

## Plasma cleaning of copper leadframe with Ar and Ar/H<sub>2</sub> gases

J.H. Hsieh <sup>a,\*</sup>, L.H. Fong <sup>a</sup>, S. Yi <sup>b</sup>, G. Metha <sup>b</sup>

<sup>a</sup> Gintic Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore 638075

<sup>b</sup> School of Mechanical and Production Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798

### Abstract

Copper (Alloy 194) leadframes, after being oxidized in an oven at 175 °C for 0.5, 1, 3, and 5 h, were plasma-cleaned. Plasma was generated by a d.c. bias of 200 V on to the substrate holder and leadframes using Ar or Ar/H<sub>2</sub> (1:4) as the working gases. Cleaning times were 2.5 min and 12 min respectively. The cleaned and uncleaned leadframes were then transfer-moulded for the subsequent pull testing. The results show that plasma cleaning improves the molded adhesion strength between leadframe and molding compound. In particular, the preoxidation of leadframes and the composition of working gases have a significant effect on adhesion. Cleaning in Ar for 2.5 min increased the adhesion strength fourfold under certain pre-oxidation treatments, whereas the addition of hydrogen as the reactive gas did not show such an improvement. Overall, a short cleaning time is sufficient to improve the adhesion strength regardless of the gas species and preoxidation time. The difference in the effectiveness of the working gases could be attributed to their cleaning mechanisms. © 1999 Elsevier Science S.A. All rights reserved.

**Keywords:** Adhesion; Leadframe; Package; Plasma cleaning

### 1. Introduction

In recent years, copper alloy has been increasingly used as a major substrate (leadframe) material in IC packaging due to its good thermal and electrical performance, good manufacturability, and low cost [1]. However, the formation of copper oxide and other contaminants on the leadframe surfaces is known to create serious reliability problems due to delamination [2,3]. The extent of delamination has been found to depend on the severity of the oxidation induced during assembly processes such as die attach curing and wire bonding [2]. Thus, maintaining leadframe cleanliness is a critical step toward high-reliability packaging.

Plasma cleaning has been used for many years as a pretreatment prior to coating processes. In a plasma chamber, surfaces exposed to the plasma will be subjected to sputtering (momentum transfer) and/or chemical reactions caused by reactive and energetic radicals. These chemical and physical processes remove oxide and contaminants from the surfaces.

It has been reported previously that hydrogen–argon plasma gas mixtures can effectively remove oxide from

metallic substrates [4,5]. During cleaning, hydrogen radicals can help to reduce the oxide, while argon can enhance the yield in hydrogen atoms by penning ionization. However, with argon as the working gas, physical sputtering is expected to occur. The present study aims to investigate the effects of leadframe oxidation, plasma-cleaning time, and plasma species on adhesion strength between the moulding compound and the leadframe.

### 2. Experimental

Plasma cleaning was performed in a cleaning module in which several copper leadframes (Alloy 194) were held by a rotating stage and surrounded by four unbalanced magnetron sputtering targets. During cleaning, the plasma was generated by a self-bias of 200 V d.c. on to the substrates (leadframes). The substrate current density was estimated at 1.4 mA cm<sup>-2</sup>. Prior to cleaning, the chamber was pumped down to 5 × 10<sup>-5</sup> Torr (6.65 × 10<sup>-3</sup> Pa). Two types of working gases were used: Ar and Ar–H<sub>2</sub> (1:4). During the process, the pressure was about 1.06 Pa. All tested leadframes were sequentially cleaned thoroughly with 20% nitric acid, DI water, and ethanol prior to oxidation treatment for 0.5, 1, 3, and 5 h in an oven. These substrates were then plasma-

\* Corresponding author. Tel: +65 799 6466; Fax: +65 792 2779; e-mail: jhhsieh@gintic.gov.sg

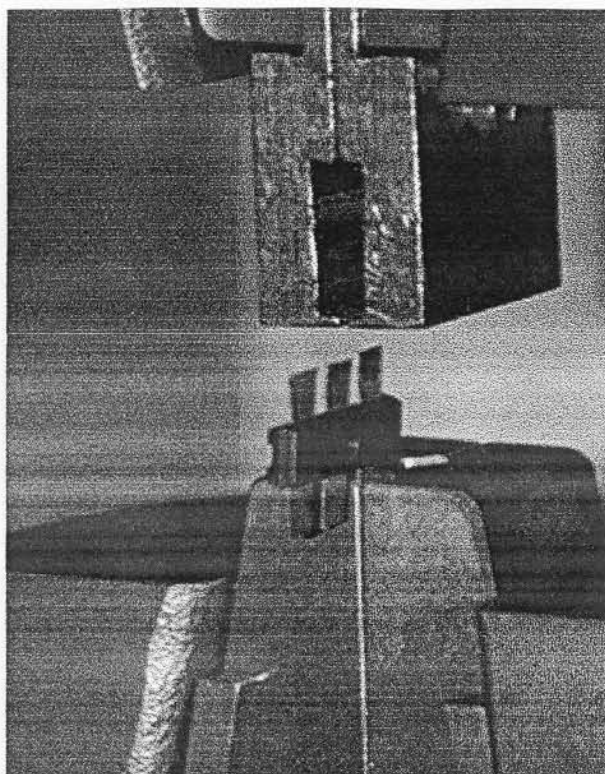


Fig. 1. Photograph of the testing set-up before pull testing.

cleaned for 2.5 and 12 min followed by packaging using the transfer molding process with commercially available epoxy moulding compound (EMC). In order to check the oxide left on the surface, some copper substrates were coated with aluminum immediately after cleaning. These coated substrates were then analyzed using a glow discharge optical spectrometer (GDOS). The leadframe used in this study was specifically designed for the purpose of adhesion (pull) testing.

The adhesion tests were performed using an Instron testing machine (Series IX) operating at a crosshead speed of  $2.54 \text{ mm min}^{-1}$ . The testing set-up is shown in Fig. 1. The adhesion strength of the copper leadframe to the mold compound was determined by the force required to pull the lead out from the package with the package being held still. Twelve measurements were carried out on randomly selected specimens with the same treatment.

Atomic force microscopy (AFM) was used to measure the surface morphologies of leadframes before and after plasma cleaning. A contact angle goniometer was used to measure the contact angle of DI water on the cleaned leadframe.

### 3. Results and discussion

The GDOS depth profile of the aluminum-coated copper leadframe revealed little oxide present at the

interface after Ar or Ar/H<sub>2</sub> plasma cleaning. The amount of oxygen detected was around 0.1 at.% for Ar/H<sub>2</sub> plasma-cleaned samples, and about 0.3 at.% for Ar plasma-cleaned samples. Also, a longer cleaning time using Ar/H<sub>2</sub> plasma did not produce a cleaner interface, and it was concluded that some oxygen may come from the surface of the aluminum target during the early stages of sputtering.

The results of the pull tests are presented in Figs. 2 and 3. Fig. 2(a) shows that the average pull strength decreased with increasing oxidation time. This finding is consistent with earlier work by Chong et al. [2] and Ohsuga [6]. They attributed this behavior to the cohesive failure of weakly bonded Cu oxide. Due to the growth of weakly bonded oxide, the adhesion strength is expected to decrease with the increase of oxide thickness. When leadframes were pre-oxidized and plasma-cleaned, the pull strength was generally increased, especially for leadframes treated in Ar for 2.5 min [Fig. 2(b) Fig. 3]. After cleaning for 2.5 min in Ar plasma, the pull strength increased fourfold greater than that of the untreated sample. One possible explanation for this increase is that the surfaces have been micro-roughened by the sputtering effect of energetic Ar particles. Surface micro-roughening is known to induce mechanical interlocking and to yield a greater surface area for chemical interactions [3]. Recently, Lee et al. [7] have reported that the increase in surface micro-roughness can lead to a significant increase in adhesion strength between the molding compound and the copper leadframe. In their paper, it was also pointed out that macro-roughness may not be directly related to adhesion change. To show the difference in surface morphologies after various cleaning processes, AFM was used to investigate the surface morphology and micro-roughness. Several AFM micrographs are presented in Fig. 4. For a short cleaning time with Ar plasma, the surface tended to be unevenly rough [Fig. 4(b)]. After 12 min of cleaning, the surface had become smoother, as shown in Fig. 4(c). When an Ar–H<sub>2</sub> plasma was used, the surface morphology remained unchanged, regardless of the cleaning time. This may partly explain why a dramatic increase in adhesion was not observed in the Ar–H<sub>2</sub> plasma, as shown in Fig. 2(c). Fig. 5 shows the results of surface roughness ( $R_a$ ) measured by AFM, as a function of plasma treatment time.

The difference between Ar and Ar–H<sub>2</sub> plasma could be due to the differences between cleaning mechanisms. When pure Ar is used as the working gas, the removal of oxide would rely mainly on physical sputtering. In the case of Ar–H<sub>2</sub>, hydrogen plasma is used to induce a chemical reaction between oxide and hydrogen. Therefore, the surface could be more uniform in terms of surface morphology [4,5]. The AFM micrographs shown in Fig. 4 also imply that Cu oxide grew from certain preferred sites, which may eventually have con-



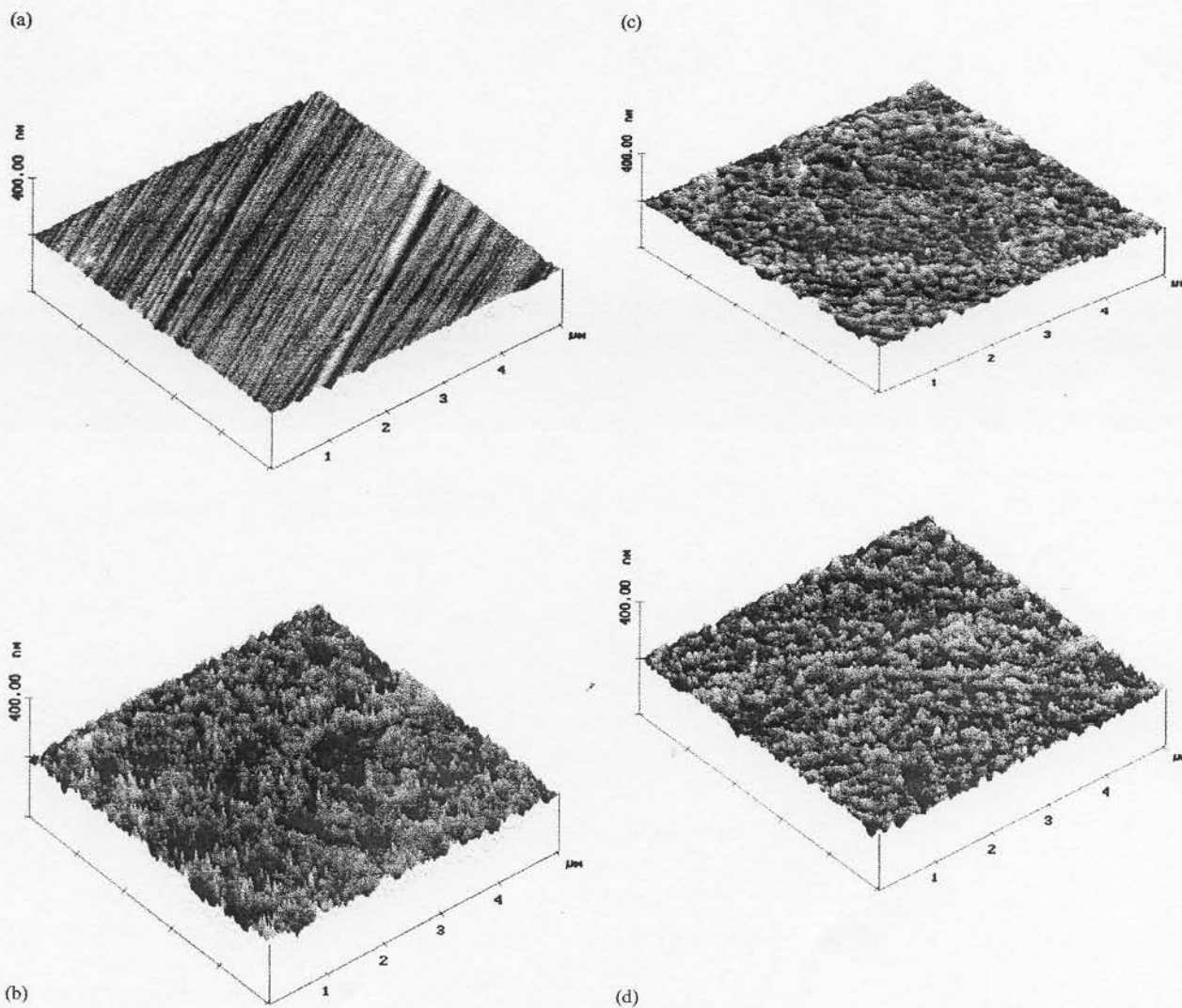


Fig. 4. AFM surface micrographs of copper surfaces: (a) before oxidation, (b) plasma-cleaned in Ar plasma for 2.5 min after 1 h of oxidation, (c) plasma-cleaned in Ar plasma for 12 min after 1 h of oxidation, and (d) plasma-cleaned in Ar-H<sub>2</sub> plasma for 2.5 min after 1 h of oxidation.

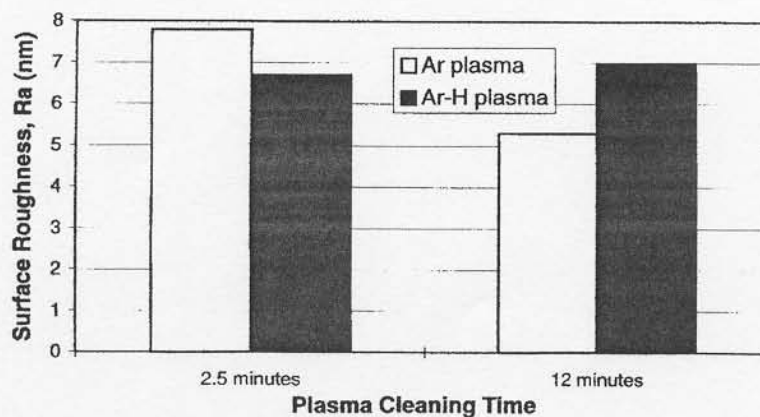


Fig. 5. Comparison of surface roughness after various plasma cleaning.

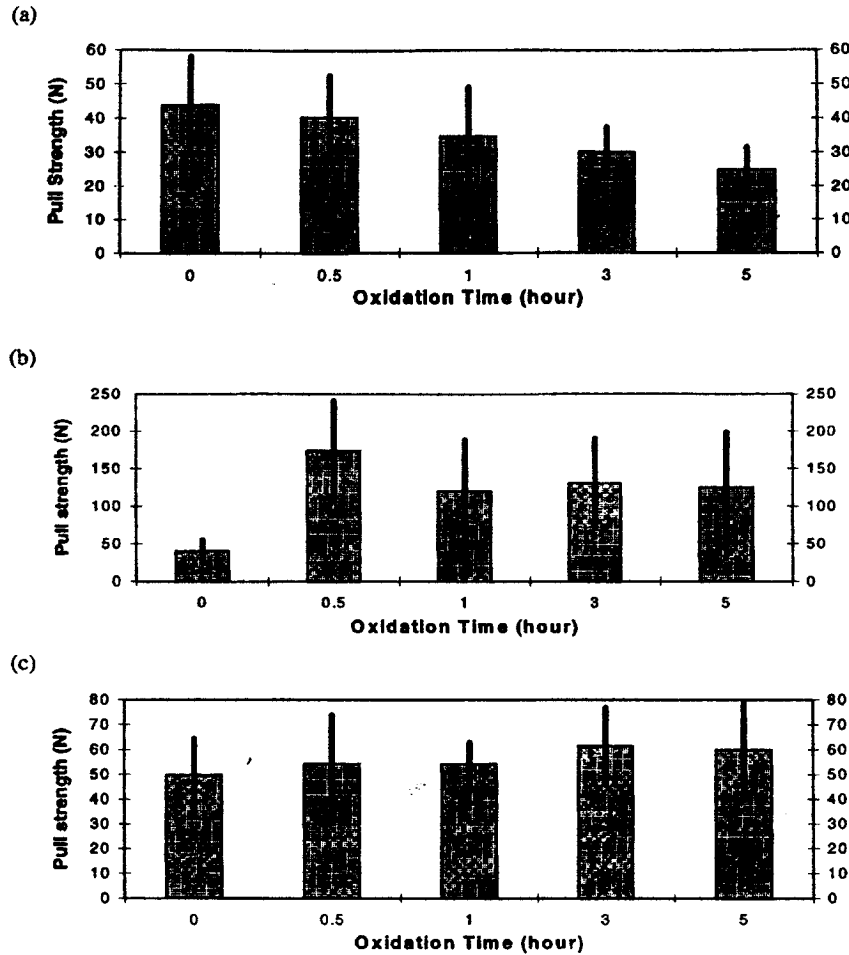


Fig. 2. Pull strength vs. oxidation time: (a) without plasma cleaning, (b) after 2.5 min of Ar plasma cleaning, and (c) after 2.5 min of Ar-H<sub>2</sub> plasma cleaning.

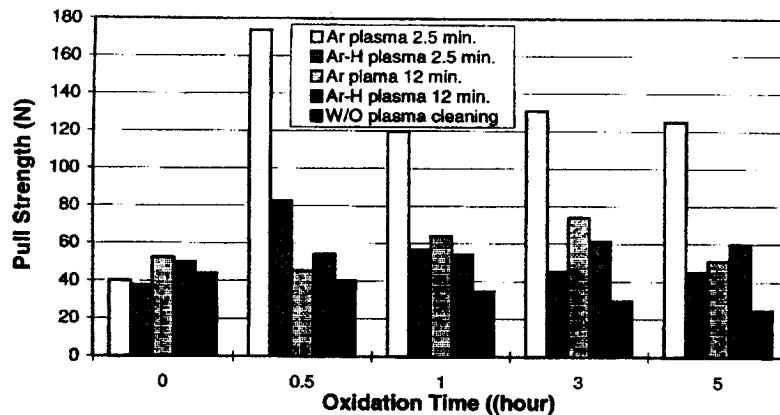


Fig. 3. Pull strength vs. preoxidation time, with the variation in plasma cleaning conditions.

tributed to the change in surface morphology of the Ar-H-cleaned surface.

Another possible reason for the increase in pull strength after 2.5-min Ar plasma cleaning could be due

to residual oxide. Schmidt et al. [8] reported that an oxide layer thinner than 25 nm can enhance the adhesion of the moulding compound to the leadframe. The trace oxide left on the copper surface after Ar plasma cleaning

can therefore contribute to the increase in adhesion strength. However, in Schmidt's study, an increase of only less than 20%, due to the growth of a thin oxide layer, was observed. It is believed, therefore, that the main reason for the significant increase in adhesion is due to micro-roughening from Ar ion sputtering.

The results of surface contact angle measurements obtained using a goniometer show that the measured contact angles were 13–16° for a plasma-cleaned leadframe. However, this result fails to explain the different effects of the Ar and Ar–H plasma.

#### 4. Conclusions

Plasma cleaning has a positive effect on the adhesion strength between the leadframe and the molding compound. In particular, it is found that the preoxidation time and working gases have a significant effect on the testing results. Cleaning in an Ar plasma for 2.5 min shows the most dramatic improvement. Overall, 2.5 min of cleaning in plasma is sufficient to improve the adhesion strength, regardless of the gas species and preoxidation time. The difference in efficiency of the working gases could be due to the difference, in cleaning mechanisms.

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