Effect of RF plasma process gas chemistry and electrode configuration on the removal of copper lead frame oxidation

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ABSTRACT

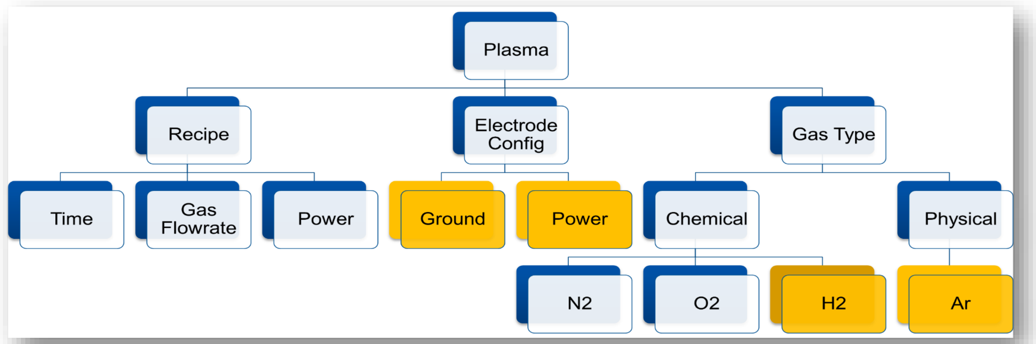
Lead frame surface oxidation can lead to surface delamination after molding or wire bonding issues. The application of plasma treatment has been proven to be safe and effective solution to address these issues. However, the effectiveness of plasma treatment for removing oxide is dependent on the correct use of recipe parameters, gas chemistry and electrode configuration.

In this paper, analytical techniques such as contact angle measurement, high magnification optical inspection and SEM-EDX are carried out on copper lead frames to evaluate the impact of using different plasma gas chemistries and electrode configurations. It is concluded that the use of Ar/H_2 is better than Ar gas chemistry in removing oxide from copper lead frames. Another conclusion is the placement of copper lead frames on ground electrode is showing higher oxide removal rate than the placement on powered electrode.

INTRODUCTION

Copper alloy is a major substrate material used in IC packaging due to its good thermal and electrical performance, good manufacturability, and low cost. However, it has very high affinity with oxygen in the atmosphere which can cause oxidation during the assembly process. The risk of oxidation on copper surface increases during manufacturing process that require heating especially during wire bonding step. [1] The oxidation can lead to higher probability of delamination or bonding issue between the mold and metal surface during post mold curing. [2] [3]. The optimum plasma configuration is known to be used for removing oxide from the copper surface and can increase the surface energy by up to 84% of its original value [4]. Placement of a product to be treated on a ground electrode subjects it to a more isotropic treatment than when it is placed on a powered electrode which gives a more anisotropic treatment. Using the powered electrode will produce higher temperature surface and give lower treatment uniformity compared to treatment on the ground electrode[5].

Active plasma species which include ions, electrons, radicals and photons are formed during ionization of the process gases by RF energy. Ions will physically collide with the target surface, breaking bonds and releasing the surface material in the process known as sputtering. The H_2 radical formed in plasma is a good reducing agent that reacts with oxygen atoms on the oxidized surface to form water vapor. It is a useful process gas for removing oxides from the metallic surfaces.



METHODOLOGY

Material used Two types of commercial copper alloy lead frames (bare Copper and rough Copper) were tested. The lead frames were exposed to temperatures that simulate the die attach, glue curing and wire bonding steps before they were sent for plasma treatment. This was done to simulate the oxidation that the lead frame will encounter during a typical assembly process.

Plasma Equipment The Nordson MARCH plasma system uses 13.56 MHz RF to generate plasma. The equipment had a H_2 safety kit that allows the use of up to 100% H_2 gas flow but for this evaluation premixed gas of 95% Ar and 5% H_2 (Ar/H_2) was used. The strip is placed directly on the electrode in a configuration that is known as OTE (On-The-Electrode). This configuration is proven to give better uniformity and focuses the plasma energy on the top surface of the lead frame since the back of lead frame sits flat on the electrode base and is not exposed to plasma. The process parameters of 600W RF power, , 180s plasma time were used for this evaluation. The variables were the different electrode configurations and the gas chemistry.

Analysis Method The analysis of the copper lead frame surface was performed using two types of equipment: SEM-EDX and contact angle goniometer. The SEM-EDX was utilized in this study to analyze the oxide concentration on the sample surface The goniometer was used to analyze the wettability and surface energy.

RESULTS

Contact Angle

- Rough copper gives higher CA than bare copper lead frame
- Lower CA reading on the surface after plasma treatment process
- Ar Plasma gives a higher CA than Ar/H_2 plasma
- No significant difference if Ar/H_2 chemistry was used and material was placed on either power or ground electrode

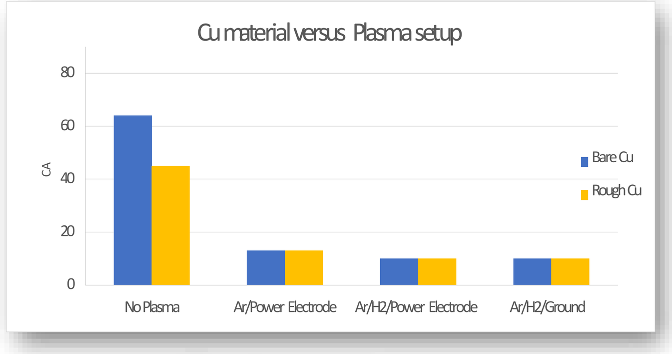


Figure 1 Contact Angle result of different configuration and material

SEM-EDX

- Rough copper lead frame detected with higher oxygen concentration on the surface than the bare copper lead frame after plasma treatment
- Ar/H_2 Plasma exhibits lower oxygen concentration than the Ar Plasma when lead frame are treated on powered electrode
- The use of Ar/H_2 on ground electrode detected with the lowest oxygen concentration on the surface
- The CA result does not directly correlate with the oxide thickness on the surface based on this result analysis

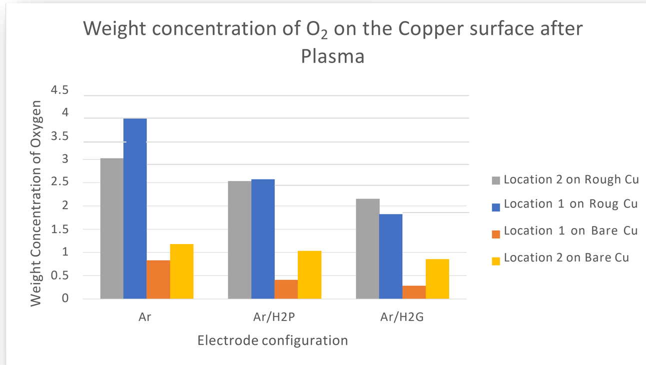


Figure 1 SEM-EDX result on the copper lead frame

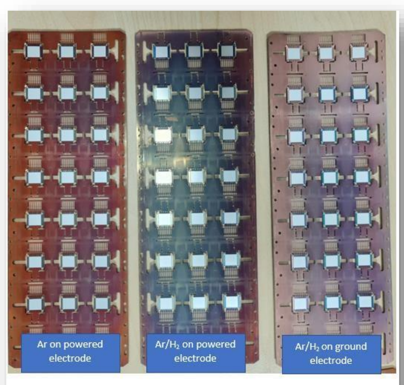


Figure 6 Appearance of Rough Copper lead frame after plasma treatment

Figure 4 Appearance of bare copper lead frame before and after plasma treatment

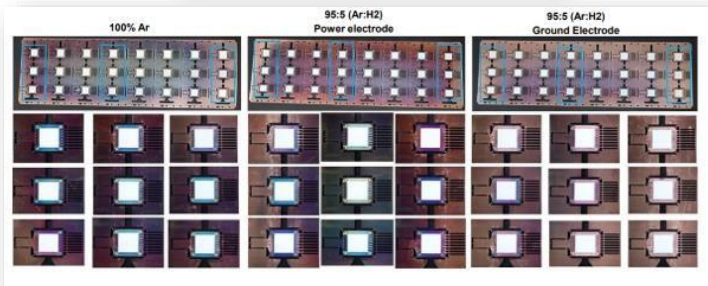


Figure 7 High magnification scope for Rough Copper lead frame after plasma treatment

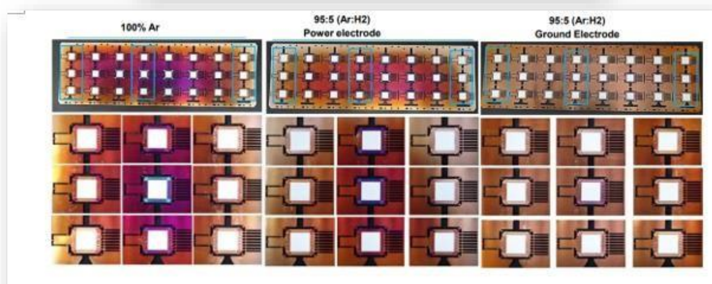


Figure 5 High magnification scope for bare copper lead frame after plasma treatment

The pre-plasma treated lead frame was observed to be discolored after the heat exposure in the different process steps. Discoloration was still found on samples treated with Ar on powered electrode and with Ar/H_2 on a powered electrode setup. However, there was no discoloration observed on the lead frame after treatment with Ar/H_2 on the ground electrode setup

Visual Inspection for Rough Cu

Type of lead frame	Configuration	Observation	Oxide Remain
Rough	No Plasma	Reddish-yellow discoloration	High
Rough	Ar/Powered Electrode	Reddish-Brown discoloration	High
Rough	Ar/H_2/Powered Electrode	Dark Bluish-purple discoloration	Mid
Rough	Ar/H_2/Ground Electrode	Slight discoloration	Low

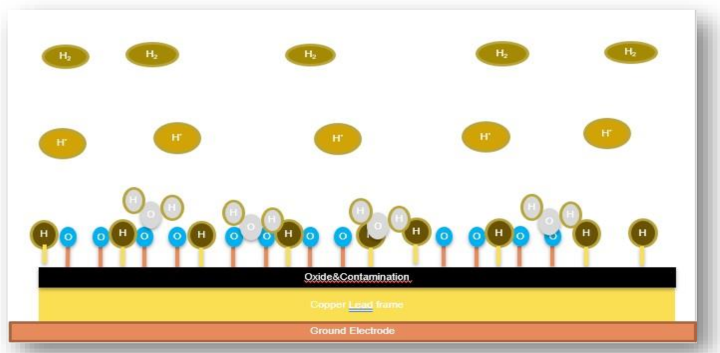
Visual Inspection for Bare Cu

Type of lead frame	Configuration	Observation	Oxide remain
Bare	No Plasma	Reddish-Brown discoloration	High
Bare	Ar/Powered Electrode	Reddish-Brown discoloration but slight reduction in colour intensity	High
Bare	Ar/H_2/Powered Electrode	Reddish-Brown discoloration but further reduction in colour intensity	Mid
Bare	Ar/H_2/Ground Electrode	No discoloration	Low

Appearance of the rough copper lead frame after plasma treatment shows different discoloration from the treated bare copper lead frame. This could be the result of the thicker oxide layer on the rough copper compared to the bare copper lead frame . On both types of lead frames there was a trend of reduction in discoloration intensity with reducing oxide thickness. There is more discoloration remaining on the rough copper compared to the bare copper lead frames that were processed with Ar/H2 on ground electrode. Further recipe optimization is required to remove the remaining oxide and attain lower discoloration on the surface.

Why the use of Ar/H_2 and ground electrode works better in removing the oxide from the surface?

- H_2 plasma can lower the activation energy of Cu_2O (from 114.53 to 75.64 kJ mol-1) due to H_2 radicals present in the H_2 plasma.
- Higher possibility of adsorption of the H_2 radical on copper surface and promotes reaction with the oxygen atoms to form H_2O and follow by desorption of H_2O as volatile byproduct
- The use of anisotropic reaction is not favored to remove oxide easily.



CONCLUSION

In summary, the use of H_2 and the placement on the ground electrode can increase the rate of oxide removal from the copper surface. It has produced the lowest contact angle, the most effective removal of the discoloration and the lowest oxide concentration on the surface based on the result obtained in this study. This is explained by the lower activation energy required to reduce copper oxide to copper when H_2 radicals are formed in the plasma. In contrast, with a physical process on the powered electrode where ion sputtering is dominant, the removal of oxide is less effective.

The key take-away from this report is that a correct gas chemistry and a suitable electrode configuration are critical to obtain an optimum plasma process that requires a shorter process time and lowers the risk of overtreatment or heat related issues. From a manufacturing perspective, this results in higher production throughputs and better yields.

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