TECHNICAL REPORT
(Contract NAS8-30876)

CONTAMINATION CONTROL IN HYBRID MICROELECTRONIC MODULES

INTERIM REPORT

JANUARY 1976

AEROSPACE GROUPS

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

CONTAMINATION CONTROL IN HYBRID MICROELECTRONIC MODULES

Continuation of Work

Interim Report

Contract No. NAS 8-30876

January 1976

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INTRODUCTION AND SUMMARY

This report covers work done as a continuation of the NASA contract NAS 8-30876. Previous work was reported in "Contamination Control in Hybrid Microelectronic Modules", P75-111 (Hughes Ref. D1927), April 1975. In that study it was found that two hybrid microcircuit coating materials were effective in preventing particulate contamination from causing device malfunction or degradation.

These materials, a Dow Corning silicone coating (DC 90-711) and a Union Carbide epoxy coating (ERL 4289), were found to be electrically, mechanically, and chemically compatible with all components and materials normally used in hybrid microcircuits. The only reservations to these findings were slightly adverse effects on some thick film resistors and on ultrasonic wire bonds.

To evaluate the extent of this influence on wire bonds an extension and change-of-scope amendment were added to the initial program. This additional investigation is reported herein.

The major objectives of this program were:

1. To investigate the effect on wire bond reliability of the two coatings (referred to here as S1 for the DC90-711 and E5 for the ERL 4289) on a large sampling of wire bonds and compare that to uncoated specimens subjected to the same tests,
2. Compare the reliability of wire bonds to thick film, thin film, and active device metallization,
3. Determine the relative reliability of 0.025 mm (0.001") aluminum, 0.025 mm (0.001") gold and 0.051 mm (0.002") gold wire bonds.

A secondary objective was to determine if particles could be removed from a package through a hole in the package lid.

Twelve thin film and twelve thick film test specimens were utilized to study the effects of the Sl and the E5 coatings on 0.025 mm (0.001 inch) diameter aluminum ultrasonic bonds, 0.025 mm (0.001 inch) diameter gold ultrasonic bonds, and 0.051 mm (0.002 inch) diameter gold pulsed-thermocompression bonds. Chip-to-substrate and substrate-to-substrate geometries were included. Because sealed packages were utilized, a test pattern design was incorporated that allowed the determination of bond failures by making resistance measurements external to the package after the various environmental tests. All wire bonds were non-destructively pull tested prior to sealing. Tests included the PIN test, temperature cycling, and high temperature storage.

The E5 coating was found to cause numerous wire bond failures. Although there was no clear demarcation between uncoated and the Sl coated wire samples, there was an apparent slight tendency for the uncoated bonds to be more reliable.

The following bond behavior was noted:

1. Aluminum or gold ultrasonic bonds to thick film were more reliable than comparable bonds to thin film
2. Ultrasonic aluminum bonds to the chip metallization were more reliable than ultrasonic gold wire bonds
3. Thermocompression bonds of 0.051 mm (0.002") gold wire to either thin or thick film gold were more reliable than ultrasonic 0.025 mm (0.001") wire bonds.
4. Though a clear separation between ultrasonic gold and ultrasonic aluminum bonds was not evident, the gold bonds, because of fewer substrate failures, appeared to exhibit slightly higher reliability.

Particles could be removed from a package by punching a hole in the lid, inverting the package on the pin tester and vibrating. These particles might then be examined to determine the cause of pin failures. Resealing of packages required the use of a replacement lid.

1.0 PREPARATION AND DESCRIPTION OF TEST SPECIMENS

1.1 WIRE BOND PATTERN CONFIGURATION

To evaluate the influence of any factor on wire bonds it is necessary to test large numbers of bonds and to incorporate the various configurations that will be encountered in typical hybrid manufacture. To accomplish this and also to allow testing of wire bonds without physically destroying them after each test, two test patterns were designed that permitted bond evaluation after the sealing of substrates in packages. This approach involved the shorting of series resistors with wire bonds either from pad-to-pad or from chip-to-pad. These configurations are shown in Figure 1. Any bond failures would be detected by a stepped increase in resistance and the magnitude of the resistance change could be converted into the number of bond failures. For example, if the series resistors that were jumpered by pad-to-pad bonds were each 170Ω and a 340Ω increase occurred after environmental testing, this would signify a loss of two wire bonds. Though there were two wires bonded to each chip in the chip-to-substrate combinations, an increase in resistance was assumed to be due to the loss of only one wire bond. Since all bonds could be visually examined at the conclusion of testing, the validity of this assumption could be checked and the appropriate corrections made at that time.

Two 44.450 x 19.050 mm (1-3/4" x 3/4") test patterns (Figures 2 and 3) were prepared, one for thin film circuitry, and the other for thick film.

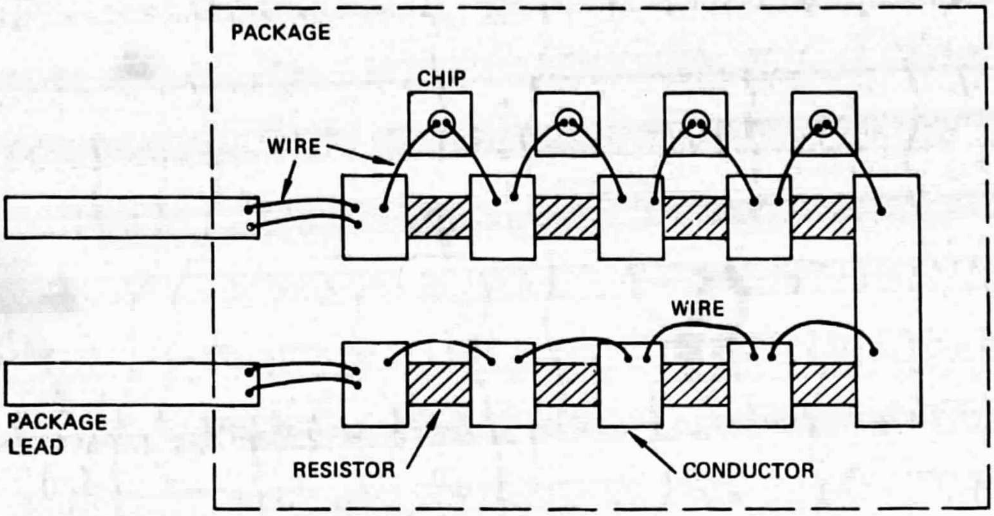


Figure 1. Illustration of chip-to-substrate and substrate-to-substrate wire bonds.

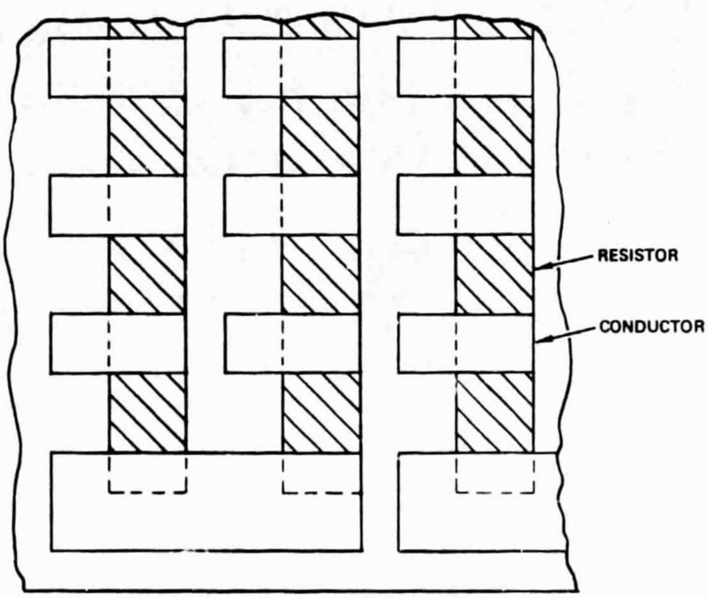


Figure 2. Thick film test pattern, detail.

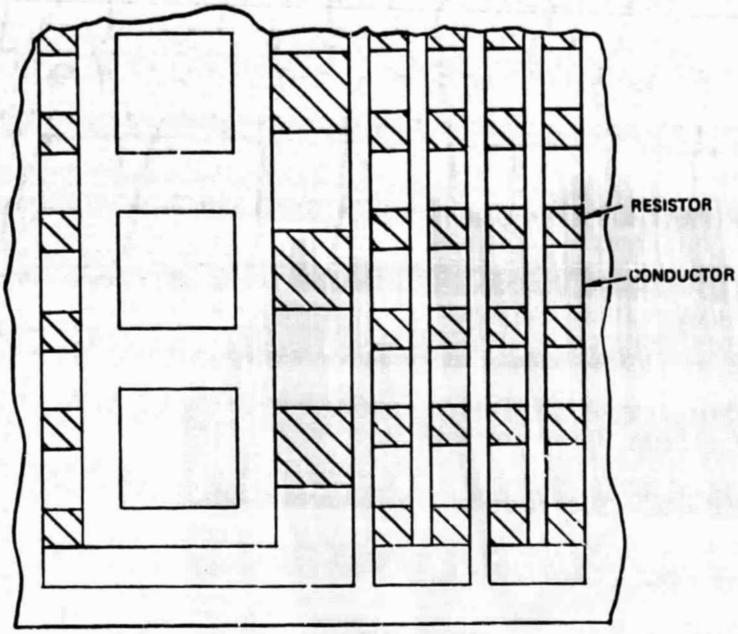


Figure 3. Thin film test pattern, detail.

The thin film pattern had locations for 1593 substrate-to-substrate wires and 416 chip-to-substrate wires. Each substrate had a total of 1801 resistors, 1593 of size 0.254 x 0.254 mm (0.010" x 0.010") and 208 of size 0.508 x 0.508 mm (0.020" x 0.020"), with each resistor having a value of 240 ± 15Ω.*

The thick film pattern had 760 resistors. Each resistor could be jumpered with a single wire, or a semiconductor chip could be placed directly on the resistor and the jumpering accomplished using two wires. Each resistor was 0.508 x 0.508 mm (0.020" x 0.020") and had a resistance of 190 ± 20Ω.

1.2 WIRE BOND TEST SPECIMENS PREPARATION

The thin film substrates were etched from 99.5 percent alumina substrates metallized with a base layer of nichrome, a nickel interface layer and a top layer of gold. The untrimmed resistors had a nominal value of 240 ± 15Ω. These were not trimmed to tighter tolerances.

*The calculations used to determine the allowable tolerances are given in the Appendix. These calculations were based on an assumed worst case loss of 25 percent of the wires in a given line of series resistors.

Thick film substrates were prepared using Electro-Oxide 06990-S conductor gold and ESL 3800 series 100Ω/□ resistor ink on 96 percent alumina. The resistors were protected with ESL 4771 B overglaze. Each substrate was then soaked in a 20 percent ammonium persulfate solution for five seconds to clean the conductor. The fired thick film resistors varied widely in resistance because of their very small size, so each low value resistor was laser trimmed to a nominal 190 ± 20Ω.

Twelve thin film and twelve thick film substrates were bonded with Scotchcast #281 non-conductive epoxy into 25.4 x 50.8 mm (1 x 2 inch) ceramic packages. Nonfunctional transistor chips were also attached to the substrates with Scotchcast #281. All transistors were Texas Instruments 2N2484 NPN mechanical samples. The epoxy was cured at 125°C for 2 hours.

Chip-to-substrate and substrate-to-substrate bonds were made by ultrasonic bonding 0.025 mm (0.001 inch) aluminum (1 percent Si) or 0.025 mm (0.001 inch) gold wire. In addition, substrate-to-substrate bonds of 0.051 mm (0.002 inch) gold wire were pulse-thermocompression bonded (PTB). A listing of the bonding methods is contained in Table I. The quantity of each bond type on each test pattern is shown in a test summary table later in this report.

TABLE I. INTERCONNECTION PROCESSES USED ON TEST SPECIMENS
(Thick and Thin Film Substrates)

Wire	Interconnection	Process	Machine Used
0.025 mm (0.001") dia Al*	Chip-to-Substrate and Substrate-to-Substrate	Ultrasonic	EMB Model 1101 C
0.025 mm (0.001") dia Au	Chip-to-Substrate and Substrate-to-Substrate	Ultrasonic ball bonding (substrate heated to 150°C)	K&S Model 472
0.051 mm (0.002") dia Au	Substrate-to-Substrate	Pulsed thermo-compression (Cold substrate)	Hughes Model HPB360
*Aluminum wire has 1% Si content.			

All wire bonds were non-destructively pull tested using a Mech El Model BT201 tester. The 0.025 mm (0.001 inch) wires were tested using a 1 gram load; the 0.051 mm (0.002 inch) wires were tested at the 3 gram level.

Each group of twelve thin film and twelve thick film test packages was divided into four control (uncoated) packages, four coated with S1 and four coated with E5. To apply the coatings listed in Table II, the coating materials were first diluted with chemically pure toluene to a 30 percent (by weight) solids content. They were then sprayed on test specimens with a Binks Wren B gun. Line air pressure was maintained at 55 to 83 kPa (8-12 psi gage). Spraying was accomplished in four separate passes, specimens being rotated 90 degrees after each pass. A period of eight minutes drying time was allowed between passes, followed by a 1-hour dry at room temperature, plus 1 hour at 100°C, plus 5 hours at 150°C.

The details of the test package and material combinations used in this study are given in Table III. Examples of wire bonded thick and thin film packages are shown in Figures 4 and 5.

All packages were vacuum baked for one hour at 125°C, nitrogen baked at 125°C for one hour, then solder sealed in dry nitrogen using SN 10 (10 percent SN, 88 percent Pb, 2 percent Ag) solder.

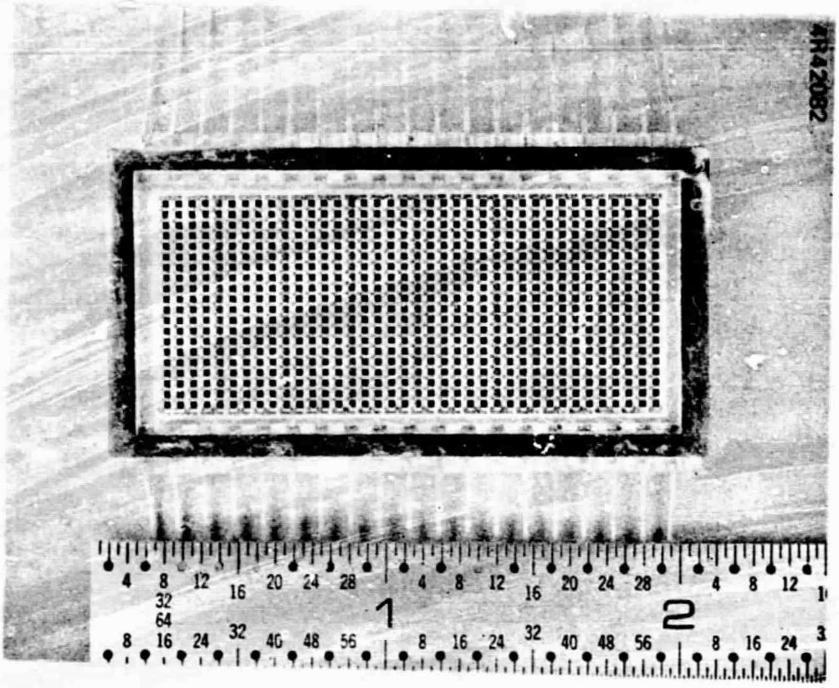
TABLE II. TEST COATINGS[1]

Designation	Formulation of Trade Name	Source
S1	DC 90-711	Dow Corning Corp. Midland, Michigan
E5	ERL 4289 plus dimer acid	Resin: Union Carbide Corp., Bound Brook, N. J. Dimer Acid; Emery Ind. Cincinnati, Ohio

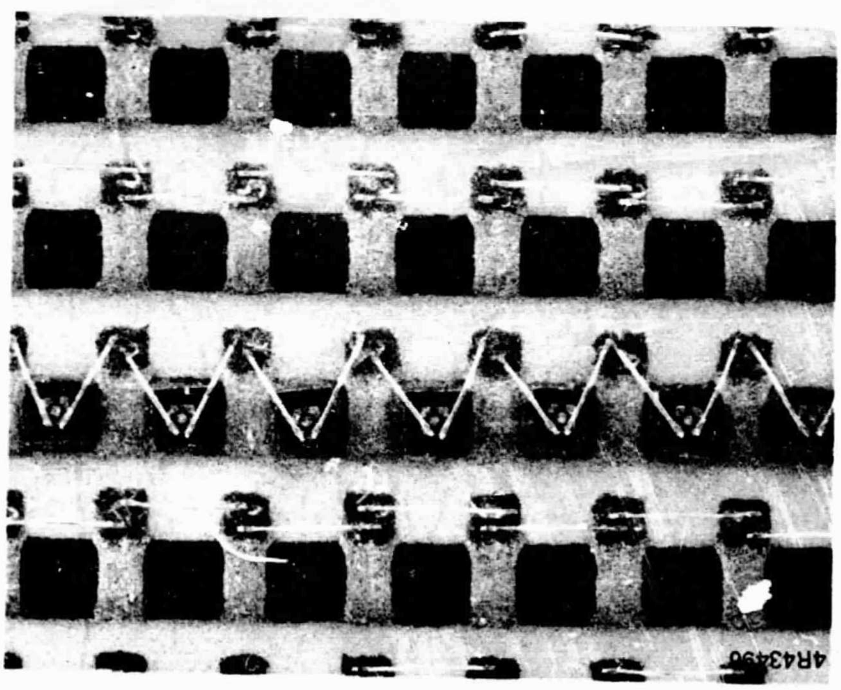
TABLE III. DESCRIPTION OF WIRE BOND TEST SPECIMENS

Part	Thick Film	Thin Film
Substrate		
Material	96 percent alumina	99 percent alumina
Dimensions	19.0 x 44.3 x 0.635 mm (3/4 x 1-3/4 x 0.025 inch)	19.1 x 44.3 x 0.635 mm (3/4 x 1-3/4 x 0.025 inch)
Conductors	Au (06990-S)*	Plated Au/evaporated Ni/evaporated Ni Cr.
Resistors	(ESL** 3800 series) 100 K Ω/□ All resistors overglazed with ESL 4771B	Ni Cr. untrimmed 225Ω/□ substrates
Wire Bonds	Aluminum (99 Al-1% Si) and gold 0.025 mm (0.001 inch) diameter, ultrasonic bonded Gold, 0.051 mm (0.002 inch) diameter, pulse thermocompression bonded	Aluminum (99 Al-1% Si) and gold 0.025 mm (0.001 inch) diameter ultrasonic bonded Gold, 0.051 mm (0.002 inch) diameter, thermocompression bonded
Package	Ceramic package, American Lava 25.4 x 50.8 mm (1 x 2 inch). Hand solder sealed tin plated Kovar lids using SN 10 solder in dry nitrogen atmosphere.	

*Electro Oxide, 3896 Burns Rd., Palm Beach Gardens, Florida
**Electro Science Laboratories, 1601 Sherman Ave., Pennsauken, N.J. 08110

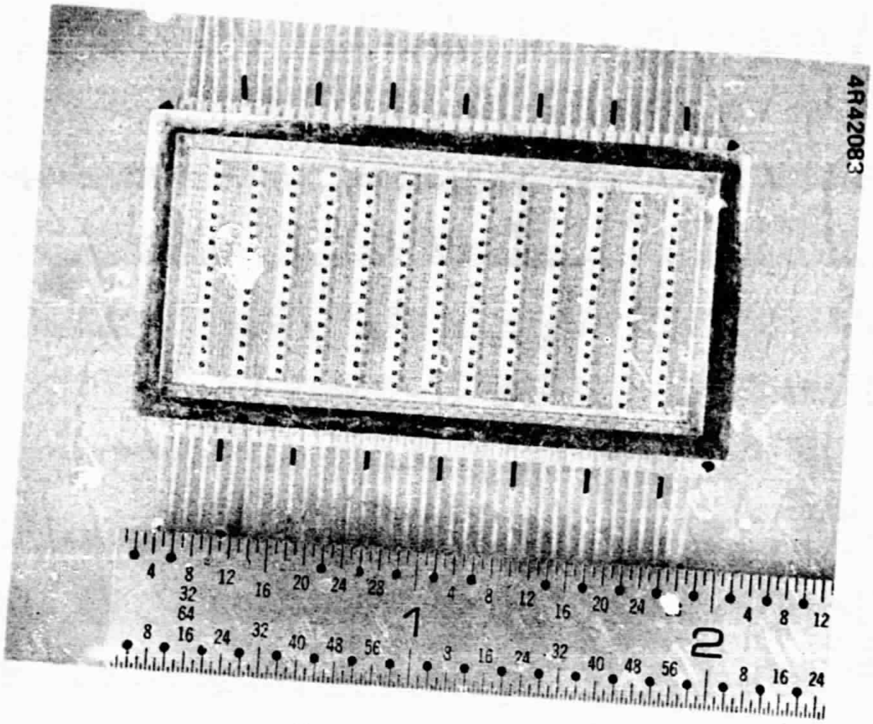


a. Complete Assembly

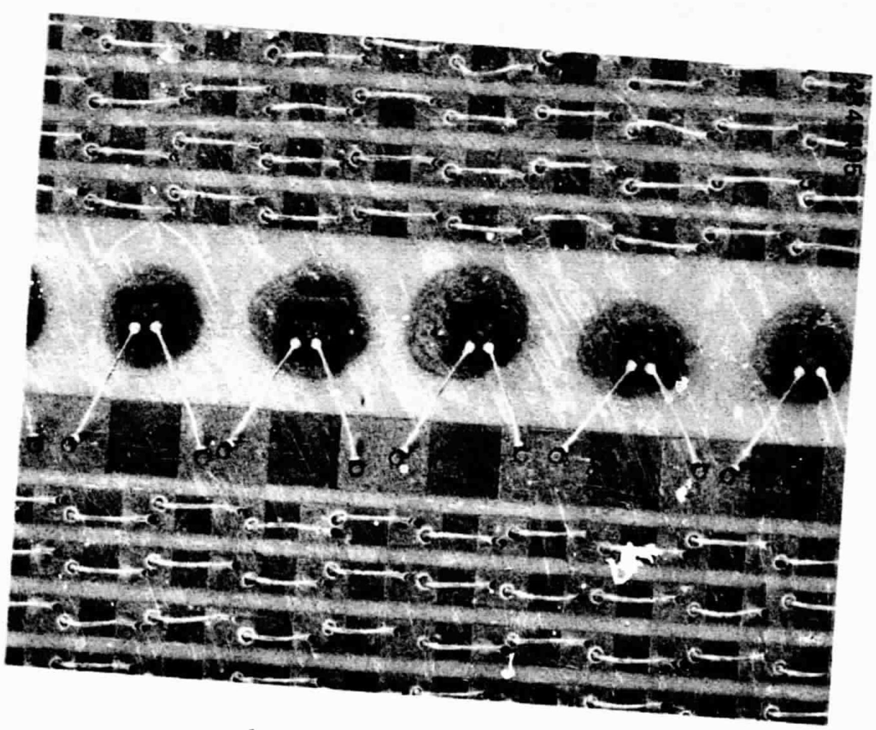


b. Assembly closeup

Figure 4. Assembled thick film test package.



a. Complete assembly



b. Assembly closeup

Figure 5. Assembled thin film test package.

1.3 HOLE PUNCHING AND PARTICLE REMOVAL

When PIN testing reveals the presence of particles in hybrids it is often desirable to remove and identify such particles. However, these particles are usually lost during lid removal or additional particles are introduced that make identification of the PIN failure cause extremely difficult. This phase of the study was concerned with removing particles by making a hole in a sealed package lid without harming the hybrid circuitry or introducing additional particles into the package.

Preliminary studies at Hughes had shown that punching a hole in a lid did not introduce particles and that if done properly the circuitry would not be harmed. It had also been noted that particles could be removed by inverting a package with a hole in the lid on the PIN tester and shaking the particle free.

After considering various hole punching approaches, it was decided that a screw-press arrangement would be the most satisfactory. The resulting fixture is shown in Figure 6. It consists of a conventional machinist's punch inserted into a threaded stem. This punch could be easily replaced when it became dull. The stem was threaded into the top plate of a fixture composed of two 152 x 152 mm (6 x 6 inch) plates separated by 152 mm (6") long posts at each corner. A handle was installed at the top of the stem and by noting the number of turns or partial turns of the threaded section, the depth of penetration of the punch into the package could be controlled.

Flat packages (with the leads passing through the sides of the package) could be positioned under the punch either by simply laying the package on the bottom plate or placing the package on suitable block. Since platform package leads pass through the package base, positioning under the punch required the use of a block slightly smaller than the distance between the rows of package leads, thereby eliminating any pressure on the package leads during the hole punching operation.

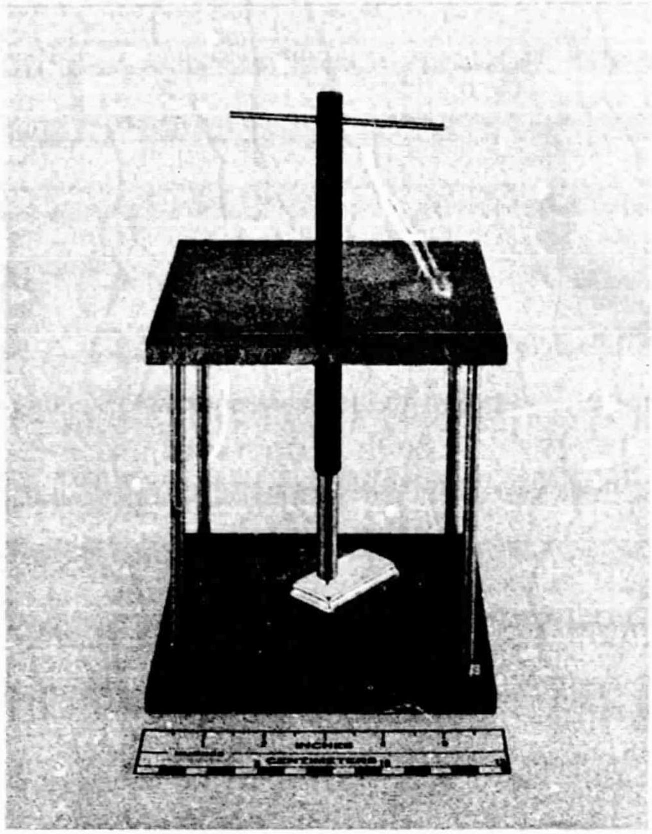


Figure 6. Hybrid package puncture fixture.

2.0 TEST PROCEDURE

2.1 WIRE BOND TESTING

After sealing, each package was fine and gross leak tested and electrical resistance measurements (ERM) made on each line of resistors in each package. The subsequent environmental test sequence, shown in Figure 7 consisted of temperature cycling from -65 to 150°C for 200 cycles, and elevated temperature storage at 150°C for 1000 hours. ERM were made before and after each 100 thermal cycles and after 100, 500, and 1000 hours at 150°C. Leak tests were made before and after thermal cycling and after 150°C exposure. PIN tests were made before and after thermal cycling. At the conclusion of all testing the packages were opened and inspected.

2.1.1 Test Description

A detailed description of the tests follows.

2.1.1.1 Leak Test

Fine leak testing – Fine leak testing was conducted per MIL-STD-883, Method 1014.1, by pressurizing the parts at two atmospheres for 160 minutes in helium and using a mass spectrometer to leak test the packages within the next 30 minutes. Parts were required to have a leak rate less than 5×10^{-7} standard atmosphere cc/sec. Gross leak testing was done in fluorocarbon fluid FC 43 at $125^{\circ}C$.

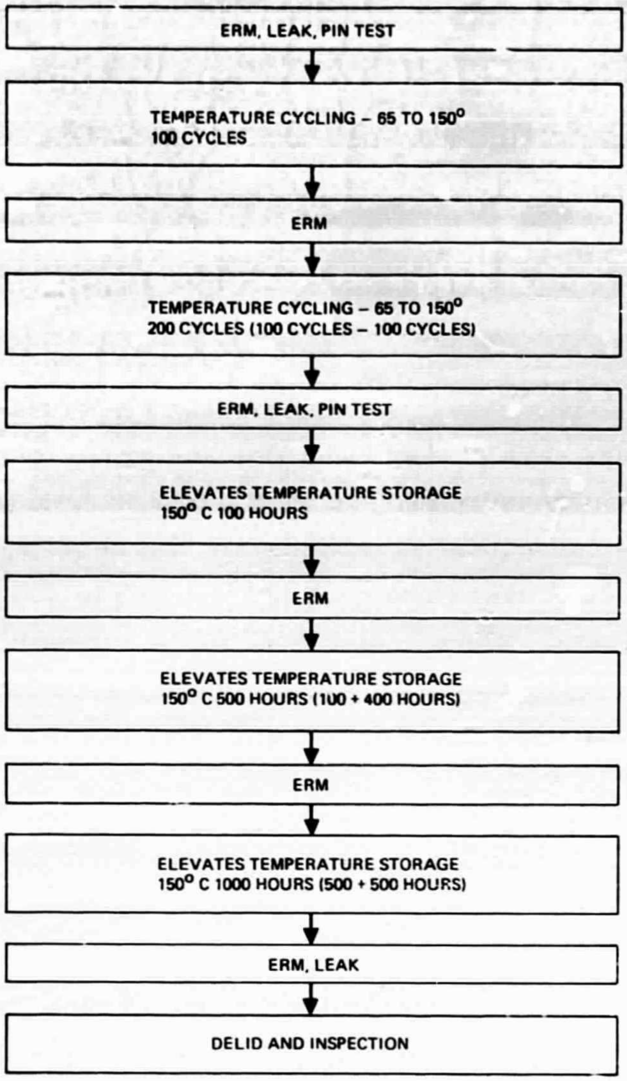


Figure 7. Environmental test procedure.

2.1.1.2 Particle Impact Noise (PIN)

The Particle Impact Noise (PIN) test was conducted using a frequency of 40 Hz and a displacement of 2.54 mm (0.1 inch), or 8 g acceleration. Audio (speaker) and visual (oscilloscope) criteria were used to monitor the results. A photograph of the PIN test assembly is shown in Figure 8.

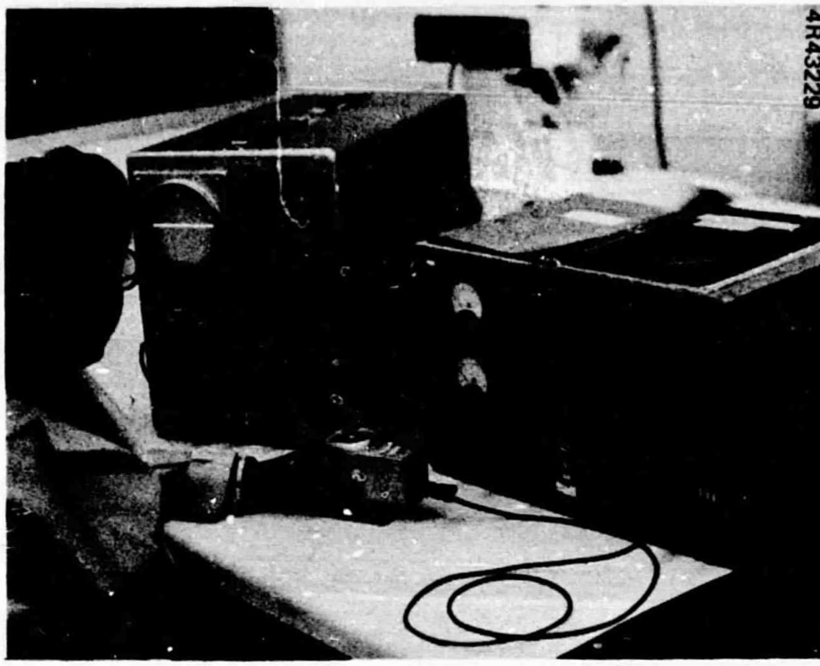


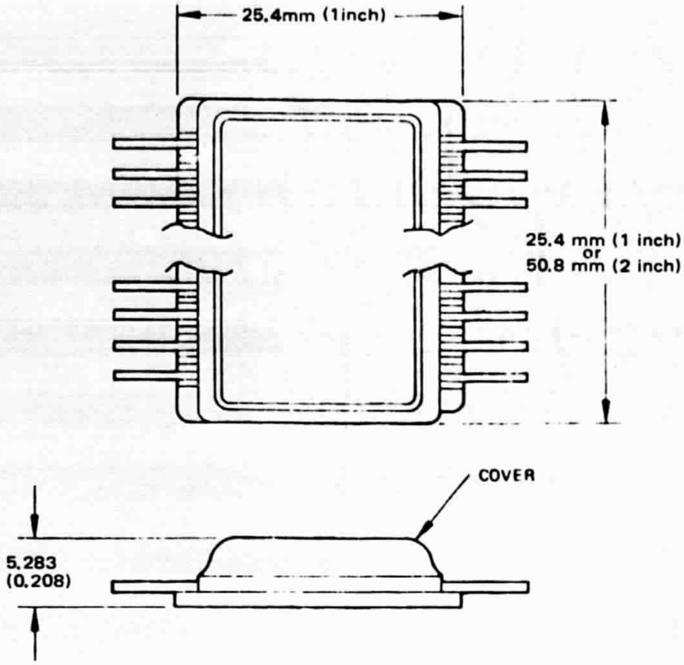
Figure 8. PIN test assembly.

2.1.1.3 <u>Electrical Resistance Measurements (ERM)</u>

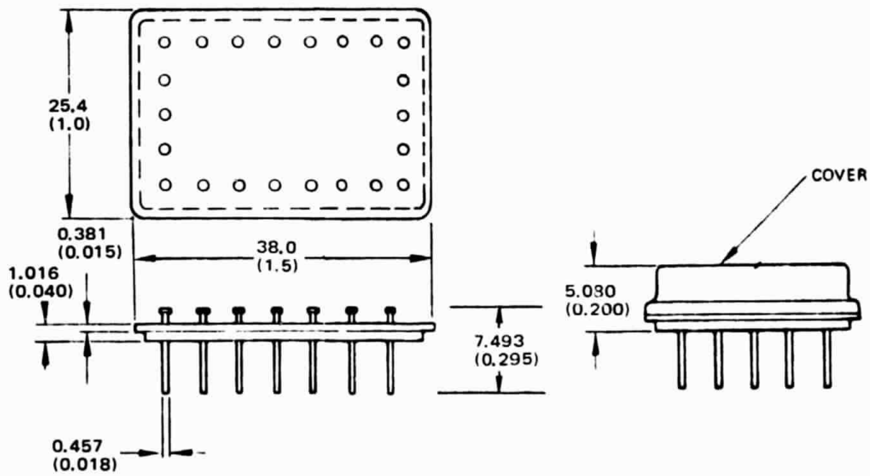
All electrical measurements were made by measuring the resistance between package leads using a Hewlett Packard Digital Voltmeter Model 3450.

2.2 PARTICLE REMOVAL

Ceramic 25.4 x 25.4 mm (1 x 1 inch) and 25.4 x 50.8 mm (1 x 2 inch) flat packages and 25.4 x 38.1 mm (1 x 1.5 inch) metal platform packages with tin plated Kovar lids 0.381 mm (0.015" thick) were sealed using SN 60 solder. The packages tested are shown in Figure 9. In some instances particles of solder, non-conductive epoxy, or aluminum and gold wires were introduced before sealing. In other cases holes were punched in the lids and the particles inserted through the hole.



a. Ceramic flat packages



b. Metal platform package

Figure 9. Particle removal test packages.

All packages were PIN tested, holes punched (if not already there) in the lids, Bordon's Mystikleer Tape No. 6432 tape placed over the holes, and each package inverted on the PIN tester transducer. A single hole size of 1.016 mm (0.040 inch) diameter was used throughout all testing. This diameter was selected because the as-received punch diameters were of that size and examination of previously punched holes showed no hybrid damage to have occurred.

The factors evaluated were: hole location, transducer angle during testing, PIN test frequency, ease of hole resealing, and any influence on the delidding and resealing of hybrid packages.

3.0 TEST RESULTS

3.1 WIRE BOND EVALUATION

3.1.1 Influence of Coatings

A description of each of the thick and thin film packages and the type and number of wire bonds in each, as well as the results of the thermal cycling and high temperature tests is contained in Table IV. A summation of the wire bond failures is listed in Table V.

These data show that the E5 coating had a detrimental effect on wire bond reliability. This was particularly noticeable in the behavior of ultrasonic aluminum substrate-to-substrate bonds to thick film gold metallization and of both ultrasonic aluminum and gold substrate-to-substrate bonds to thin film gold. In these cases the failures ranged from more than one percent to more than three percent of all wires.

Three of the four E5-containing packages that had many bond failures also failed leak testing at some point during environmental exposure. Though the three non-hermetic packages contained thin film substrates and the single hermetic package had a thick film substrate, there was no correlation between package hermeticity and bond failures.

The S1 coating had only a slightly detrimental influence on bond reliability. This was evident only among ultrasonic chip-to-substrate gold wires bonded to thin film gold in a hermetic package.

TABLE IV. BOND FAILURES RESULTING FROM ENVIRONMENTAL TESTS

PACKAGE NO.	SUBSTRATE TYPE	COATING MAT'L	CHIP-TO-SUBSTRATE NO. OF CHIPS	CHIP-TO-SUBSTRATE TYPE OF BOND	CHIP-TO-SUBSTRATE NO. OF WIRES	SUBSTRATE-TO-SUBSTRATE TYPE OF BOND	SUBSTRATE-TO-SUBSTRATE NO. OF WIRES	PIN TEST	INITIAL FINE LEAK	100 CYCLES WIRE LOSS	200 CYCLES WIRE LOSS	PIN TEST	200 CYCLES FINE LEAK	100 HRS 150°C WIRE LOSS	500 HRS 150°C WIRE LOSS	1000 HRS 150°C WIRE LOSS	1000 HRS FINE LEAK
1	THICK	S1	100	0.001* Al, U.S.	200	0.001 Al, U.S.	660	OK	4.6×10^{-9}	0 0	0 0	OK	5.9×10^{-6}(FFL)	0 0	0 0	0 0	F.G.L.
2	THICK	S1	100	0.001 Al, U.S.	200	0.001 Al, U.S.	660	OK	4.0×10^{-7}	0 0	0 0	OK	7.0×10^{-7}(FFL)	0 0	0 0	0 0	6.7×10^{-6}(FFL)
3	THICK	E5	100	0.001 Al, U.S.	200	0.001 Al, U.S.	639	OK	1.8×10^{-8}	0 2D,2C_2	0 0	OK	F.G.L.	0 0	0 0	0 0	F.G.L.
4	THICK	E5	100	0.001 Al, U.S.	200	0.001 Al, U.S.	660	OK	1.0×10^{-9}	0 0	0 0	F	5.1×10^{-9}	0 0	0 0	11B_1,30B_2	2.3×10^{-8}
5	THICK	NONE	100	0.001 Al, U.S.	200	0.001 Al, U.S.	660	OK	2.5×10^{-8}	0 0	0 0	OK	1.8×10^{-8}	0 0	0 0	0 1B_1, 1B_2	3.6×10^{-7}
6	THICK	NONE	100	0.001 Al, U.S.	200	0.001 Al, U.S.	660	OK	2.0×10^{-8}	0 0	0 0	OK	F.G.L.	0 0	0 0	0 0	F.G.L.
7	THICK	S1	100	0.001 Au, U.S.	200	0.001 Au, U.S. 0.002 Au, PTC	320 340	OK	3.4×10^{-9}	0 0 0	0 0 0	OK	5.9×10^{-6}(FFL)	0 0 0	0 0 0	0 0 0	4.8×10^{-5}(FFL)
8	THICK	S1	100	0.001 Au, U.S.	200	0.001 Au, U.S. 0.002 Au, PTC	320 340	OK	6.1×10^{-9}	0 0 0	0 0 0	OK	3.0×10^{-9}	0 0 0	0 0 0	0 0 0	5.5×10^{-8}
9	THICK	E5	100	0.001 Au, U.S.	200	0.001 Au, U.S. 0.002 Au, PTC	318 340	OK	1.8×10^{-7}	0 1D,1C_1 0	0 0 0	OK	F.G.L.	0 0 0	0 0 0	0 0 0	F.G.L.
10	THICK	E5	100	0.001 Au, U.S.	199	0.001 Au, U.S. 0.002 Au, PTC	320 340	OK	3.0×10^{-7}	0 0 1C_2	0 0 0	OK	F.G.L.	0 0 0	0 0 0	0 0 0	F.G.L.
11	THICK	NONE	100	0.001 Au, U.S.	200	0.001 Au, U.S. 0.002 Au, PTC	320 340	F	5.0×10^{-9}	0 0 0	0 0 0	F	1.0×10^{-8}	0 0 0	0 0 0	1C_2 0 0	4.0×10^{-8}
12	THICK	NONE	100	0.001 Au, U.S.	200	0.001 Au, U.S. 0.002 Au, PTC	320 340	OK	1.0×10^{-8}	0 0 0	0 0 0	OK	4.0×10^{-7}	0 0 0	0 0 0	0 0 0	3.1×10^{-8}

NOTE: U.S. ULTRASONIC BOND PTC: PULSED THERMO COMPRESSION BOND

.001 = 0.025 MM (0.001 INCH) DIA
.002 = 0.051 MM (0.002 INCH) DIA

A. LIFTING WIRE AT CHIP SURFACE
B. LIFTING WIRE AT SUBSTRATE INTERFACE, B1 INITIAL BOND, B2 FINAL BOND
C. WIRE BREAK SUBSTRATE TO SUBSTRATE, HEAL OF INITIAL BOND C_1, HEEL OF FINAL BOND C_2
D. WIRE BREAK IN LOOP AREA AWAY FROM INITIAL OR FINAL BONDS

F.G.L. FAIL GROSS LEAK
F.F.L. FAIL FINE LEAK

*EPOXY (SCOTCHCAST 281) SEALED IN AN ATTEMPT TO HERMETIC SEAL PKG THAT FAILED FINE LEAK TESTING

(Continued next page)

(Table IV, concluded)

PACKAGE NO.	SUBSTRATE TYPE	COATING MAT'L	CHIP-TO-SUBSTRATE NO. OF CHIPS	CHIP-TO-SUBSTRATE TYPE OF BOND	CHIP-TO-SUBSTRATE NO. OF WIRES	SUBSTRATE-TO-SUBSTRATE TYPE OF BOND	SUBSTRATE-TO-SUBSTRATE NO. OF WIRES	PIN TEST	INITIAL FINE LEAK	100 CYCLES WIRE LOSS	200 CYCLES WIRE LOSS	PIN TEST	200 CYCLES FINE LEAK	100 HRS 150°C WIRE LOSS	500 HRS 150°C WIRE LOSS	1000 HRS 150°C	1000 HRS FINE LEAK
13	THIN	S1	208	0.001 Al, U.S.	414	0.001 Al, U.S.	1592	OK	2.7 x 10	0 0	0 0	OK	F.G.L.	0 0	0 0	0 0	F.G.L.
14	THIN	S1	208	0.001 Al, U.S.	416	0.001 Al, U.S.	1593	OK	1.3×10^{-7}	0 0	0 0	OK	F.G.L.	0 0	0 0	0 0	F.G.L.
15	THIN	E5	208	0.001 Al, U.S.	416	0.001 Al, U.S.	1593	OK	5.9×10^{-6}(FFL)*	0 0	0 7C1 4C2	OK	F.G.L.	0 0	0 0	0 0	F.G.L.
16	THIN	E5	208	0.001 Al, U.S.	416	0.001 Al, U.S.	[illegible]93	OK	5.0×10^{-9}*	0 0	21C1, 6C	OK	2.5×10^{-6}(FFL)	0 0	0 0	0 0	4.8×10^{-5}(FFL)
17	THIN	NONE	208	0.001 Al, U.S.	416	0.001 Al, U.S.	1593	F	5.9×10^{-6}(FFL)*	0 0	0 0	F	F.G.L.	0 0	0 0	0 0	F.G.L.
18	THIN	NONE	208	0.001 Al, U.S.	416	0.001 Al, U.S.	1593	F	1.0×10^{-8}	0 0	0 0	F	2.0×10^{-9}	0 0	0 0	0 0	1.3×10^{-7}
19	THIN	S1	208	0.001 Au, U.S.	416	0.002 [illegible]u, PTC 0.001 Au, U.S.	811 782	OK	2.9×10^{-7}	0 0 0	0 0 0	OK	5.4×10^{-6}(FFL)	0 0 0	29A 0 0	13A 0 0	4.8×10^{-5} L)
20	THIN	S1	208	0.001 Au, U.S.	412	0.002 Au, PTC 0.001 Au, [illegible]S.	810 782	OK	2.9×10^{-6}(FFL)*	0 1B1 0	1A 0 0	OK	F.G.L.	0 0 0	0 0 0	0 0 0	F.G.L.
21	THIN	E5	208	0.001 Au, U.S.	416	0.002 Au, PTC 0.001 Au, U.S.	811 782	OK	1.0×10^{-9}	0 0 0	0 $1C_2$ $1C_2$	OK	2.1×10^{-8}	0 0 4C2	0 0 0	0 0 0	5.6×10^{-7}(FFL)
22	THIN	E5	208	0.001 Au, U.S.	416	0.002 Au, PTC 0.001 Au, U.S.	811 782	OK	4.0×10^{-6}(FFL)*	0 0 1B1.1C2	0 0 0	OK	F.G.L.	0 0 1C1 5B1 16C2	0 0 0	0 0 3A 1D1	F.G.L.
23	THIN	NONE	208	0.001 Au, U.S.	416	0.002 Au, PTC 0.001 Au, U.S.	811 782	OK	0.10×10^{-9}	0 0 0	0 0 0	OK	5.9×10^{-6}(FFL)	0 0 0	0 0 0	0 0 0	F.G.L.
24	THIN	NONE	208	0.001 Au, U.S.	416	0.002 Au, PTC 0.001 Au, U.S.	811 782	F	2.0×10^{-9}	0 0 0	0 0 0	F	2.0×10^{-9}	0 0 0	0 0 0	14A 0	1.2×10^{-7}

TABLE V. SUMMARY OF WIRE BOND FAILURES

Metallization	Coating	Wire (1)	Chip-Substrate			Substrate-Substrate		
			Total Bonds	No. of Bond Fail.	% Bond Fail.	Total Bonds	No. of Bond Fail.	% Bond Fail.
Thick Film	None	0.002 Au	-	-	-	680	0	0
	None	0.001 Au	400	1	0.25	640	0	0
	None	0.001 Al	400	0	0	1320	2	0.15
	E5	0.002 Au	-	-	-	680	1	0.15
	E5	0.001 Au	399	0	0	638	2	0.3
	E5	0.001 Al	400	6	1.5	1299	45	3.5
	S1	0.002 Au	-	-	-	680	0	0
	S1	0.001 Au	400	0	0	640	0	0
	S1	0.001 Al	400	0	0	1320	0	0
Thin Film	None	0.002 Au	-	-	-	1622	0	0
	None	0.001 Au	832	14	1.7	1564	0	0
	None	0.001 Al	832	0	0	3186	0	0
	E5	0.002 Au	-	-	-	1622	1	0.06
	E5	0.001 Au	832	0	0	1564	33	2.1
	E5	0.001 Al	832	0	0	3186	38	1.2
	S1	0.002 Au	-	-	-	1621	1	0.06
	S1	0.001 Au	828	43	5.2	1564	0	0
	S1	0.001 Al	830	0	0	3186	0	0
Thick and Thin Film	All	0.002 Au	-	-	-	6905	3	0.04
		0.001 Au	3691	58	1.6	6610	35	0.5
		0.001 Al	3694	6	0.2	13496	85	0.6

Note (1) : 0.002 = 0.051 mm (0.002 inch) diameter wire
0.001 = 0.025 mm (0.001 inch) diameter wire

The only significant control failures occurred among ultrasonic chip-to-substrate gold wires bonded to thin film gold in hermetic packages. There were only one-third as many failures in this instance as among comparison bonds in the S1 package.

There were some scattered PTB 0.051 mm (0.002") gold wire bond failures in the control, E5, and S1 test groups but these failures were few and no significance could be attached to their occurrence.

The S1 and E5 coatings remained transparent during all testing, though the originally colorless E5 turned amber in the non-hermetic packages. Since the E5 coating prevented the wires from lifting after bond failure, these parts had to be plasma cleaned before the failure modes could be ascertained by visual inspection.

3.1.2 Wire Bond Failure Modes

The failures of the various bonds were classified into four different modes

1. Lifting of the wire at the chip surface
2. Lifting of the initial or final bonds from a substrate
3. Wire fracture at the heel of the initial bond or the heel of a final bond to a substrate.
4. Fracture of a wire in an area away from either bond point.

The mode of each bond failure is listed in Table IV.

The majority of aluminum bond failures on the thick film patterns were characterized by a lifting of either the initial or final bond from the bonding surfaces. Examples of such failures are shown in Figure 10. There were few aluminum wire fractures in the necked down region of the wire, such as that illustrated in Figure 11.

In contrast, the majority of thin film bond failures were due to aluminum wire fracture in the necked-down regions, or from the fracture of gold wire. These gold wire failures were primarily characterized by fracture of either the wire near the initial ball bond or the flattened wire of the final bond. Examples of these are shown in Figure 12. However, there were some initial gold wire bonds that lifted from the thin film gold. Figure 13 illustrates this latter condition.

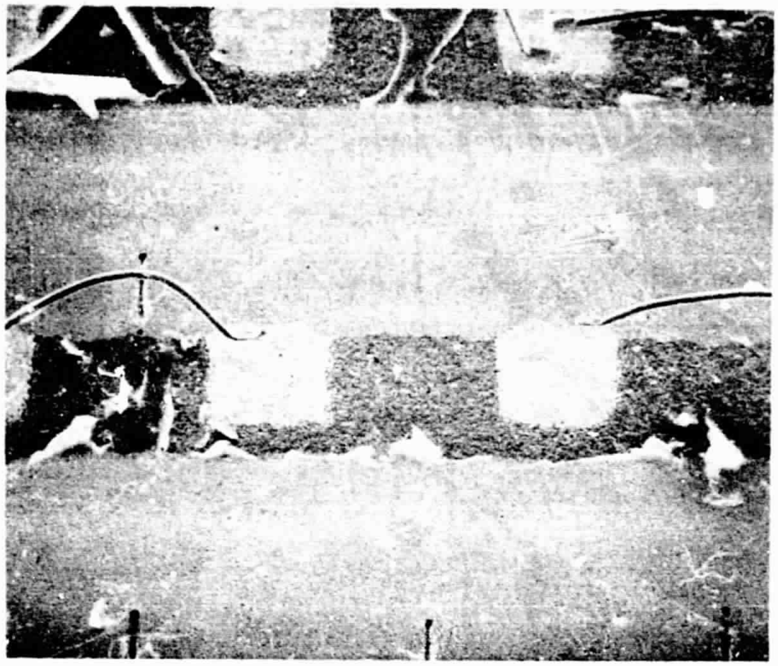


Figure 10. Ultrasonic aluminum wire bond failures. These failures of initial (right) and final (left) bonds occurred by the bonds lifting from the thick film gold pads. The plasma cleaned part had been coated with E5 epoxy. 49X

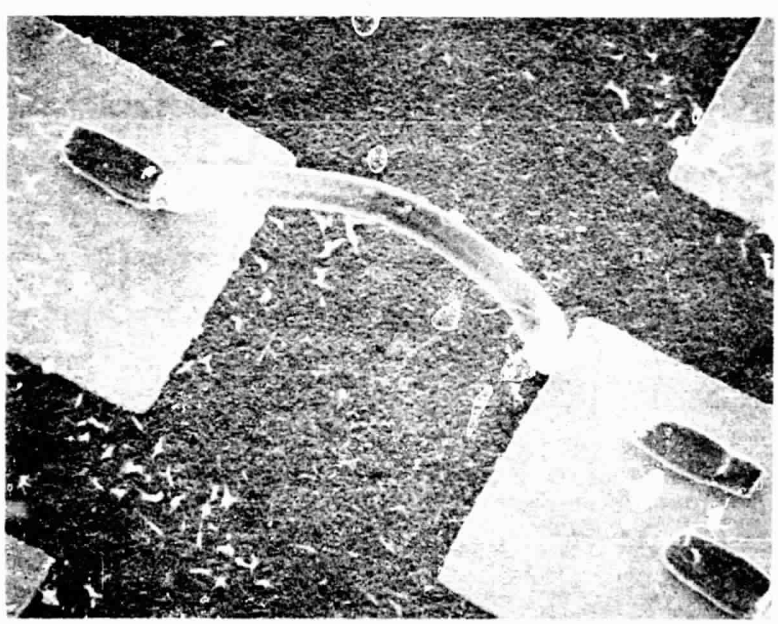


Figure 11. Ultrasonic aluminum wire bond fracture. Failure was due to ductile fracture. The plasma cleaned part had been coated with E5 epoxy. 196X

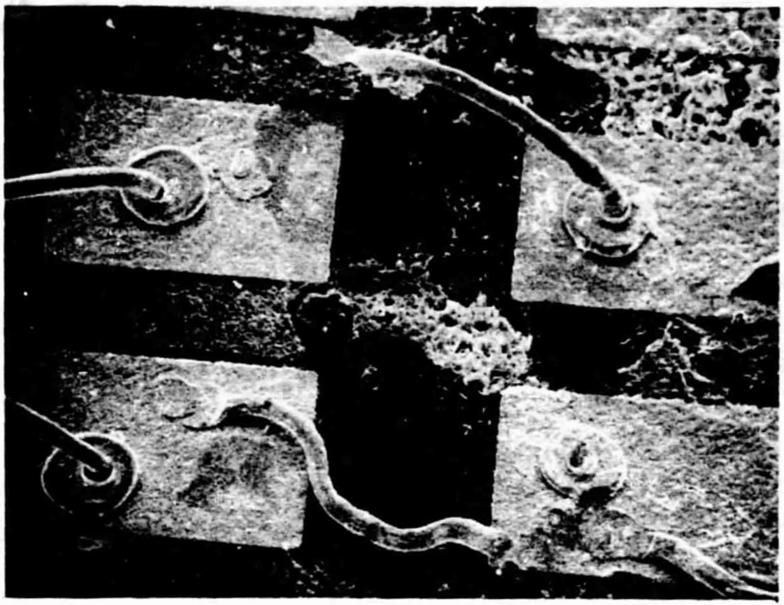


Figure 12. Ultrasonic gold wire bond fractures. Both the substrate bond at the top and the wire break at the bottom failed by ductile fracture. The plasma cleaned part has been coated with E5 epoxy. 110X

Figure 13. Ultrasonic gold wire bond failure. The ball had lifted from the thin film gold of the plasma cleaned E5 coated part. 200X

It must be noted that the flattened appearance of the final gold wire bonds made it difficult to differentiate between bond fracture and bond lifting. The following criterion was adopted: If there was any section of wire left on the substrate the failure was judged to be a ductile fracture. This effectively eliminated bond lifting as a failure mode.

The initial gold bond failures were much easier to classify and the fracture mode was readily identified in each case. This is why the initial bond failures were a mixture of fracture and lifting.

The differences between thick and thin film bond failure modes apparently resulted from two factors:

1. the copper oxide was not completely removed from the thick film gold surface during the ammonium persulfate immersion, and
2. the E5 epoxy exerts a tensile or wedging force during environmental exposure. This thin oxide layer on the thick film gold would tend to weaken any bonds, which would then lift under the constant load introduced during the E5 expansion. In contrast, there was no oxide on the thin film gold and the majority of failures would therefore occur by fracturing of the wires.

3.1.3 The Influence of Environmental Testing

The majority of bond failures occurred during high temperature exposure. Of the sensitive combinations (those having large numbers of failures) involving 0.025 mm (0.001 inch) dia wire, only the E5 coated aluminum substrate-to-substrate wire bonds to thin film substrates failed primarily during thermal cycling. These failures occurred after 200 cycles and, as mentioned above, were characterized by bond fracture in the necked-down portions of the wires.

Since thermal cycling preceded high temperature exposure it is not possible to ascertain how the thermal cycling influenced the high temperature exposure behavior, but there is evidence that thermal cycling had a relatively minor influence. For example, the thin film E5 coated aluminum wire bond groups with many failures after thermal cycling did not have any failures during the subsequent 1000 hours at 150°C.

PIN testing during the initial stages of environmental testing revealed two packages with internal particles. These were later found to be caused by loose aluminum wires. One package, having a thick film substrate with E5 coating, failed PIN testing after thermal cycling. The other package, having a thin film substrate and no coating, failed PIN testing immediately after sealing. It is unlikely that particles in these packages could have caused bond failures. The packages were not shaken except for normal handling during any of the environmental testing. The bonds of one package were protected with an epoxy coating. Also all failures occurred during the last stages of the high temperature exposure; if the particles had been a cause of failure, then some bond failures would have been noted during the earlier test stages Also, the remaining wires would have been bent or deflected from their normal positions. No such wire movement was noted when the packages were delidded.

3.1.4 Wire Bond Reliability

The data of Table V show 0.051 mm (0.002") pulse-thermocompression gold bonds to be much more reliable than either the ultrasonic gold or ultrasonic aluminum bonds. There were only 3 failures or 0.04% of 6906 0.051 mm (0.002") gold wire bonds tested in the entire program.

Deciding on the comparative reliability of ultrasonic gold and ultrasonic aluminum bonds was difficult. Comparing the total failures of both wire materials showed a slightly lower percentage of gold substrate-to-substrate failures, but the percentage of aluminum chip-to-substrate failures was noticeably smaller.

Attempts to relate the percentage failures to the sample conditions, i.e., whether coated and what type of coating, were less conclusive because there was no duplicate sample for correlation. As an example, though 15 of 1664 control sample gold ultrasonic bonds failed, 14 of these failures occurred in one test package and were all characterized by the lifting of the initial bonds from the chips.

Though duplicate behavior among replicates was lacking, the failures of aluminum ultrasonic substrate-to-substrate bonds to both thick and thin film E5 coated samples did indicate that these bonds were somewhat more likely to fail than ultrasonic gold wire bonds. A comparison of substrate-to-substrate bonding showed that 0.3% of the E5 thick film gold bonds and 3.5% of the aluminum bonds failed, while the E5 thin film gold and aluminum failure rates were 2.1 and 1.2 percent respectively.

In summary, the general behavior of these ultrasonic 0.0254 mm (0.001") diameter wire bonds shows that gold bonds to gold metallizations are slightly better than aluminum bonds to gold metallizations, and that aluminum bonds to aluminum metallizations were less likely to fail than gold bonds to aluminum. An overall comparison based on the influence of the E5 coatings on both the thin and thick film substrates slightly favors gold ultrasonic bonding.

3.2 PARTICLE REMOVAL

The most satisfactory method of particle removal involved the punching of a hole in the corner of the package, placing a small piece of tape over the hole, inverting the package and attaching the package to the transducer head of the PIN tester with double-backed tape, and tilting the transducer assembly so that the particles had a natural tendency to migrate to the package hole area. By gradually increasing the vibration frequency and watching the particle indication on the oscilloscope it was possible to remove particles in a few seconds. When there was a large number of particles it was sometimes necessary to replace the tape since particles still in the package would bounce off those previously captured.

The inward taper of the hole resulting from the punching operation was no obstacle to particle removal.

The most important factors were the location of the hole, frequency of vibration, and tilting of the package. It was quite difficult to remove particles through a hole in the center of the lid because the dent in the lid (produced during hole-punching) opposed particle movement to the hole, and no advantage could be gained by tilting the package. Holes along package lid edges were more satisfactory, since tilting would aid particle movement to the desired area. Placing the hole at the package corner facilitated even easier particle removal since the particles would be essentially funneled to the hole when the package was tilted. Examples of the various particles that have been removed in this manner are shown in the scanning electron microscope pictures of Figures 14, 15, and 16. Pieces of gold or aluminum wire, solder balls, and sections of damaged chips or substrates were all recovered from packages using this method.

Attempts to reseal the particle-removal hole in the tin plated package lid were unsuccessful. The solder used for hole sealing would not wet the punctured surfaces or satisfactorily bridge the hole opening and though attempts were not made to solder-seal punched holes in gold plated lids, it would appear that this would be unsuccessful for the same reason. Naturally, flux could not be used for sealing because of possible hybrid contamination. Perhaps the use of smaller exit holes would have allowed resealing of some packages, but there remained the question of solder ball contamination either by the formation of new particles, or the shorting of hybrid circuitry to the lid by the creation of "solder stalacites". It may appear that this latter occurrence is unlikely since package lids with dimpled vent holes are in use and are soldered shut following lid-base sealing. However, the dimpled hole is considerably smaller, is completely covered with plating, and the walls of a dimpled hole do not extend inward to the same extent as the walls of punched holes.

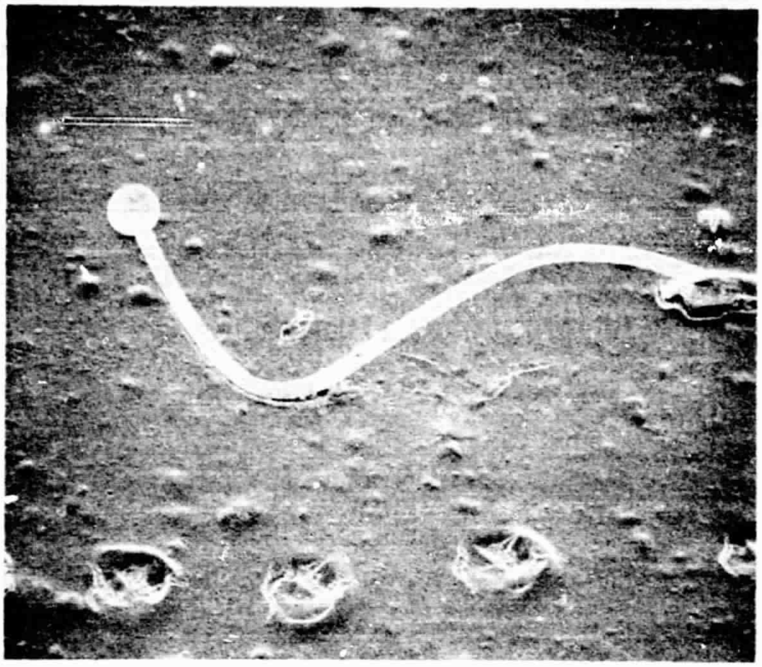


Figure 14. Gold wire, 0.051 mm (0.002 inch) diameter, captured by tape during PIN testing.

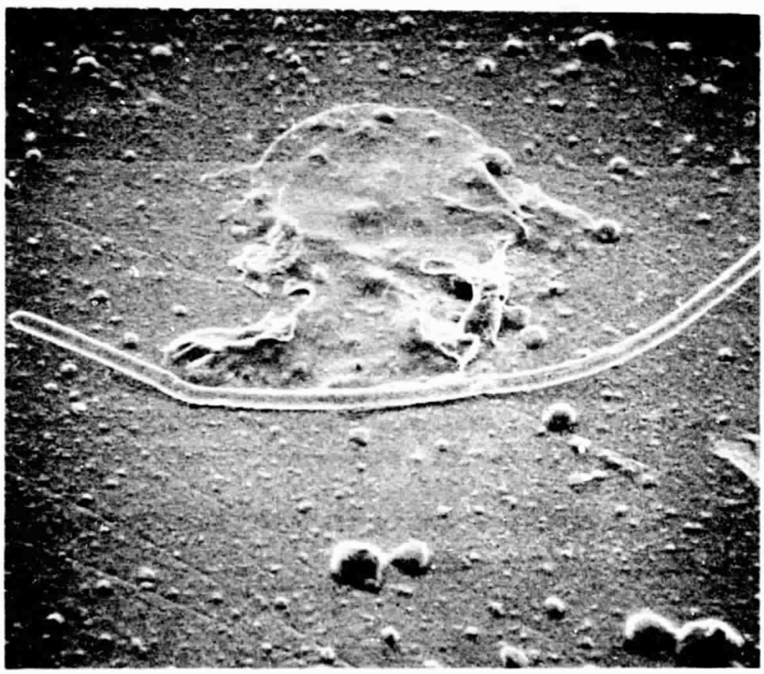


Figure 15. Aluminum wire 0.025 mm (0.001 inch) diameter captured by tape during PIN testing.

Figure 16. Solder particle 0.203 mm (0.008 inch) diameter captured by tape during PIN testing.

4.0 CONCLUSIONS

The following conclusions were made based on the results of this investigation:

- The E5 coating had a significantly detrimental effect on wire bond reliability.
- The S1 coating had a slightly detrimental effect on wire bond reliability.
- Ultrasonic bonds to thick film were more reliable than comparable bonds to thin film.
- Ultrasonic aluminum bonds to the chip metallization were more reliable than ultrasonic gold wire bonds.
- Thermocompression bonds of 0.051 mm (0.002 inch) gold wire were more reliable than ultrasonic 0.025 mm (0.001 inch) aluminum or gold wire bonds.
- Though a clear separation between ultrasonic gold and ultrasonic aluminum bonds was not evident, the gold bonds, because of fewer substrate failures, appeared to provide slightly greater reliability.
- It is possible without first removing the lids to remove the vast majority of particles (for identification purposes) from flat package or platform package hybrids that have failed PIN testing. This can be done without harming the hybrids, but a new lid must be used to once again seal such hybrids.

5.0 REFERENCE

1. Contamination Control in Hybrid Microelectronic Modules (Final Report), Contract NAS 8-30876, April 1975.

APPENDIX

The following is the approach used to determine the allowable resistor tolerances when designing wire bond test patterns.

Let

V = mean resistance value

T = resistor tolerance

R = resistance reading of a given series of resistors

n = number of open bonds

1. The nominal value of any resistor is $V \pm TV$
2. The number of opens (assuming R_o, the original resistance, ~ 0) would be $R/V \pm TV = n$
3. For (a) $n = 1$, R_1 is $V-TV \leq R_1 \leq V+TV$

   (b) $n = 2$, R_2 is $2V(1-T) \leq R_1 \leq 2V(1+T)$

   (c) $n = x$, R_x is $XV(1-T) \leq R_x \leq XV(1+T)$
4. Then the next open resistor, $n = X+1$, would produce a resistance $R_x + 1$ of

   $(X+1)(V)(1-T) \leq R_{X+1} \leq (X+1)(V)(1+T)$
5. To detect a difference of one ohm (1Ω) between the maximum resistance obtained for a given number of resistors (X) and the minimum additional resistance realized by including one more resistor (X+1), the right hand term of item 3c plus 1Ω would have to equal the left hand term of item 4.

   $XV(1+T) + 1 = (X+1)(V)(1-T) = (XV+V)(1-T)$

   $XV + XVT + 1 = XV + V - XVT - XT$

   $2\,XVT + XT = T(2XV+X) = V - 1$

Then the tolerance would be

$$T = \frac{V-1}{X(2V + 1)}$$

6. Condition 1 — Thick Film

There was a maximum of 20 resistors in each resistor line of the thick film pattern. Assuming that five bonds failed (25 percent of the 20 wires) then

$$T = \frac{V-1}{V(2X+1)} = \frac{190 - 1}{190\ (5(2) + 1)} = \frac{189}{190\ (11)} = 9.0 \text{ percent}$$

$(190)\ (0.09) = 17\Omega$

$190 \pm 17\Omega$

7. Condition 2 — Thin Film

There was a maximum of 29 resistors in each resistor line of the thin film pattern. Assuming that 7 wires (25 percent of 29) failed then:

$$T = \frac{V-1}{V(2X+1)} = \frac{240 - 1}{240\ (14+1)} = \frac{239}{240\ (15)} = 6.7 \text{ percent}$$

$(240)\ (0.067) = 16\Omega$

$240 \pm 16\Omega$