A Study on the Bombardment of Fast
H⁺ on Aluminium Surface

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Fast H⁺—bombardment on aluminium is studied by a bombardment-induced photon emission method. H, H, and H are observed in the back scattering during the bombardment and hydrogen atoms are also found to be implanted in the sample after the bombardment. The thermal spike temperature of the H-implanted sample is estimated accordingly. However, the stripping effect on the host material does not occur even after a long time bombardment is carried out.

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I. Introduction

The erosion of surfaces by sputtering during bombardment of energetic particles has been the subject of research for many years. (e.g. Gritsyna et al. (1)). The subject is still progressing actively in the recent years. The bombardment of a solid surface with the fast particles usually results in changes in the crystal lattice of the solid, emission of secondary particles and emission of radiation in the visible and ultraviolet ranges. In this work we use photon emission techniques to study the changes. Due to the simplicity in theory (Kerkdijk and Thomas (2)) and prospective practical purposes (e.g. hydrogen embrittlement, hydrogen in fusion reactor) (Ziegler (3), Picraux (4)) fast light particles such as H, He, etc. are always chosen as incident projectiles. Among the recent experimental reports, for instance, H⁺ impact on Mo by McCracken and Evort (5), H⁺ and He⁺ impact on Cu (6) and H⁺ and He⁺ impact on Au and Ni (2) both by Kerkdijk and Thomas, very little information of fast H⁺ was given and especially aluminium as a target has never been studied. The objective of the present work is to report on the observation of the fast H⁺—bombardment on the Al metal surface.

II. Experimental

Pure aluminium (99.9999%) polycrystalline discs of 40 mm diameter and 0.5 mm thickness were used as specimens in this experiment. They were properly cleaned in HF prior to each measurement in order to have an uncontaminated surface. The experimental set-up was shown in Fig. 1 schematically, which included ion-sources, focusing and accelerating units, collision chamber and detection device as indicated in the diagram. The sample was mounted in the collision chamber as a target for bombardment. During the experiment, the

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Fig. 1 Schematic diagram of the experimental set-up.
pressure was held at about $1.33 \times 10^{-4}$ Pa in the whole system by two diffusion pumps with cold traps and the temperature was about 12°C (room temperature) for the collision chamber. A positive hydrogen ion beam, confined to an area of 0.28 cm$^2$ by a diaphragm, generated by a conventional RF plasma oscillator, accelerated to 12 keV, was applied to bombard the target for the purpose of implantation. This gave a rate of bombardment dose to be about $4.5 \times 10^{-6}$ A since the ion flux was about $10^{15}$ ion/cm$^2$·s. Similarly a positive krypton ion beam was applied for the purpose of detection which provided a rate of removal of thickness by sputtering to be $3.6 \mu g/cm^2$·min if the sputtering coefficient was assumed to be 2.4(7)(8).

The technique used in this study was called "Bombardment-Induced Photon Emission" by Kelly and Kerkdijk(9). By means of this technique, the bombardment of Kr ion on the surface of the Al sample resulted in the sputtering of surface particles, of which a significant fraction was ejected in excited states. The particles could then de-excite by few different mechanisms, such as photon emission. Spectroscopic investigation of the photons emitted from the bombarded sample could thus give information about the surface of the sample. However if hydrogen beam was applied the bombarding H$^+$ ions could be either back scattered or penetrate the solid surface, coming to rest when their energy had fallen and were implanted in the sample. The spectra observed during the Kr-bombardment of the H-implanted samples consisted of discrete well defined lines. The identification and intensity of any specified spectral line could be easily found by using the available spectra-tables. The equation showing the intensity was given by Good(10) as follows:

$$I_{\text{eff}} = \text{constant} \exp \left( -\varepsilon_0/kT \right).$$

Plotting the logarithm of $I_{\text{eff}}$ against $\varepsilon_0$ the thermal spike temperature, $T$ could be estimated from the slope of the straight line. $I_{\text{eff}}$ is the effective intensity of the spectral line, obtained by normalising the recorder-efficiency and the multiplicity of the particular energy level to unity. $\varepsilon_0$ is the excited energy level of the electron, and $k$ the Boltzmann constant.

III. Results and Discussion

1. Back scattering

Light projectiles, like H$^+$-ions, usually constitute a special problem to bombardment studies because of the low sputtering yield and the dominating electronic-stopping and the significant contributions were always reported to be found from the back scattered projectiles (Behrisch and Weissmann(11)(12)). In this study the following back scattering spectral characteristics of hydrogen were found as shown in Fig. 2:

- line I H$_\beta$, 410.1 nm, corresponds to $2p^2P^0 \rightarrow 6d^2D$
- line II H$_\gamma$,
434.0 nm, corresponds to $2p^2P^0 \rightarrow 5d^2D$

line III $H_\beta$,

486.1 nm, corresponds to $2p^2P^0 \rightarrow 4d^2D$

However, line IV $H_\delta$,

656.2 nm, corresponds to $2p^2P^0 \rightarrow 3d^2D$

was not observed. The relative intensities of lines I, II and III were basically 1: 2: 5 ratios which were in good agreement with the published results. The shapes and the intensity distribution of the broad emission lines of $H_\beta$, $H_\gamma$ and $H_\delta$ are plotted in Fig. 3 which showed that the broadening of spectral lines were about 9.78, 8.15 and 4.89 nm for $H_\beta$, $H_\gamma$ and $H_\delta$ respectively. This broadening could be ascribed primarily to Doppler shifts\(^2\) of emission from the scattered projectiles. The disappearance of $H_\delta$ line could be due to either the limitation of the present device or the non-existence of the transition.

2. Hydrogen implantation

If the fast $H^+$ beam has bombarded the target for sufficient time, for instance, 10 min in this experiment, the hydrogen ions might be implanted into the aluminium target. This was detected by using the 12 keV Kr-scanning after the bombardment of the aluminium surface with $H^+$-ions. Figure 4 shows the feature of the spectral lines. Lines of $H_\beta$, $H_\gamma$ and $H_\delta$ could be easily located. Once again $H_\delta$ was not detected. It should be noted that the lines were very much broadened and the relative intensities of the lines were distorted. These were probably caused by the strong background continuum.

The hydrogen-profile was studied by means of the Kr-scanning with varying times of bombardment, i.e. the different sputtered depths of the sample from its surface. This was shown in Fig. 5 in which it was interesting to see that different shapes of profiling curves for different $H$-implantation times, i.e. different bombardment doses. The details of this profile study will be discussed in another report.

3. The temperature of thermal spike

The thermal spike temperature of this $H$-implanted aluminium sample could be estimated from the slope of the linear plot, as shown in Fig. 6, giving $T = 3600$ K which was in good agreement with the previous works on Al alloys and pure Al (Good\(^7\)). This suggests that the thermal spike temperature mainly

![Fig. 3 Intensity distribution of H-lines.](image)

![Fig. 4 Spectra lines for the implanted H.](image)
depends on the host material, aluminium. The hydrogen ions, once implanted into the aluminium surface the thermal spike temperature will be the same as that of the host aluminium.

4. Stripping effect and blistering dose effect

Even the H\(^+\)-bombardment was prolonged to 120 min, which was equivalent to have a bombardment dose of \(7 \times 10^{18}\) H-ions/cm\(^2\), the emission from the sputtered aluminium-atoms was not observed; and the stripping of aluminium material was also not observed. It is understood that the projectile ions are too light that they cannot actively give effective sputtering (Mackintosh\(^{(13)}\)). Blistering on the aluminium surface was also not found. (Das et al.\(^{(14)}\)). It is believed that the introduced hydrogen can remain in the sample as impurity-solution but not as bubble precipitates\(^{(15)}\).

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