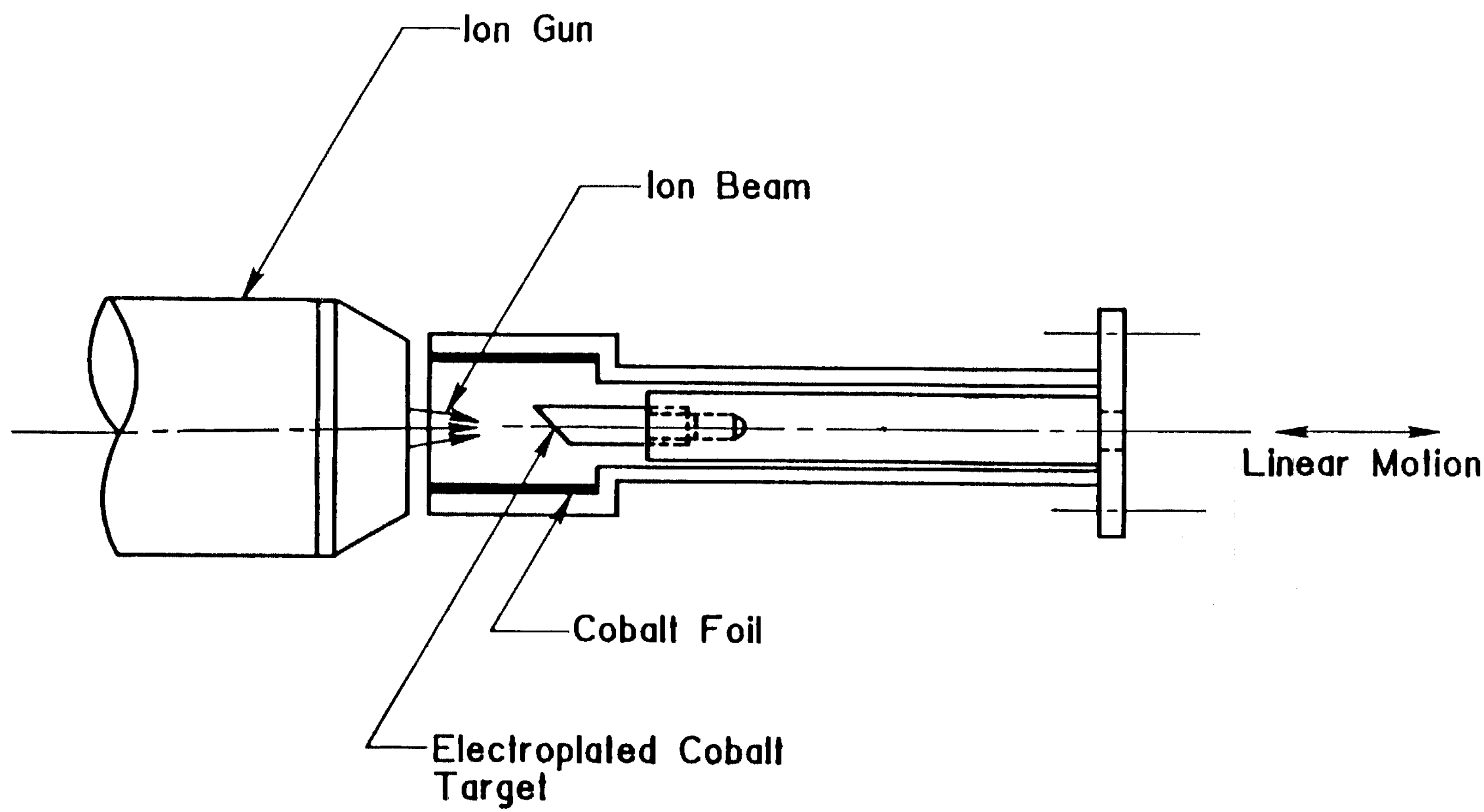

Figure 1. Schematic diagram of the experimental setup.

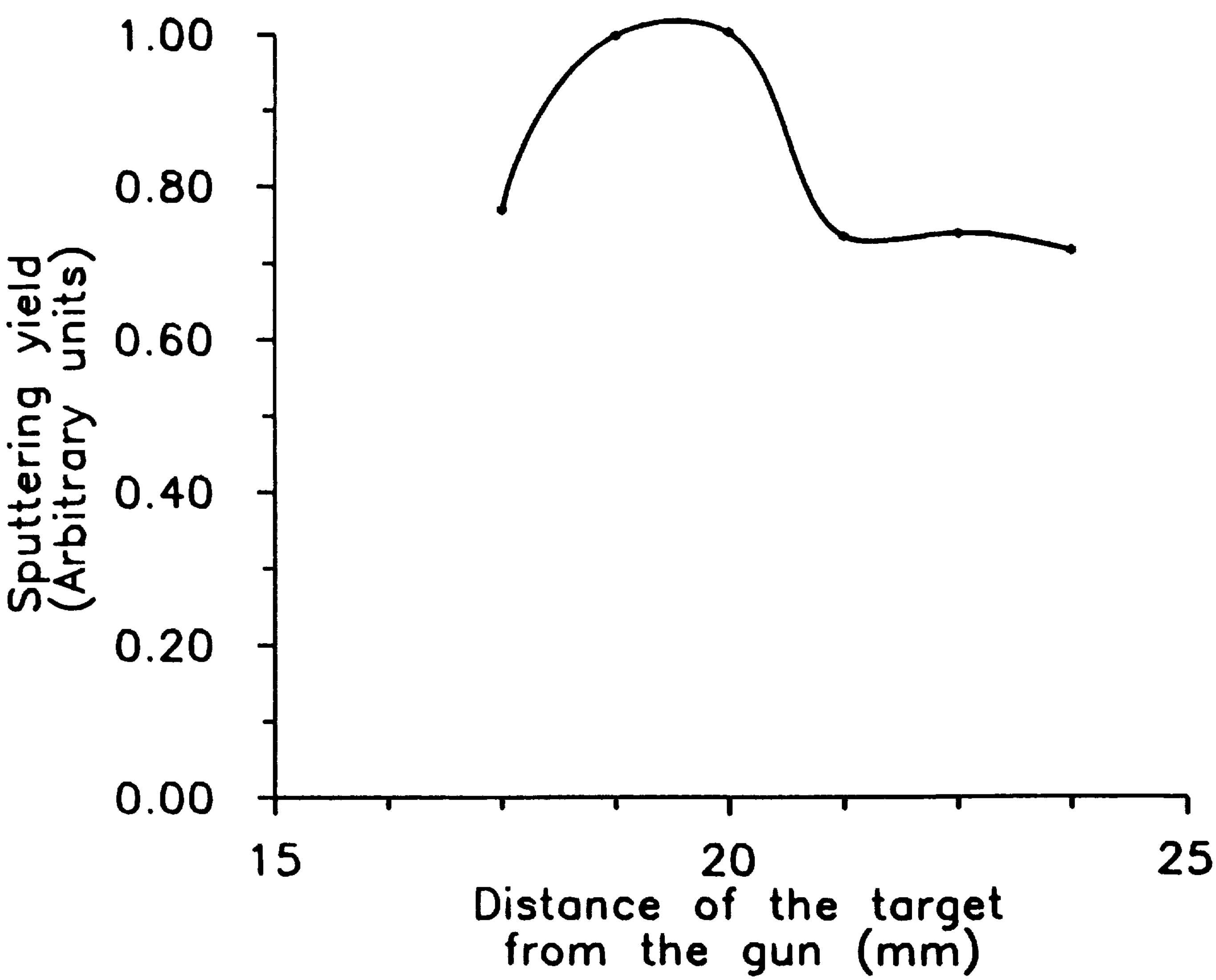

Figure 2. Variation of sputtering yield with distance.

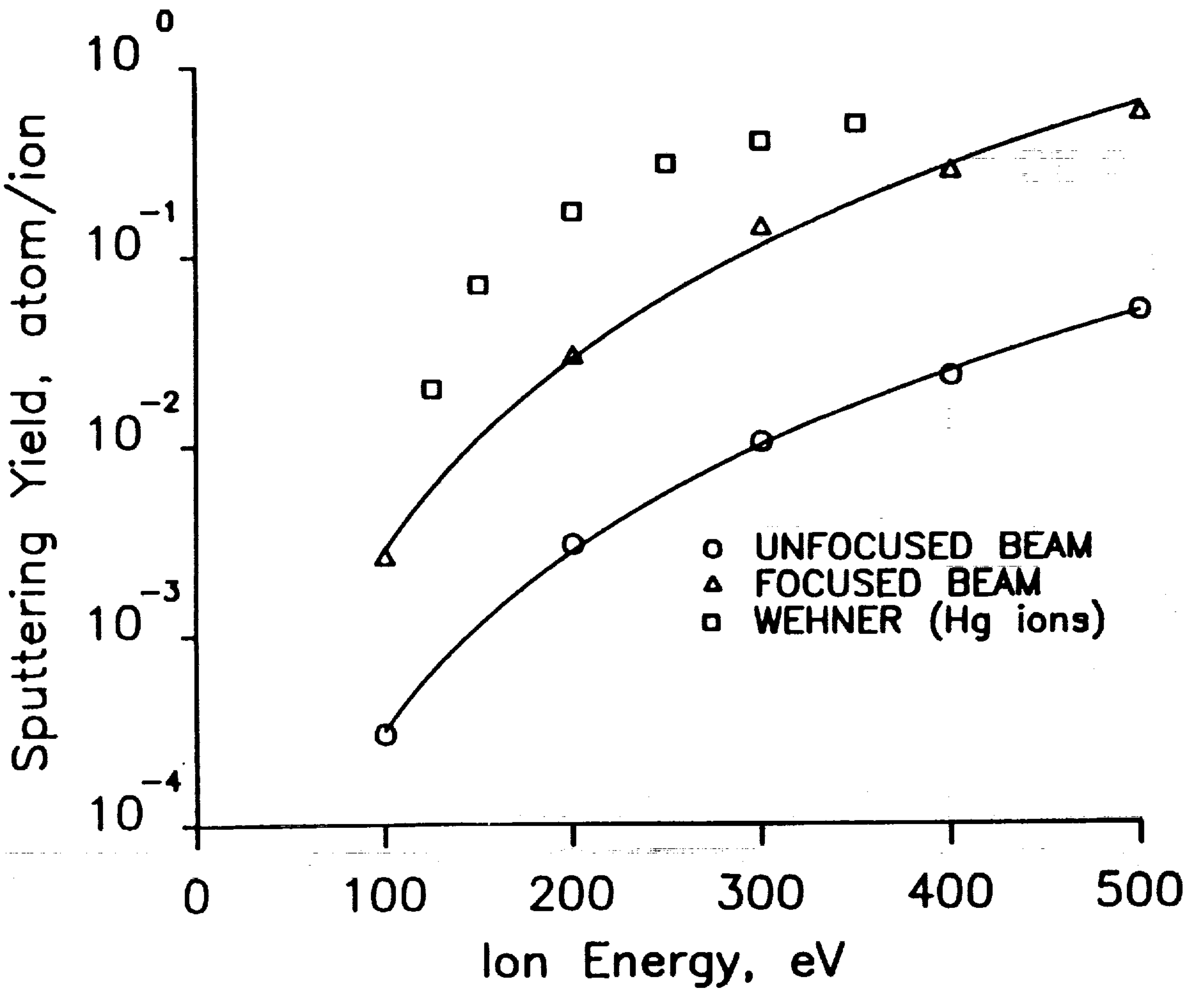

Figure 3. Sputtering yield of cobalt by cesium ions at various ion energies.