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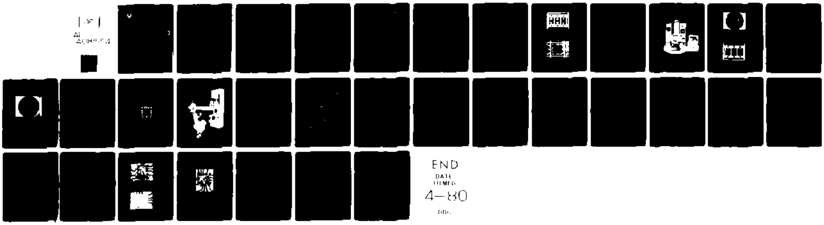

LEVEL II

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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# FAILURE STUDIES OF Au-Sn AND Au-Au INNER LEAD BONDS

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Stanley Firestone
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

January 1980

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| Inner Lead Bonding | Plating Thickness |
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| Tape-Chip Carrier | Bond Failure Modes |
| Bumped Wafers | Metal Systems |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Criteria for determining the quality of inner lead bonds were developed from pull test failure studies. Two thickness types of gold plated copper lead-gold bump samples and one type of tin plated copper lead-gold bump sample were evaluated. Bonding conditions and bond quality were related. Pull testing was performed on bonded samples which had been subjected to elevated temperatures. The types of bond and lead failure modes are described. Pull test results include the percentage of each failure type, average pull strengths in grams and kg/mm$^2$, and standard deviations. The thicker type of gold plated lead-gold bump system was superior in quality to the other two

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Block #20 Abstract Continued

metallurgical systems. No pull test (destructive) failures occurred at the bump-lead interface for the thicker gold plated lead system. An average pull force value of 48 grams was determined for that system. Minimum values obtained in this study were approximately 1 order of magnitude in excess of bond strengths associated with wire bonds. It was determined that 20 grams force would be a reasonable limit value for non-destructive pull testing of inner lead bonds.

CONTENTS





TABLES

## TABLES (contd)



## FIGURES

## INTRODUCTION

The electrical connection of integrated circuit chips to lead frames and ceramic substrates by automatic, accurate gang-bonding of leads has been demonstrated by industry and the military.[1-7] The automaticity and accuracy features are obtained through the use of a "Tape-Chip Carrier" (TCC) process, also known as "Tape Automated Bonding" (TAB). Another process for accomplishing the same end results is "Bumped Tape Automated Bonding" (BTAB). Each process provides for the carrying of IC chips and the bonding of leads. The use of these techniques eliminates the unreliable and costly flying wire leads of conventional chip and wire bonding. The techniques can potentially provide chip device evaluation prior to mounting of the device on a substrate during hybrid microcircuit fabrication. The BTAB process involves the bonding of bumped leads-on-tape to metallized IC chips. This bonding process was not evaluated in this study. The TCC process begins with conventional semiconductor wafers which are further processed to produce gold bumps over the device's bonding pads. The bumped wafers are mounted to a support plate using adhesive or wax; then are diamond-sawed to produce individual chips which continue to adhere to the plate. A photograph of an individual chip, thus processed, is shown in Figure 1. Individual chips are later gang-bonded to sprocketed tape, generally fabricated from a Kapton (Du Pont polyimide) - copper foil composite. The foil is etched and plated to form leads which are designed to match the bump layout of a specific chip. Figure 2 is a photograph of several frames of a reel of 16mm tape containing lead patterns. The tape was fabricated by Fairchild Semiconductor for use with their Quad, 2-input NAND Gate 7400 chip shown in Figure 1. Details of the tape and chip construction and their metallurgical combination will be discussed later.

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1 Dehaine, G., Kuzweil, K., "Tape Automated Bonding Moving into Production", ISHM Proceedings, October 1975, p. 306.

2 Oswald, R. G., Rodrigues de Miranda, W. R., "Application of Tape Chip Carrier Technology to Hybrid Microcircuits," ECOM Hybrid Microcircuit Symposium, June 1976, p. 215.

3 Umbaugh, C. W., "Tape Automated Mass Bonding," Electronic Packaging and Production, Kiver Publications, October 1976, p. 49.

4 Oswald, R. G., Rodrigues de Miranda, W. R., "Tape Chip Carrier for Hybrid Microcircuits", Technical Report, ECOM-76-1401-1, April 1977.

5 Smith, J. M., Stuhlbarg, S. M., "Hybrid Microcircuit Tape Chip Carrier Materials/Processing Trade-Offs", 27th Electronic Components Conference, May 1977, p. 34.

6 Rose, A. S., Scheline, F. E., Sikina, T. V., "Metallurgical Considerations for Beam Tape Assembly," 27th Electronic Components Conference, May 1977, p. 130.

7 Ludwig, D. P., "Chips-in-tape: A Study in Automated Hybrid IC Assembly", Electronic Packaging and Production, Kiver Publications, April 1978, p. 77.

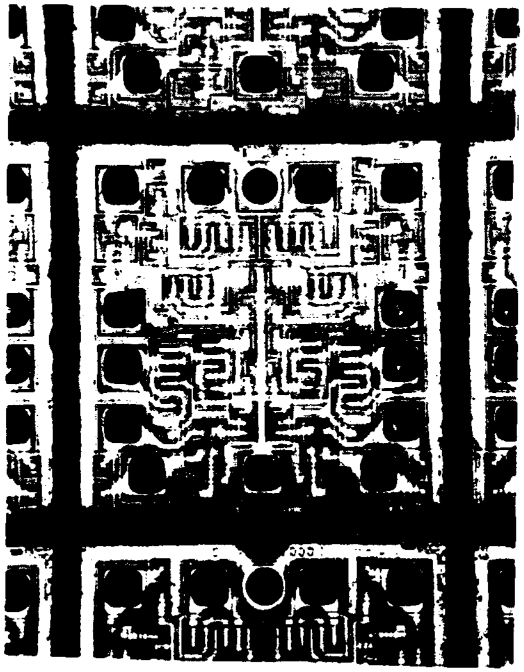

Figure 1. Gold Bumped 7400 chip isolated from wafer (55x)

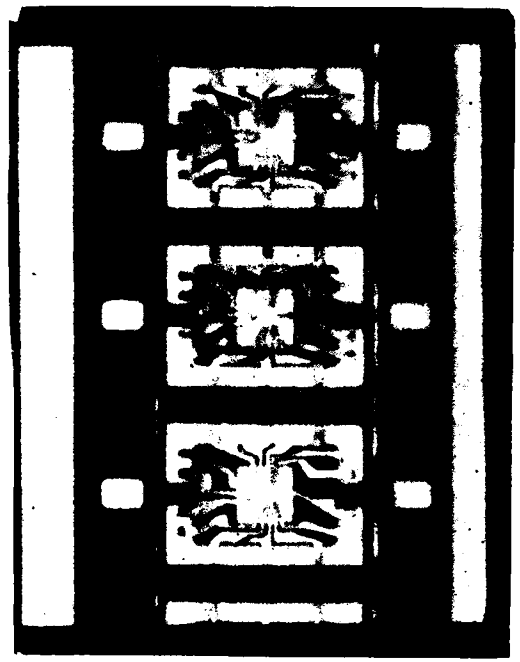

Figure 2. Tape containing lead patterns (3.5x)

The gang-bonding of leads to bumps is known as inner lead bonding (ILB) and is accomplished with such bonding equipment as the JEMS/LAB Bonder (Jade Corp.) shown in Figure 3. The ILB process requires the application of a suitable amount of heat and pressure to effectively mate the bumps and leads and subsequently provide for release of the ILB chip from the adhesive-coated or waxed support plate. A photograph of ILB 7400 chips is shown in Figure 4. A magnified view of an individual ILB chip is shown in Figure 5. The chips-on-tape can then be electrically tested automatically by probing of tape pads. After screening, good devices and their ILB leads are excised from the tape, lead formed (only for hybrid assembly) and outer lead bonded (OLB) at their leads' ends to lead frames or to hybrid microcircuit substrates. The semiconductor industry has already established a broad base of technology for gang-bonding leads to chips in the packaging of discrete devices.[8,9] The extension of the TCC concepts toward automatic bonding of chip devices to military hybrid microcircuit substrates is less developed. Recent programs[10,11] have been supported by Electronics Technology and Devices Laboratory, ERADCOM, to identify one or more feasible metallurgical systems for ILB and OLB processes. The system most widely used by industry, to date, is that of gold (Au) bumps, tin (Sn) plated copper (Cu) leads, and Au thick films on hybrid microcircuit substrates.[12,13] A eutectic ILB of Au (bump) and Sn (plating on Cu lead) is simply formed at 280°C[13] by thermocompression bonding. OLB of samples having a Au-Sn metallurgical system is not as direct. The OLB process most often uses a solder reflow procedure to bond the leads to Au thick-film pads.[14] Solder flux, which is potentially corrosive, is generally used, but its complete removal is extremely difficult. For this reason, the selection of metallurgical systems for military applications have been directed toward thermocompression ILB and OLB of an all-Au system, i.e., Au plated bumps, Au plated leads, and Au thick-film pads.[15] Au is known for its high tolerance to corrosive chemical environments.

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8 Khajezadek, H., Rose, A. S., "Reliability Evaluation of Hermetic Integrated Circuits in Plastic Packages," 13th Annual Reliability Physics Symposium, April 1975, p. 87.

9 Burns, C., Keizer, A., Toner, M., "Beam Tape Automated Assembly of DIPS," Nepcon/West Proceedings, 1975.

10 ECOM Contract DAAB07-76-C-1401, "Tape Chip Carrier for Hybrid Microcircuits," Honeywell Inc., September 1977 (Final Report).

11 ERADCOM Contract DAAB07-77-C-2708, "Tape Chip Carrier for Hybrid Microcircuits," Honeywell Inc., August 1978 (Interim Report).

12 Umbaugh, p. 1, ref. 3

13 Liu, T. S., "Aspects of Gold-Tin Bump-Lead Interconnection Metallurgy," ISHM Proceedings, October 1977, p. 120.

14 Umbaugh, p. 1, ref. 3

15 Oswald, Smith, Rose, etc. p. 1, refs 4-6

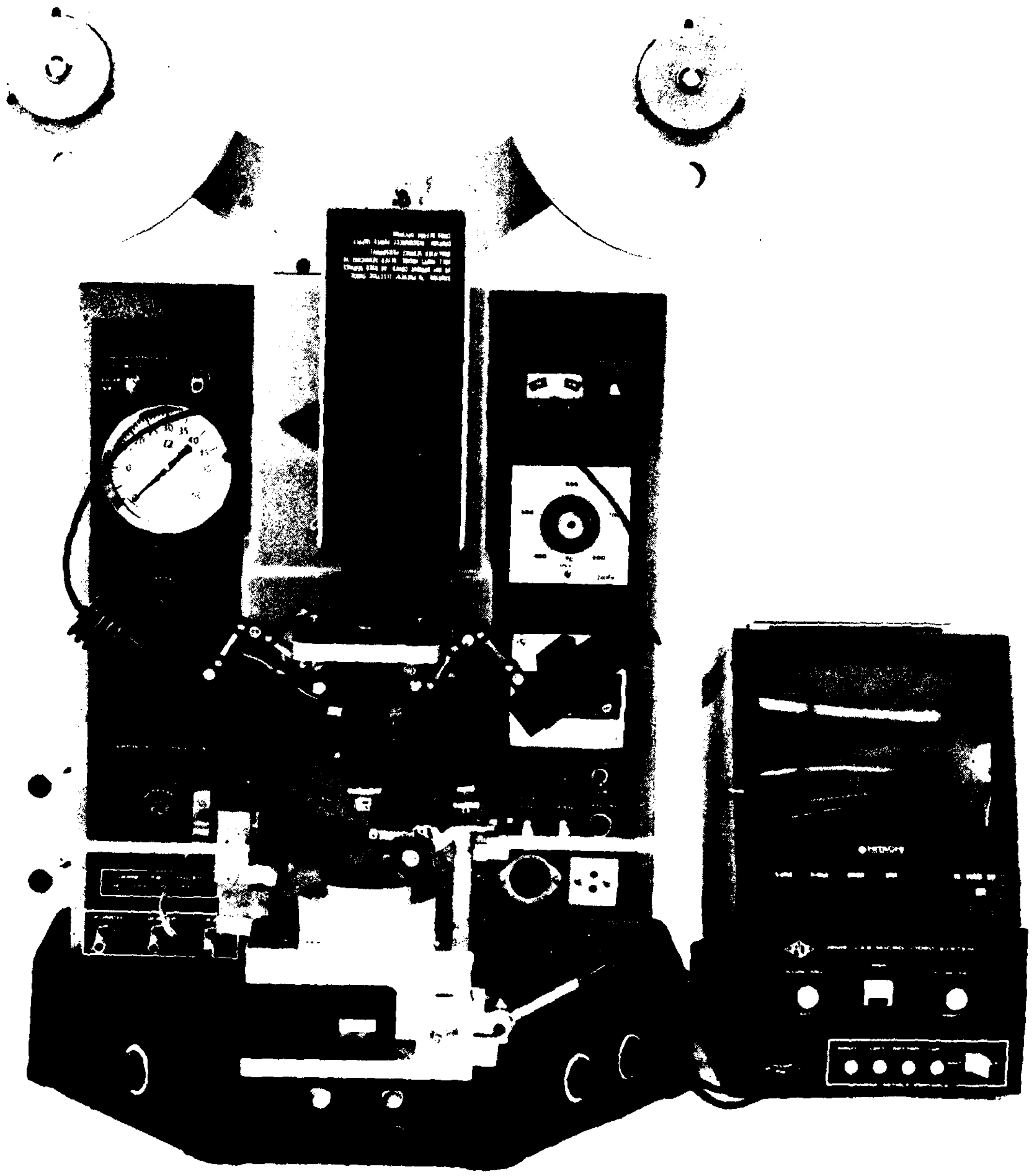

Figure 3. JEMS/LAB Inner Lead Bonder

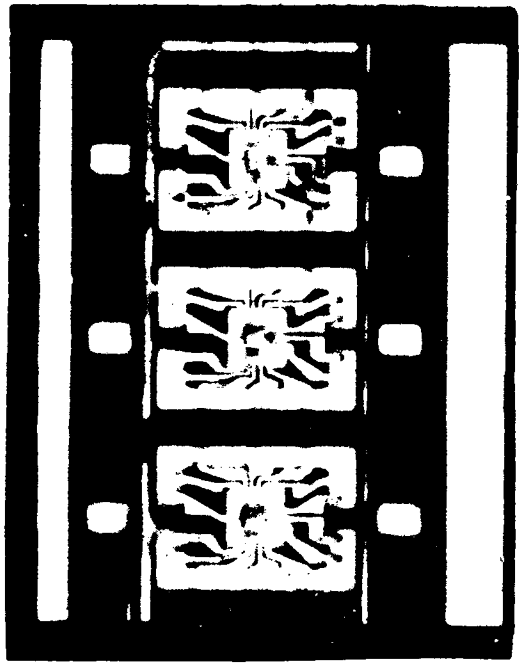

Figure 4. ILB 7400 chips-on-tape (3.5x)

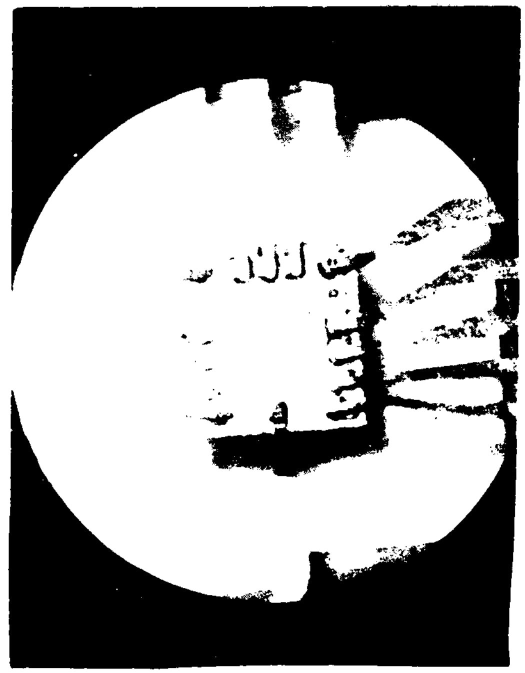

Figure 5. Close-up of ILB 7400 chip (27.5x)

DISCUSSION

An in-house program was begun with the objective of developing inspection criteria to determine the acceptability of inner and outer lead bonds. The only studies performed to date have been ILB; results from those studies will be discussed in this report. Two basic metallurgical combinations were investigated; Au plated bump-Au plated lead system and the Au plated bump-Sn plated lead system. (The latter was chosen to obtain in-house bonding information which could be used as a comparative data base.)

Each metallurgical combination was investigated from the standpoint of ease of bonding, mode of bond failure and bond quality. The bond quality was determined from pull strength values obtained before and after exposure to elevated temperatures.

a. Description of Samples

Each ILB sample contained fourteen leads gang-bonded to a device chip. The bonding involved the use of two components, such as those shown in Figure 6 (bumped wafer) and Figure 2 (tape-chip carrier). Bumped wafers were fabricated from 76.2 mm (3 inch) diameter conventional wafers. (The bumping of a 7400 type device wafer was done by Fairchild.) Other ILB samples were made with a 5410 Transistor-Transistor-Logic (TTL) device wafer bumped by the Avionics Division of Honeywell, Inc. Aluminum (Al) metallization was used for the interconnection and bonding pad network in each device type. At pad locations, Au bumps were plated to a thickness of 0.0127 mm (0.5 mil) for the 7400 device and 0.0254 mm (1.0 mil) for the 5410 device. The bump length and width dimensions were 0.097 mm (3.80 mils) square with a 0.0094 $mm^2$ area for the 7400 device and 0.103 mm (4.06 mils) square with a 0.0106 $mm^2$ area for the 5410 device. Diffusion barrier metal layers between the Al pads and the Au bumps were used in both devices. Fairchild used sputtered 90% tungsten (W) - 10% titanium (Ti) alloy as the barrier layer prior to bumping the 7400 device wafers.[16] Honeywell used sputtered Ti followed by sputtered palladium (Pd) as the diffusion barrier system for the bumped 5410 devices. After Au bumping, wafers were mounted to a glass support plate using a low temperature wax (Fairchild) or adhesive (Honeywell). Part of the heat used in ILB is used to release the bonded chip from the support plate.

In this study, 16 and 35 mm tape-chip carriers were used with the 7400 and 5410 devices, respectively. For the tape preparation, sprocket holes and window openings were punched out of 0.127 mm (5 mils) thick Kapton film, followed by epoxy adhesive lamination of 0.036 mm (1.4 mils) thick Cu foil to the Kapton. Using photo-resist and chemical etching techniques, Cu leads were then delineated to match the bumped device chip. The final process in preparing the tape was the deposition of metal on the Cu leads. An electroless plating of Sn (5000 angstroms thick) was used for the tape-7400 chip carrier. An electroplated Au (32000 angstrom thick) was used to complete the preparation of the tape-5410 chip carrier.

16 Smith, etc. p. 1, ref 5

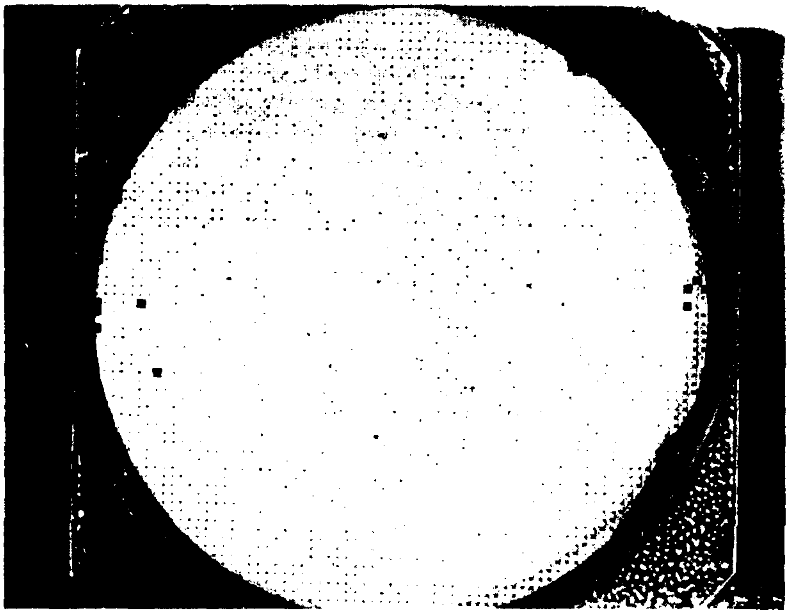

Figure 6. Bumped 7400 wafer on support plate

Additional ILB samples were fabricated to evaluate a third metallurgical system. This system differed from the previously described Au-Au system in that the Au coating on the Cu leads was thinner. A Au thickness of 10,000 angstroms was selected for study. The Sn metallization of the 16 mm tape leads was replaced by sputtered Au thin film. This was accomplished by first etching the Sn from the Cu leads. The nitric-hydrofluoric acid etching of Sn was closely monitored to prevent undue physical alteration of the Cu surface. Finally, a 10,000 angstrom thick Au film was RF sputtered (99.99 percent Au target) onto both faces of the tape for complete Cu lead coverage. The 14-lead configuration for the 7400 device was designed with various lead widths at bond sites. The average lead width, average bump-lead bond (ILB) area, and average bond heel cross-sectional area values at the fourteen locations are noted in Table 1 and are graphically described in Figure 7. For the 5410 device leads, dimensions did not differ significantly from lead location-to-location and therefore, average values for all bond sites were used. The average values for lead width, bump-lead bond area, and bond heel cross-sectional area are 0.072 mm, 0.0088 $mm^2$, and 0.0026 $mm^2$, respectively.

Table 1. Lead Width, Bump-Lead Bond Area, and Bond Heel Cross-Sectional Area Dimensions of ILB 7400 Type Devices.

| Bond Site | Lead Width (mm) | Bond Area ($mm^2$) | Heel Area ($mm^2$) | Bond Site | Lead Width (mm) | Bond Area ($mm^2$) | Heel Area ($mm^2$) |
|---|---|---|---|---|---|---|---|
| 1 | 0.081 | 0.0079 | 0.0029 | 8 | 0.053 | 0.0051 | 0.0024 |
| 2 | 0.081 | 0.0079 | 0.0030 | 9 | 0.071 | 0.0069 | 0.0028 |
| 3 | 0.071 | 0.0069 | 0.0028 | 10 | 0.081 | 0.0079 | 0.0030 |
| 4 | 0.053 | 0.0051 | 0.0024 | 11 | 0.081 | 0.0079 | 0.0029 |
| 5 | 0.048 | 0.0047 | 0.0021 | 12 | 0.084 | 0.0082 | 0.0028 |
| 6 | 0.079 | 0.0077 | 0.0031 | 13 | 0.071 | 0.0069 | 0.0028 |
| 7 | 0.048 | 0.0047 | 0.0021 | 14 | 0.084 | 0.0082 | 0.0028 |

After ILB of samples and their exposure to elevated temperatures, destructive type pull testing was done to evaluate bond quality. Pull testing was performed with a model MBT-ND Micro Bond Tester (Engineered Technical Products Inc.) shown in Figure 8.

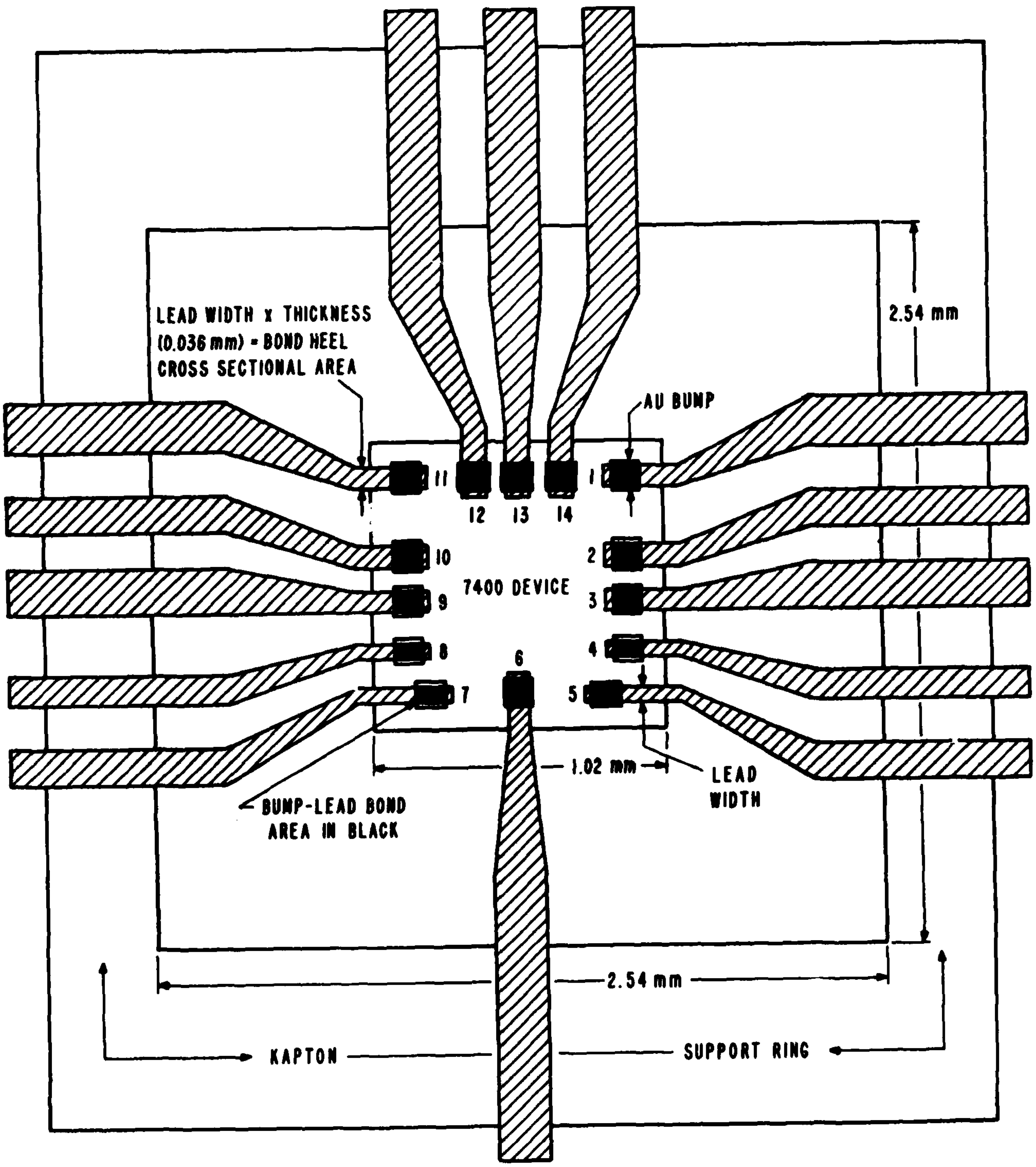


Figure 7. Configuration of an ILB 7400 device

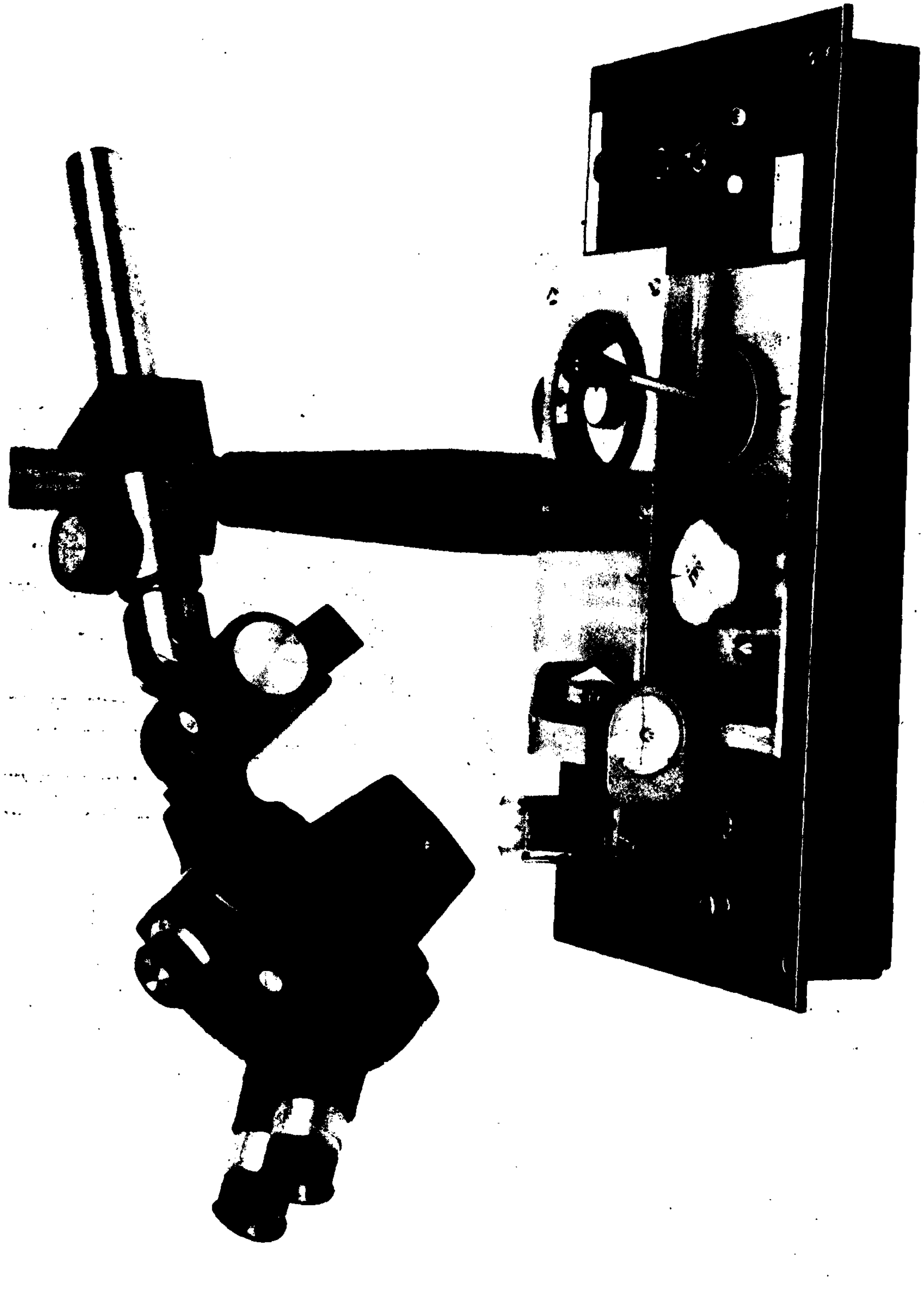

Figure 8. Micro Bond Tester

b. Pull Testing Procedure

(1) Prior to the pull testing operation, each ILB sample was prepared as follows:

(a) The Kapton tape frame containing an ILB chip was cut to size for mounting on a glass substrate (ceramic or rigid plastic can also be used).

(b) The back side of the chip was mounted to the glass substrate using a room temperature cured epoxy.

(c) The Kapton frame was then taped to the substrate so that only the sample leads had freedom of movement.

(2) The pull testing operation on each interconnect lead was accomplished as follows:

(a) The "J" hook of the pull tester was placed under the nominal center of the lead length.

(b) The "J" hook was then brought up to contact the lead without "impacting" it.

(c) Activation of the tester applied a vertical pull to the lead until interconnect failure occurred.

(d) The pull test was viewed under 20X magnification and the failure mode observed.

(e) The stress (grams) which caused interconnect failure was noted.

c. Pull Tests

Destructive type pull tests were used in evaluating approximately 2800 ILB which were comprised of an almost equal number of Au Bump-Sn, Au Bump-10000 angstrom Au, and Au Bump - 32000 angstrom Au samples. A suitable ILB sample was one that exhibited only lead tensile failure. Under that condition, the bond strengths at chip-bump and bump-lead interfaces would necessarily be greater than the lead tensile strength. Therefore, the greater the percent lead failure - the more reliable the ILB metallurgical system. Pull tests were performed first to determine the combination of bonding parameters which would yield the greatest ILB pull strengths for each of the three evaluated systems. The bonding parameters varied were: thermode temperature (°C), thermode pressure (psi), and thermode dwell time (s). The optimum combination of parameters also had to provide the proper amount of bonding heat to release the ILB chip from its wax-mounting or adhesive-mounting. Excessive heat could undesirably change the orientation of chips surrounding the ILB chip and therefore affect subsequent inner lead bonding. Pull testing of ILB samples revealed several failure modes: bond failure at the Al pad-bump metallization interface (hereafter referred to as chip-bump failure), failure of the ILB (bump-lead failure), and tensile failure of the lead (lead failure). Failure at the heel of the bond also occurred, but only with the Au-Au samples. The pull test failures modes are graphically described in Figure 9.

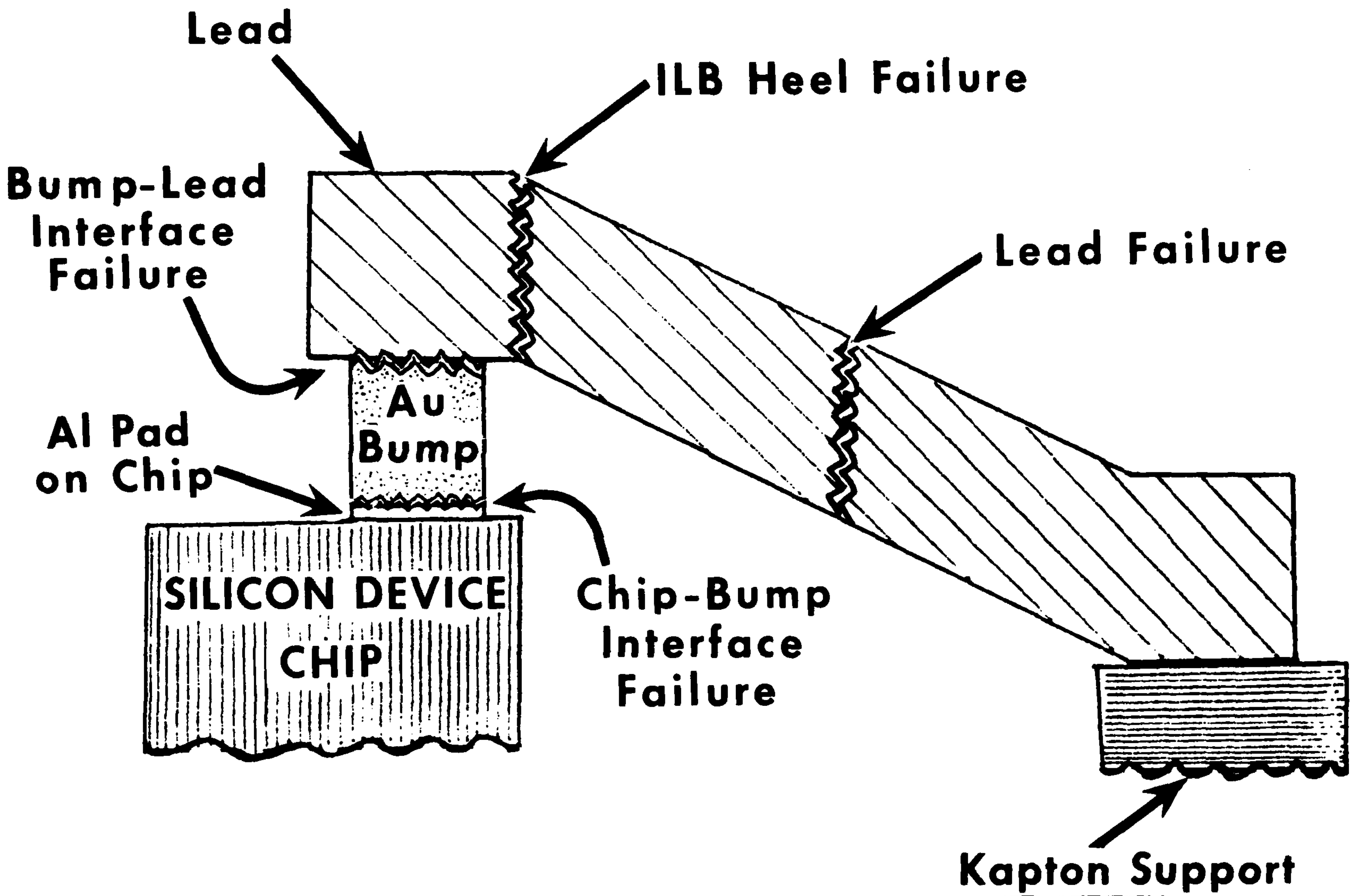


Figure 9. Pull test failure modes related to ILB

In cases where pull test results did not clearly identify the optimum combination of bonding parameters, replicate samples were pull tested after exposure to elevated temperatures. It was anticipated that inducing metallurgical degradation of the ILB would aid in selecting the optimum bonding combination. The selection was made and used to bond additional samples. Destructive pull testing was performed again to determine bond strengths of Au-Sn and Au-Au ILB after long-term exposure to 150°C. Replicate samples were evaluated to develop an accelerated stress test of equivalent effect to that of long-term temperature exposures.

The pull strength of each sample was measured as the gram (g) value at which failure occurred. Average g values and average pull strengths, in terms of $kg/mm^2$, are presented in the discussion of results. The area ($mm^2$) values used in $kg/mm^2$ calculations for various types of failures are: 0.0094 $mm^2$ and 0.0126 $mm^2$ chip-bump failure of the 7400 and 5410 devices respectively; values previously presented in Table 1 for bump-lead (ILB) and heel failures at each bond site; and cross-sectional lead failure areas (calculated individually and not reported herein).

d. Gold Bump-Tin Results

Au-Sn samples were prepared by various combinations of bonding thermode parameters. The bonding temperature ranged from 450°C to 550°C and the pressure ranged from 5 to 15 psi. Dwell times of 0.5s and 1.0s were used. A summary of bonding performance and pull test results is presented in Table 2. This table and subsequent tables of this report include: the percent of each failure type in relation to the total number of ILB pulled, average pull strengths in grams and $kg/mm^2$ for each failure type, standard deviations based on $kg/mm^2$ values, and average pull strength in grams for each bonding combination group.

A combination of 550°C - 10 psi - 1s caused many bumps to become detached from the chips during lead bonding. Generally, the detachment included the removal of the Al pad from the chip. Pull tests of completed 550°C samples resulted in a large percentage of bump-lead (ILB) failures.

A 450°C - 10 psi - 0.5s combination alleviated the bump detachment problem but introduced a problem of non-release of the ILB chip from the waxed support plate. Some samples prepared with that combination were released satisfactorily and subsequently pull tested. Results of only lead failures indicated that the bonding combination had produced an acceptable Au-Sn ILB system. Various thermode pressures, ranging from 5 to 15 psi with the other bonding parameters held constant at 500°C and 0.5s, were evaluated to solve the chip non-release problem. Combinations which included bond pressures of 8 psi and greater provided consistent chip release. Pressures of 12 and 15 psi caused significantly greater bump deformation or "squash" than lower pressure combinations. The 15 psi combination, however, produced samples having the most suitable pull strength characteristics (see Table 2).

Table 2. Pull Test Results of Gold Bump - Tin Plated Copper Leads Bonded by Various Parameter Combinations

| No. of Bonds | Thermode | | | Consist. Chip Release | Chip-Bump Failures | | | | Bump-Lead Failures | | | | Lead Failures | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. (°C) | Press. (psi) | Dwell (S) | | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | |
| 13 | 550 | 10 | 1 | Yes | 7.6 | 42.9 | 4.6 | * | 46.2 | 36.2 | 5.3 | 2.3 | 46.2 | 33.7 | 16.4 | 7.3 | 36 |
| 17 | 550 | 10 | 0.5 | Yes | 41.2 | 26.0 | 2.8 | 1.2 | 0 | – | – | – | 58.8 | 32.6 | 13.5 | 5.2 | 30 |
| 40 | 450 | 10 | 0.5 | No | 0 | – | – | – | 0 | – | – | – | 100 | 40.4 | 15.6 | 4.8 | 40 |
| 51 | 500 | 5 | 0.5 | No | 0 | – | – | – | 2.0 | 50.0 | 6.4 | * | 98.0 | 42.8 | 16.2 | 4.7 | 43 |
| 89 | 500 | 8 | 0.5 | Yes | 27.0 | 41.1 | 4.4 | 0.9 | 13.5 | 54.8 | 8.8 | 3.3 | 59.5 | 49.7 | 20.0 | 8.3 | 49 |
| 55 | 500 | 10 | 0.5 | Yes | 47.3 | 40.1 | 4.3 | 0.6 | 0 | – | – | – | 52.7 | 44.3 | 18.6 | 4.3 | 42 |
| 42 | 500 | 12 | 0.5 | Yes | 47.6 | 41.0 | 4.4 | 1.1 | 4.8 | 43.0 | 8.8 | 1.5 | 47.6 | 44.7 | 19.1 | 5.6 | 43 |
| 40 | 500 | 15 | 0.5 | No | 20.0 | 39.8 | 4.3 | 0.8 | 0 | – | – | – | 80.0 | 44.6 | 17.1 | 3.2 | 44 |

* No value - only one sample failed

Replicate samples of the aforementioned 8 to 15 psi group were exposed to a 300°C (air) environment for four hours and later pull tested. The exposure was used to promote metallurgical degradation at the bump-lead interface. Pull test results given in Table 3 show that the 10 and 12 psi bonding combinations offered the least bump-lead failures (14.3%). A visual evaluation of ILB produced by these combinations revealed that the 10 psi combination caused less bump deformation.

Au-Sn samples bonded with optimum parameters of 500°C - 10 psi - 0.5s were exposed to a 150°C (air) environment for 250, 500, and 1000 hour periods. Comparatively, replicate samples were exposed to 250°, 275°, 300° and 350°C temperatures (air) for four hour periods. Destructive pull testing was again used. Results of chip-bump and bump-lead bond strengths and the pull strength of leads are included in the data given in Table 4. The most significant results follow:

(1) Up to 52.4% failures occurred at the chip-bump interface.

(2) The average bond strength of unexposed (control) samples which failed at the chip-bump interface is 4.3 kg/mm$^2$.

(3) The average lead pull strength of unexposed samples is 18.6 kg/mm$^2$.

(4) The average bump-lead (ILB) strength for 150°C - long term exposed samples is 6.0 kg/mm$^2$ for those interface failures.

(5) The average bump-lead strengths for 300°C - 4 hour and 350°C - 4 hour samples are 3.3 and 2.7 kg/mm$^2$, respectively.

(6) No bump-lead failures occurred with samples exposed to 250°C or 275°C for four hour periods.

(7) A maximum of 5% bump-lead failures occurred with samples exposed to 150°C for periods up to 1000 hours.

e. Gold Bump-10000Å Gold Results

Initial trials of inner lead bonding Au plated bump-10000 angstrom thick Au coated Cu lead samples were performed with bonding parameter combinations ranging from 450° to 500°C thermode temperature, 10 to 32 psi bond pressure, and 0.5 to 1.0s dwell time. Noted in Table 5 are the trials considered unsatisfactory because of their inability to consistently provide chip release after bonding. A few combinations which had offered the most promise were tried again along with several new ones. Table 6 gives the combinations evaluated and their pull test results. All combinations consistently provided chip release except for the 475°C - 30 and 31 psi trials. Conditions of 550°C - 10 psi - 0.5s caused many bumps to become detached from the chips during bonding. Samples prepared satisfactorily using those conditions showed unfavorable pull test results of 67.7% sample failure at the chip-bump interface (see Table 6). The table also gives the resultant bump size after bonding with different conditions.

Table 3. Pull Test Results of Gold Bump - Tin Plated Copper Leads Bonded by Selected Parameter Combinations and Exposed to 300 °C - 4 Hours

| No. of Bonds | Thermode | | | Chip-Bump Failures | | | | Bump-Lead Failures | | | | Lead Failures | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. (°C) | Press. (psi) | Dwell (s) | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | |
| 42 | 500 | 8 | 0.5 | 28.6 | 25.5 | 2.7 | 0.7 | 66.7 | 22.5 | 3.5 | 1.2 | 4.7 | 27.5 | 10.3 | 3.6 | 24 |
| 42 | 500 | 10 | 0.5 | 76.2 | 31.8 | 3.4 | 1.1 | 14.3 | 25.7 | 5.2 | 1.4 | 9.5 | 42.5 | 14.7 | 5.3 | 32 |
| 42 | 500 | 12 | 0.5 | 52.4 | 33.9 | 3.6 | 0.9 | 14.3 | 25.8 | 4.8 | 0.8 | 33.3 | 28.4 | 11.8 | 2.6 | 31 |
| 42 | 500 | 15 | 0.5 | 52.4 | 32.1 | 3.5 | 0.8 | 21.4 | 29.1 | 5.3 | 1.3 | 26.2 | 33.6 | 11.9 | 3.4 | 32 |

Table 4. Pull Test Results of Gold Bump—Tin Plated Copper Leads Bonded by 500°C-10 psi-0.5 s and Exposed to Temperature-Time Tests

| Exposure | No. of Bonds | Chip-Bump Failures | | | | Bump-Lead Failures | | | | Lead Failures | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | |
| Controls | 55 | 47.3 | 40.1 | 4.3 | 0.6 | 0 | — | — | — | 52.7 | 44.3 | 18.6 | 4.3 | 42 |
| 150°C-250h | 84 | 38.1 | 35.0 | 3.8 | 0.9 | 4.8 | 40.3 | 6.4 | 1.5 | 57.1 | 41.2 | 16.1 | 4.2 | 38 |
| 150°C-500h | 100 | 37.0 | 34.3 | 3.7 | 1.1 | 5.0 | 38.4 | 6.0 | 1.6 | 58.0 | 40.6 | 14.6 | 4.0 | 37 |
| 150°C-1000h | 149 | 48.3 | 32.9 | 3.5 | 1.0 | 2.7 | 37.0 | 5.6 | 0.9 | 49.0 | 39.3 | 14.8 | 4.1 | 36 |
| 250°C-4h | 42 | 38.1 | 30.8 | 3.3 | 0.9 | 0 | — | — | — | 61.9 | 39.0 | 14.9 | 4.3 | 36 |
| 275°C-4h | 42 | 52.4 | 27.1 | 2.9 | 0.7 | 0 | — | — | — | 47.6 | 33.2 | 12.8 | 2.7 | 30 |
| 300°C-4h | 42 | 4.8 | 29.0 | 3.1 | 0.2 | 71.4 | 21.3 | 3.3 | 1.1 | 23.8 | 38.2 | 12.3 | 3.3 | 26 |
| 350°C-4h | 7 | 28.6 | 15.0 | 1.6 | 1.1 | 57.1 | 13.3 | 2.7 | 0.5 | 14.3 | 40.0 | 12.0 | * | 18 |

* No value - only one sample failed

Table 5. Bonding Trials with Gold Bump-10000Å Gold Coated Copper Leads -- No Chip Release

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Thermode Temp (°C) | 500 | 500 | 500 | 500 | 475 | 475 | 475 | 450 | 450 |
| Bond Pressure (psi) | 10 | 20 | 25 | 30 | 30 | 30 | 31 | 32 | 32 |
| Dwell (s) | 0.5 | 0.6 | 0.6 | 0.8 | 1.0 | 1.2 | 1.0 | 0.8 | 1.0 |

Table 6. Pull Test Results of Gold Bump – 10000 Å Gold Coated Copper Leads Bonded by Various Parameter Combinations

| No. of Bonds | Thermode | | | Bump Size | Chip-Bump Failures | | | | Bump-Lead Failures | | | | Lead Failures | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. (°C) | Press. (psi) | Dwell (s) | mm x mm | % of All Failures | g (avg) | $Kg/mm^2$ (avg) | std. dev. | % of All Failures | g (avg) | $Kg/mm^2$ (avg) | std. dev. | % of All Failures | g (avg) | $Kg/mm^2$ (avg) | std. dev. | |
| 99 | 550 | 10 | 0.5 | 0.119 x 0.119 | 67.7 | 19.2 | 2.1 | 0.7 | 23.2 | 59.6 | 8.7 | 6.1 | 9.1 | 16.9 | 7.8 | 4.5 | 28 |
| 14 | 500 | 30 | 0.8 | 0.127 x 0.127 | 0 | – | – | – | 35.7 | 23.8 | 3.8 | 1.0 | 64.3 | 22.7 | 8.2 | 2.8 | 23 |
| 41 | 500 | 35 | 0.8 | 0.152 x 0.152 | 31.7 | 22.7 | 2.4 | 0.6 | 9.8 | 29.5 | 5.1 | 1.9 | 58.5 | 24.5 | 8.9 | 2.1 | 24 |
| 13 | 500 | 32 | 1.0 | 0.152 x 0.152 | 7.7 | 32.0 | 3.4 | * | 0 | – | – | – | 92.3 | 23.9 | 9.2 | 2.6 | 25 |
| 37 | 475 | 30 | 1.0 | 0.127 x 0.127 | 0 | – | – | – | 0 | – | – | – | 100 | 26.0 | 10.1 | 2.5 | 26 |
| 41 | 475 | 32 | 0.8 | 0.152 x 0.152 | 0 | – | – | – | 0 | – | – | – | 100 | 24.1 | 9.3 | 3.1 | 24 |
| 24 | 475 | 31 | 0.9 | 0.152 x 0.152 | 4.2 | 43.0 | 4.6 | * | 0 | – | – | – | 95.8 | 29.9 | 11.1 | 3.3 | 30 |
| 14 | 475 | 31 | 1.0 | 0.152 x 0.152 | 0 | – | – | – | 0 | – | – | – | 100 | 20.1 | 7.9 | 2.8 | 20 |

* No value – only one sample failed

Bump size before bonding was 0.097 mm by 0.097 mm. Bonding pressures greater than 30 psi caused bump deformation with an increase in bump areas up to 135%. The deformation caused some bumps to contact each other at their edges; this effect however, did not interfere with subsequent pull test evaluations. Favorable results were evident for samples bonded by 475°C thermode conditions as almost all failures were of the lead failure type. Several trials, using a 450°C thermode, did not release the bonded chip.

Additional 10000 angstrom thick Au-Au samples were bonded with conditions of 475°C - 32 psi - 0.8s. After bonding, samples were exposed to 150°C (air) environment for 250, 500, and 1000 hour periods. For comparison, replicate samples were exposed to 250°C, 275°C, and 300°C temperatures (air) for 4 hour periods. Exposed and control (unexposed) samples were evaluated using the destructive pull test procedures described earlier in this report. Gram and $kg/mm^2$ values (average) for each of the failure modes and standard deviations (based on $kg/mm^2$ values) are presented in Table 7. The overall average pull strength, in grams, for each exposure group is also included. The most significant results follow:

(1) No chip-bump interface failure occurred with unexposed samples.

(2) A maximum of 7% sample failure occurred at the chip-bump interface with 150°C - 1000 hour samples.

(3) The average bump-lead strength is 4.1 $kg/mm^2$ for all 150°C samples.

(4) The average bump-lead strength is 2.5 $kg/mm^2$ for the 300°C - 4 hour samples.

(5) A maximum of 5.3% bump-lead failure occurred with samples exposed to 150°C for periods up to 1000 hours.

(6) Exposures of 275°C and 300°C for 4 hours in each case caused 20 and 49.1% of samples, respectively, to fail at the bump-lead interface.

(7) Pull strength values for lead failures of control and 150°C exposed samples ranged from 10.3 to 14.1 $kg/mm^2$. Honeywell has reported[17] average values for lead failures to be within a range of 28.3 to 42.1 grams. This converts to 11.0 and 16.4 $kg/mm^2$, respectively. Test samples used by Honeywell in their evaluation consisted of 32000 angstrom thick Au plated Cu leads (some samples with an intermediate plating of nickel) bonded to 0.0254 mm (1 mil) high Au plated bumps.

f. Gold Bump-32000Å Gold Results

Inner lead bonding trials for Au bump - 32000 angstrom thick Au plated Cu lead samples were performed with bonding conditions previously found optimum for the 10000 angstrom thick Au system. The trials resulted in ILB chips with intolerable bump deformation and bump contact. This is

17 ERADCOM Contract etc., p. 3, ref. 11

Table 7. Pull Test Results of Gold Bump – 10000 Å Gold Coated Copper Leads Bonded by 475 °C – 32 psi – 0.8 s and Exposed to Temperature – Time Tests

| Exposure | No. of Bonds | Chip-Bump Failures | | | | Bump-Lead Failures | | | | Lead Failures | | | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | No. of Heel Type | No. of Non-Heel Type | g (avg) | Kg/mm² (avg) | std. dev. | |
| Controls | 47 | 0 | – | – | – | 2.1 | 30.0 | 3.8 | * | 97.9 | 14 | 32 | 29.6 | 11.1 | 3.5 | 30 |
| 150 °C-250 h | 70 | 5.7 | 26.8 | 2.9 | 0.5 | 2.9 | 36.0 | 4.7 | 0.5 | 91.4 | 29 | 35 | 28.1 | 10.3 | 3.0 | 28 |
| 150 °C-500 h | 112 | 1.8 | 34.5 | 3.7 | 0.1 | 5.3 | 25.8 | 3.3 | 0.9 | 92.9 | 46 | 58 | 30.4 | 11.6 | 3.6 | 30 |
| 150 °C-1000 h | 186 | 7.0 | 39.5 | 4.3 | 0.8 | 4.3 | 29.8 | 4.4 | 1.5 | 88.7 | 60 | 105 | 35.3 | 14.1 | 5.0 | 35 |
| 250 °C-4 h | 42 | 2.4 | 37.0 | 4.0 | * | 4.8 | 32.5 | 7.1 | 1.0 | 92.8 | 16 | 23 | 43.7 | 16.7 | 3.0 | 43 |
| 275 °C-4 h | 55 | 3.6 | 29.0 | 3.1 | 0.5 | 20.0 | 35.5 | 4.9 | 1.4 | 76.4 | 19 | 23 | 35.5 | 14.2 | 4.0 | 35 |
| 300 °C-4 h | 53 | 1.8 | 17.0 | 1.8 | * | 49.1 | 16.4 | 2.5 | 0.8 | 49.1 | 13 | 13 | 19.7 | 7.1 | 1.7 | 18 |

* No value - only one sample failed

illustrated in Figure 10. Bonding temperature, dwell time, and pressures were then reduced to try to resolve the problem of excessive deformation of bumps. As shown in Figure 11, essentially the same effect occurred using reduced condition levels including a 12 psi bonding pressure (instead of 32 psi). The problem of excessive bump deformation was attributed to an extra thick support plate used in mounting the bumped 5410 wafer. Significant reduction of deformation was obtained using a combination of 5 psi bonding pressure and 2.5 psi approach pressure. The resultant bumps are shown in Figure 12. Conditions of 450°C thermode - 5 psi bonding pressure - 2.5 psi approach pressure, and dwell times of 0.2, 0.3, and 0.4s were evaluated to determine optimum bonding for the 32000 angstrom samples. Bonded samples were later subjected to 275°C for 4 hours prior to pull tests. Table 8 below summarizes the pull test results. The largest gram force values were obtained with samples bonded with a 0.2s thermode dwell.

Table 8. Pull Test Results of Gold Bump - 32000Å Gold Plated Copper Leads Bonded by 450°C - 5 psi Bond - 2.5 psi Approach - Various Dwell Times and Exposed to 275°C - 4 hours

| Thermode Dwell (s) | Sample 1 Grams (avg) | Sample 2 Grams (avg) | Samples 1,2 Grams (avg) |
|---|---|---|---|
| 0.4 | 39.9 | 40.9 | 40.3 |
| 0.3 | 41.1 | 46.7 | 43.8 |
| 0.2 | 51.0 | 50.5 | 50.8 |

NOTE: Each sample group consisted of 14 pull tested bonds for each thermode dwell condition.

Optimum bonding conditions of 450°C thermode - 5 psi bond pressure - 2.5 psi approach pressure - 0.2s dwell time were used to ILB additional Au bump - 32000 angstrom thick Au plated Cu lead samples. After bonding, the samples were subjected to elevated temperatures in a range from 150°C to 300°C for various time periods. Exposed samples (and controls) were destructively pull tested using the procedure described previously in this report. Gram and $kg/mm^2$ values (average) for chip-bump and lead failures and standard deviations (based on $kg/mm^2$ values) are presented in Table 9. The overall average pull strength, in grams, for each exposure group is included. The most significant results of this evaluation follow:

(1) No bump-lead interface failures occurred with any ILB samples (869 bonds tested).

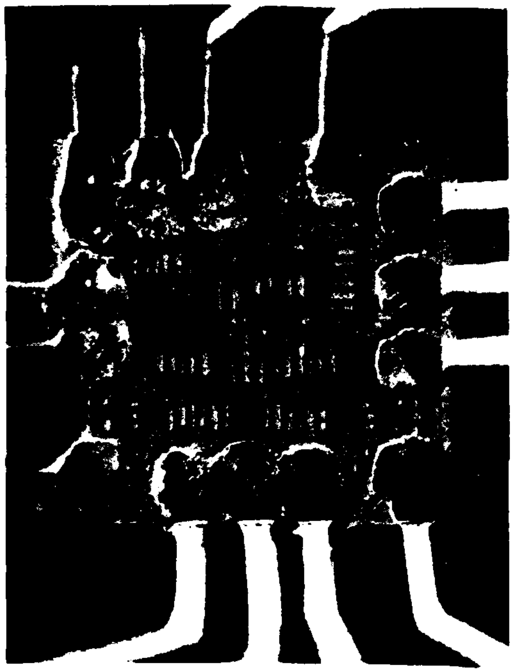

Figure 10. $475^{\circ}C$ - 32 psi - 5 psi - 0.8s Effect on Bump Deformation (55x)

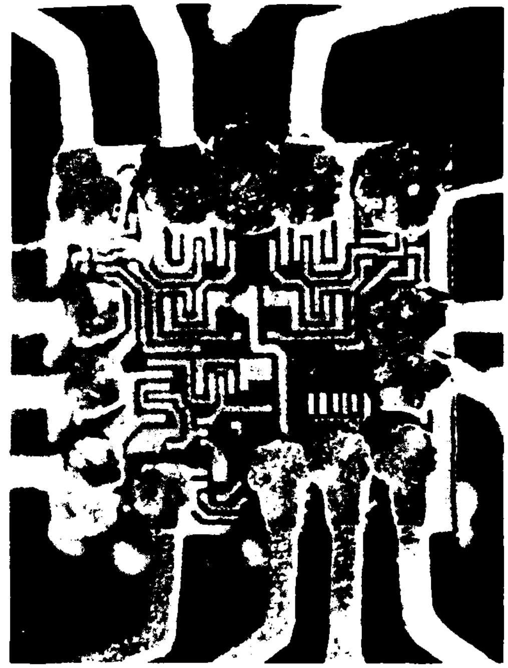

Figure 11. $450^{\circ}C$ - 12 psi - 5 psi - 0.5s Effect on Bump Deformation (55x)

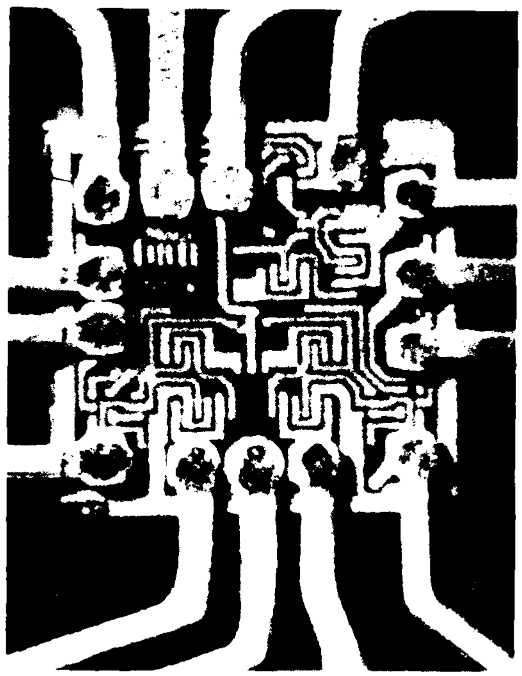

Figure 12. 450$^{o}$C - 5 psi - 2.5 psi - 0.2s
Effect on Bump Deformation (55x)

Table 9. Pull Test Results of Gold Bump – 32000 Å Gold Plated Copper Leads Bonded by 450 °C – 5 psi Bond – 2.5 psi Approach – 0.2 s and Exposed to Temperature – Time Tests

| Exposure | No. of Bonds | Chip-Bump Failures | | | | Lead Failures | | | | | | g (avg) of All Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % of All Failures | g (avg) | Kg/mm² (avg) | std. dev. | % of All Failures | No. of Heel Type | No. of Non-Heel Type | g (avg) | Kg/mm² (avg) | std. dev. | |
| Controls | 54 | 0 | – | – | – | 100 | 47 | 7 | 45.5 | 16.9 | 1.6 | 46 |
| 150°C-250h | 69 | 2.9 | 59.0 | 4.7 | 0.1 | 97.1 | 57 | 10 | 48.3 | 18.7 | 3.0 | 49 |
| 150°C-500h | 138 | 0.7 | 34.0 | 2.7 | * | 99.3 | 115 | 22 | 49.0 | 19.0 | 3.5 | 49 |
| 150°C-1000h | 202 | 0.5 | 30.0 | 2.4 | * | 99.5 | 170 | 31 | 48.1 | 18.7 | 3.3 | 48 |
| 200°C-500h | 56 | 10.7 | 34.8 | 2.8 | 0.7 | 89.3 | 36 | 14 | 49.8 | 19.4 | 3.1 | 48 |
| 200°C-1000h | 55 | 9.1 | 35.4 | 2.8 | 0.4 | 90.9 | 31 | 19 | 45.5 | 17.7 | 3.0 | 45 |
| 250°C-4h | 50 | 2.0 | 59.0 | 4.7 | * | 98.0 | 46 | 3 | 47.6 | 18.9 | 3.4 | 48 |
| 250°C-100h | 52 | 5.8 | 44.7 | 3.6 | 0.7 | 94.2 | 32 | 17 | 50.5 | 19.6 | 2.5 | 50 |
| 250°C-250h | 55 | 9.1 | 37.6 | 3.0 | 0.9 | 90.9 | 35 | 15 | 44.4 | 17.5 | 3.8 | 44 |
| 275°C-4h | 70 | 4.3 | 48.0 | 3.8 | 0.9 | 95.7 | 55 | 12 | 50.7 | 19.7 | 2.9 | 51 |
| 300°C-4h | 68 | 5.9 | 42.3 | 3.4 | 1.2 | 94.1 | 49 | 15 | 48.9 | 19.0 | 3.5 | 49 |

* No value – only one sample failed

(2) A maximum of 10.7% failure of samples resulted at the chip-bump interface for the 200°C - 500 hour exposure group.

(3) A 0.5% failure resulted at the chip-bump interface for the 150°C - 1000 hour group.

(4) Exposure of samples to 250°C for periods up to 250 hours did not promote bump-lead interface failure.

(5) Exposure of samples tc 300°C for 4 hours did not promote bump-lead interface failure.

(6) The average gram force (All Failures Column of Table 9) for each exposure group was within a range of 45 to 51 grams.

(7) Only 20 out of 953 bonds failed with gram force values less than 30 grams. The lowest value measured was 25 grams. (Data obtained of individual gram force values have not been presented in this report.)

CONCLUSIONS/RECOMMENDATIONS

The ILB 32000 angstrom thick Au plated Cu lead - Au plated bump system is considered superior in quality to the two other systems investigated. No pull test (destructive) failures occurred at the bump-lead interface for 953 bonds of the 32000 angstrom system. The 10000 angstrom thick Au system was not as reliable, as a significant number (46 out of 368) of bump-lead failures did occur with the 150°C exposed samples. Panousis and Hall[18] have reported that samples of 7300 angstrom thick Au plate on Cu leads were judged acceptable by them. Their leads were thermocompression bonded to titanium-palladium-gold metallized alumina substrates.

Pull testing of ILB Au bump systems of 10000 and 32000 angstrom thick Au plated leads, revealed small numbers of chip-bump interface failures in both cases, with the 32000 angstrom system having fewer failures. A considerable number of chip-bump failures did occur with the Au bump - 5000 angstrom thick Sn plated Cu system, although optimum bonding conditions were apparently used. It is believed that chip-bump failures associated with the Au-Sn samples were caused by thermal degradation of the Al - barrier metallization interface during bonding. Substantial reduction of bonding thermode temperature, however, prevented the ILB chip from being released from the waxed support plate. Bonding conditions required for "optimum" ILB of Au-Sn samples were undesirably controlled by conditions necessary for chip-release. Apparently, the temperature characteristics of the mounting wax played a significant role.

A 300°C - 4 hour exposure of samples caused extensive deterioration of bump-lead interfaces of Au-Sn plated lead and Au-10000 angstrom thick Au plated lead systems. The degradations were reflected in the occurrence of many pull test bump-lead failures (Tables 4 and 7). No such failure occurred with the Au - 32000 angstrom Au plated lead system (Table 9).

18. Panousis, N. T., Hall, P. M., "Thermocompression Bonding of Copper Leads Plated with Thin Gold", 27th Electronic Components Conference, May 1977, p. 220.

These conclusions suggest that a 300°C - 4 hour exposure could be used advantageously as part of a pull test evaluation to indicate long-term performance potential of candidate ILB metallurgical systems.

The average gram force was 48 grams for pull test failures of all ILB Au bump-32000 angstrom thick Au plated Cu lead samples. This gram force value compares favorably with results reported by Honeywell.[19]

Only 2% of the 32000 angstrom type ILB samples tested in this study (20 out of 953) exhibited pull test failure values less than 30 grams, with 25 grams being the lowest. It should be noted that these minimum results are far in excess of the average bond strengths associated with wire bonding. Based on the results of this ILB study, it is concluded that 20 grams would be a reasonable limit value for use in determining ILB acceptability via non-destructive pull test evaluation.

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19. ERADCOM Contract etc., p. 3, ref. 11