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Investigation of Adhesion Mechanism at the Metal-Organic Interface Modified by Plasma Part I

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Abstract: For the mold die sticking mechanism, the major explanation is that the silica as a filler in EMC (epoxy molding compound) wears die surface to be roughened, which results in increase of adhesion strength. As the sticking behavior, however, showed strong dependency on the EMC models based on the experimental results from different semiconductor manufacturers, chemisorption or acid-base interaction is apt to be also functioning as major mechanisms. In this investigation, the plasma source ion implantation (PSII) using O_2, N_2, and CF_4 modifies sample surface to form a new dense layer and improve surface hardness, and change metal surface condition from hydrophilic to hydrophobic or vice versa. Through surface energy quantification by measuring contact angle and surface ion coupling state analysis by Auger, major governing mechanism for sticking issue was figured out to be a complex of mechanical and chemical factors.

Keywords: Molding, Sticking, Surface modification, Plasma source ion implantation, Adhesion

1. Introduction

As the thickness of memory TSOP type package is getting slimmer from 1.0 mm to 0.6 mm, the Biphenyl and/or Multi-function system EMC have been used to prevent the popcorn crack mostly occurred during reliability test.[1)]

On the other point of view, since its high adhesion strength seriously induces sticking problem between package and mold die, if the hot hardness of EMC cannot endure the sticking condition from die contamination, the chip encapsulated in the slimmer TSOP can be broken into two parts during ejection of pre-cured package component. Therefore, it is necessary to minimize the adhesion strength between the floating-out constituents from EMC molded and die surface, and to lessen the amount of the constituents accumulated on the die surface, which lengthens the cleaning period definitely.

In order to eliminate this kind of sticking problem, the waxing and cleaning operation should be done frequently, which causes cost-up for productivity and cumbersome issues for by-product disposition. The waxing mechanism can be described as follows. Resin piled-up on cavity wall adsorbs to melamine and the resin is detached from the cavity wall as melamine shrinks. The cleaning is done by physical scrub of contaminants with silica in molten resin. In general for TSOP, waxing moves in a 320 shot cycle for OCN type and in a 240 shot cycle for low molecular EMC. The cleaning moves generally in a 3 shift cycle for both OCN and low molecular EMC. However, it strongly depends upon the make.

If you look for the major governing factor for the sticking issue in real world, it can be categorized in two mechanisms. One is the mechanical adhesion concerning mechanical interlocking and large contact area. According to a manufacturers experimental result showing that the filler content variation from 75% to 85% reveals nothing distinguishable, it cannot be a sole governing mechanism for sticking issue. The other one is the chemical adhesion con-

cerning chemi-sorption, acid-basic interaction, electrostatic coupling, inter-diffusion, and polymer entanglement.[2,3,4,5] It is well known that hydrogen bond mechanism is working on the EMC and metal oxide interface. In order to reveal the real working mechanism, surface roughness and energy are examined, which are modified by plasma.[6,7]

2. Experimental Procedure

The mold die sample was modified by plasma source ion implantation (PSII). The schematic diagram of the PSII apparatus is depicted in Fig. 1.

The size of the SUS-304 vacuum chamber is 500 mmΦx560 mm. The 13.56 MHz RF power supply and a matching network system was used to generate plasma by a single-turn aluminum strip antenna of 250 mmΦ and 25 mm wide. The antenna surface was coated with 10 alumina. The chamber outside is arranged with permanent magnets and lead sheets. A magnetron source was located at the top of the chamber for ion-beam-enhanced deposition. The negative high voltage pulse generator was constructed with a tetrode as a switch tube. The maximum voltage and current ratings are 100 kV and 10 A. The grid swing was controlled by the IGBT (insulated gate bipolar transistor). The repetition rate and variable pulse width were monitored during implantation.

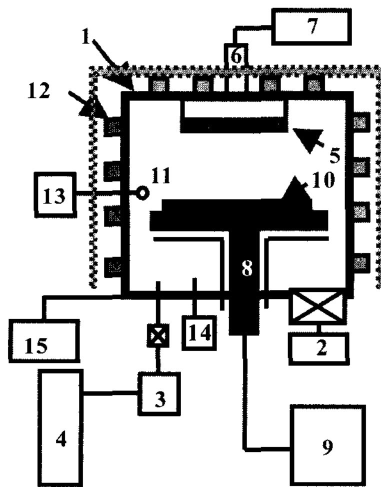


Fig. 1. Schematic diagram of PSII system.[7]

The molding die sample is made of ASP23, the composition of which is C 1.28 %, Cr 4.2 %, Mo 5.0%, W 6.4%, V 3.1%. The samples were fine ground, matte finished and hard Cr plated of 1 m thickness. The sample dimension is 24x5.3x0.25 mm.

The chamber was evacuated to the base pressure of 10^{-6} Torr and then filled with Ar back to 0.5 mTorr. Then Ar plasma was generated by RF power of 200 W and target was biased at 2 kV D.C. for 10 minutes for removal of oxide and contaminants. After re-vacuum the chamber down to the base pressure, the process gases, O_2, N_2, and CF_4, were introduced to the chamber. The gas pressure was set to 0.5 mTorr and the RF power was 200 W during PSII process. The target bias was 60 kV. The pulse width and repetition rate were 20 and 100 Hz. The samples were implanted for 30 minutes.

The modified samples were examined for depth profile with the PHI-670 scanning Auger nanoprobe, and for surface energy with the Rame-Hart 100 contact angle apparatus, and for surface roughness with SEM. The sputtering rate by 3 kV Ar ion with a raster size of 2x2 mm was equivalent to 100 Å per minute of SiO_2.

The adhesion strength of samples was compared to the releasing force. The samples were book

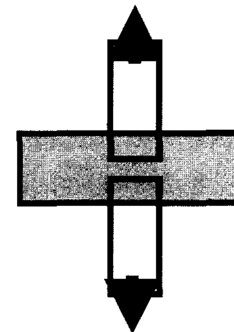
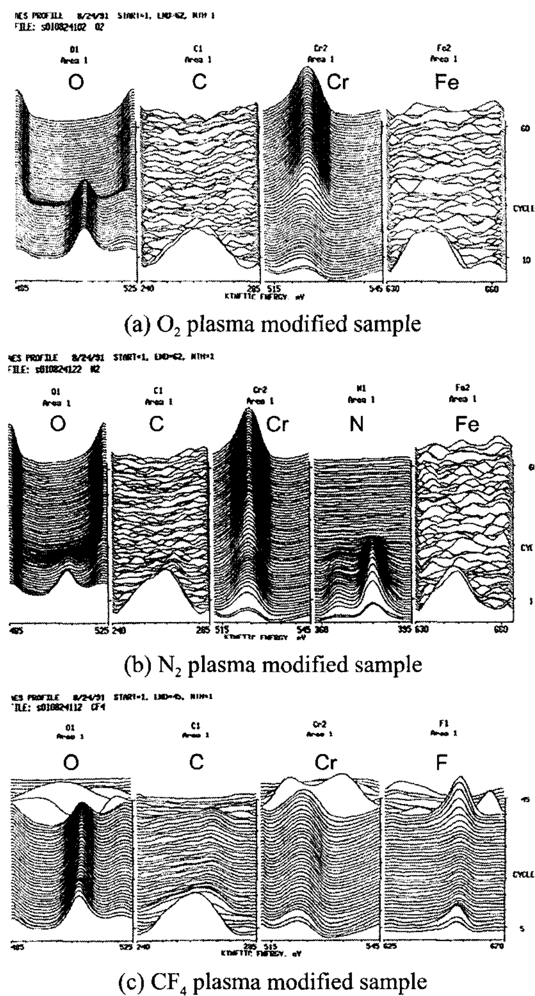


Fig. 2. Schematic diagram of pull-out mold (dark area). The white rectangles are package samples, which are pulled out against each other. The arrows show the pulling direction.

molded and pull-out test (Fig. 2) to measure the releasing force was carried out in 6 hours. And the modified samples were compared with the unmodified samples and the lead frame samples.

3. Results and Discussion

As shown in Fig. 3a)-c), the Auger depth profiles indicate that sample surfaces modified by O_2 and N_2 are changed in chemical states, which is realized by the energy shift of Cr peak. But sample surface modified by CF_4 shows no shift of Cr peak and the fluorine piled up at the bottom of the modified surface layer which was preferentially sputtered away by Ar ion, which means that the surface was etched by CF_4 rather than modified. The modified depths by plasma source ion implantation are 1000 Å for the O_2 modified sample, 1000 Å for the N_2 modified sample. In the CF_4 modified sample, the thickness of chrome layer left over after the plasma source ion implantation is 1800 Å.



(a) O_2 plasma modified sample

(b) N_2 plasma modified sample

(c) CF_4 plasma modified sample

Fig. 3. Auger depth profiles. The energy shift of Cr peak in O_2 and N_2 samples reveals the change in surface chemical states, but not in CF_4 sample.

Table 1 shows contact angles and pull-out strengths obtained from samples PSII treated differently. As expected, the surfaces modified by O_2 and N_2 exhibit same tendency of low contact angle, which is characteristic of hydrophilic surfaces. But surfaces modified by CF_4 have the same high contact angles as Cr hard coated surfaces which were not modified, which is characteristic of hydrophobic surfaces. The facts described above are well matched with the Auger depth profile results. The chemical states of surfaces modified by O_2 and N_2 are indeed changed. The A42 stands for the alloy 42 lead frame material, the composition of which is Fe42Ni. The HCr stands for hard chrome coating.

If the pull-out strengths are correlated with the contact angles, they seem to be irrelevant. However, if the samples are grouped in the modified and the unmodified, the following results can be deduced. The hydrophilic samples, which were modified by O_2 and N_2, showed relatively low strength values compared to the hydrophobic sample, which was modified by CF_4. These measured strengths are, however, quite higher than the strength of unmodified samples of HCr and A42. This result can be explained like that as the Ar plasma is applied to remove oxide and contaminants at the initial stage just before the re-evacuation of the plasma chamber, the sample surface is preferentially sputtered away

Table 1. Contact angle and adhesion strength

Gas	O_2	N_2	CF_4	HCr	A42
Angle (°)	7	6	76	69	–
Strength (Kgf)	86 72	116 72	101,107 98, 64	51 41	56,54,52 50,50,48

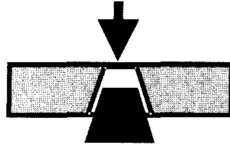


Fig. 4. Schematic diagram of Trapezoid mold test.

the coated chrome to make grinding marks exposed, which leads to increase the surface area. Especially in the CF_4 treated sample, as described earlier, the surface was etched by CF_4 down to the bottom of the so-called modified surface layer where the fluorine piled up, which results in more increase surface area compared to the other modified samples.

It can be summarized that the major governing mechanism for sticking issue is mechanical adhesion if the samples are compared between the modified and the unmodified. On the other hand, if the adhesion strengths are compared between samples modified, the hydrophilic samples show lower value than the hydrophobic samples, which means that surface energy state can be also taken into account as a governing factor in somewhat extent.

At this point, two things important should be addressed. At first, it is better to use trapezoid mold instead of pull-out mold to attain the adhesion strength more reasonably (Fig. 4).

However, the cost issue is a huddle to make many trapezoid molds modified with different source gases. Secondly, the package mold die is usually EDM processed, not mechanically ground. EDM stands for electrical discharge machining and its dimensional tolerance within a couple of microns.

4. Conclusion

1. Sticking mechanism is a complex of mechanical and chemical.

2. Contact angle represents the surface energy states and can be correlated to the adhesion strength.

3. Pull-out test is not a good method for measuring the adhesion strength, but it can be utilized if it is compensated with the trapezoid mold test results.

4. The EDM sample should be evaluated to figure out the actual difference in adhesion strength resulted from the surface finish.

In order to confirm the governing mechanism for the sticking issue, the site run test should be performed along with the academic study. And also information exchange between EMC manufacturers, die maker, and assembly house will be mandatory to accelerate problem solving.

5. Further Research

Even though there is a budget confinement at the moment, surface finish condition will be varied to distinguish the mechanical and chemical effect.

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