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Comparative Study on Decapsulation for Copper and Silver Wire-Bonded Devices

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Abstract

The introduction of silver as bonding material led to new failure analysis issues. This study compares the efficiency of wet and dry chemistries for decapsulation on Cu and Ag-based alloy wires. It is shown that dry chemistry allows better control and selectivity on the EMC/ Cu and Ag-based bond wires.

Introduction

For the past decade, developments to switch wire bonding material from gold to copper have been done regarding process, reliability and failure analysis. More recently, new silver alloy bonding wires have been developed and raised specific problems due to silver alloy properties. Whereas this new type of wiring material seemed to fulfill most challenges, like physical properties and reliability [1,2], it was suggested that specific Epoxy Molding Compound (EMC) should be adopted in order to ease decapsulation [3]. With the move from gold to copper, the failure analysis community had had to come up with new decapsulation techniques [4,5]. As well, the introduction of silver alloys raised new problems of decapsulation. Furthermore, failure analysts do not always have all required information on the type of EMC and the true composition of the bonding wires.

Two major techniques of decapsulation regarding wire-bonded devices are known: wet (acid) and dry etching (plasma); LASER ablation or mechanical milling being used for pre-opening. This study will compare the capabilities of these techniques on Cu wiring and four types of Ag-based wiring integrated circuits (IC) (Table 1).

Table 1: Wire diameter and composition for each IC type (supplier data).

IC #	Dia. (µm)	Composition
1	20	Cu 100%
2	15	Ag 95%, Au 0.5%, Pd 4.5%
3	15	Ag 90%, Au 10%
4	18	Ag 97%, Au 3%
5	20	Ag based

Experimental

All samples were pre-opened using an infra-red pulsed laser system (SesameLASER) to reduce the process time and exposure time for both wet and dry chemistry. This pre-opening step, which is most often stopped just before reaching the bonding wires, must not alter the wire integrity, as shown on Figure 1.

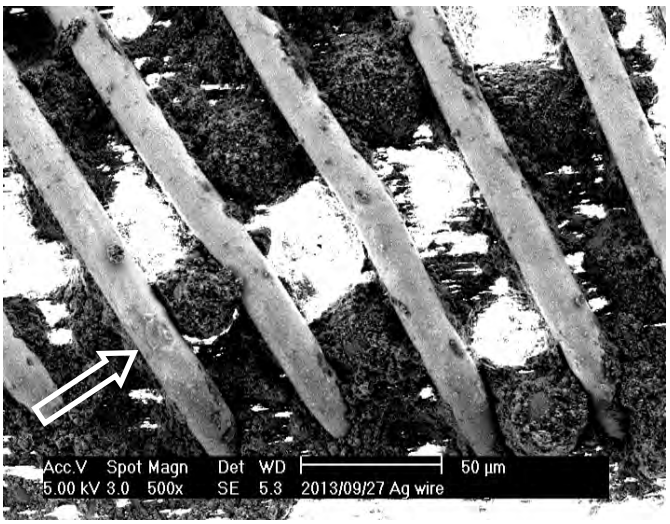

Figure 1: SEM picture of undamaged silver wires after laser ablation, exhibiting one crater (arrow).

Wet chemistry was performed with automated equipment running on nitric and sulfuric acid (SesameACIDCu). This common method for plastic package decapsulation uses mixture of nitric and fuming (f) or non-fuming (nf) sulfuric acids. This removes EMC efficiently while preserving Au wires. But copper and silver are attacked by nitric and sulfuric acids, see reactions (1) to (4).

$$Cu + 4\ HNO_3 \rightarrow Cu(NO_3)_2 + 2\ NO_2 + 2H_2O \quad (1)$$

$$Cu + H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2\ H_2O \quad (2)$$

$$3\ Ag + 4\ HNO_3 \rightarrow 3\ AgNO_3 + 2\ H_2O + NO \quad (3)$$

$$2\ Ag + H_2SO_4 \rightarrow Ag_2SO_4 + H_2 \quad (4)$$

Based on our experience of copper wired ICs, we know that low temperature (10 °C) decapsulation is efficient to preserve wires, as the activity of the acid on the wires is lowered, while still etching the EMC [4]. At 10°C, we use 100% fuming nitric acid and fuming sulfuric acid with 20% SO_3, with nitric to sulfuric ratios ranging from 2:1 up to 5:1.

Dry chemistry was performed with a RF plasma chamber running on three gases at 13.56 MHz (SesamePLASMADcap) [6]. In order to preserve the package mechanical integrity, the device is wrapped with copper tape [7]. But plasma still finds its way around and etches the protected part of the package, thus making the device fragile or non-testable. Therefore we use green silicone paste (originally meant for dental impressions) to protect the package around the pins, pads or balls.

In these case studies, we used oxygen and fluorinated gas CF_4 to etch the EMC away. As the epoxy turns into ashes, a silica filler layer builds up and prevents the plasma attack. Therefore the equipment is fitted with a CO_2 blast to remove these fillers between each 10 minutes-long cycle and start again plasma attack on a clean surface. Plasma generation raises the temperature of the whole chamber, therefore the tray and sample holder can be cooled down from 80°C down to 25°C. The working pressure in the chamber has to remain around 4000 mTorr to allow proper RF tuning between the generator and the chamber. The RF power can be set up to 300 W, but we will use it in the 50-100 W range as too much power would damage the parts.

Looking for any damage on the wires and/or chips, the decapsulated samples were controlled with optical microscopy and Scanning Electron Microscopy (SEM). Energy Dispersive X-ray spectrometry analyses were also performed to evaluate the composition of the Ag-based wires and characterize the observed residues if any.

Results

Copper wire – type #1

This case study shows wet and dry chemistry decapsulation on a copper wire-bonded device, with wire diameter of 20 µm. Front-side opening was necessary in order to realize photoemission microscopy on the die and should not affect the electrical functionality of the opened ICs.

Copper wire – acid decapsulation

Low temperature acid decapsulation was proven to work on copper wire. Gold-wired package allows multi-step opening with wet chemistry, as the acids only etch the EMC away. It is possible to under-etch the package, rinse it and run a second step. Regarding copper wires, we observed that it is better to do a one-shot decapsulation, based on bonding quality and coating material around the wires. Below is an example of an opened device in two 600 s-step process with a 2:1 ratio chemical at 10°C, followed with several rinse baths, acetone to stop the acid attack, hot water and finally alcohol to remove water traces [4]. Broken wires are observed after this two steps process (Figure 2). But this phenomenon is not seen by using one-step process, where the sample is kept in the equipment under pressurized nitrogen, and broken wires in two step process may be due to oxygen or air humidity exposure between the two steps.

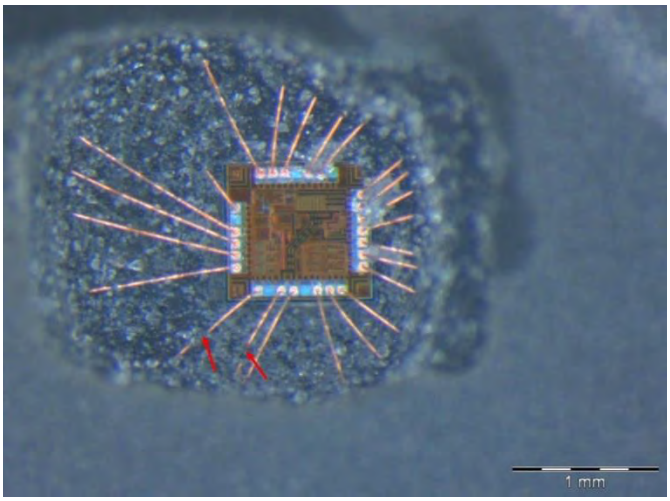

Figure 2: Acid decapsulation of a device in two steps of 600 s, total of 1200 s, which shows broken wires (red arrows).

To open gold based ICs, one step etching times can be reduced about 10 to 20% of total time from those of the multi-step decapsulation in order to avoid over-etching. Thus, using the same parameters with 1000 s process, we could expose the die and preserve the wires, though the wire surface is slightly attacked (Figure 3 and 4).

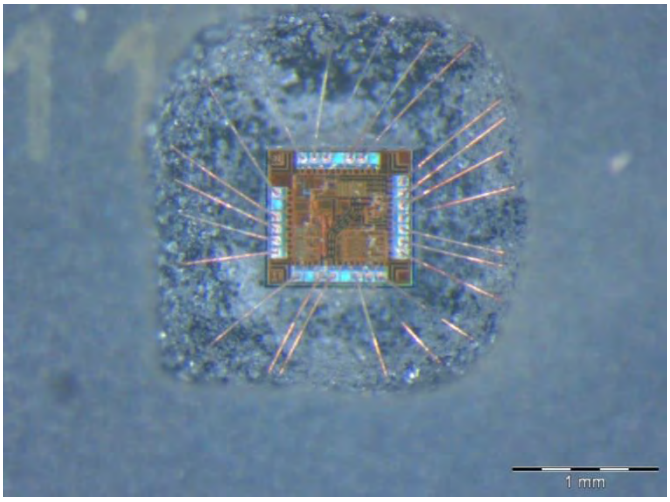

Figure 3: Acid decapsulation on device in a single step of 1000 s.

Indeed, copper is not as forgiving as gold and requires special care. Most often, sacrificial samples should be etched first to establish the right conditions based on the package type and die size. This is not possible for critical analysis. Plasma decapsulation appeared to be an interesting route to open such devices.

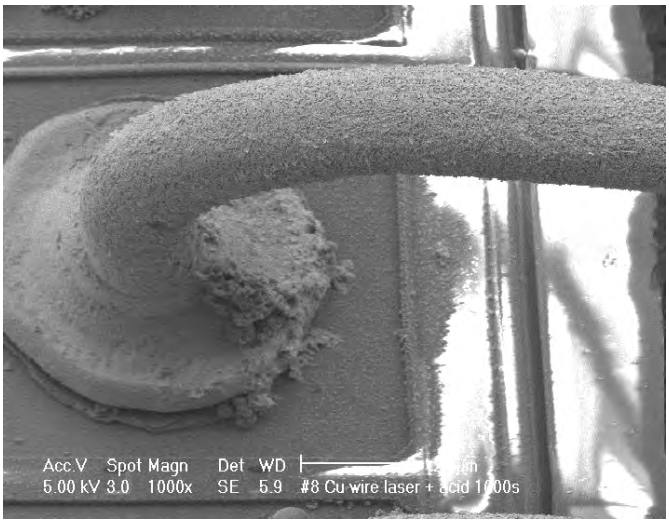

Figure 4: SEM picture of ball bond after acid decapsulation in a single step of 1000 s.

Copper wire - plasma decapsulation

So, we tested plasma decapsulation along with acid decapsulation. Samples have been processed in the plasma chamber. Dry chemistry parameters are 40% CF_4, 60% O_2, 50 W power and low temperature of 25°C with a CO_2 blast between each cycle. When the passivation is visible, we then reduce the amount of CF_4 down to 10% to avoid damaging the nitride passivation of the die. Total etching time for those samples is between 3 to 4 hours. A final acetone rinse in ultrasonic bath was needed to remove residues on the surface of the die.

Table 2: Plasma parameters

Process	Temp. (°C)	%CF_4	%O_2
Fast	25	40	60
Slow	25	10	90

As seen on Figure 5 and 6, ball-bond and wire surface are much more preserved with plasma etching than with acid etching. Furthermore, the electrical functionality of the opened devices was also checked before the photoemission microscopy analysis which could be successfully performed.

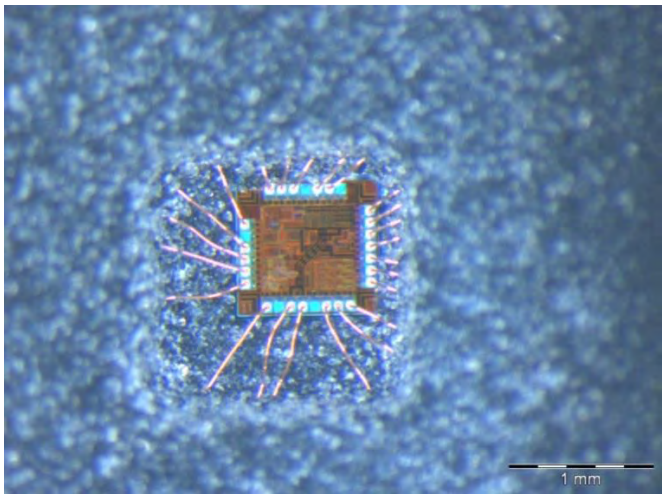

Figure 5: Plasma decapsulation on device showing slightly bent wires probably due to direct CO_2 blast.

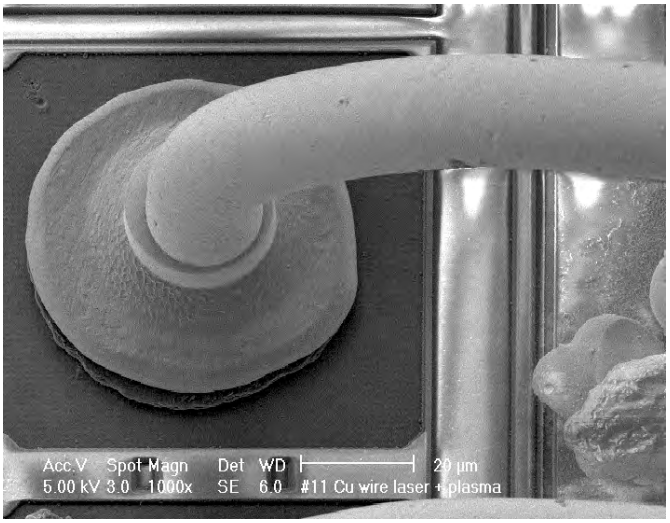

Figure 6: SEM picture of ball-bond after 230 min of plasma etching.

Silver wires, type #2

This case study shows wet and dry chemistry decapsulation on a silver-alloy wire-bonded device, with wire diameter of 15 µm. The aim was to demonstrate feasibility of the decapsulation technique with silver wire.

Silver type #2 – acid decapsulation

Several experiments of acid etching were performed with different acid ratios at low temperature on different type of silver-based ICs. All were unsuccessful. We will only detail here results for type #2 IC. We used a 2:1 ratio at 10°C for 120 s. It confirmed, unfortunately, that the Ag wires are more sensitive to acid attack than the Cu ones. All wires are attacked, severely thinned and/or broken (Figure 7).

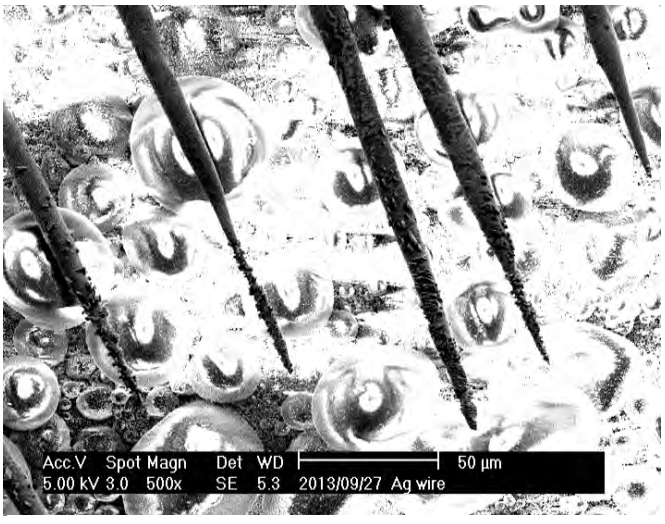

Figure 7: SEM image of thinned and broken silver wires after acid decapsulation, type #2

Silver type #2 – plasma decapsulation

Samples have been processed with the mixture 40% of CF_4, 60% of O_2, variable power and temperature of 80°C, following the plasma chamber manufacturer's advices.

First plasma trial was done at 100 W of RF power. This plasma appears too reactive as all wires exhibit strong surface modifications, some of them being completely broken (Figure 8). Therefore, the power has been reduced down to 50 W (Figure 9). There still is surface modification, but only one cut wire.

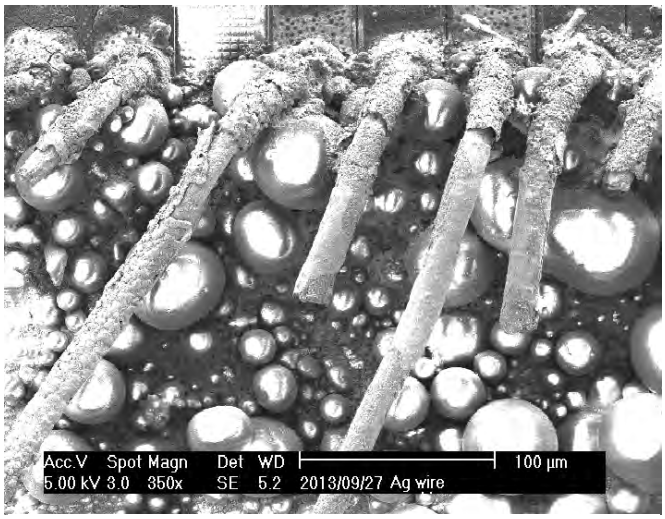

Figure 8: SEM image after plasma decapsulation at 100 W, type #2 IC; broken wires and some wires are still embedded in resin (arrow).

In order to increase selectivity between wire and resin, we lowered the temperature of the chiller down to 25°C. This decrease in temperature also makes the plasma less reactive and then reduce the resin etch rate. A total etch time of 200 minutes was necessary to completely expose the die. On one hand, it is a very long duration for a single sample. On the other hand, this allows a step by step procedure with a precise control over the etching. Table 3 summarizes etch times for acid and plasma etching, showing that a lower reactivity induces a longer etch time but better results.

Table 3: Measured wire diameter, type #2 IC

Technique	Mean Dia. (µm)	Diameter Range	Etch time (min)
Laser*	16.0	15.5 – 17.0	0.5
Acid	n/a	n/a	2
P. 80°C 100W	17.2**	15.8 – 20.0	20
P. 80°C, 50W	19.2**	16.2 – 21.4	60
P. 25°C, 50W	14.8	14.1 – 15.3	200

** laser ablation pre-opening on all samples*
*** most wires are still embedded in resin*

SEM observation shows that none of the wire is broken (Figure 10). The surface appears to be slightly modified, but the overall result is good. Small spheres remain on the wires after etching (Figure 11). EDXS-SEM showed it was silicon.

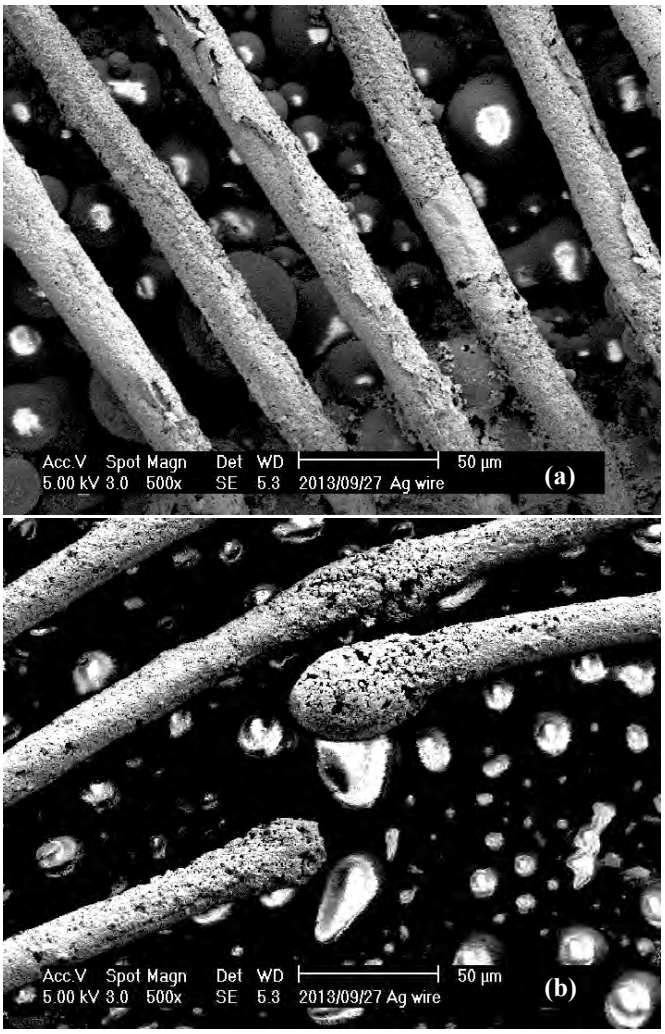

Figure 9: SEM images after plasma decapsulation at 50 W and 80°C, type #2 IC. a) wires are still embedded in resin, b) only one single broken wire.

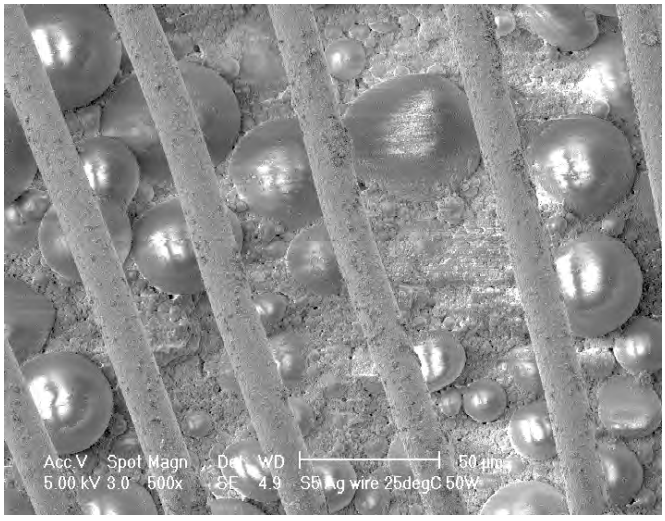

Figure 10: SEM image of slightly attacked wires after plasma decapsulation at 50 W and 25°C, type #2 IC.

Wire diameters have been measured showing that once EMC is completely removed, the wires are etched, and their diameter decreases (Table 3). A reference value of wire

diameter was obtained after laser ablation, while wires are partially exposed.

Figure 11: SEM close-up image of wires with remaining silica fillers after decapsulation at 50 W and 25°C, type #2 IC.

Silver wire: type #3, Stacked die

Same gas mixture was tried on a device with wires containing Ag 90% and Au 10%, which is less silver than in the previous package type. The device contains 4 memory dice and a smaller top die, confined in an eMMC package. The sample was processed at 50 W and 80°C also. All wires are attacked, but none is broken. We observed cracks on the balls and passivation damages when trying to fully expose the pads of the top die (Figure 12).

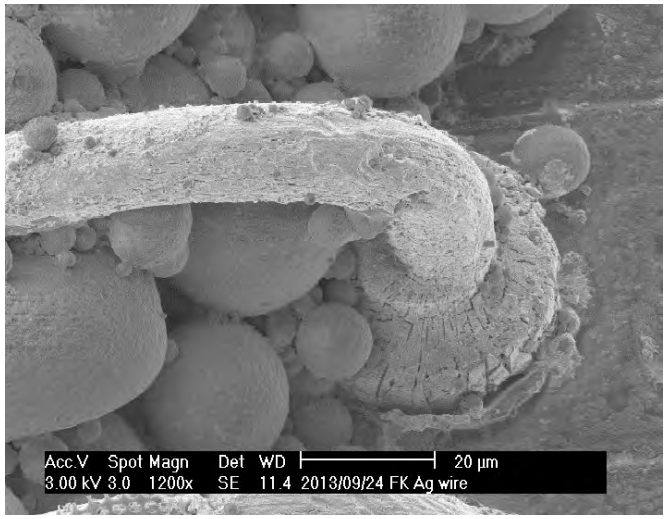

Figure 12: SEM image showing cracks on the ball, type #3 #3 IC, 50 W 80°C, top die

Decapsulation at 25°C seems to be less corrosive with fewer cracks on the balls and less damage on the wire, but there is still a strong surface modification (Figure 13).

Same SEM observations were obtained on the connections between the stacked memory dice (Figure 14 and 15).

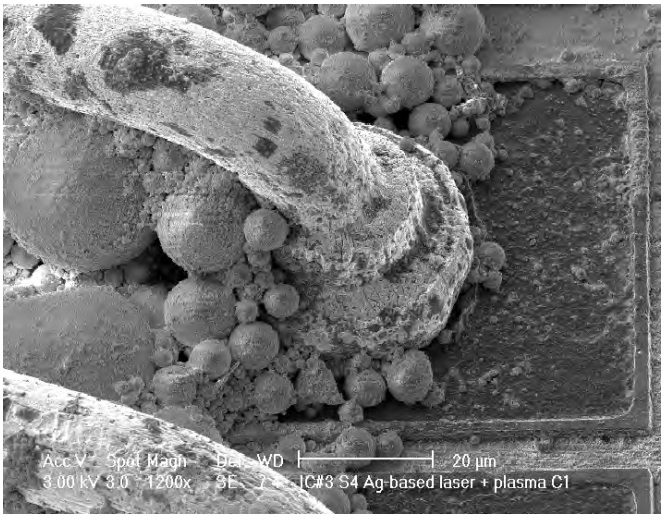

Figure 13: SEM picture showing fewer cracks on the ball with surface modification on the wire, type #3, 50 W 25°C, top die

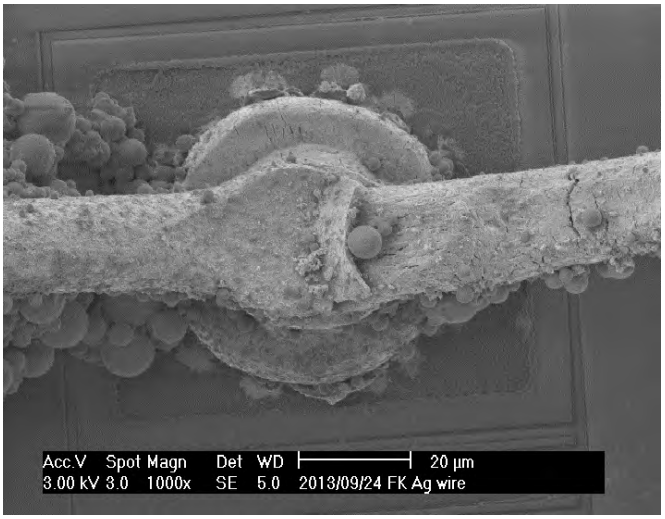

Figure 14: SEM image showing a crack on the wire, type #3 IC, 50 W 80°C, stacked die

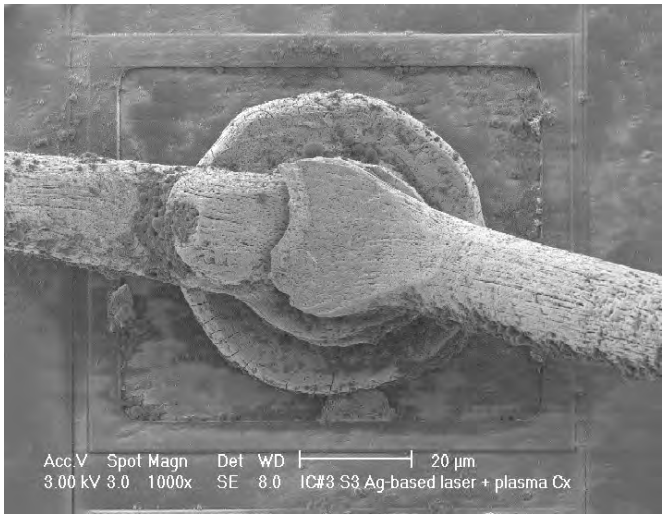

Figure 15: SEM image showing surface modification on the wire, type #3 IC, 50 W 25°C, stacked die

Silver wire : type #4

This device contains Ag 97% and Au 3%, it has the highest Ag percentage of all sample types. The sample was processed at 50 W and 80°C. We were not able to even partially expose the die without breaking all the wires (Figure 16).

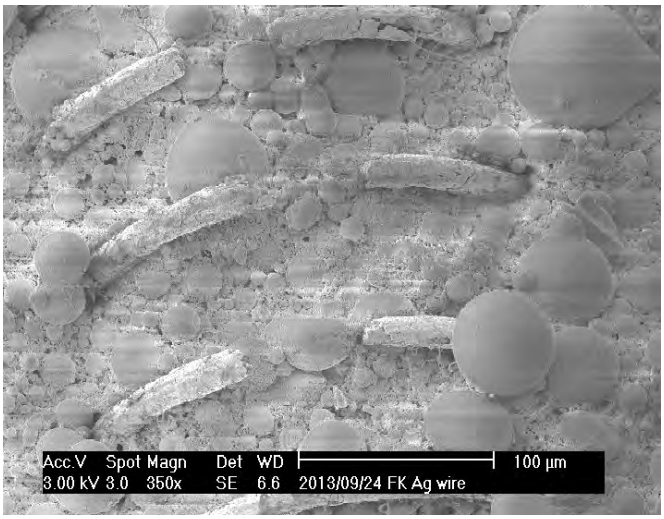

Figure 16:SEM image of attacked and broken wires 50 W 80°C, type #4

At 25°C, we were able to almost fully expose the die, but we observed strong surface modifications and at least one broken wire (Figure 17).

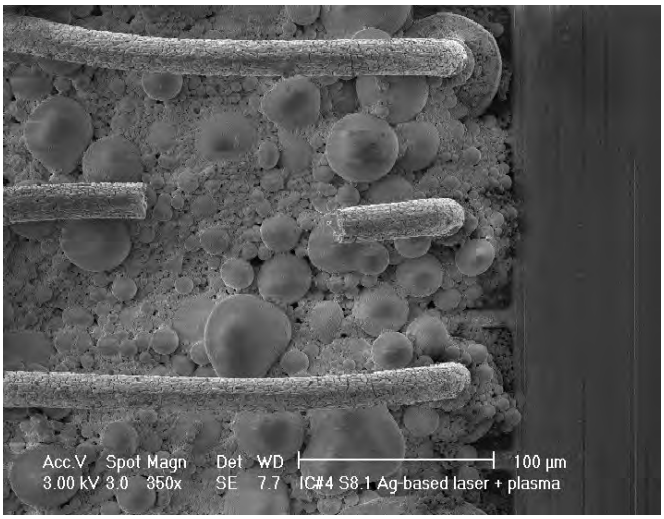

Figure 17: SEM image of attacked and broken wires, 50 W 25°C, type #4

Silver wire: type #5, crystal artifact

The type #5 silver (unknown composition) wire-bonded device was processed at 50 W and 25°C. After the plasma decapsulation, we observed needle-like crystals, very unstable under the electron beam (Figure 18). EDXS-SEM analysis showed, it contained Si, F, O, N and C elements and no trace of Ag metal (Figure 19). The Si EDXS signal may be due to the true presence of Si in these crystals, as a result of contamination by the protective silicone paste used for plasma experiments, which more precisely is polyvinyl siloxane or reaction with the SiO_2 fillers. As we did not observe these needles in the other silver ICs, the Si EDXS signal is most probably due to X-ray fluorescence artifact because of the surrounding SiO_2 silica fillers. Furthermore, as the analysed crystals collapsed under the electron beam during the EDXS spectrum acquisition, it was very difficult to keep manually the beam on them and avoid the interference with surrounding EMC. The strong F EDXS signal shows that fluorine is the main component of the crystals, coming from the CF_4 gas used for plasma etching.

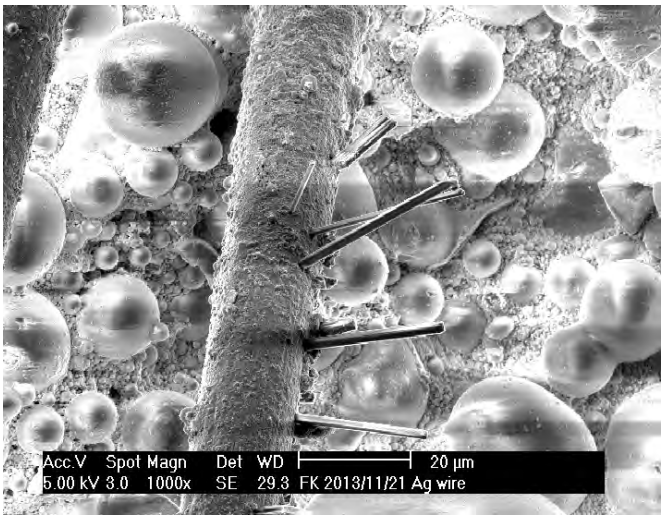

Figure 18: SEM picture of non-conductive crystal on wire.

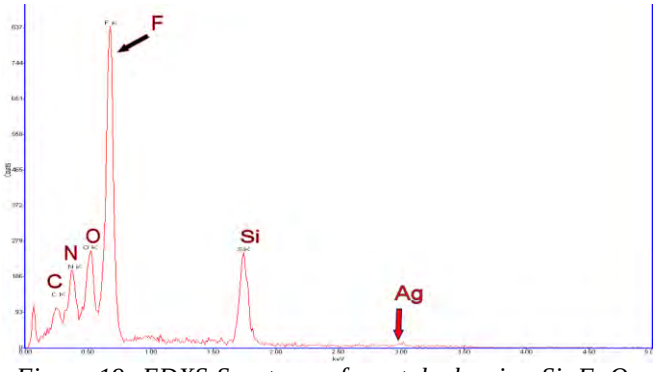

Figure 19: EDXS-Spectrum of crystal, showing Si, F, O, N and C signals (40 s, 5 kV).

Discussion

Analysis before and after plasma etching, IC type #3

In order to understand the impact of the plasma etching on the silver-based wires, EDXS analysis has been performed first after the laser ablation and second after plasma etching.

The EDXS spectra are superimposed on Figure 20. EDX spectrum of the wire after laser ablation (green graph) shows proportions of Ag and Au matching the ones given by the supplier for type #3 IC. Besides, traces of palladium were detected though they were not given in the manufacturer specifications. After plasma etching, the central area of the

wire (red graph) shows a higher peak of Au compared to Ag (red arrow) and the Pd peak also increases. It means that the plasma etches the Ag away. In the area of the wire closest to the top surface of the device and thus to the neighboring remaining EMC (top wire, purple graph), EDXS analysis shows that the wire composition is similar to the composition found after laser ablation. This part of the wire has been plasma etched for little time, but we observed crystals in the same area (Figure 21). The light blue graph of the crystal analysis shows Si, O (silica filler), Ag but neither Au, nor Pd anymore.

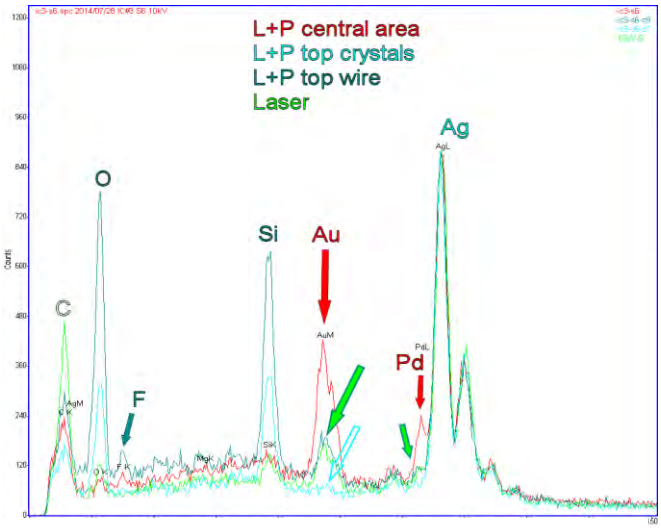

Figure 20: EDXS spectra of a type #3 sample after laser ablation only, and after laser and plasma etching on 3 different spots of the wire (30 s, 10 kV).

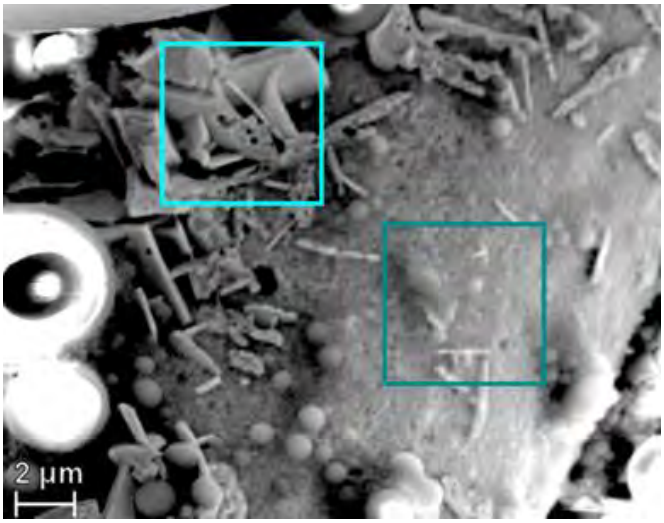

Figure 21: SEM image of type #3 IC after plasma decapsulation. Colored squares show regions of interest for EDXS analyses near the top end of the exposed wire.

This might explain how the Ag is taken away from the wire. The plasma reacts with the silver leading to the formation of Ag-based crystals, which are further destroyed by the plasma, or removed by the CO_2 blast. This plasma composition should be adapted to silver-based devices.

Conclusion

This study showed that both acid and plasma decapsulation can be successful with copper wire packages. Wet chemistry at low temperature provides a relatively quick decapsulation mean, yet consuming a lot of acid for large packages or hard EMCs and offering less control on the endpoint of the opening. Plasma decapsulation seems to offer more latitude regarding EMC etching and preservation of the wires, yet etch time is long. Regarding silver wires, our experiments show acid etching at low temperature does not work, but plasma could be a solution, even though it slowly consumes the silver in the wire and may lead to breaking of the wires which depends on the wire composition. Thus, further experiments should be performed at low temperature and with different plasma compositions to study the selectivity and sensitivity on silver wires.

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