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Technological Aspects of Applying Adhesives in Small Diameter Vias

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Abstract: One of the key problems for more efficient use of conventionally PCBs is plated through holes, because they consume a large fraction of PCB surface area. One of the solutions that can permit to save the PCB surface is using of blind and buried vias. Currently, many expensive plating and sequential lamination steps create the blind/buried vias.
Electrically conductive adhesives are the materials, which can be used as hole fills in PCB manufacturing. The aim of the paper is to present how the adhesive viscosity, the way of adhesive printing and the way of preparing the hole can influence the efficiency of fill process as well as resistance of such prepared fills. The holes diameter 0.8, 0.5 and 0.3 mm (aspect ratio 1.25:1, 2:1 and 3.3:1), were used in experiments.

Key words: electrically conductive adhesives, PCBs, printing, viscosity

1. INTRODUCTION

The electronic industry is looking for high density PCBs (Printed Circuit Board) manufactured with acceptable costs. Conventionally available PCBs with plated through holes consume a large fraction of PCB surface area. One of the solutions that permit to save the PCB area is using smaller vias or applying blind and buried vias. The idea of such processes is based on applying electrically conductive adhesives for buried or blind vias [1,2]. The filling of plated through holes has been practiced for many years in order to improve the thermal performance of PCBs, particularly with BGA packages [3]. Other applications can be hole-filling procedure instead of electroplating in inner layers and blind vias in outside layers of PCBs made by SBU (sequential build-up) technology [4].

The material and technological aspects of applying conductive adhesives in small diameter vias for electrical joint both sides of PCB (top and bottom) is the aim of the paper.

2. TEST SAMPLES AND PROCEDURES

The test samples were manufactured of FR-4 laminate (1.0 mm thick) with copper on both sides (thickness 18 μm). There were mechanically drilled holes diameters 0.3, 0.5 and 0.8 mm (with aspect ratio 3.3:1, 2:1 and 1.25:1 respectively). Two kinds of contact pads were used: namely bare Cu and Cu pads covered by Ni/Au metallization. Each sample contains 40 holes every three diameters. The layout of test sample was presented in paper [5]. The metal stencil with thickness of 100 μm was used for adhesive printing. The printing process was done with no space between the substrate and the stencil.

In our experiments, the thermosetting, one-component, silver filled epoxy adhesives Elpox EXP 2 and Elpox EXP 8 manufactured by Amepox Microelectronics were applied. The adhesives contain the silver fillers in the form of flakes with average dimension 4 μm. The curing procedure of applied adhesives is as follows: drying 100°C (10 minutes) and curing 165°C (15 minutes).

The quality of adhesive interconnections was estimated by measurements of the electrical resistance of hole fill. The idea of individual adhesive fill resistance measurements is based on the four-probe measurement method. The measured resistance of through hole fill consists of: the contact resistances between Cu pads or Ni/Au pads finishes on the top and bottom layers and the resistance of adhesive fill. The Keithley 2001 multimeter with four wires option was used for resistance measurements. Automated data acquisitions were possible by using home-elaborated software.

3. THE BASE LINE OF INVESTIGATION

The physical data analyze of pure metals and conductive adhesives shows big differences in the resistivity of mentioned materials. The Au resistivity is 2.25 μΩcm. The resistivity of investigated adhesives is in the range 300÷600 μΩcm. The difference in resistivity of mentioned materials is more than 100 times.

If the differences in the resistivity of metals and adhesives are known, it is possible to predict the range of resistance of adhesive fill. To do this it is necessary to know the resistance of electroplated holes. The test samples with electroplated through holes diameter 0.3, 0.5 and 0.8 mm were done and their resistances were measured. The results of such measurements were presented in Tab.1. As it can be seen, the average metallised hole resistances are in the range between 0.1÷0.7 mΩ. On the base of described above experiments and it is possible to predict that the adhesive fill resistance can be 100 times more than electroplated holes, i.e. near 70 mΩ plus contact resistance between pads and adhesive fill.

Table 1. The through hole vias resistance made by electroplating

	Ni/Au			Immersion Sn		
Hole diameter [mm]	N	Resistance [mΩ]	σ	N	Resistance [mΩ]	σ
0.30	40	0.583	± 0.011	40	0.720	± 0.010
0.50	40	0.285	± 0.005	40	0.337	± 0.013
0.80	40	0.097	± 0.008	40	0.120	± 0.006

4. MATERIAL ASPECTS OF APPLYING ADHESIVES IN SMALL DIAMETER VIAS

For investigation of influence of adhesive parameters on fill process and final resistance, the following experiments, based on orthogonal arrays, so called Taguchi method, were applied. As a response, the value of hole fill resistance was measured; samples with Cu metallization were used. The influence of following factors on filling procedure was examined:

- an adhesive viscosity, named as factor A: A1 very low viscosity 4000 cP (Elpox EXP2) and A2 20000 cP (Elpox EXP8) (1 rpm, Brookfield DVII),
- an additive which increase adhesive surface tension (factor B): B1 lack of additive, B2 presence of additive,
- an additive, which increase the wettability of Ag powder by resin (factor C): C1 lack, C2 presence of additive.

The parameters of printing process were unchanged during whole experiments: the squeegee rate 8 mm/s, the squeegee load 3 N per whole squeegee. The mentioned above factors and interactions are assigned to the columns of orthogonal array L8 (2^7). The experiment was performed and results are summarised in Tab.2.

Table 2. Experimental data: the influence of adhesive parameters on fill efficiency and resistance (N_{max}=40)

Test	Factors							Diameter 0.3 mm			Diameter 0.5 mm			Diameter 0.8 mm		
no	A	B	AB	C	AC	BC	ABC	N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]
1	1	1	1	1	1	1	1	40	2.769	3.67	40	0.368	0.285	40	0.247	0.119
2	1	1	1	2	2	2	2	36	2.139	1.69	38	1.297	1.003	37	0.435	0.255
3	1	2	2	1	1	2	2	35	2.574	2.18	40	0.611	0.424	40	0.427	0.317
4	1	2	2	2	2	1	1	40	1.472	1.07	39	0.422	0.216	40	0.240	0.115
5	2	1	2	1	2	1	2	16	3.551	2.49	40	0.726	0.315	38	0.291	0.193
6	2	1	2	2	1	2	1	12	4.047	2.88	40	0.892	0.339	40	0.267	0.129
7	2	2	1	1	2	2	1	19	4.391	2.85	40	0.937	0.476	40	0.448	0.307
8	2	2	1	2	1	1	2	21	4.165	2.76	40	0.906	0.521	40	0.241	0.097

Data collected from experiments were analyzed by a method called analysis of variance (ANOVA). The results of calculations were summarized in condensed ANOVA table (Tab.3). Only percentage contributions of each factor on experiment results are given in Tab.3. The mathematical background of calculation can be found in paper [6]. The filling efficiency for hole diameter 0.3 mm was unsatisfactory, sees Tab.2. For holes diameter 0.3 mm only the influence of investigated factors and interactions on filling efficiency was analysed. The filling efficiency for holes 0.5 and 0.8 mm was fully acceptable and the percentage influence of factors and interactions on the fill resistance was analysed in last two columns of Tab.3.

Table 3. The influence of factors A, B and C on via hole filling efficiency and resistance [percentage]

	Filling efficiency [%]	Percentage influence of factors on fill resistance	
Factor	hole diameter 0.30 mm	hole diameter 0.50 mm	hole diameter 0.80 mm
A	66.8	7.4	-
B	-	--	--
AxB	-	9.6	3.2
C	-	10.2	7.9
AxC	-	4.2	8.1
BxC	4.8	24.6	43.2
AxBxC	4.8	11.9	--
e	23.6	32.1	37.6

As it can be seen in Tab.3, the error connected with performed experiments is high. Probably not all factors influence the results were found and analyzed. Nevertheless the biggest influence on filling holes of diameter 0.3 mm has the adhesive viscosity (factor A). The adhesive with lower viscosity has better flow into small holes and fill efficiency is higher (see Tab.2). For holes diameter 0.5 and 0.8 mm, the influence of adhesive viscosity on adhesive flow is negligible. The interaction of the additive which increases surface tension of adhesive and additive which increases wettability Ag flakes by resin, influence significantly the resistance of fill in holes, see Fig.1. The smallest fill resistances were obtained for adhesives without additives and for adhesives with both additives (for holes diameter 0.5 and 0.8 mm). Further investigations will be done to check which adhesive: with or without additives is more suitable.

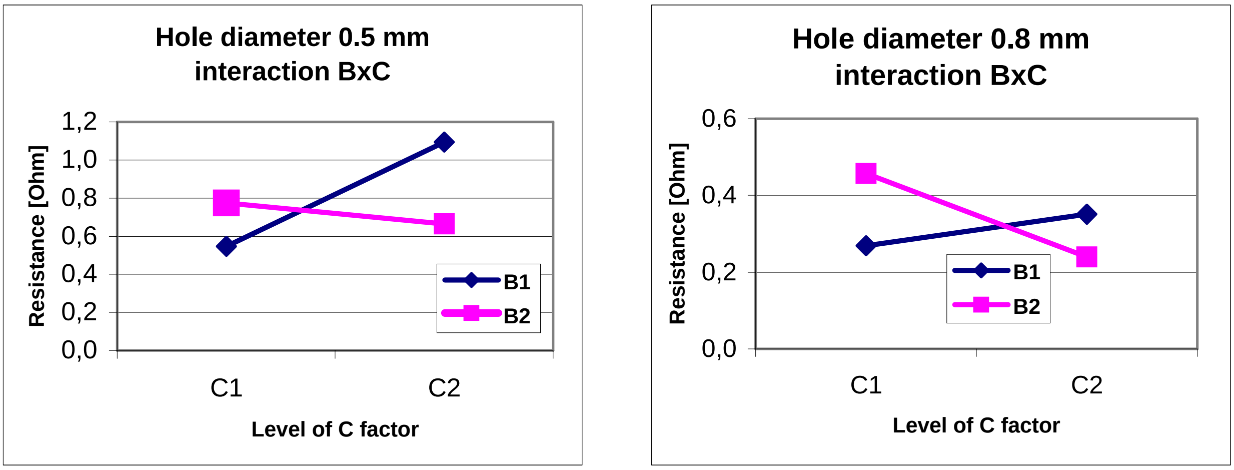

Figure 1. The graphs of main effects for holes 0.5 mm and 0.8 mm filled by adhesives

5. TECHNOLOGICAL ASPECTS OF APPLYING ADHESIVES IN SMALL VIAS

To establish which adhesives are better: with or without additives, the following experiment was performed. Two adhesives type A2 were prepared (the viscosity 20 000 cP each). The adhesive without additives was marked as D1 and the adhesive with both additives as D2. Next the conditions of adhesive printing process were defined: stencil printing on test samples two times from one side marked as E1 (samples with Cu metallization) and printing once from the top and once from the bottom, marked as E2. Additionally special treatment was applied which create "tube shape fill", marked as F1 and F2 where samples remained only printed. The scheme of experiments and results are shown in Tab. 4. As it can be seen from Tab.4, the most important factor which influence via fills process in small vias is special treatment (factor F), which created "tube fill shape". The filled holes diameter 0.3 mm without special treatment does not connect the top and bottom PCB layer. The best results were obtained for adhesive D2 (both additives) and "tube fill shape". The adhesive D2 with the additive increasing its surface tension and wettability of Ag fillers by resin was chosen for next experiments.

Table 4. The influence of presence of adhesive additives and way of printing on fill resistance (N_{max}=80)

Test	Factors			Diameter 0.3 mm			Diameter 0.5 mm			Diameter 0.8 mm		
no	D	E	F	N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]
1	1	1	1	34	1.833	1.54	76	0.155	0.09	71	0.066	0.02
2	1	2	2	0	--	--	30	0.810	1.08	80	0.077	0,14
3	2	1	2	0	--	--	11	4.595	2.26	39	3.161	2.18
4	2	2	1	68	0.488	0.207	78	0.153	0.268	80	0.068	0.02

The final experiments were done on test samples with Ni/Au metallization. Three different hole shapes were prepared in test samples: holes without cone shape on edges, holes with cone 90 degree on edges and holes with cone edges 90 degree with "tube shape" filling. The results of resistance measurements are presented in Tab.5. For test no 2 and 3 good efficiency (78/80 and 40/40) was achieved even for holes diameter 0.3 mm.

Table 5 The influence of hole fill shape on small diameter hole fill resistance (N_{max}=80 or 40, respectively)

Test	Hole fill shape	Diameter 0.3 mm			Diameter 0.5 mm			Diameter 0.8 mm		
no		N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]	N	R[Ω]	σ[Ω]
1	Full fill no cone	70	0.178	0.283	80	0.043	0.007	80	0.039	0.007
2	Full fill with cone	78	0.114	0.034	80	0.053	0.005	80	0.039	0.007
3	With cone tube shape	40	0.075	0.030	40	0.067	0.024	40	0.034	0.011

The results show that by applying specially designed adhesives and prepare the proper hole shape it is possible to fill the small holes diameter 0.3 mm in laminate 1 mm thick (aspect ratio 3.3:1) with fully acceptable efficiency. The obtained hole resistance are in the range 100 mΩ for diameter 0.3 mm and 40 mΩ for hole diameter 0.8 mm. Such results are comparable with calculations presented in section 3.

6. CONCLUSIONS

The analyze of material and technological aspects of applying conductive adhesives in small diameter vias for electrical joint both sides of PCB (top and bottom) was the aim of the paper. The thermosetting, one-component, silver filled epoxy adhesives Elpox EXP 8 manufactured by Amepox Microelectronics was used in final experiments. The obtained average adhesive fill resistances were in the range between 34 mΩ (holes 0.3 mm) and 75 mΩ (holes 0.8 mm). Such resistance values are acceptable in practice.

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