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Investigation of atmospheric pressure plasma treatment on PCB surface finishes

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***Abstract* – Flux is a necessity in the lead-free soldering process. Inactivated flux residues can cause electrical shortages and functional issues by ion migration. Because of miniaturization and the complexity of recent electronic products a cleaner manufacturing process is required. Atmospheric pressure plasma treatment (PT) is a commonly applied surface cleaning method in the manufacturing industry and has been proved to be effective in improving the wettability in case of metal and polymer surfaces. Three different types of printed circuit board (PCB) surface finishes were investigated before and after plasma treatment. The aim of this study is to investigate the mechanisms of plasma cleaning and to possibly determine the root cause of the improvement of solderability on printed circuit boards resulting from atmospheric pressure plasma treatment. For this investigation of the PCB surface finishes, scanning electron microscopy (SEM) images were taken, and the composition of the surfaces were analyzed by energy dispersive X-ray spectrometry (EDAX) and laser-induced breakdown spectrometry (LIBS) as well.**

***Keywords* – atmospheric pressure plasma treatment, immersion tin, immersion silver, ENIG, LIBS**

I. INTRODUCTION

Atmospheric pressure plasma treatment is a widely used surface modification method in manufacturing. The purpose of plasma pre-treatment is microfine cleaning, surface activation and plasma coating of a variety of materials such as plastics, metals, textiles, and glass. Conventional industrial pre-treatment methods are being replaced by plasma technology in order to make processes more effective and environmentally friendly. In the electronics industry, plasma treatment can be found as a process step in the manufacturing of base materials such as PCBs or as pre-treatment of electronic assemblies before conformal coating.

With the growing demand of more and more complex products, electronic manufacturing is facing new challenges as well. Miniaturazition and the compactness of products lead to the need of precise, fine and clean production. Nowadays ionic contamination and electromigration presents a major issue. This type of contamination can be derived from flux residues. Flux is a neccessity in the process of lead-free soldering; it has three crucial role: cleaning the metal sufraces from metal-oxides, promoting the wetting of the solder alloy and preventing re-oxidation. However, flux residues are no longer advantageous after the soldering process. Under suitable conditions – in the presence of water and voltage – ionic residues are able to migrate between conducting leads, resulting in shortage thus functional failure.

Plasma treatment offers an alternative method for preparing pure and activated metal surfaces. The quantity of flux used during the soldering process could be decreased and minimized. Atmospheric pressure plasma technology has the advantages to be automated and programmable as well as integrated into the manufacturing line.

The impact of plasma treatment on PCB surface finishes and the improvement on wettability and solderability has already been demonstrated. This work aims to analyse and investigate the modification of PCB surface finishes after plasma treatment.

II. RELATED RESULTS IN THE LITERATURE

Plasma treatment is often used on polymers. Berczeli and Weltsch [1] were able to enhance wetting and adhesive properties of HIPS polymer by atmospheric pressure plasma surface treatment. They managed to increase the bonding strength of High Impact PolyStyrene by 297% with plasma treatment.

Shin et al. [2] investigated PCB surface modifications resulting from plasma treatment by chemical and mechanical analysis methods. It was dicovered that the surface became soft and weak if plasma treatment was too excessive. It was observed that roughness increased at the first treatment, but after the third treatment the roughness decreased.

The interest for minimizing the usage of flux hase risen before. Deltschew et al. [3] worked with plasma generated from CF_4-air 10:1 gas mixture. This plasma treatment makes the elimination of the application of conventional flux in reflow soldering process possible, in case of SnPb solder materials.

Godard et al. [4] used Ar/H_2 plasma because the generated hydrogen radicals act as reducing agents. The plasma treatment was performed in vacuum.

The impact of plasma treatment on solderability of printed circuit boards were demonstrated in a previous paper [5]. Wettability was compared by contact angle measurement as well as solderability by wetting balance testing. Improvement on both solderability and wettability has been shown.

III. DESCRIPTION OF THE METHOD

In this study three types of PCB surface finishes were investigated: immersion tin (ImSn), immersion silver (ImAg) and electroless nickel – immersion gold (ENIG). These surface finishes are some of the most used in the electronics industry. Immersion tin surface finish is very common because of its good wettability and plain manufacturing as well as economic reasons. Although high humidity and temperature storage can easily worsen solderability. Immersion silver surface finish has great wetting properties, and also economically friendly, but it is susceptible to contamination from air e.g. sulphur compounds. Electroless nickel – immersion gold surface finish is the most expensive due to its material, but it is the most resistant against oxidation and contamination.

Plasma treatment was executed with a Plasmatreat PTU1208 atmospheric plasma generator with RD1004 rotating plasma nozzle. Forming gas – containing 5 vol% hydrogen in nitrogen – was applied. Distance between the rotating plasma nozzle and PCB surface was set to 10 mm. The samples were investigated before plasma treatment (PT) as reference and after plasma treatment as well in order to observe surface modifications.

Tescan Mira 3 scanning electron microscope was used to conduct topographic studies on the original and plasma treated surfaces. In this investigation the images were taken by the secondary electron (SE) detector in order to detect any difference caused by plasma treatment. Elemental analysis of the surfaces was conducted by energy dispersive X-ray spectroscopy (EDAX).

Laser-induced breakdown spectroscopy (LIBS) measurements were taken before and after plasma treatment. Keyence VHX-7000 EA-300 machine was used for this analysis with Nd:YAG laser. This atomic spectroscopy method allows a very thin surface layer to be investigated, which is the interested area of plasma treatment as well.

In addition, surface roughness measurement was performed with a GOM Atos Q type 3D scanner to observe the topographical changes caused by forming gas plasma treatment.

IV. RESULTS AND DISCUSSIONS

Scanning electron microscopy images of the PCB surface finishes by SE detector can be seen in Figure 1. It shows the state of the surface before and after forming gas plasma treatment respectively. Based on the images after plasma treatment the surfaces are presumably rougher in nano scale.

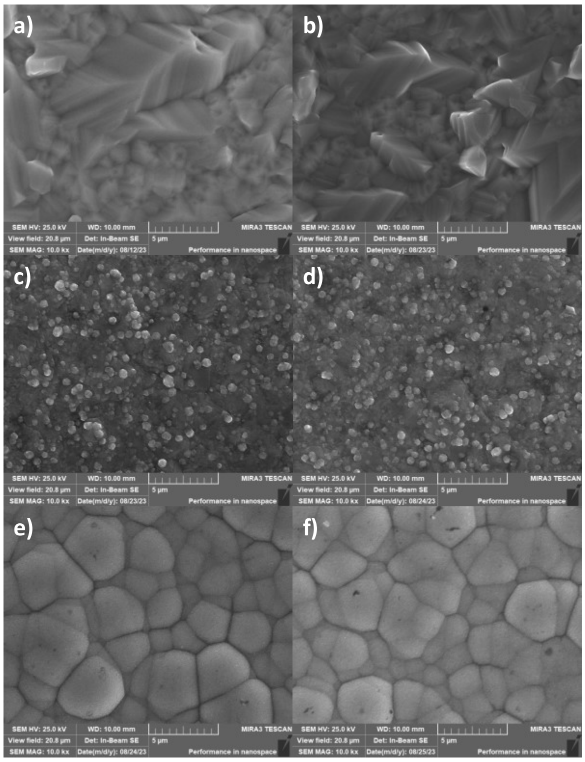

Fig. 1. SEM SE images of ImSn before (a) and after (b), ImAg before (c) and after (d), ENIG before (e) and after (f) plasma treatment

The composition of the surfaces was investigated by energy-dispersive X-ray spectroscopy (EDAX). The amount of oxygen measured before and after plasma treatment is presented in Table 1.

Table 1. EDAX results in Atomic% of Oxygen before and after plasma treatment (PT)

	Before PT [at%]	After PT [at%]
ImSn	13.3	13.5
ImAg	25.8	26.1
ENIG	23.4	23.8

15 measurements were taken before plasma treatment on each surface finishes, and the same samples were used for the measurements taken after plasma treatment. The maximum standard deviation was 0.66% in case of electroless nickel-immersion gold finish. All three types of surface finish show similar behaviour. The results show a minimal increase in oxygen atomic percent.

Comparison of the surface composition before and after plasma treatment by LIBS analysis is presented on Figure 2. These composition percentages represent an average of 250 measurements, with maximum standard deviation of 5.9% for immersion tin.

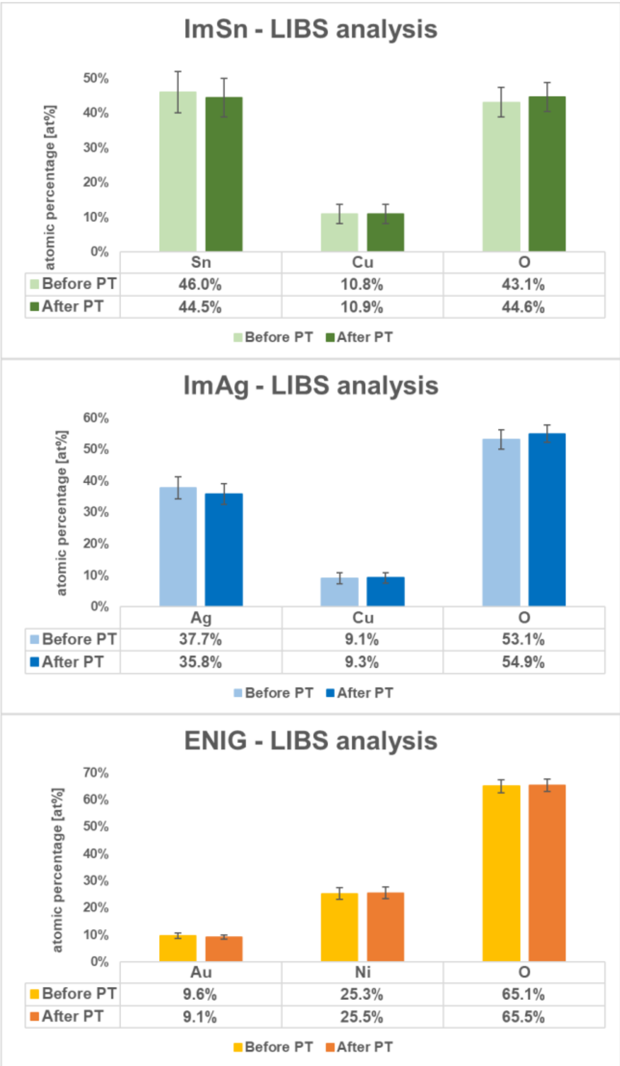

Fig. 2. LIBS analysis comparison of the surface composition before and after plasma treatment

The measured oxygen contents show the same tendencies as in the EDAX measurements in case of all three types of surface finishes. The amount of oxygen on the surfaces appears to be risen, although the difference between before and after plasma treatment is more compelling with LIBS analysis in case of immersion tin and immersion silver than the EDAX measurements.

Figure 3 shows the scanned surface of the immersion silver surface finish before and after plasma treatment. Difference in maximum peak height was observed. In case of immersion tin and immersion silver, the maximum peak height was reduced form 1.87 µm to 1.06 µm and from 0.45 µm to 0.15 µm, respectively. This decline could indicate better wettability. On the other hand, maximum peak height measured on the electroless nickel-immersion gold surface increased form 1.25 µm to 2.68 µm after plasma treatment. The difference in behaviour might be originated from the materials below the outer surface. Under the outer layer of immersion tin and silver, copper can be found which is the base material for soldering. However, in case of electroless nickel-immersion gold, the base material is nickel, which determines the topography of the surface given its characteristic grain pattern, as it can be seen in the SEM images (Fig. 1.)

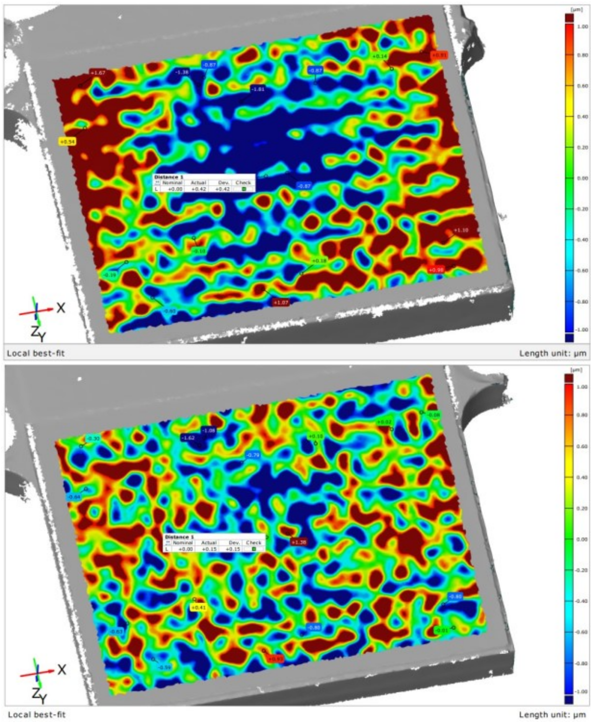

Fig. 3. 3D images of ImAg surface finish before (above) and after (below) plasma treatment

V. CONCLUSIONS AND OUTLOOK

In this study investigation on three different PCB surface finishes were conducted before and after plasma treatment. SEM-EDAX and LIBS analysis were presented and 3D scanned roughness measurement were exhibited which suggests a presumably rougher surface and show some changes in the composition of the outer layer.

Theoretically, reduction of the amount of oxygen on the surface is assumed as a result of using hydrogen as reducing agent in the forming gas plasma. However, the presented experiments may in fact suggest that the amount of oxygen increases slightly after plasma treatment.

For future prospects, surface roughness could be measured by atomic force microscopy for more detailed investigation. Surface composition could be also determined and analyzed with X-ray photoelectron spectroscopy.

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