Investigations of Plasma Cleaning on the Reliability of Electrically Conductive Adhesives

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Abstract

For the replacement of solder as the usual connection between electrical components by Isotropic Electrically Conductive Adhesives (ICAs), it is important to maintain mechanical and electrical properties comparable to solder's. One performance area capable of improvement is the mechanical adhesion between the ICA and the contact surface. Plasma cleaning of surfaces should provide better mechanical strength and contact resistance. This paper describes the effects of varying plasma process time and applied power on adhesion and electrical performance of ICA-connections.

Introduction

The development of new electronic components and attempts to reduce the lead in connecting technology both require a search for alternative, environmentally friendly connection technologies. Today Surface Mount Technology (SMT) is the most common form of electronic assembly.

It is easy to think of a replacement of the usual solder connection in SMT by Electrical Conductive Adhesive (ECA). ECA does not need such a high temperature as solder in the process to connect the components with the Printing Wiring Board (PWB). The second enhancement is the ability to produce anisotropic conductive adhesive (with electrical connection only in the z-axis). With these products it is easier to connect leads with small pitch than with solder, which starts to flow in the soldering process.

Different plasma technologies

Plasma technologies play an important part in science and industry, especially in semiconductor production for etching and deposition, in automotive technology for coating plastic reflectors, and in mechanical engineering for surface treatment.

With the development of flexible boards, plasma technologies have also gained importance in the board manufacturing industry for plasma drilling. Other applications in the same industry are desmearing of holes for multilayer production and flux free soldering of components.

With plasma technology already introduced in the field of printed board production, it is effective to see other opportunities of applying this technology. Plasma treatment can be one way to reach a better mechanical strength and a lower electrical resistance between copper (PWB), ICA and component lead.

Goal of Investigation

The goal of this investigation is the development and optimization of a component manufacturing process using ICAs. In this process a plasma treatment should guarantee a good mechanical adhesion of components to a PWB. In particular, the plasma should remove organic contamination and oxidation on surfaces to be joined.

Mechanisms of Plasma Cleaning

Plasma cleaning is a form of plasma etching. Principles of plasma etching can be divided into physically and chemical enhanced ones. Physical plasma, which means plasma of inert gases, interacts with all materials essential identically. Chemically enhanced plasma etching depends on the gas used and provides a higher etching rate on some materials. That means that chemically enhanced plasma etching needs less energy for the selective removal of organic treatment residues on a copper surface than physical plasma etching without damaging the surface.

The plasma radicals of a chemical enhanced plasma-etching process "react" with the contaminations. In this reaction the long chains of the organic molecules are cracked into small gaseous ones (Figure 2, [1]). As shown, the most likely

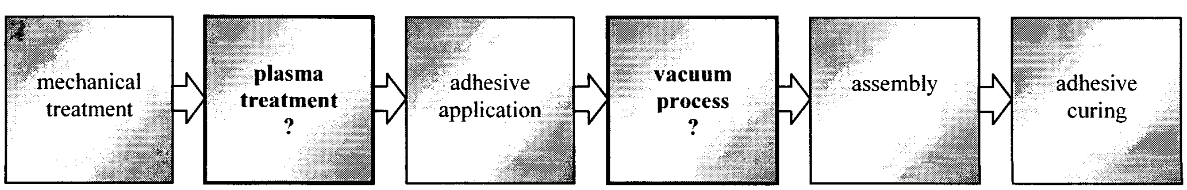

Figure 1: Process sequence

gaseous molecules should be water and carbon-oxide conjunctions. These particles can be evacuated from the system by the vacuum pump.

$$CH_3\text{–}CH_3 + O^{2+} \rightarrow CH_2^{+}\text{–}CH_3 + OH^{+}$$
$$RH + OH^{+} \rightarrow R^{+} + H_2O$$
$$CH_3\text{–}CH_2^{+} + O^{2+} \rightarrow CH_3^{+} + CH_2O$$

Figure 2: Samples of possible reaction within plasma

After the surface is cleaned of oxide, a layer of atoms available in the chamber will deposit on the clean surface. This layer protects the metal from new oxidation and will evaporate during the curing of the ICA.

For the complete treatment, oxygen plasma is applied for cleaning the organic substances as a first step. In the second step, hydrogen plasma reduces the oxidation layer.

Selected and varied properties

For the test the ICA Ablebond 8175, manufactured by Ablestik, was used. It is a one component adhesive designated as solder replacement. The conductive part of this adhesive is silver.

Stencil printing was used to apply the ICA to the copper board. On all samples a 5x2mm strip was printed.

Before printing, all boards were cleaned mechanically. Mechanical treatment was performed with a 3M synthetic fiber pad. For comparison, some test samples were printed without the PWB substrate being plasma cleaned.

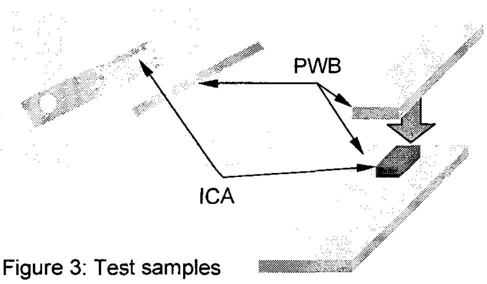

Figure 3: Test samples

In the plasma treatments, the gases and their proportion to each other, the working pressure, the time, and the amount of power were varied. Also the use of high vacuum before and after stencil printing was investigated (Figure 1).

The curing was realized according to the ICA manufacturer specification (150°C – 60min). Detailed information about the realization of the curing process are available in the paper "Electric Field Effects in the Production of ICA Joints " [3].

Valuation criterions

On the test samples, the stability and the contact resistance were subjects of investigation. All samples were first tested for their electrical contact resistance. This was performed with a 4-point resistance measurement. The test could show influence of plasma treatment on the contact resistance between copper and ICA.

The mechanical stability was evaluated in a shear test. After shearing, the broken connection was the object of optical investigation. There were 4 samples in every lot.

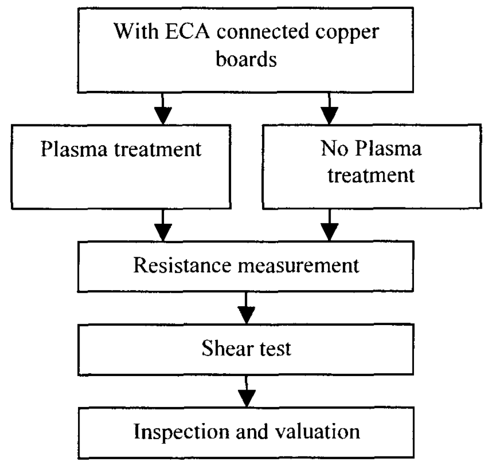

Figure 4: Tests

Results

The shear test results on all samples show large variations.

Plasma treated test samples, without a high vacuum process after the stencil printing of the ICA, do not show better results of mechanical strength. This can be explained by corrosion processes on the highly cleaned surface, caused by the moisture in the ICA.

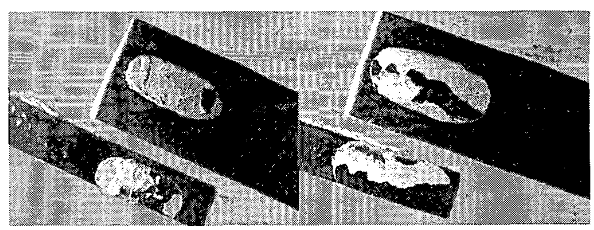

Figure 5: Sheared samples

Test samples treated with oxygen plasma before stencil printing and a high vacuum environment of 2 hours at a pressure of 10^{-6} Torr afterwards also seemed to show better results than for any other test combination except the application of vacuum alone.

It can be assumed that most of the moisture stored in the ICA has been sucked off. Also air bubbles in the ICA should have gone. Thereby a change in the shape of the ICA is noticeable after the vacuum process (Figure 7).

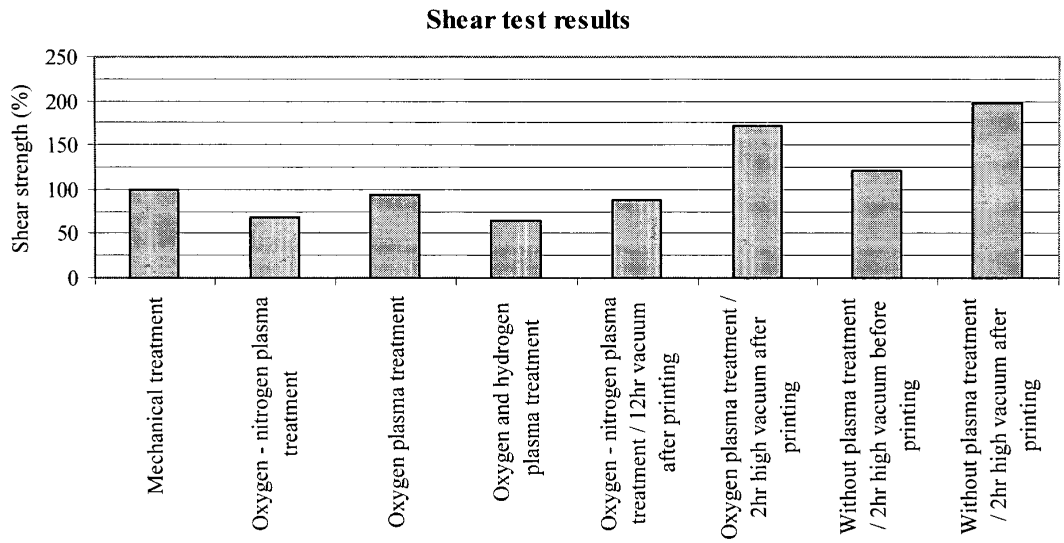

Figure 6: Average effects of treatments on shear strength

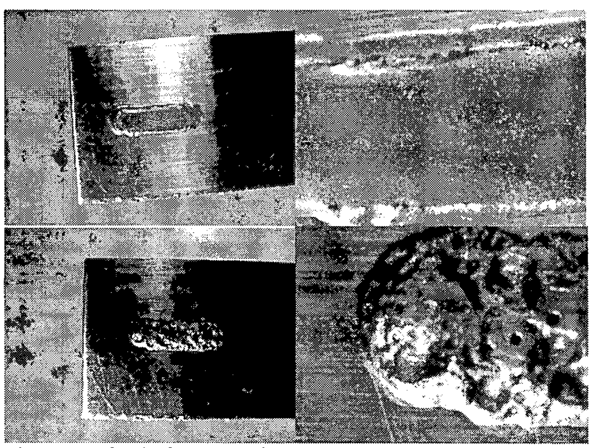

Figure 7: ICA before and after high vacuum process

The optical inspection shows oxidation, resulting from the corrosion process, on the fracture surface during the shear tests. The oxidation was stronger on samples without a high vacuum process than on those with one.

The electrical resistance of the ICA connection did not change significantly. All test samples stay in nearly the same ranges with equal dispersion.

Conclusions

A positive influence of a high vacuum process before curing has been discovered. A more accurate investigation of this subject is now needed.

Plasma treatment seems to show a negative influence in the collected data. It could be that the very clean surface enters into unwanted reactions with the environment during the curing, e.g. moisture induced corrosion.

There was no obvious effect of plasma treatment or high vacuum process on the electrical resistance after curing.

References

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[3] "Electric Field Effects in the Production of ICA Joints" Mark D. Heuschkel, James E. Morris, Proceeding 4th International Conference Adhesive Joining and Coating Technology in Electronics Manufacturing, Helsinki, February 2000

[4] Internship Report: "Conductive Adhesives and Plasma Cleaned Substrates" Albrecht Kleye, James E. Morris, State University of New York at Binghamton, 1999

Appendix - Data

Test A 1:
Test with only mechanically treatment

No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	Shear strength (psi)	No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	Shear strength (psi)
1 / I	1.51	7.47	1083	2 / I	1.29	12.97	1881
1 / II	1.44	8.67	1258	2 / II	2.10	1.87	271
1 / III	1.14	9.10	1320	2 / III	1.43	12.92	1874
1 / IV	1.15	7.51	1089	2 / IV	1.32	7.30	1059
Average	1.31	8.2	1188	Average	1.54	8.8	1271
St. Dev.[1]	0.17	0.71	104	St. Dev.[1]	0.33	4.60	788

Test A 2:
Test with nitrogen and oxygen plasma treatment without high vacuum process after stencil printing.

Plasma treatment process:
Time: 20min
Working pressure: 60mTorr
Power: 200W
O_2 / N_2: 1.8

No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	Shear strength (psi)
3 / I	1.51	6.85	994
3 / II	1.64	7.41	1075
3 / III	1.57	6.22	902
3 / IV	1.56	2.43	352
Average	1.57	5.7	831
St. Dev.[1]	0.05	1.95	283

Test A 3:
Test with oxygen plasma treatment.

Plasma treatment process:
Time: 20min
Working pressure: 100mTorr
Power: 100W

No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	Shear strength (psi)
4 / I	Broken	–	–
4 / II	1.33	8.80	1276
4 / III	1.31	5.47	793
4 / IV	1.34	9.47	1374
Average	1.33	7.9	1148
St. Dev.[1]	0.01	1.75	254

Test A 4:
Test with oxygen and hydrogen plasma treatment.

1.) Oxygen plasma treatment
Time: 20min
Working pressure: 100mTorr
Power: 100W

2.) Hydrogen plasma treatment:
Time: 10min
Working pressure: 0.5mTorr
Power: 100W

No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	Shear strength (psi)
5 / I	1.40	6.99	1014
5 / II	1.28	4.87	706
5 / III	1.25	4.68	679
5 / IV	Broken	–	–
Average	1.31	5.5	800
St. Dev.[1]	0.06	1.05	152

[1] Standard deviation

Test A 5: Test with oxygen – nitrogen plasma treatment and long time vacuum process after stencil printing.				
1.) Plasma treatment: Time: 30min	No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	(psi)
Working pressure: 60mTorr	6 / I	2.78	6.49	941
Power: 200W	6 / II	15.84	6.66	966
O_2 / N_2: 1.8	6 / III	2.34	8.43	1222
2.) Vacuum process	6 / IV	2.24	8.34	1209
Time: 12 hours	Average	5.80	7.5	1084
Pressure: 50mTorr	St. Dev.[1]	5.80	0.91	131

Test A 6: Test with oxygen plasma treatment and high vacuum process after stencil printing.				
1.) Oxygen plasma treatment: Time: 20min	No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	(psi)
Working pressure: 100mTorr	7 / I	1.45	17.45	2532
Power: 100W	7 / II	1.67	16.15	2342
2.) Vacuum process	7 / III	1.54	17.56	2546
Time: 2 hours	7 / IV	1.56	7.21	1046
Pressure: 4×10^{-6}Torr	Average	1.56	14.6	2116
	St. Dev.[1]	0.08	4.30	623

Test A 7: Test without plasma treatment and high vacuum process before stencil printing.				
Vacuum process: Time: 2 hours	No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	(psi)
Pressure: 4×10^{-6}Torr	8 / I	1.35	13.44	1949
	8 / II	1.59	9.59	1391
	8 / III	1.69	8.53	1237
	8 / IV	1.37	9.70	1407
	Average	1.50	10.3	1496
	St. Dev.[1]	0.14	1.86	270

Test A 8: Test without plasma treatment and high vacuum process after stencil printing.				
Vacuum process: Time: 2 hours	No. of sample	Electrical resistance (mΩ)	Shear strength (N/mm^2)	(psi)
Pressure: 4×10^{-6}Torr	9 / I	1.26	18.92	2744
	9 / II	1.60	12.55	1820
	9 / III	1.75	19.32	2802
	9 / IV	1.09	16.45	2386
	Average	1.43	16.8	2438
	St. Dev.[1]	0.26	2.69	391