Substrate Cleanliness for Gold Ball Wire Bonding

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Purpose:

1. Determine the effects of contamination on gold ball bonding to substrates caused by handling of the substrates.
2. Establish a cleaning procedure to eliminate contamination of substrates caused by handling.

Conclusions:

1. Handling of substrates with bare fingers leads to a greatly reduced level of adhesion between the gold ball bond and the gold metallization on the substrate due to organic contamination and surface topography changes.
2. The use of a high pressure spray (30 - 80 PSI) of 1,1,1-Trichloroethane will remove contaminants (primarily organic) from the substrate surface thereby allowing optimum conditions for gold ball bonding.
3. The use of latex finger cots to handle substrates eliminates organic contamination and surface topography changes thereby giving an increased level of bond strength.

Discussion

Due to a high incidence of failures during non-destructive bond pull strength testing on Microwave Integrated Circuits (MIC) a study was initiated to determine the primary cause of the failures and establish a method for reducing the failure rate.

Initial investigations of the questionable parts revealed the primary failure mode to be an adhesive failure at the interface of the gold ball or wedge and the gold metallization on the substrate surface. The tensile strength of the gold wire tested to well within specifications and there were no failures as a result of the wire breaking above the actual bond. Based upon these initial findings, it was decided to look at the interface of the gold metallization to the gold wire bond as the primary cause of failure.

The primary reliability problem in thermosonic gold ball bonding lies with the adherence of the bond to the substrate surface. In order for the bond to be able to meet the pull test requirements of MIL-STD-883 there must be a true metallurgical weld formed between the gold wire and the substrate surface. The introduction of surface contaminants on the substrate causes a poor bond to occur which leads to either a non-bondable condition or a weakened structural integrity of the formed bond. Surface contaminants could also cause poor electrical performance due to a boundary layer of contamination existing within the bond interface. This study will concentrate only on the effects of surface contaminants on the structural integrity of the bond as related to bond pull strength and shear strength testing. I will also look at establishing a simple but effective cleaning method to remove contaminants from the substrate surface and thereby increase ball bond reliability on questionable substrates.

In order to evaluate the gold metallization on the substrate where bonding would occur (henceforth called the substrate surface), Scanning Electron Microscopy (SEM) analysis was performed on a clean substrate directly out of the packaging material (Fig. 1). The new substrate surface exhibits no signs of contamination or surface irregularities. When 1.0 mil gold wire was bonded to this surface, the only failure modes identified were attributed to surpassing the break strength of the wire itself (Table I). Theoretically, this would be considered a cohesive failure. The standard deviation associated with the bond pull results indicates a statistically accurate sample and these results will be used as a control group for the remaining portions of the investigation. Shear test results on this sample (Table II) showed that 85% of the ball bonds were cohesive failures (Fig. 7), indicating that the ball bond to substrate interface was reliable and the gold/gold weld was correctly formed.

Introduction of surface contaminants to a substrate surface was accomplished by picking the substrate up with a bare finger. This technique was used since it is the most probable cause of contaminant introduction to the substrate due to the current in-plant handling procedures. SEM analysis of the substrate surface after being picked up (Fig. 3) indicates a high degree of surface contamination and surface topography changes. Further analysis revealed that the identifiable constituents of the contamination were organic in nature. Attempts at placing wire bonds on this surface were extremely difficult and yielded only a 30.9% success rate at the bonding operation. Pull testing of the successful bonds revealed that the primary mode of failure in this case was also cohesive failure, however, shear testing revealed that 86.6% of the ball bonds failed as a result of adhesive failure between the ball and the substrate (Fig. 6).

In order to determine whether the surface contamination and topography changes were the primary cause for the change from a cohesive to an adhesive failure mode in the bonds, a method was developed to return the substrate to a condition as close to the control substrate as possible. 1,1,1-Trichloroethane was chosen as the solvent to remove organic contamination from the gold surface due to it's high activity level. Application of the solvent was accomplished by using an airbrush with 30 PSI of pressure. The combination of solvent and pressure would either dissolve or dislodge any contaminants on the substrate surface.

The contamination and particulate matter are easily seen on the test substrate (Fig. 3). Once the test substrate has been cleaned using the solvent/air pressure method previously described, the surface (Fig. 4) is free of any visible contaminants and appears to have the same topography as the control sample (Fig. 1). Bonding to the newly cleaned surface was considerably easier with an 85% success rate at the bonding operation as compared to the previous 30.9%. Bond pull testing revealed a return to the higher strengths seen in the control substrate and shear testing indicated primarily cohesive failures with a closer sample grouping as indicated in the standard deviations.

Additional testing of the cleaning method was conducted on the control substrate to determine the effects of the process on an "uncontaminated" substrate. SEM analysis of the surface revealed no visible changes (Fig. 2), however, there was a complete elimination of adhesive failures in the bonds. Based upon these results, it appears that the use of the new cleaning method is beneficial on new parts to remove any surface contamination left during manufacture and packing of the substrates.

Having determined a method for cleaning the substrates, the necessity now exists for a method of handling them without leaving any contaminants on the surface or affecting the surface topography. The use of latex finger cots was evaluated for handling by using them to pick up and wipe across a substrate surface. Analysis of the surface which was contacted by the finger cots shows no evidence of contamination (Fig. 5) or topography changes and bond pull and shear strength testing reveals a level of reliability consistent with the control substrate.

Summary:

The existence of organic contaminants on the surface of substrates leads to a decreased level of wire bond reliability. The primary reason for failure appears to be the buildup of a layer of organic material on the surface of the gold metallization which reduces the area actually welded during the bonding operation. Adhesive failures of the bond (Fig. 6) indicate almost no disruption of the metallization when the ball is sheared from the surface while cohesive failures are firmly adhered to the metallization (Fig. 7) and shear within a plane internal to the ball bond itself. An additional problem with organic contamination of the surface is the hygroscopic nature of organic materials which could lead to corrosion within the weld over time. Particulate material on the bonding surface is also detrimental to the process if the particles are harder than the gold in which case they could punch through the gold during the thermosonic bonding operation.

The high pressure solvent spray has no negative effects on the substrate or components and the wire bonds remain intact under a pressure as high as 80 PSI. Based upon the results of this study, the new cleaning process has been instituted as a standard part of the bonding operation and will be performed on substrates prior to actual gold ball bonding.

TABLE I

RESULTS OF BOND PULL TESTING

TEST SAMPLE DESCRIPTION	% OF BONDS ADHERING TO GOLD CIRCUIT	PULL TEST RESULTS (GRAMS)		FAILURE MODE	
		AVG.	STD. DEV.	TYPE	QTY.
A)NEW SUBSTRATE	100	8.42	0.67	1	7
(CONTROL)		8.51	0.50	2	10
		--	--	3	0
		--	--	4	0
		--	--	5	0
B)SUBSTRATE SPRAYED WITH	100	9.30	0.40	1	2
1,1,1-TRICHLOROETHANE FOR		9.04	0.64	2	15
20 SECONDS AT 30 PSI		--	--	3	0
		--	--	4	0
		--	--	5	0
C)SUBSTRATE WIPED ACROSS WITH	30.9 (17/55)	9.02	0.81	1	5
FINGER TO INTRODUCE ORGANIC		8.02	0.58	2	4
CONTAMINATION		7.80	0.0	3	1
		1.20	0.0	4	1
		3.25	1.08	5	6
D)SUBSTRATE WIPED ACROSS WITH	85.0 (17/20)	9.65	0.88	1	9
FINGER TO INTRODUCE ORGANIC		9.06	0.46	2	5
CONTAMINATION FOLLOWED BY		7.30	0.0	3	1
1,1,1-TRICHLOROETHANE SPRAY		--	--	4	0
FOR 40 SECONDS AT 30 PSI		7.95	0.45	5	2
E)SUBSTRATE SPRAYED WITH	100	10.59	1.11	1	11
1,1,1-TRICHLOROETHANE FOR		9.02	0.48	2	4
20 SECONDS AT 30 PSI		--	--	3	0
FOLLOWED BY WIPING ACROSS		--	--	4	0
TRACES WITH A FINGER COT		8.00	0.20	5	2

FAILURE MODE KEY:
1 - WIRE BREAK MID-SPAN
2 - WIRE BREAK ABOVE THE BALL OR FIRST BOND TRANSITION
3 - "LIFT-OFF" OF SECOND BOND
4 - "LIFT OFF" OF THE BALL OR FIRST BOND
5 - HEEL BREAK AT WEDGE ON SECOND BOND

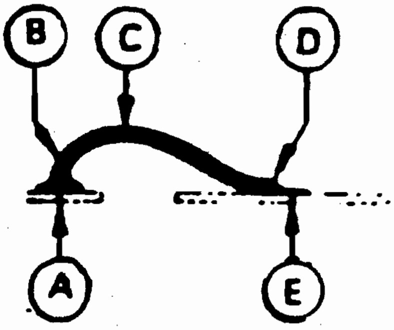
TABLE II

RESULTS OF BOND SHEAR TESTING

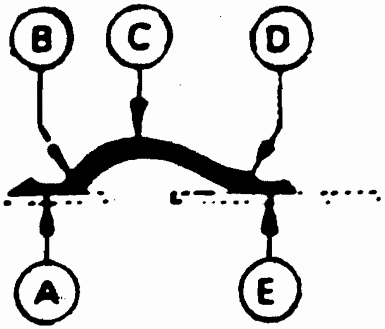
TEST SAMPLE DESCRIPTION	SHEAR TEST RESULTS (GRAMS) AVG.	STD. DEV.	FAILURE MODE TYPE	QTY.
A)NEW SUBSTRATE (CONTROL)	65	5.25	1	3
	78	7.68	2	17
B)SUBSTRATE SPRAYED WITH 1,1,1-TRICHLOROETHANE FOR 20 SECONDS AT 30 PSI	--	--	1	0
	74	12.36	2	14
C)SUBSTRATE WIPED ACROSS WITH FINGER TO INTRODUCE ORGANIC CONTAMINATION	53	22.11	1	39
	51	14.22	2	6
D)SUBSTRATE WIPED ACROSS WITH FINGER TO INTRODUCE ORGANIC CONTAMINATION FOLLOWED BY 1,1,1-TRICHLOROETHANE SPRAY FOR 40 SECONDS AT 30 PSI	51	7.87	1	8
	67	5.63	2	11
E)SUBSTRATE SPRAYED WITH 1,1,1-TRICHLOROETHANE FOR 20 SECONDS AT 30 PSI FOLLOWED BY WIPING ACROSS TRACES WITH A FINGER COT	50	12.25	1	4
	62	4.94	2	11

SHEAR MODE KEY
1 - ADHESIVE FAILURE (BALL POPPED)
2 - COHESIVE FAILURE (BALL SHEARED)

WIRE BOND FAILURE MODES



Tailless ball and stitch



Multiple stitch

DESTRUCT CODE	
4	**A. "Lift-off" of the ball or first bond.**
2	**B. Wire break above the ball or first bond transition.**
1	**C. Wire break mid-span.**
5	**D. Heel break at wedge on second bond.**
3	**E. "Lift-off" of second bond.**

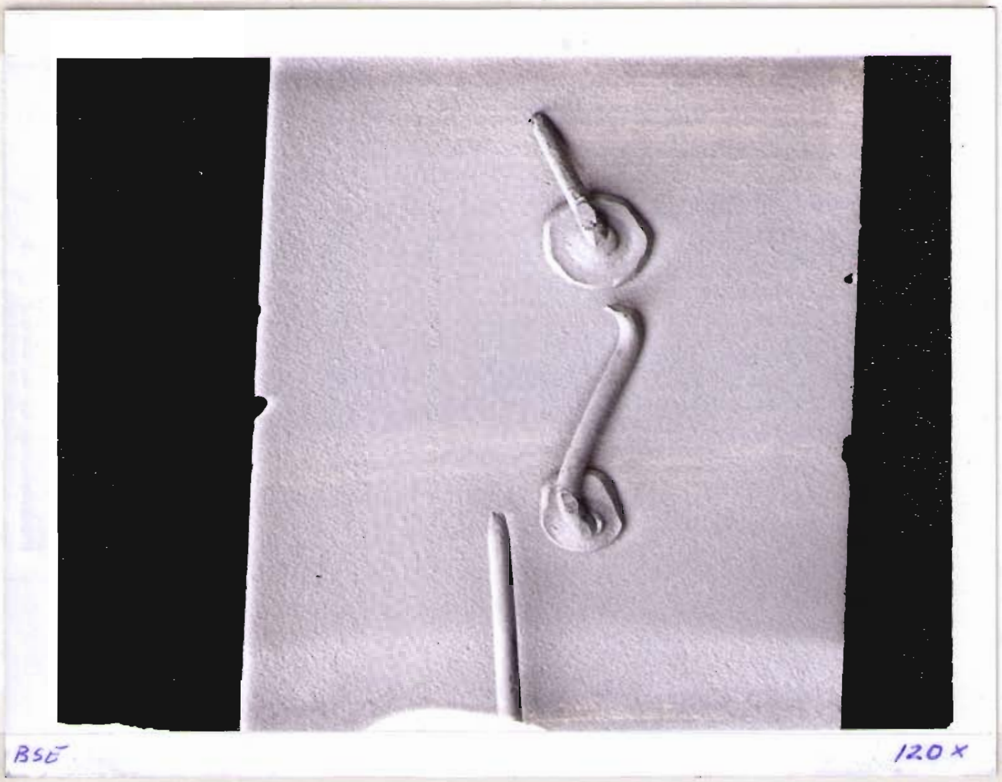


Fig. 1

NEW SUBSTRATE (CONTROL)

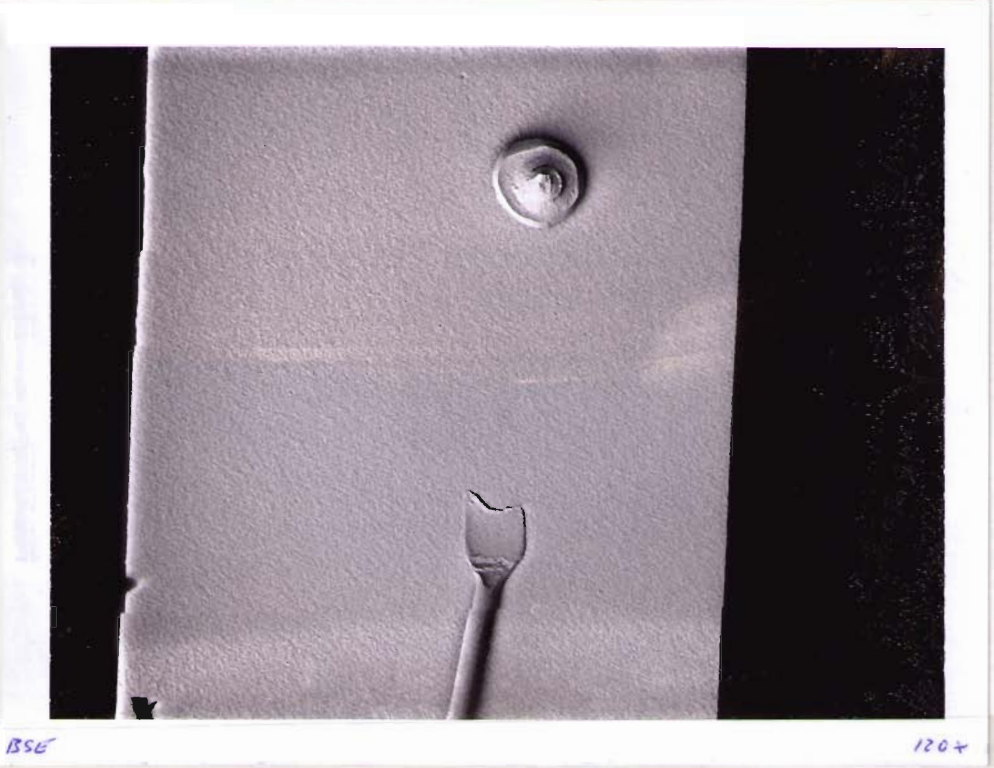


Fig. 2

SUBSTRATE SPRAYED WITH 1,1,1 - TRICHLOROETHANE FOR 20 SECONDS AT 30 PSI

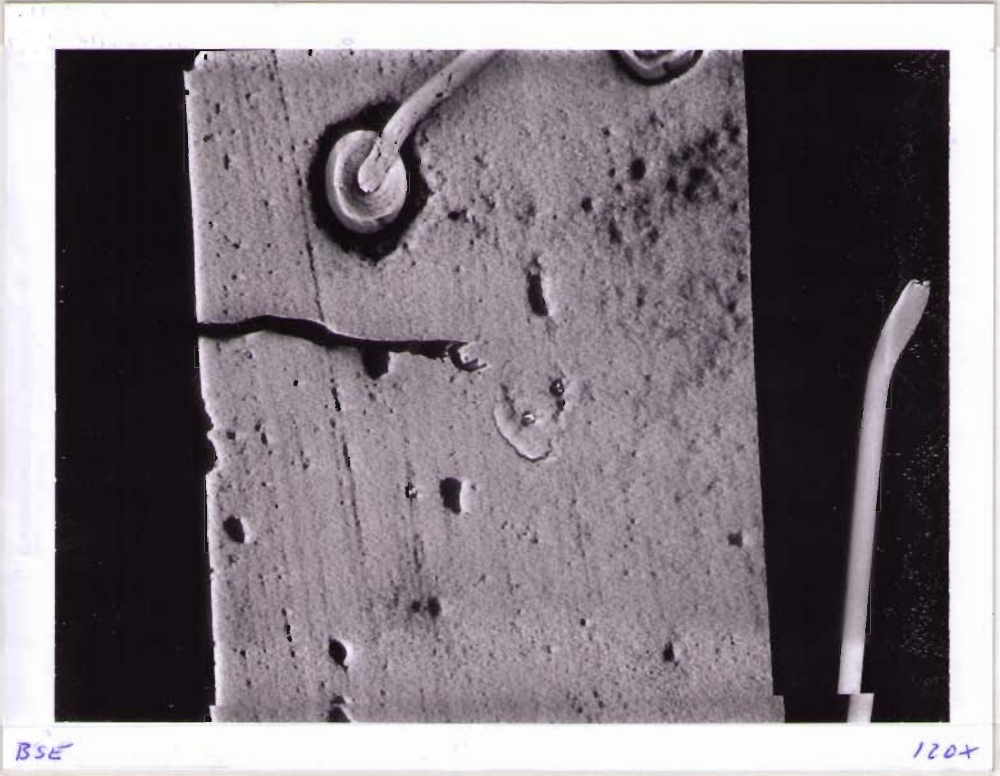


Fig. 3

SUBSTRATE WIPED ACROSS WITH FINGER TO INTRODUCE ORGANIC CONTAMINATION

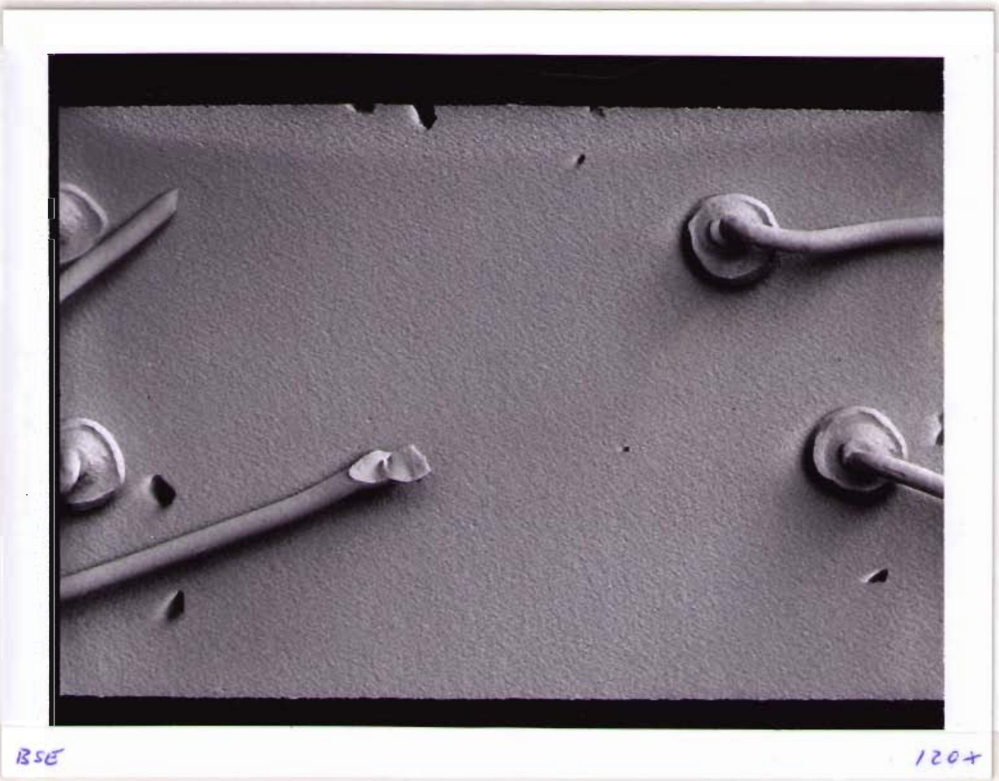


Fig. 4

SUBSTRATE WIPED ACROSS WITH FINGER TO INTRODUCE ORGANIC CONTAMINATION FOLLOWED BY 1,1,1 - TRICHLOROETHANE SPRAY FOR 40 SECONDS AT 30 PSI

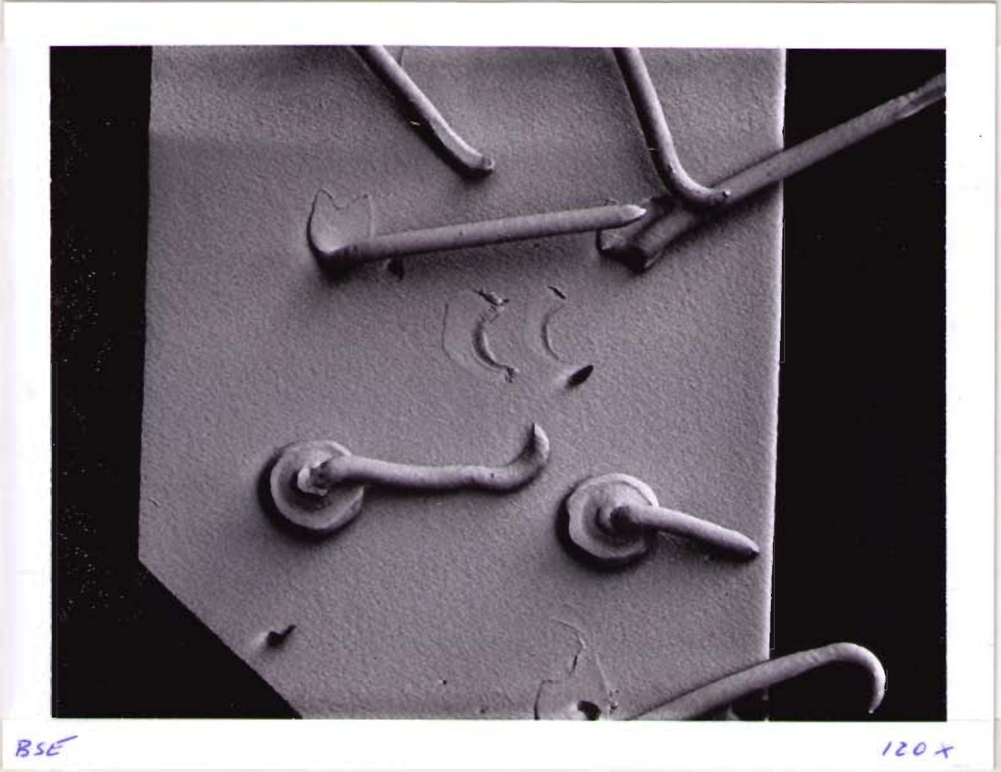


Fig. 5

SUBSTRATE SPRAYED WITH 1,1,1 - TRICHLOROETHANE FOR 20 SECONDS AT 30 PSI FOLLOWED BY WIPING ACROSS TRACES WITH A FINGER COT

Fig. 6

ADHESIVE FAILURE FROM SHEAR TEST OF BALL BOND

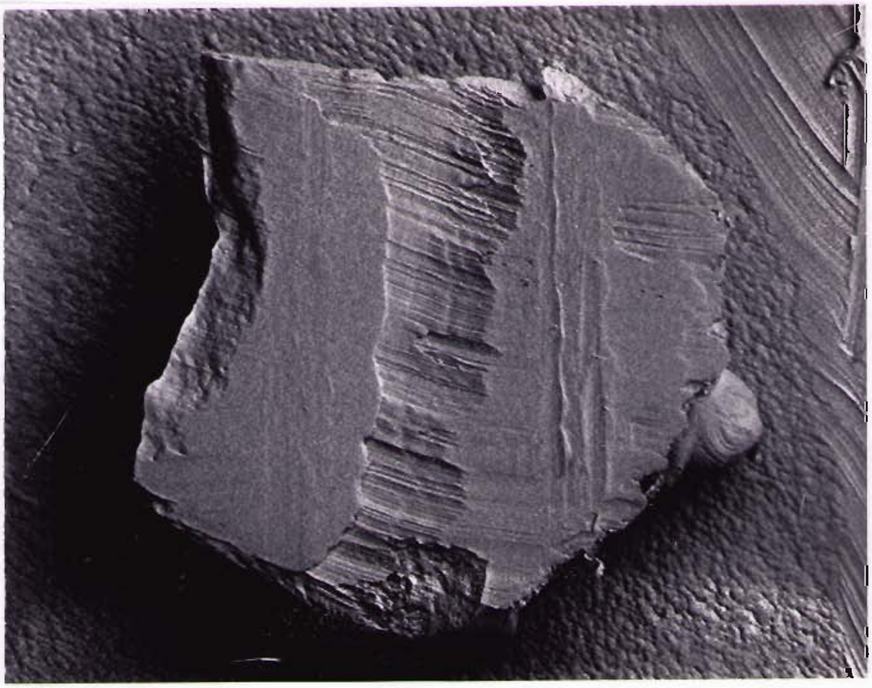


Fig. 7

COHESIVE FAILURE FROM SHEAR TEST OF BALL BOND

Equipment and Materials:

Mech-El 829Z Gold Ball Bonder

Power 1 - 4.5
Power 2 - 4.0
Time 1 - 5.0
Time 2 - 4.0
Tip - 3.0
Stage - 110 C
Capillary - UTS-15S-CM-1/16-L
(Small Precision Tools)
Wire - 99.99% gold
1.0 mil diameter
8.0 grams minimum break load
1-3% elongation
(Sigmund Cohn Corp.)

Substrate

99.6% Alumina
grain size - <1.5 micron
surface finish - <5 micro-inches center line average
Rockwell hardness (45N) - 81
(Materials Research Corporation)

Metallization

underlay sputtered Titanium-Tungsten
thickness - 250 ±50 angstroms

conductor sputtered Gold
0.9999% minimum purity
thickness - 160 micro-inches ±20%

(Materials Research Corporation)