Electrocomponent Science and Technology 1980, Vol. 7, pp. 69–75
0305–3091/80/0701–0069$06.50/0

APPLICATION OF CONDUCTIVE ADHESIVES IN MICROCIRCUITS FOR "LONG-LIFE" EQUIPMENT

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(Received June 11, 1979)

The results of a study of the application of conductive adhesives for attaching semiconductor chips to thin film Au conductors is presented.

The study concentrates on measuring the stability of the electrical conductivity of adhesive bonds for semiconductor chips.

Four types of conductive bonding agents and two types of semiconductor back metallization were tested at raised temperatures for up to 10,000 hours.

1. INTRODUCTION

The use of polymer adhesives for high-reliability microcircuit application is a radical change in electronic packaging. This new approach prompted Philips' Telecommunicatie Industrie to conduct research programs to evaluate adhesives for use in hybrid microcircuits employed in telephone equipment (low current application).

This paper presents the results of a study of the application of conductive adhesives for attaching semiconductor chips to thin film Au conductors. The study concentrates on measuring the stability of the electrical conductivity of adhesive bonds for semiconductor chips.

Four conductive adhesives were selected for testing: three types of Ag-filled epoxy adhesives and one type of Au-filled epoxy adhesive. A problem associated with the use of conductive adhesives for attaching semiconductor chips is the necessity of low contact resistance between the adhesive and, both N and P, low resistivity silicon.

For this study the following chip contact metallizations were tested:

– AsAu sintered for N-doped Si, and Au sintered for P-doped Si. These two form the standard metallization systems generally used for chips intended for eutectic bonding.

– Ti+Au for both N and P doped silicon was tested as an alternative contact metallization system.

– For recognizing any changes in the series resistance of an epoxybonded chip caused by the metallization, gold pellets were used as a reference.

The variables tested in this program are listed in Table I

TABLE I
Variables tested

		Components: Silicon chips with: AsAu on N-silicon			Au on P-silicon			Ti + Au on N-silicon			Ti + Au on P-silicon			Au pellets		
	Test temp.	100 °C	125 °C	150 °C	100 °C	125 °C	150 °C	100 °C	125 °C	150 °C	100 °C	125 °C	150 °C	100 °C	125 °C	150 °C
Adhesive	A	x	x	x	x	x	x							x	x	x
	B		x			x									x	
	C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	D		x			x		x	x	x	x	x	x	x	x	x

Note: Ni back metallization has not been tested because this metallization cannot be used for transistors with Au bonding pads.

2. DEVICE TESTED

In most publications dealing with the study of the electrical conductivity of metal-filled adhesives the resistance of a conductor track made from the adhesive under test is measured. To be able to measure the resistance under realistic conditions, a test module was designed for this program, see Figure 1.

The test module consists of 2 thin film circuits with a conductor pattern of 12 μm annealed electrodeposited gold.

Using the adhesive under test, 34 Si chips were bonded to the outer rows of mounting pads and 18 Au pellets were bonded to the inner rows of mounting pads. The adhesives were applied by screen printing (screen 200 mesh).

The cure schedule for the various adhesives is shown in Table II.

To enable the measurement of individual adhesive joints, a maximum number of connections was made between bonding pads and package leads.

To reduce series resistance and to exclude semiconductor properties, special Si chips without

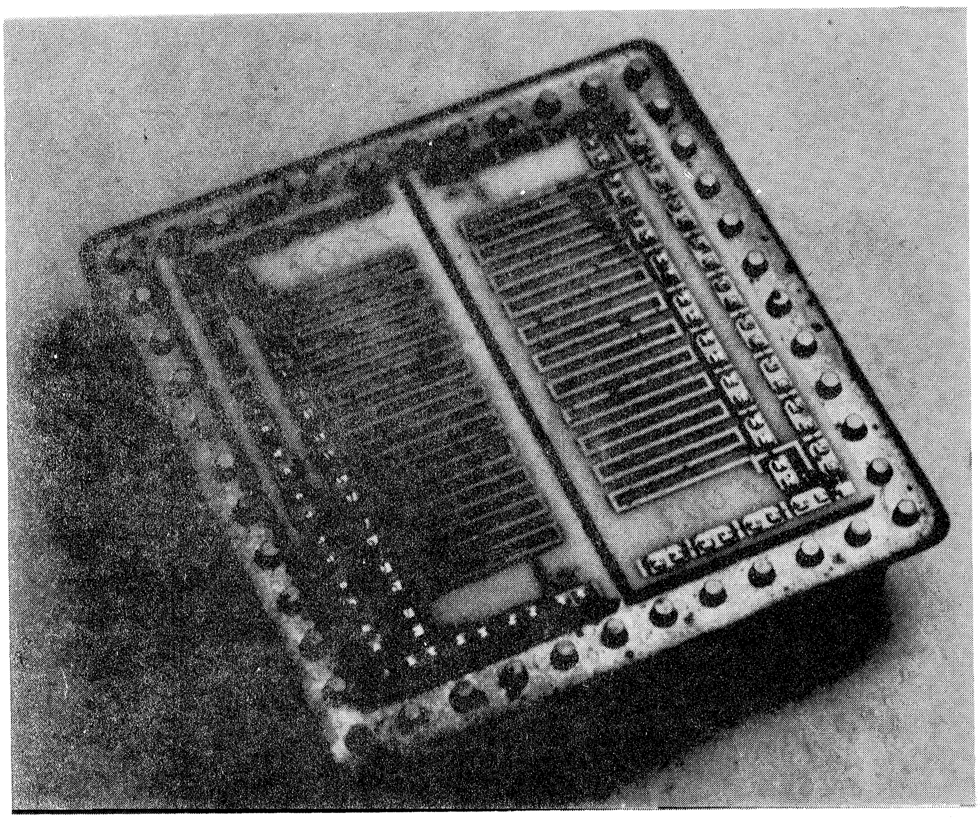

FIGURE 1 Device tested

TABLE II
Cure schedule of tested adhesives

Adhesive	Type	Cure temp.	Cure time	Notes
A	1 component Ag-filled epoxy resin	150°C	75 min.	
B	1 component Ag-filled epoxy resin	150°C	75 min.	
C	2 components Ag-filled epoxy resin	150°C	10 min.	
D	1 component Au-filled epoxy resin	125°C	75 min.	batch 6
		150°C	60 min.	batch 4,5

TABLE III
Chips tested

Chip	Chip resistivity	Chip dims mm	Bonding pad dia. (μm)	Top metallization	Back metallization
N doped Si	8 mΩcm	.5 x .5 x .12	∅200	Ti-Pt-Au	AsAu,sintered
P doped Si	18 mΩcm	.5 x .5 x .12	∅300	PtSi-Ti-Pt-Au	Au,sintered
N doped Si	5 mΩcm	.5 x .5 x .12	∅200	Ti-Pt-Au	Ti + Au
P doped Si	35 mΩcm	.5 x .5 x .12	∅300	PtSi-Ti-Pt-Au	Ti + Au
Au pellets 99.99% Au		.5 x .5 x .15	—	—	—

epitaxy and with low Si bulk resistivity were made for this program by Elcoma, Nijmegen. The data of the chips tested are listed in Table III.

The components were interconnected by annealed gold wire, bonded with Hughes TC bonder HPB 360 (thermocompression bonder with pulse-heated capillary), the circuit was preheated to 130°C and the capillary temperature was 350°C (1.5 sec.).

The assembled circuits were secured in a metal plug-in package with a glass-fabric supported epoxy adhesive. The cure schedule was 2 hrs at 125°C.

The encapsulations were filled with N_2 and sealed by soldering (leakrate $\leqslant 5.10^{-7}$ atm. cc/sec.).

3. EVALUATION CRITERIA AND MEASURING METHOD

To determine the stability of the adhesive joints, the series resistance of the bonded components was measured.

When resistance drift of the adhesive joints was observed, measurements were carried out on parts of the outer rows of adhesive joints to check whether the observed drift was caused by one adhesive joint or equally distributed over the series-conducted joints. The measurements were carried out with the aid of an HP Multi-Function meter 3450B, which is a 5-digit integrating digital Volt/Ohm meter with a specified accuracy ±(0.01% of reading + 0.01 ohm). The design of the test module permits a Kelvin measurement, so that the influence of the lead resistance on the measuring result can be avoided. The signal current was 1 mA. All measurements were carried out at an ambient temperature of 21° C ± 2°C. To avoid the influence of thermo-voltages in the measuring set-up, the resistance was measured twice in short succession, with different current source polarities.

One module of each type was not subjected to tests but was used as a reference. Immediately before or after measuring the resistance of the test modules of one type, the reference module was measured. When the measuring values of the test modules were corrected for the deviation of the reference modules, an accuracy ⩽5 mohm was achieved.

4. TESTS AND TEST RESULTS

4.1 *Tests*

To determine the stability of the electrical conductivity of the adhesive bonds of semiconductor chips as a function of time and temperature, the test modules were tested as per IEC 68-2-2, test Ba: dry heat test.

To get some understanding of the temperature dependence of adhesive bonds, three test temperatures were chosen, viz. 100°C, 125°C and 150°C (a list of the variables tested in this program is given in Table I).

4.2 *Test Results*

4.2.1. Adhesives For comparing various epoxy compounds tested, only the test results from the adhesive-bonded Au pellets were used in order to exclude the influence of the contact metallization. The test results of the adhesive–bonded Au pellets are shown in Table IV and are given per batch of test modules manufactured at the same time.

The spread in the mean 0-hour batch values per pellet is caused by the tolerances of the sheet resistance (thickness) of the substrate metallization and the bonding method (1 or 2 wires). The resistance of a conductive adhesive bond (Au–Au) derived from the 0-hour values of the test modules was found to be 0.5 mohm at most and no significant difference between the 4 tested adhesives was found. The measured increase of the contact resistance (maximum 18 mohm) is of minor importance for present-day applications. The failure mode which

TABLE IV
Test results of adhesive-bonded Au pellets

Component	Adhesive	Mean 0-hour value per component mohm	Number of components	Batch No	Test temp °C	Mean ΔR in mohm per component after .... test hours 100	250	500	1K	2K	4K	7K	10K
Gold pellets	A	9.2	36	2	100	0	0	0	+0.3	+0.3	+0.3	+0.3	+0.3
		[b]5.7	140	1	125	0	0	+0.2	+0.3	+1.2	+6.1	*a*	*a*
		9.2	36	2		0	0	0	+0.2	+0.5	+0.8	*a*	*a*
		9.7	36	2	150	+9.1	*a*	*a*	*a*	*a*	*a*	*a*	*a*
	B	[b]5.4	72	3	125	0	+0.8	+0.9	+1.1	+1.2	+2.0	+3.4	+4 6
	D	10.9	72	5	100	–0.1	–0.1	0	0	0	0	0	0
		11.3	72	6		0	–0.1	0	–0.1	0	–0.1	0	+0.1
		9.8	108	4		0	0	0	0	0	–0.1	–0.1	–0.1
		11.1	108	5	125	0	–0.1	0	0	0	0	–0.1	0
		11.3	108	6		–0.1	–0.1	–0.1	–0.2	–0.2	–0.2	–0.1	–0.1
		11.5	72	5		+0.1	+0.1	+0.2	+0.1	+0.1	0	–0.2	–0.3
		11.2	72	6	150	0	0	0	0	0	0	–0.2	–0.3
	C	9.5	36	8		–0.1	+0.1	+0.1	–0.1	+0.1	+0.1	+0.1	0
		10.8	72	9	100	+0.1	+0.1	+0.1	+0.4	+0.6	+0.9	+1.0	+1.1
		10.5	72	10		–0.3	0	0	0	+0.1	+0.1	+0.3	+0.3
		9.5	108	7		0	0	0	0	0	+0.2	+0.3	+0.4
		9.7	36	8	125	0	0	–0.1	–0.1	+0.1	+0.1	+0.1	+0.6
		10.9	72	9		+0.1	+0.2	+0.3	+0.6	+0.9	+3.2	+7.4	+11
		10.6	108	10		–0.1	+0.1	+0.1	+0.2	+0.3	+0.4	+0.8	+1.0
		9.8	36	8		0	–0.1	–0.1	+2.3	+8.0	+18	*a*	*a*
		10.6	72	9	150	+0.1	+0.7	+3.6	+17	*a*	*a*	*a*	*a*
		10.4	72	10		0	+0.4	+1.3	+3.7	+7.0	*a*	*a*	*a*

[a]unstable (noise contact)
[b]bonded with 2 parallel wires which gives lower 0-hour values

governs end of life was found to be the instability of the electrical resistance.

Discussion of the test results:

For long-term high-reliability applications, adhesive D is obviously the most suitable one. Because this Au-filled adhesive can stand testing at 150°C, it is suitable for hybrid micro-electronic circuits of quality level B-1 as laid down in MIL-HDBK-217B.

Of the tested Ag-filled epoxy compounds, both adhesives B and C give good results at 125°C. The spread observed in the test results of the type C adhesive is probably caused by tolerances in the weighing and mixing process of this two-component adhesive. Measurements on parts of the outer rows of adhesive joints demonstrated that the observed drift was distributed over the series-connected joints.

To exclude any detrimental influence of the bonding technique used for the top contact, a number of bondings were made with an ultrasonic gold ball bonder (KS 472). No difference in test results was observed.

4.2.2 Chip metallizations. In the test results the influences of the adhesives and of the chip metallizations have been added up. Because the results obtained from the adhesive bonded Au pellets showed adhesive D to give a stable contact resistance in the tested contact metallization combinations, the results of the chips bonded with adhesive D are the most interesting. They are shown in Table V.

The tables show 3 salient points.

1) The contact resistance of P-doped chips with sintered Au coating becomes unstable after 7000 hours at 125°C.

2) The contact resistance of N-doped chips with sintered AsAu coating increases considerably after 10,000 hours at 125°C and is expected to become unstable after that time.

3) Ti + Au chip metallization gives better results a resistance increase was observed at 125°C. Instability was observed after 5000 and 7000 hours at 150°C for respectively P-doped and N-doped chips.

Discussion of the test results:

One of the problems that arise when evaluating a chip metallization system is the quality of the contact resistance between the metallization and both N and P-doped silicon. Moreover, the quality of the contact resistance depends on the impurity concentration, particularly with P-doped silicon. To get some understanding of the phenomena of the increase of the

TABLE V

Test results of Au-filled adhesive bonded chips

Component	Adhesive	Mean 0-hour value per component	Number of components	Batch No	Test temp	Mean ΔR in mohm per component after .... test hours							
		mohm			°C	100	250	500	1K	2K	4K	7K	10K
Nchip/AsAu		77	100	4	125	+1.0	+3.1	+5.2	+9.1	+20	+23	+24	+77
Pchip/Au		134	93	4	125	+0.3	+0.5	+1.3	+9.0	+51	+106	+124	^{a}
Nchip/Ti + Au	D	55	68	6	100	−0.1	−0.1	−0.1	−0.1	−0.1	0	−0.1	0
		56	102	6	125	−0.1	−0.1	−0.2	−0.2	−0.3	−0.2	+0.1	+0.1
		55	68	6	150	0	+0.1	+0.2	+0.8	+5.4	+22	+35	^{a}
Pchip/Ti + Au		276	68	6	100	−1.5	−1.8	−1.4	+0.2	+1.8	+3.1	+7.1	+8.3
		278	102	6	125	−0.1	+0.9	+4.8	+9.9	+13	+14	+15	+17
		278	68	6	150	+14	+16	+19	+23	+26	+25	^{a}	^{a}

^{a}unstable (noise contact)

TABLE VI

Test results of Ag-filled adhesive bonded chips

Component	Adhesive.	Mean 0-hour value per component	Number of components	Batch No	Test temp	Mean ΔR mohm per component after .... test hours							
		mohm			°C	100	250	500	1K	2K	4K	7K	10K
		91	33	2	100	+2.0	+3.1	+3.5	+3.4	+2.9	+2.9	+3.1	+2.5
Nchip/AsAu		73	136	1	125	+7	+14	+17	+22	+45	+106	*a*	*a*
	A	97	34	2	150	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
		144	34	2	100	+0.1	+0.2	+0.2	+0.2	+0.2	+0.1	+0.4	+0.5
Pchip/Au		145	33	2	125	+0.5	+0.6	+0.7	+1.3	+2.8	+5.5	+125	*a*
		145	34	2	150	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Nchip/AsAu	B	69	115	3	125	+32	+94	+227	*a*	*a*	*a*	*a*	*a*
Pchip/Au		132	112	3	125	+3.5	+5.0	+7.5	+3.6	*a*	*a*	*a*	*a*
		80	33	8	100	+0.7	+1.1	+1.9	+3.7	+8.4	+16	+20	+19
Nchip/AsAu		79	68	7	125	+2.0	+4.6	+8.0	+12	+15	+17	*a*	*a*
		81	34	8	150	+20	+30	+40	*a*	*a*	*a*	*a*	*a*
		141	31	8	100	+0.6	+0.8	+1.2	+1.7	+2.4	+4.9	+5.4	+5.5
Pchip/Au		135	68	7	125	+0.3	+0.5	+0.8	+1.4	+2.9	+3.7	+122	*a*
		140	34	8	150	+3.6	+4.4	+15	*a*	*a*	*a*	*a*	*a*
	C	48	68	10	100	–0.1	0	0	0	+0.1	+0.1	+0.1	+0.1
Nchip/Ti + Au		48	102	10	125	+0.2	+0.2	+0.1	+0.1	+0.1	+0.2	+0.5	+0.7
		47	68	10	150	–0.1	0	+0.6	+2.1	+4.2	*a*	*a*	*a*
		275	34	10	100	+1.5	+1.6	+2.2	+3.0	+4.5	+6.4	+9.4	+11
Pchip/Ti + Au		277	102	10	125	+3.2	+6.0	+9.6	+13	+19	+20	+22	+23
		278	68	10	150	+15	+16	+19	+23	+29	+26	+25	+25

[a]unstable (noise contact)

contact resistance, we opened the test modules of batch No. 4 after the 10,000-hours measurement.

The chips were prized off and the force necessary to do so showed that the adhesive strength had not significantly degraded. Most chips were severely damaged by lifting. For both N and P-doped chips with sintered AsAu and Au, the fractures occurred more or less at the silicon-metallization interface. As the 0-hour point the fracture always occurs at the metallization-epoxy interface, it may be concluded that the adherence of the back metallization has degraded as a result of testing at 125°C for 10,000 hours.

The observations, combined with the results of the Au-pellets, demonstrate that the observed resistance increase is a property of semiconductors, and this is beyond the scope of this study. In our opinion, the subject of stability of the contact resistance has to be studied by the semiconductor manufacturer(s) prior to introducing a standard metallization intended for adhesive bonding. The results of testing the various Ag-filled adhesive Si chip combinations are shown in Table VI. The Table shows that the adhesive behaviour dominates and that for the Ag-filled adhesive-bonded Si chips instability (noise contact) is the failure mechanism which causes end of life.

5. CONCLUSIONS

Of the 4 conductive adhesives tested, only the resistance of the Au-Au bonds made by means of a Au-filled epoxy adhesive is still stable after 10.000 hours of testing at 125°C and at 150°C.

When Au-Au bonds are made with Ag-filled adhesives, instability of the resistance (noise contact) is the failure mechanism which determines the end of life.

For Si chips bonded with Ag-filled adhesives, the adhesive properties in combination with the chip back metallization system determine the end of life.

Ti + Au metallization of semiconductor chips (collector) gives the best results. This is valid for Ag and Au-filled epoxy compounds.