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ANISOTROPIC CONDUCTIVE JOINTS UTILIZATION FOR JOINING OF FLEXIBLE CABLES AT RIGID SUBSTRATES

Slavomír Kardoš — Miloš Somora — Stanislav Slosarčík — Ján Urbančík — Igor Vehec *

Key motivation of this work is the industrial task of standard lead based solders joints elimination in electronics, which comes out from the European Council requirement to exclude lead from the soldering process before the middle of 2006. The main emphasis was laid on the new approaches in tasks solving by using standard electrotechnologies and available production facilities. Results of this work were based on two types of anisotropic interconnections usability as an alternative of soldered joints in the production process, which is generally used for a reflow of the standard SnPb solder between the contact areas. Practical results of the performed study indicate that realized joints with applied anisotropic conductive adhesive have comparable electrical resistance with soldered interconnections. The lower mechanical strength is less relevant with concerning of operating conditions. The anisotropic conductive paste application demonstrates their suitability for copper-to-gold plated contacts conductive joining; however, adhesive joints realized by an anisotropic conductive tape were not satisfactory.

K e y w o r d s: anisotropic conductive adhesive, anisotropic conductive joints

1 INTRODUCTION

The requirements for living environment protection brought the limit specifications to the use of materials in electronic industry production. In electronics, lead solders are materials that have to be eliminated from the production process because of lead toxicity. One opened way is utilization of lead free solders, various alloys based on two, three or four metals. Using of anisotropic conductive adhesives represents another advanced way. Each approach has its own significant properties and field of applicability. The process transformation is so less expensive as simplest adaptable are the existing production facilities [1, 7].

2 ANISOTROPIC CONDUCTIVE ADHESIVES

The basic structure of anisotropic conductive adhesives (ACA) consists of thermoplastic and thermosettic polymers which are filled with conductive particles. Instead of a pure metallic nature of solders, the fillers are relatively tenuously distributed, so despite metallization by high conductive metals they obviously have a lower electrical conductivity. While the soldered joint is metallurgical, the adhesive one is formed by a springy mechanic contact between adherends and conductive particles in a polymer matrix. The application range of ACA is hence mainly delimited from their electrical properties because of limited current loadability.

The ACAs are manufactured in the form of pastes and films and they are non-conducting in unapplied state. Contact areas with deposited adhesive are interconnected with component contacts by a relatively high mechanical pressure. There are created multi-parallel electrically conductive contacts by pushing the conductive particles together. The particles besides of contact areas remain sparsely distributed, so the isolation state still remains unspoiled. Thereat the ACA can be applied nonselectively through the whole contact area.

ACA materials are generally used in tape automated bonding (TAB) and flip chip bonding (FCB) technologies for contacting of flat panel displays and in precise surface mount technology (SMT).

3 TECHNOLOGY BACKGROUND

Polymer thick-film technologies (PTFT) represent the extension of standard thick-film technologies. In many applications they are the only useful alternative for creation of thick-film structures.

Main advancements of the PTFT are:
- simple production processes,
- low production expenses,
- integration possibility of passive devices including potentiometers.

The PTFT are limited by:
- temperature range,
- higher resistivity than of copper plated,
- power load,
- lower solderability.

Polymer thick films are the conductive, resistive and dielectric layers in the topological structure of thick-film circuitry, generally on a planar substrate. Standard types of printed circuit boards (PCB), ceramics and flexible foils can be used as substrates for this technology [1, 2].

Epoxies, polyimides and acryls are used as supporting materials for polymer thick-film pastes. Polymer based pastes have short-time usability, usually six months at proper storing conditions. The used fillers in conductive pastes are Ag, Cu and Ni and carbon compositions in resistive pastes [3, 4].

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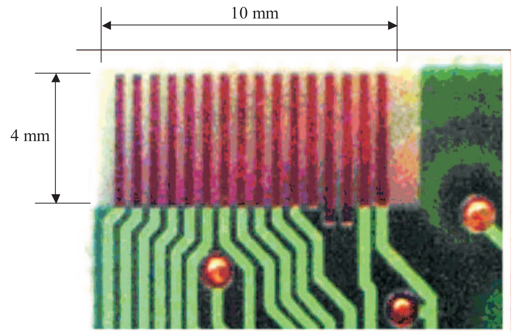

Fig. 1. FR4 rigid substrate with gold coated connector contacts

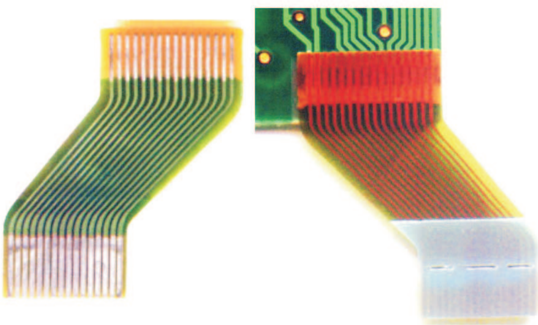

Fig. 2. Polyimide foil cable (left) soldered onto rigid FR4 substrate (right)

Table 1.

ACA type	Loctite 3447	3M 9703
Adhesion paste / filler:	epoxy base / 7 μm Au plated Ni particles	50 μm acrylate adhesive, filler not specified
Application technique:	dispensing or screen-printing	punching and then at 15–70 °C and pressure of 0.01 kg/mm^2
Hardening conditions:	180 °C at least 5 s and pressure of 0.5–1 kg/mm^2	1 kg/mm^2, nominal adhesion after 24hours
Contact resistance	not specified	$1.6 \times 10^{-2}\Omega$m

The topology of thick-film motives is created by using specialized computer aided design (CAD) software with output for production of film templates. Then the motive is exposed on a light-sensitive layer on the screen-printing mesh and the unwanted areas are washed-up. In the screen-printing process the polymer paste is forced trough the opens in the mesh onto the substrate by squeegee.

Generally, the polymer thick-film pastes do not require drying after screen-printing and their hardening is carried out by thermal or ultraviolet radiation [5].

Production of polymer thick-film layers is a sequence of screen-printing and hardening steps, repeated for each layer, at conditions for individual PTF paste. Thermal hardening is realized in a standard box or in a continuous furnace in the range of 80–140 °C for thermoplastic pastes and 150–250 °C for thermosettic pastes. Microwave heating is also possible. Dielectric pastes naturally require ultraviolet hardening.

Conductive interconnections of the etched copper foil contacts are realized by screen-printing too. PTF contacts are realized in the same motive as conductive paths and they are covered by a chemically more stable PTF carbon layer to prevent migration of silver atoms. A continual unreeling system, followed by screen-printing and hardening cycles are used for batch production of flexible modules [3].

Manufacturing of touch panels and membrane keyboards, production of PCB-PTF hybrid modules, chemical sensors, and modifications of standard PCBs and repairs represent the main areas of PTFTs utilization. Carbon polymer layers can substitute more expensive gold keyboard layers and PTF interconnections can substitute more expensive standard coppered via holes as well [3, 6].

4 EXPERIMENTAL SAMPLES

Several samples were designed, prepared and evaluated for this demonstration. The chosen sample substrates were based on the standard copper plated FR4 laminate and finished by a strip connector at the corner with 4×10 mm dimensions and 0.55 mm raster of contacts. The surface of contacts and through-holes were galvanically coated by a thin gold layer (Fig. 1).

Flexible foil cables were produced from a polyimide foil and finished by a standard lead-solder coated strip connector at both terminations. The foil-cable connectors (Fig. 2 left) are in the standard production process connected onto rigid substrates (Fig. 2 right) by reflow soldering.

5 ACA MEDIA AND EQUIPMENT

The anisotropic conductive paste Loctite 3447 and anisotropic conductive tape 3M 9703 were chosen for realization of conductive joints. The basic parameters are shown in Tab. 1.

The reflow equipment Covatec SA SR10-1135/1 with one substrate feeder was chosen for foil connector contacting. The thermal process of conductive adhesive has a different nature as compared with reflow soldering. The thermal profile at the reflow head has to be adapted and there is a compromise between the temperature and hardening time. The adaptation dependence curves were created because the temperature gradient from the heat source to the adherends emerged and they were based on a set of temperature measurements. The temperature of 180 °C for Loctite 3447 adhesive was readout by temperature of 348 °C at the heat source and the temperature of 70 °C for 3M 9703 adhesive was readout by temperature of 125 °C at the head.

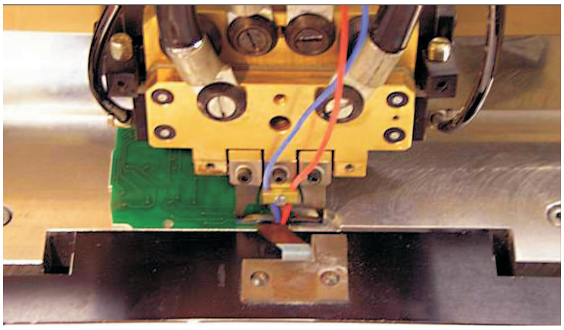

Fig. 3. Hardening head at process

Table 2. Electrical resistance statistics with standard deviation of measurement, the statistical set are contacts within the sample.

Sample No.	ACA @ 8 s curing time		ACA @ 5 s curing time		Sn63Pb solder	
	R_{avg} (mΩ)	σ	R_{avg} (mΩ)	σ	R_{avg} (mΩ)	σ
1	33.92	7.72	46.38	9.52	21.23	3.12
2	27.85	7.39	47.23	23.76	21.19	2.75
3	30.01	9.14	33.92	6.50	29.85	8.22
4	27.76	7.01	44.77	7.21	31.69	8.21
5	28.54	5.98	40.77	7.96	18.54	3.48
6	31.77	6.94	29.38	5.79	28.08	8.94
7	27.00	7.17	41.46	12.06	18.85	3.44
8	27.62	6.40	32.77	7.74	30.46	8.20
9	25.92	5.88	36.31	7.04	19.54	4.13
10	25.90	6.28	43.23	11.34	22.85	4.91
11	29.15	9.17	43.92	7.89	36.08	6.91
12	26.00	5.99	35.31	6.41	21.22	4.10

Table 3. Electrical resistance statistics with standard deviation of measurement, the statistical set are equivalent contacts.

Contact No.	ACA @ 8 s curing time		ACA @ 5 s curing time		Sn63Pb solder	
	R_{avg} (mΩ)	σ	R_{avg} (mΩ)	σ	R_{avg} (mΩ)	σ
1	26.25	2.89	40.17	7.91	26.75	25.67
2	23.08	2.47	33.17	5.06	23.92	29.17
3	23.33	1.70	31.25	2.77	20.50	21.17
4	26.67	2.25	38.58	5.33	16.83	18.25
5	20.50	1.85	30.67	3.90	29.08	25.25
6	24.58	2.18	34.50	7.75	22.92	37.25
7	23.50	3.59	37.25	9.17	27.83	6.29
8	24.75	3.14	35.42	5.35	6.24	4.29
9	31.00	2.61	45.67	6.00	9.42	6.02
10	30.75	2.62	41.50	6.51	4.67	3.10
11	31.00	3.19	35.92	4.23	4.25	8.61
12	44.92	4.54	56.42	8.77	5.63	3.66
13	39.58	7.06	54.58	23.82	10.96	5.00

6 REALIZATION OF ANISOTROPIC CONDUCTIVE JOINTS

Raw cuts of 12 substrate pieces before surface mounting were selected for anisotropic conductive adhesives application. Corresponding foil connectors without solder metallization were prepared. Protected metallization is useful, but unprotected copper foil surface is convenient in this case because of adhesive conductive particles penetration into the adherends surface.

It is really necessary to solve the problem of technologic operations sequence before ACA application in industrial practice. Both operations, screen-printing and tape punching, require using of flat substrate. However, keyboard substrates and other module types obviously contain surface mounting devices which are attached by machine onto the substrate sheet stock. This technological step is not possible after ACA paste application. In addition, the used production equipment generally allows treatment of single substrate only. So, it is necessary to apply ACA onto a single substrate. The best way represents their application directly after attaching the foil connector. In the case of an automatic line assembly, there is no prolongation in the production process. But in an operator performed line, the process brings about an increase in manufacturing expenses.

The miniature screen-printing equipment was made with 200 mesh screen and simple rectangle motive for application of ACA paste. The raw cut of 3×10 mm tapes with a protecting foil was prepared for application of the ACA tape.

Loctite 3447 anisotropic conductive paste was deposited onto the screen by injection dispensing. After manual screen-printing, the substrate was stocked by a purified foil connector. After vacuum fixation of the sample, the adapted hardening process was performed at 8 s hardening time and subsequently at 5 s curing time. The process was repeated for the whole 12-piece series of samples. Correspondingly, the hardening process was performed at applied ACA tape.

6.1 Electrical resistance of joints

Measurement at 13 leaded connector contacts was realized by RLCG bridge. Statistical processing of the values obtained on substrates with applied Loctite 3447 anisotropic conductive adhesive with 8 s hardening time is in Tab. 2 and Tab. 3, likewise for 5 s hardening time in the same tables.

After 24 hours, *ie*, the time required for adhesion processes finishing, the electrical properties tests was performed at samples with applied 3M 9703 ACA tape. The values fluctuated within tithes of mΩ, which is more than 100 % out of the average value. Because of unsatisfactory result they were not treated further. The joints were fluctuating in electrical resistivity on light pressing of adherends together. So the next sample series was realized with a modified hardening profile, the hardening time being prolonged to 30 s. After adhesion processes formation, the measured resistivity values did not give satisfactory results either. The last measurement series was realized on a 12-piece set of substrates with applied PbSn solder

Table 4. Statistics of terminal strength values of contacts with applied Loctite 3447 anisotropic conductive adhesive at 8 s hardening time

Average (N)	Minimum (N)	Maximum (N)	Specific strength (N/mm)	Standard deviation
3.07	2.46	3.62	0.31	0.32

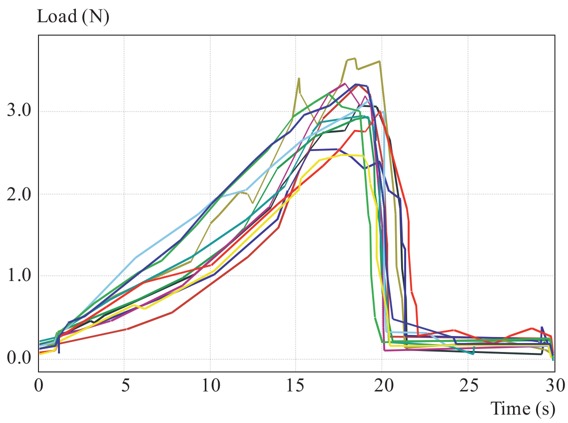

Fig. 4. Behaviour diagram of mechanic strength of joints with applied Loctite 3447 anisotropic conductive adhesive at 8 s hardening time – as measured on 12 different samples

Table 5. Statistics of terminal strain values of contacts with applied Loctite 3447 anisotropic conductive adhesive at 5 s hardening time

Average (N)	Minimum (N)	Maximum (N)	Specific strength (N/mm)	Standard deviation
1.50	0.41	2.06	0.15	0.45

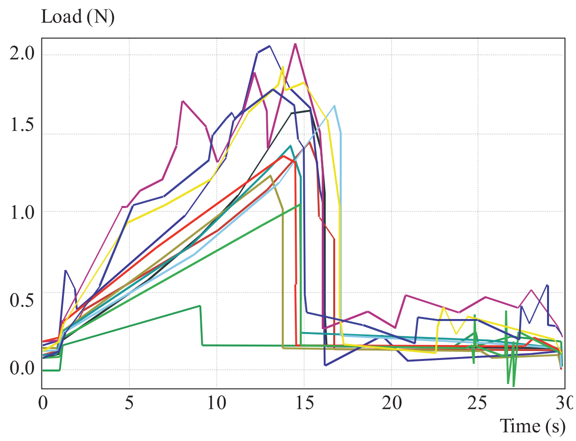

Fig. 5. Behaviour diagram of mechanic strength of joints with applied Loctite 3447 anisotropic conductive adhesive at 5 s hardening time – as measured on 12 different samples

Table 6. Statistics of terminal strain values of contacts with applied SnPb solder

Average (N)	Minimum (N)	Maximum (N)	Specific strength (N/mm)	Standard deviation
11.61	9.04	14.87	1.16	1.51

for mutual confrontation. Statistical processing of the acquired electrical resistance values is shown in Tab. 2 and 3.

6.2 Tests of mechanical stress

Mechanical peeling tests were performed to check the mechanical properties of the realized joints. The test conditions and continuances are specified in the international standard (STN IEC 326-2 (359010) — Printed Circuits Boards. Testing Methods) [9] and were realized in tension equipment LLOYD Instruments LRX Model Level 23. Generally, the strength in peeling is denoted by the minimum force at width unit of the wire which is needed for its peeling-off from the adjacent surface of the substrate.

Statistical processing of the values obtained at substrates with applied Loctite 3447 anisotropic conductive adhesive with 8 and 5 s hardening time and at substrates with applied SnPb solder is in Tab. 4 to Tab. 6 and behaviour diagrams during the peeling tests in Fig. 4 to Fig. 6.

7 RESULTS AND DISCUSSION

Measurement of electrical resistance at samples with applied Loctite 3447 anisotropic conductive adhesive reveals a small value dispersion (Tab. 2), and then good process repeatability. Even better results can be anticipated after its implementation into the batch production process. In contrast, the dispersion of the acquired data of joints within the sample is noticeable, which indicates that the processing head must be more coplanar with the substrate compared to soldered joints. Otherwise the boundary joints become conductive particles insufficiently pressed between adherends. It corresponds to higher values of standard deviation in Tab. 3 at boundary joints No. 12 and 13.

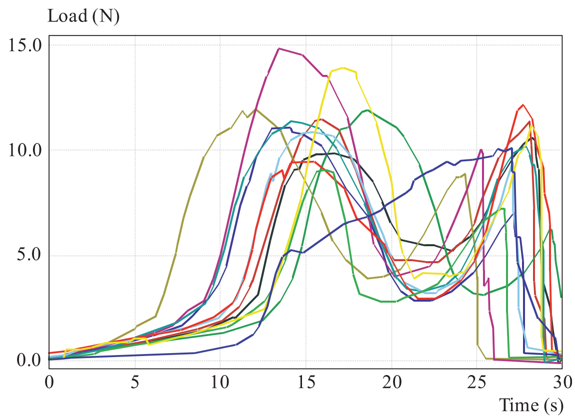

Fig. 6. Behaviour diagram of mechanic strength of joints with applied SnPb solder – as measured on 12 different samples

The samples with 5 s hardening time were realized for boundary capabilities investigation of the used adhesive. The dispersion exhibited higher values of standard deviation in Tab. 3 and evidently higher values of electrical resistance point at a not fully finished hardening process. Sufficient mechanical bonds were not established for retaining of elastic mechanical contact among conductive particles in adhesive.

Comparison of electrical resistance values at samples with applied Loctite 3447 anisotropic conductive adhesive in Tab. 2 with values at samples through applied SnPb solder in Tab. 2 shows slightly better values at soldered joints.

At the soldered joints, the mechanical stress is transferred to the contact area only. Adhesive joints have the acting force distributed over the whole connector area, which contributes to higher stress ability of the joints. However, it cannot be expected that adhesive joints exceed the metallurgic joints, whose mechanical stress ability is obviously superior to the adhesion properties of a copper foil onto a foil or rigid substrate. These assumptions were confirmed by tests of mechanical stress ability. Adhesion joints with applied Loctite 3447 anisotropic conductive adhesive have on average only 25 % of mechanical strength compared to soldered interconnections (Tab. 4 and Tab. 6), which caused copper foil ripping from the substrate at peeling tests.

Mechanical stress dependences of adhesive joints indicate different load force profiles during the peeling tests (Fig. 4) compared to soldered joints (Fig. 6) because of the joint shape and of the joint material structure.

8 CONCLUSION

The work deals with utilization of anisotropic conductive adhesives in industrial practice. The Main tasks of the work were the methodology setup and practical realization of anisotropic interconnections between foil connectors and rigid substrates based on the polymer thick film technologies. The temperature profiles between the foil connector and rigid substrate contacts were measured in the preliminary work phases and adaptation of temperature behaviours were formed afterwards. The needed hardening profile peak temperatures were determined for particular adhesives in this way. Resultant behaviours will be applicable for any adhesive material in the future after the final SnPb solder elimination from production process. The resistance values at samples with applied Loctite 3447 anisotropic conductive adhesive suggested to be nearly comparable with the values at samples with applied SnPb solder after the joints resistivity measurements. Under reviewing of mechanical stress ability in point of view of acceptability in applications, there is proper to consider that the foil cable is bent in 180 in the test process as in a typical application. The force acting on the foil cable in zero position was 0.2 N in average, which represents only 10 % of the averaged maximal strain (Tab. 3).

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Miloš Somora and **Stanislav Slosarčík**, biographies not supplied.