RECEIVED BY TIC JUL 40 1974

300000

RECEIVED BY TIC

1974

Kansas City
Division

IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**MICROBONDING
AND PACKAGING
FOR HYBRID
MICROELECTRONIC
CIRCUITS**

BDX-613-153

February, 1971

**Prepared by:
B. J. Driscoll
Department 842-2**

**PDO 6985257
Final Report**

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Technical Communications

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

GG

This report was

Prepared by:

B. J. Driscoll
D/842-2

Approved by:

A. O. Bendure
D/842-2

Contributors

F. E. Bales D. O. Moore
H. B. Bonham J. H. Pusch
R. Umholtz

THE BENDIX CORPORATION
KANSAS CITY DIVISION
KANSAS CITY, MISSOURI

A prime contractor for the Atomic Energy Commission
Contract Number AT(29-1)-613 USAEC

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ABSTRACT

Processes to bond and package microcircuits are needed to support the microelectronics technology development at Bendix Kansas City. Investigations have encompassed bonding, packaging, and testing processes, such as fine wire ultrasonic bonding, eutectic die bonding, and epoxy channel bonding; substrate sectioning; hermetic sealing; centrifuge testing; and visual inspection. A new flatpack design is discussed which is stronger, more reliable, and cheaper to make. Four process specifications and four material standards have been written because of the work performed during this project.

CONTENTS

	Page
SUMMARY	1
DISCUSSION OF ULTRASONIC FINE WIRE BONDING	5
THEORETICAL CONCEPT	5
MATERIAL PARAMETERS	6
MACHINE PARAMETERS	9
<u>Clamping Force</u>	9
<u>Acoustic Wave Frequency</u>	10
<u>Power Input to the Acoustic Transducer</u>	11
<u>Acoustic Pulse Width</u>	12
PROCESS PARAMETERS	13
BOND QUALITY CRITERIA	14
<u>Summary of Investigations</u>	14
<u>Process Procedures</u>	27
<u>Major Findings</u>	28
ACCEPTANCE CRITERIA FOR FINE WIRE BONDS	28
FINE WIRE PULL TESTER	28
DISCUSSION OF EUTECTIC DIE BONDING	35
DISCUSSION OF EPOXY CHANNEL BONDING	37
INVESTIGATION OF EPOXY CHARACTERISTICS	37
<u>Bendix Single Component Paste</u>	39
<u>Bendix Conductive Film</u>	39
<u>Bendix Nonconductive Film</u>	39
<u>Duroseal Nonconductive Film</u>	39

	Page
INVESTIGATION OF HEAT DISSIPATION IN CHANNEL-MOUNTED TRANSISTORS	40
DISCUSSION OF SUBSTRATE SECTIONING	41
DISCUSSION OF HERMETIC SEALING	43
HERMETICITY DEFINITION	43
SEALING TECHNIQUES	43
<u>Welding</u>	43
<u>Soldering</u>	44
<u>Epoxy Sealing</u>	47
TEST CRITERIA	47
CONCLUSIONS	50
DISCUSSION OF TOP HAT PACK	53
DISCUSSION OF CENTRIFUGE EVALUATION	57
TEST PROCEDURES FOR 1 INCH BY 1 INCH FLATPACKS	57
CENTRIFUGE TEST ON HYBRID CIRCUITS	58
DISCUSSION OF ANALYTICAL OPTICAL MICROSCOPY	61
DISCUSSION OF RESISTOR TRIMMING	63
APPENDICES	
A. NOMARSKI INTERFERENCE CONTRAST	A-1
B. PROCESS SPECIFICATIONS AND MATERIAL STANDARDS	B-1
DISTRIBUTION	B-3

ILLUSTRATIONS

Figure		Page
1	Microhardness Tester (P67292).	7
2	Scratch Tester (P67290)	8
3	Ultrasonic Bonding System, Showing Force Diagram	9
4	Ultrasonic Bond Strength (Mean) Versus Clamping Force	10
5	Bond Strength Versus Input Power to the Ultrasonic Transducer	12
6	Ultrasonic Bond Strength (Mean) Versus Pulse Width	13
7	Capillary, Transducer, and Waveguide Geometry	13
8	Aluminum Substrates Photographed With Nomarski Interference Contrast Process and Classified by Texture and Color (Polaroids).	15
9	Lowest Expected Bond Strength Contour Map, Run 116, Class II--Bonder No. 2-CF93.	17
10	Lowest Expected Bond Strength Contour Map, Run 112, Class III--Bonder No. 2-CF93	17
11	Lowest Expected Bond Strength Contour Map, Run 106, Class IV--Bonder No. 2-CF93	18
12	Lowest Expected Bond Strength Contour Map, Run 126, Class V--Bonder No. 2-CF93.	18
13	Bond Strength (Mean) Versus Power, Run 116, Class II--Bonder No. 2-CF93.	20
14	Bond Strength Versus Clamping Force, Run 126, Class V--Bonder No. 3, Power 4.2, Pulse Width 2	23
15	Sonobond Output Dummy Load	25
16	Typical Failure Modes (Polaroids)	26
17	Bond Acceptance Criteria	29

ILLUSTRATIONS

Figure		Page
18	Bond Acceptance Criteria	30
19	Glycol Phthalate Pull Test Apparatus (P67294)	31
20	Diagram of Glycol Phthalate Pull Test Apparatus	32
21	Typical Stress/Strain Curve	33
22	Pull Strength Versus Angle of Pull	34
23	Failures in Hermetic Seals Caused by Non-Flat Lids and Ring Frames (Polaroids)	45
24	Flatpack Sealer (P67293).	46
25	Temperature Monitors in Flatpack During Sealing Cycle. . .	48
26	Calibration Run	49
27	Flatpack Run	51
28	New Top Hat Pack (P63636).	54
29	Resistor Trimming Methods	64

TABLES

Number		Page
1	Batch 152--Substrate Texture Classes.	19
2	Bond Test Results, Runs 106, 112, 116, and 126	21
3	Bond Strengths, 45° Pull--Five Bonds on Each Substrate	22
4	Bond Test Results.	24
5	Epoxy Characteristics	38
6	Results of Centrifuge Tests on 1 Inch by 1 Inch Flatpacks . .	58

SUMMARY

This project is part of an effort to develop microelectronics technology at Bendix Kansas City, and is an extension of earlier process development efforts. The project's objective is to develop bonding and packaging capabilities for microcircuits into consistent, reliable processes compatible with the production of hybrid microelectronic circuits.

The scope of the project includes:

- ultrasonic fine wire bonding;
- eutectic die bonding;
- epoxy channel bonding;
- substrate sectioning;
- hermetic sealing of flatpacks;
- alternate packaging techniques;
- package testing;
- analytical optical microscopy; and
- resistor improvement.

FINE WIRE ULTRASONIC BONDING

Wire bonds cause most failures in hybrid circuits. Three machines, two types of tips, and three types of wire have been used to develop a reliable bonding process. The Axion bonder, used strictly with gold wire, has produced acceptable bonds. Both a Hughes and a Hugle bonder have been used with aluminum wire, but most bonding has been performed with the Hugle machine. A grooved bonding tip and Ultrasonic Bonding Grade (UBG) aluminum wire have given the best bonding performance. Use of the glycol phthalate pull tester has been found to be the best method for evaluating fine wire bonds.

The mechanical strength and consistency of fine wire bonds have been greatly improved, but fine wire bonding still is not as reliable as is required for WR production. Three bond quality criteria have been established: film texture,

bond shape and location; and pull testing. However, these three criteria do not result in adequate control of material, film, and wire properties.

The study of fine wire ultrasonic bonding has resulted in these recommendations.

- A quantitative test for characterization of aluminum films should be developed.
- Means of ensuring uniformity of metalization characteristics should be established.
- A more repeatable method of applying clamping forces on the Hugle bonders should be installed.
- A longer (bond length) bonding tool should be tested.
- Even though comprehension of and reliability of the ultrasonic bonding process has been improved substantially, methods such as flip-chip and beam-lead bonding appear to be more reliable. Therefore, these methods of device mounting and bonding should be investigated.

EUTECTIC DIE BONDING

Eutectic die bonding involves the bonding of silicon devices directly onto gold conductor pads by the application of scrubbing action and heat. The process was successful for a single die. A point source of heat was needed to provide sequential bonding of several chips on one substrate without overheating previously bonded chips; but an attempt to modify the Lindberg Hevi-Duty die bonder for point source heating was not successful.

Eutectic die bonded devices have produced a more reliable circuit than channel-mounted devices, but flip-chip and beam-lead devices may be better than eutectic bonding. If the eutectic process is to be used for production, an improved machine must be procured which will bond a number of chips on one substrate. In addition, flip-chip and beam-lead devices should be investigated.

EPOXY CHANNEL BONDING

Rigorous physical properties are demanded of epoxies used in hybrid circuits: high thermal conductivity; low electrical conductivity; high adhesive strength; and low outgassing. An epoxy bonding system has been found and employed. Failures due to inadequate epoxy have been eliminated. The present epoxy system (Delta Bond 152 with ETC hardener) is adequate but not optimum. It is recommended that if channel-mounted devices are to be used on future

weapons systems, an investigation to select better epoxy systems should be continued.

SUBSTRATE SECTIONING

During the metallization and photolithographic steps in the fabrication of a hybrid circuit, the substrate is larger than what is used for the final product; so the substrate must be reduced to its final size somehow. In this study, two substrate sectioning methods were investigated--diamond saw cutting, and scribing with a diamond-tipped scribe. Diamond sawing is a lengthy process, somewhat dirty, and presents some problems with chipped edges. A cleaning problem has been solved by Bendix Kansas City Process Specification 1520884 entitled Procedure for Sawing and Cleaning Substrates. Scribing with a diamond-tipped scribe was very erratic. So pre-scribed substrates and laser scribing should be investigated.

HERMETIC SEALING

Hermetic sealing is the final step in the fabrication of a hybrid circuit. The step is important because an unreliable flatpack sealing process wastes man-hours and material. The hermetic sealing effort was directed towards evaluating various materials and sealing parameters, determining causes for leakage in flatpacks, and defining a consistent, reliable process. When this investigation was initiated, a hermetic seal was not obtained in most attempts. No confidence could be placed in the ability to successfully seal a flatpack. However, hermetic seals have been produced by soldering or epoxying lids onto flatpacks. A 95-percent confidence level is now obtained with the epoxy method, and process specifications for two methods of hermetic sealing have been written. If contamination and flatness can be controlled, soldering can produce the same confidence level. Hermetic sealing and the testing of such seals has become a reliable process. It is suggested that more stringent inspection and acceptance criteria should be implemented for the purchase of flatpacks. If sealing is to be performed on a production basis, an automatic solder sealer should be purchased.

TOP HAT PACK

Problems with hermetic sealing and flatpack control led to the conception of a new flatpack called the "top hat pack". The top hat pack eliminates the need for wire bonds from substrate to leadouts. The all-ceramic construction gives added strength. The top hat pack represents a substantial advance in packaging technology. Its advantages over conventional flatpacks are many. It is less expensive; it is more rugged and reliable; it is simpler; and, when used with flip-chip or beam-leaded devices, it will eliminate all wire bonds

in hybrid circuits. It is recommended that future hybrid circuits be fabricated using this packaging concept.

CENTRIFUGE TESTING

The screening value of centrifuge testing on flatpacks, wire bonds, and component bonds was investigated. It was found that centrifuge tests are not adequate screening methods for aluminum wire bonds, but are adequate in the detection of defective solder bonds, epoxy bonds, and flatpacks. The design and fabrication of a custom rotor eliminated fractured flatpacks caused by the centrifuge.

Mechanical tests are essential to ensure the reliability and integrity of hybrid microelectronic circuits. Since centrifuge testing is a valid criterion for evaluating packaging quality, testing methods developed during this study should be used for future evaluation of packaging ruggedness.

ANALYTICAL OPTICAL MICROSCOPY

A microscope is an essential part of work in microelectronics. Visual inspection is a good screening method for various processes. Techniques and skills in use have increased so that microscopy is now an essential tool of failure, manufacturing, and post mortem analyses. Failure modes have been observed and eliminated with analytical optical microscopy. Consequently, three recommendations are made. Microscopy techniques should be used in evaluation of hybrid microelectronic work. Personnel involved in the fabrication of hybrid circuits should be trained in microscopy techniques. Additional microscopy equipment should be procured and additional techniques should be developed.

RESISTOR STUDIES

Several techniques for trimming, and for the addition of trim pads to improve the tolerances of resistor trimming, have been investigated: notching by scratching; electrical sparking; airbrasive; and ultrasonic abrasion. The method using ultrasonic abrasion is suitable for automatic trimming to ± 0.4 percent; however, the other three methods were found unsatisfactory. Alternate methods should be developed (such as laser trimming) which produce less chance of mechanical damage to the substrate and circuit elements.

DISCUSSION OF ULTRASONIC FINE WIRE BONDING

The major activities of this effort were to investigate ultrasonic bonding, to determine the best combination of machine and material variables that will easily produce reliable electrical and mechanical bonding of fine wires into hybrid microcircuits, and to determine the allowable tolerances for each of these variables.

THEORETICAL CONCEPT

The following general metallurgic and thermodynamic statements will explain most of the conditions and effects of ultrasonic welding.

Welding processes are based upon the principle that metal surfaces have associated with them a certain energy called Gibbs free energy. If two surfaces are brought into intimate contact during welding, they will bond resulting in a net loss of energy. An equal amount of energy is required to fracture the bond. Two absolutely smooth, perfectly clean metallic surfaces have a high free energy. Thus, if such surfaces are brought into intimate contact, the loss of Gibbs free energy will be large and the resulting metallurgical bond will be strong.

In practice, metallic surfaces have irregularities, oxides, and adhered gases; therefore, the free energy of such surfaces is small and the metallurgical bonds created by placing them in contact are weak. Typical thin films under consideration have irregularities averaging 500 atomic layers in depth. These films in their pure states have highly energetic surfaces. Molecules from the atmosphere surrounding the surface are adsorbed by or react with the film. At a thickness of approximately 50 atomic layers, oxides are crystalline and the energy of the surface is somewhat reduced. The surface energy of the crystalline oxide is such that bonds may be achieved to asymmetric atoms such as water vapor. Therefore, a film approximately 10 molecules thick of adsorbed gases, including a substantial amount of water vapor, is formed on the metal oxide surface. These barriers reduce the surface energy of a film to the point that bonds to an adjacent material are of very low strength. These barriers must be removed if bonds of reasonable strength are to be created.

Ultrasonic bonding is a welding process which applies lateral ultrasonic pressure waves and normal static forces to produce high stresses in the weld zone. It is postulated that when these stresses exceed the bond strength of the adsorbed gases and the oxide barriers, local slipping occurs to force dispersion of these materials. In addition, when the stresses exceed those supportable by weld materials, local slipping in these materials forces the irregular surfaces of the wire and the substrate to conform to each other. Thus, ultrasonic bonding stimulates plastic deformation and the dispersion of

surface barriers so that in the metallurgical bond the pure weld materials have stronger surface energies.

In this description, local slipping must be distinguished from sliding. Local slipping is a microscopic phenomenon by which ultrasonic energy welds; it is the result of an internal stress of such intensity that the materials' structure cannot support it. Sliding is a gross phenomenon in which the weld materials move with respect to each other; sliding does occur, but it is detrimental and results in deformation and weakening of the weld materials.

A secondary effect, which increases ductility and promotes plastic deformation, is a temperature rise resulting from the elastic hysteresis of the highly stressed portions of the weld zone. This higher temperature is lower than the melting point of the weld materials and is so highly localized that it results in only a slight increase in weldment temperature.

MATERIAL PARAMETERS

Since ultrasonic bonds are the result of local slipping which is produced by large local stresses, it is reasonable to assume that the welding process would be dependent upon the local strength of weldment materials. Because of the complex nature of microscopic material, it is difficult to obtain a meaningful measure of such strength. An approximate measure can be obtained by placing a load on a sufficiently small indenter and measuring the resulting deformation. The ratio of this load to the resulting deformation indicates an approximate measure of the material's local strength. Since microhardness is measured in this manner, a microhardness tester was specified and purchased (Figure 1). Experimental confirmation of bond quality versus weldment hardness was not possible in this development since the tester was not received in time. However, this relationship will be investigated in future work.

In general, the weldment materials of interest to microelectronics are fine aluminum wires 0.0007 to 0.003 inches in diameter and aluminum thin films 0.00004 to 0.00005 inches in thickness. The aluminum film is deposited over tantalum which has been deposited upon a ceramic substrate. The strength of a thin film depends on both its thickness and its composition, so ultrasonic bond quality also depends on the film's thickness and its composition. In addition, bond quality depends on the adhesion of the aluminum film to the tantalum film. This dependency is a result of the bonding mechanism. During bonding enough energy must be applied to the film to force local slipping. But if aluminum adhesion is less than this threshold energy, the applied ultrasonics will fracture the film-to-substrate adhesion bonds and result in an inferior weld--if a weld is produced. Therefore a scratch tester has been fabricated to evaluate film adhesion in terms of the force required to produce a uniform scratch. (Figure 2).

Finally, it has been shown that bond repeatability is dependent upon film texture (film appearance under 1750X Nomarski optics). See Appendix A.

Figure 1. Microhardness Tester.

Figure 2. Scratch Tester.

MACHINE PARAMETERS

Local slipping is the mechanism by which bonds are formed using ultrasonic energy, and this local slipping is forced by large local stresses which result from a normal static force (clamping force) and a lateral dynamic force (an ultrasonic pressure wave). These forces are illustrated in Figure 3. Thus,

Figure 3. Ultrasonic Bonding System, Showing Force Diagram

the major properties of ultrasonic bonding machines are: clamping force; frequency of the acoustic wave; power input to the acoustic transducer; efficiency of transducer and coupling; and the time the acoustic energy is applied (that is, the acoustic pulse width). For repeatable bonds (bonds with consistent pull strength) all of these properties must be controlled.

Clamping Force

The effect of clamping force on the resulting pull strength of fine wire bonds is shown in Figure 4.

As the figure illustrates, the strength of bonds increases monotonically with increasing clamping force to an optimum value. After reaching this optimum value, a further increase of the clamping force results in a nearly linear decrease in bond pull strength. Since clamping force merely holds the weldment materials in contact and prevents the sliding of these materials relative to each other, this unusual relationship between clamping force and bond strength is easily explained. When the clamping force is less than optimum, its magnitude is less than that required to prevent sliding. Sliding causes bonds with

Figure 4. Ultrasonic Bond Strength (Mean) Versus Clamping Force

excessive deformation and low strength. Clamping forces larger than optimum prevent sliding; but since fine wire is a soft material (stress-relieved aluminum), such values of clamping force result in a plastic deformation of the wire's cross-section which, in turn, reduces the wire's pull strength. The reduction in pull strength is directly proportional to clamping force; that is, if clamping force is doubled, the cross-section deformation is doubled and the pull strength is decreased by a factor of two.

Acoustic Wave Frequency

The effects of frequency are related in the changing topological and composition properties of both the film and wire. Thus, a comprehensive discussion of these effects quickly becomes bogged down in conditional statements; however, certain statements may be made by considering the weld zone and weldment materials as a discontinuity in an acoustical wave guide. The power delivered to a load in any guide system is dependent upon the load impedance in such a fashion that when the characteristic impedance of the guide is equal to the load impedance, maximum power is transferred into the load and a state of resonance exists. In acoustics, as in electromagnetics, the load impedance is dependent upon the frequency of the incident wave; that is, the frequency at which resonance exists depends upon the composition and geometry of the weldment materials and upon the coupling between the transducer

horn and weldment materials. Thus, achieving a resonance requires not only that all material compositions and geometries remain constant, but also that the degree of coupling between horn and weldments be repeatable. Such requirements border on the ridiculous if the system is to be used in a production environment. Therefore, typical machines operate at a nominal frequency, around 60.5 kilohertz, with a wobble frequency superimposed around this nominal frequency to compensate for minor resonant frequency differences between loading conditions. This nominal frequency, typically, is not variable and is so selected that the acoustic distance between transducer and the weldments will produce an anti-node at the weld zone.

Power Input to the Acoustic Transducer

The relationship between weld quality and power delivered to the weld zone is described as follows.

- If insufficient power is applied, then the resultant weld is equivalent to that achieved when two materials are lightly pressed together.
- Upon increasing the power, contaminants with low internal strength are dispersed. Further increasing the power disperses more contamination but does not supply enough energy to force the weldment materials to conform.
- Upon reaching the optimum power setting, contaminants are dispersed, weldments conform, and strong welds are achieved.

Excessive power produces the following condition which result in poor weld strength.

- Hysteresis of the highly stressed portion of the weld zone produce work hardening.
- Excessive local slipping forces dispersion of weldment materials and causes excessive deformation.
- Finally, the forces resulting from large acoustic waves exceed the clamping forces, and sliding occurs.

Since local slipping is a discontinuous function of applied energy, the rate is high at which weld pull-strength falls off with increasing or decreasing applied power. Figure 5 illustrates this relationship. Acoustic power is difficult to measure, so the electrical power input to the acoustic transducer was

measured and used in plotting Figure 5. This illustration assumes that the efficiency of the transducer and coupler are consistent and that resonance is always achieved.

Figure 5. Bond Strength Versus Input Power to the Ultrasonic Transducer

Acoustic Pulse Width

The final significant machine parameter is acoustic pulse width; that is, the time the acoustic force is applied. This parameter is significant since too little time will not provide sufficient energy to force slipping and bonding. Too much time will create bonds but will also destroy previously created bonds; that is, bonds are created, destroyed, recreated, and so on, with the result a workhardened bond zone of poor quality. Thus a threshold pulse width exists. Pulse widths below this value do not create welds. Pulse widths beyond this value create inferior welds. Figure 6 illustrates this relationship. Pulse width should always be the minimum value which will create welds.

Figure 6. Ultrasonic Bond Strength (Mean) Versus Pulse Width

PROCESS PARAMETERS

In addition to material and machine parameters, there are other variables in the welding process itself which will affect the quality of a bond. These variables are: capillary geometry and extension; capillary wetting and cleanliness; and wire, capillary, and land alignment.

Capillary geometry and extension are significant because they represent a discontinuity in the acoustical waveguide (Figure 7).

Figure 7. Capillary, Transducer, and Waveguide Geometry

As they are shifted, the acoustical energy delivered to the weld zone changes. The efficiency of the transducer and coupling system also changes. Since power input to the transducer is a front panel adjustment, these geometric parameters are of little concern if they are kept constant. If they are allowed to vary beyond that which is compensated for by the frequency wobble, then the weld schedule cannot be implemented.

It is desirable to keep the bonding capillary clean. However, cleanliness can be over-emphasized. To obtain uniform joints--joints of consistent pull strength--the surface of the bonding capillary must first be coated with the material being bonded. This is done by making several welds before the welding of the product is initiated. Because of the importance of this coating, the capillary should not be cleaned too often.

The final processing variable is that of wire, capillary, and land alignment. In all cases the wire must lie beneath the capillary wedge and generally toward the center of the wedge. Note Figure 3. This is particularly important when grooved capillaries are used. Furthermore, for wedge bonding (the technique most often used), the second bond must always be directly behind the first bond; that is, in line with the wire from the first bond. This prevents stresses on the first bond which may result in bond degradation.

BOND QUALITY CRITERIA

Extensive study was performed to establish an optimum fine wire bonding process and to determine test criteria for ascertaining bond quality. The objectives of the bond quality study were: to determine causes of bonding scars (blemishes due to unsuccessful bonds) on substrates; to eliminate scars if possible; and to optimize bond strength.

Summary of Investigations

Aluminum Texture

The texture of the surface of the vacuum-deposited aluminum (over tantalum) was observed at approximately 1750 diameters magnification using a 1.25 numerical aperture objective lens and Nomarski interference contrast. With the aid of color photographs, a visual grouping with regard to the aluminum texture was made, resulting in the establishment of certain classes (Figure 8). The texture class bore a direct relationship to the number of scars on the bond test substrates for batches 100 through 126, but this phenomenon was later found to be a function of the particular bonder setting used (Figures 9-12). A study of all substrates from batch 152 showed that several texture classes can be produced in the same run (Table 1). The table is arranged to show the position of each substrate inside the vacuum system during the deposition.

Class 1

Class 2

Class 3

Class 4

Class 5

Figure 8. Aluminum Substrates Photographed With Nomarski Interference Contrast Process and Classified by **Texture** and **Color**

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Figure 9. Lowest Expected Bond Strength Contour Map, Run 116, Class II--Bonder No. 2--CF93.

Figure 10. Lowest Expected Bond Strength Contour Map, Run 112, Class III--Bonder No. 2--CF93.

Figure 11. Lowest Expected Bond Strength Contour Map,
Run 106, Class IV--Bonder No. 2--CF93.

Figure 12. Lowest Expected Bond Strength Contour Map,
Run 126, Class V--Bonder No. 2--CF93.

Table 1. Batch 152--Substrate Texture Classes

Substrate Class	1 IV	2 V		4 V	5 IV
Substrate Class	6 IV	7 V	8 V	9 IV	10 II
Substrate Class	11 IV	12 V	13 V	14 IV	15 II
Substrate Class	16 III	17 IV	18 V	19 IV	20 III
Substrate Class	21 IV	22 V	23 V	24 IV	25 III

A study of the effect of temperature has shown that within normal deposition limits, the texture of the aluminum becomes more coarse as the substrate temperature during deposition is increased. Furthermore, it has been shown that a fine texture can be changed into a more coarse texture by heat-treating the substrate after the deposition. The rate of deposition and deposition thickness have been shown to be of relatively little importance in determining the surface texture.

Power-Pulse-Width Sweeps

The range of settings that produce bonds at a constant clamping force was found by a sweep of power settings at the various pulse widths. At low power settings (at all pulse widths), it was nearly impossible to obtain satisfactory bonds: as a result, the aluminum surface was left badly scarred. (Scars are defined as blemishes due to unsuccessful bonds.) At relatively high power settings, the bonds were made, but the wire tended to break near the bond because of excessive deformation. This "wire" failure was even more pronounced at the longer pulse widths. Between these power settings, bonds were made relatively easily; that is, with few scars.

When the successful bonds were subjected to a 45° angle pull test, it was found that the strength varied considerably, with optimum values occurring at certain power and pulse width combinations (Figures 9-12). These optimum settings varied for the different substrate texture classes and for

different bonders. Any variation from the optimum power-pulse-width settings resulting in a larger range of values for bond strengths (particularly low strengths) and tended to produce more scars (especially at the lower power settings). Small variations in bonder settings from the optimum reduced the bond strength significantly (Figure 13).

Figure 13. Bond Strength (Mean) Versus Power, Run 116, Class II--Bonder No. 2--CF93.

The overlapping of contours on the power-pulse-width strength plots (Figures 9-12) suggested that good, but not necessarily optimum, bonds could be obtained using a single setting for the four identified texture classes. This possibility was verified by rebonding the bond test substrates from runs 106, 112, 116, and 126 as shown in Table 2.

Table 2. Bond Test Results, Runs 106, 112, 116, and 126

Run	Class	Original Bonding				Rebonding			
		$\bar{X}^*$	σ	Bonder	Settings	$\bar{X}^*$	σ	Bonder	Settings
106	IV	51.1	19.2	2	P3.2 PW3 CF87	66.0	9.12	2	P4.2 PW2 CF93
112	III	65.2	15.2	1	P4.15 PW3 CF110	63.9	9.20	2	P4.2 PW2 CF93
116	II	65.9	10.0	1	P3.85 PW3 CF110	63.3	9.95	2	P4.2 PW2 CF93
126	V	32.4	19.1	2	P4.0 PW3 CF92	64.9	9.37	2	P4.2 PW2 CF93
*Mean strength in grams from 45° angle pull test for approximately 45 bonds.									

The mean bond strength obtained was very near the values predicted by the contour plots and the standard deviation was quite uniform. Another test in this same vein involved bonding all substrates from run 152 at one bonder setting (Table 3). The results of this test, while evidently not optimum, yielded good bonds for all substrates.

Clamping Force Sweeps

The clamping force was less sensitive in eliminating scars; that is, a relatively large range of values above the minimum value required to make a satisfactory bond was used with relatively few scars occurring. However, the clamping force affected the strength of the bonds materially (Figure 14).

Table 3. Bond Strengths*, 45° Pull--Five Bonds on Each Substrate

Substrate	Class	Mean Strength (g)	Low Strength (g)
1	IV	67	61
2	V	67	54
4	V	75	58
5	IV	71	64
6	IV	72	66
7	V	71	68
8	V	72	60
9	IV	69	62
10	II	59	51
11	IV	68	59
12	V	78	70
13	V	71	57
14	IV	73	57
15	II	70	60
16	III	69	54
17	IV	74	67
18	V	77	74
19	IV	77	71
20	II	68	42
21	IV	65	53
22	V	71	69
23	V	73	67
24	V	69	51
25	III	70	49
* Bonds made on bonder 3 at P4 PW2 CF100

Figure 14. Bond Strength Versus Clamping Force, Run 126, Class V--Bonder No. 3, Power 4.2, Pulse Width 2.

The narrowest range of strengths and the maximum strength occurred at the same clamping force. Lower and higher clamping forces resulted in lower mean strengths and a larger range (particularly toward low strength bonds). Examples of strengths obtainable using data obtained from clamping force sweeps are shown in Table 4.

A typical result for 3 mil wire is a strength of approximately 80 grams with a standard deviation of about 5 grams. When run 144 was also optimized for power, the mean strength increased about 10 percent. The difficulty encountered in optimizing the clamping force is the inherent inaccuracy of

Table 4. Bond Test Results

Optimized Clamping Force							
Run	Class	$\bar{X}$	σ	Bonder	Power Setting	Pulse Width	Clamping Force
144	II	78.8	5.77	3	4.2	2	102
146	IV	80.6	5.99	3	4.2	2	102
148	IV	76.5	4.71	3	4.2	2	102
Optimized Clamping Force, Power and Pulse Width							
Run	Class	$\bar{X}$	σ	Bonder	Power Setting	Pulse Width	Clamping Force
144	II	86.5	5.18	3	3.5	2	102

the measurement. The dial indicators do not provide repeatable measurements. A more consistent method of applying the clamping force is presently being designed. It is recommended that this system be installed on the Hugel bonders without delay.

Bonder Variation

A measurement of the bonder output to the dummy load has indicated that bonder settings represent different energy levels on the three Hugel bonders (Figure 15).

The output even varied appreciably on the different channels on bonders 2 and 3. A test conducted on bonder 3 indicated that the transducer load was proportional to the dummy load at the lower energy levels used for most microcircuit bonding processes. Since the bonder outputs vary, optimum bonder settings for one bonder will not be the same as those for another, even though the energy level desired is the same. The conclusion is that if a substrate is optimized on one bonder, the same bonder should be used for the production run.

Figure 15. Sonobond Output Dummy Load

Mode of Failure

A microscopic study of the mode of failure of bonds pulled at 45° (Figure 16) has indicated that the primary mode of failure for satisfactory bonds is a "wire" type failure; that is, the wire breaks near the bonded portion which is still attached to the aluminum surface. Other common failure modes include the "flat," where a considerable portion of the deformed wire remains bonded but at a level very near the aluminum surface; the "pull-out," where the removed wire pulls up the aluminum and tantalum surfaces and also removes some glass from the substrate; and the Ta(N) mode, where the removed wire pulls up the aluminum down to, and possibly into, but not through the nitrided tantalum surface. The nature of the failure bears little, if any, relationship to the strength of the bond. Wire mode failures were especially common at relatively high power settings. The decrease in strength of these bonds is most probably due to the increased deformation of the wire. The other common failure modes were more apt to occur at relatively low power settings. Neither the mode of failure, nor the strength of the bond, appeared to be dependent upon which end of the wire was pulled. But the angle used in the pull test did affect the mode of failure, with wire failures less likely to occur when nearly vertical pull angles were used.

Flat (180X)

Pullout (180X)

Ta(N) Mode (444X)

Wire (70X)

Figure 16. Typical Failure Modes.

Bonding Tools

A bonding tool search height of from 1 to 3 diameters for 3 mil aluminum wire is the normal range yielding satisfactory bonds. Lower heights still produce strong bonds, but have a relatively high scar frequency. Higher search heights do not provide sufficient contact to ensure that a bond will be made.

A test to determine the effect of the length of the bonding tool below the horn indicated that, within normal limits (0.250 inches to 0.300 inches), the strength of the bond was not materially different. It is believed that a longer (bond length) bonding tool would be advantageous in minimizing scars. A longer tool has been ordered and tests will be made when it is received.

Process Procedures

Optimum Bonder Settings (Hugle Bonder Model 1300)

The following procedures result in optimized bonder settings.

- Set pulse width and power to moderate values. (For instance, for 3 mil aluminum wire, use about P4.0 and PW2.) Adjust clamping force to a value at which bonds can be made relatively easily.
- Run a power-pulse-width sweep at this clamping force, putting down at least two bonds at power increments of one-quarter to one-half turn. (For instance, for 3 mil wire use P3 through P7 at PW1, 2, and 3.) Determine the strength of these bonds using a 45° angle pull test. Select the clamping force setting yielding highest bond strength.
- Use settings yielding the highest low strength (as determined from a power-pulse-width plot) to make a clamping force sweep. Put down at least two bonds at increments of approximately 5 grams. Determine the strength of these bonds using a 45° angle pull test. Select the clamping force setting yielding highest bond strength.

Film Texture Control

- Observe each substrate from an aluminum deposition run at approximately 1000 diameters magnification using a high resolution dry objective and Nomarski interference contrast.
- Determine the texture of the film by comparison with Figure 8.

Major Findings

- It is possible to maximize bond strength while minimizing scars.
- Optimum bonder settings depend on the characteristics of the individual substrates.
- The aluminum texture depends on the temperature history of the substrate.
- The 45° angle single wire pull test is an effective method of determining bond strength.
- The mode of failure of the bond is not indicative of the bond strength.
- The aluminum texture normally indicates the bonding characteristics of the substrate.

ACCEPTANCE CRITERIA FOR FINE WIRE BONDS

Based on information developed during the study of fine wire bonding techniques and bond quality criteria, further work was done to develop acceptance criteria for fine wire bonds. The acceptance criteria are outlined in Figures 17 and 18.

FINE WIRE PULL TESTER

To develop fine wire bonding, a method of bond evaluation was needed. The obvious criterion, bond pull strength, presented many difficulties. First, a method for clamping fine wires (0.0007 to 0.003 inch in diameter) had to be devised. Second, a means of translating input data, force, and rate of pull into meaningful output data was required. The tester described below used glycol phthalate as a clamp for the wire and provided permanent data in the form of a stress-strain curve.

The pull tester developed for the bond strength testing consists of a bond cell, a dc motor with gear drive, and a resistance loop to melt the glycol phthalate adhesive (Figure 19). Glycol phthalate is a low-temperature thermoplastic which clamps the fine wire without straining or deforming its cross section. The glycol clamp consists of a current loop in which a goblet of

REJECT 30

REJECT 1.20

REJECT

ACCEPT

Any bond which deforms the wire greater than 3 times the wire diameter or less than 1.2 times the wire diameter shall be rejected.

Fractured bonds shall be rejected if greater than 20 percent of the weld zone is missing, or if a crack separates 20 percent or more of the bond zone.

ACCEPT

REJECT

The bond zone shall be entirely within the confines of the land. Bonds shall not be placed over previous bond attempts.

Bonds shall have tails no longer than 3 mils.

Figure 17. Bond Acceptance Criteria.

REJECT

$$a + b + c \geq \frac{W}{2}$$

REJECT

$$a \geq \frac{W}{2}$$

VOIDS DUE TO BOND FAILURES. Any void or combination of voids which reduce the current path 50 percent or more shall be the cause for rejection of the entire circuit.

Wires displaced more than three wire diameters from the ideal connection shall be cause for rejection. X is the displacement of the wire from the ideal connection. If X is greater than 3D the connection shall be rejected.

TO ACCEPT: $3D \leq X \leq 7D$

Bonds shall be rejected when their loop is less than three wire diameters or greater than seven wire diameters.

Figure 18. Bond Acceptance Criteria.

Figure 19. Glycol Phthalate Pull Test Apparatus.

glycol phthalate is placed as shown in Figure 20. When current is applied to the loop, the glycol melts. The wire to be tested is then placed in the melted glycol and the current is removed. Solidification occurs in a few seconds and is strong enough to hold the wire in 150 grams of tension. The advantage of this system is that since it does not apply a mechanical force to the wire, it does not deform the wire. So the test results are a measure of bond strength rather than of the deformation imposed by a mechanical clamp. The pull tester also insures that the geometry of all pulls is repeatable.

Figure 20. Diagram of Glycol Phthalate Pull Test Apparatus

Pull test data is automatically recorded on a strip chart in the form of a stress-strain curve as shown in Figure 21. Such curves provide not only the breaking strength of the bond but also provide data to indicate the wire-bending modulus of elasticity and Young's modulus of elasticity. The stress data is recorded to an accuracy of ± 2 percent, the strain data to ± 5 percent. Tests may be made at any angle of pull and at any pull rate between 0.5 and 3 centimeters per minute. An investigation of the angle of pull of the wire has shown that the strength increases as the angle from vertical decreases.

For instance, a 90° (vertical) pull will yield about 60 percent of the strength of a 45° angle pull. Furthermore, pulls near horizontal yield strengths double that of 90° pull. Pulling the wire sidewise does not appreciably affect the strength (Figure 22).

This tester has provided information which has greatly increased the quality of fine wire bonds and the repeatability of bonding. Furthermore, it may be easily implemented as a production tool for developing and certifying bond schedules and may be used to verify the quality of microelectronic devices.

Figure 21. Typical Stress/Strain Curve

Figure 22. Pull Strength Versus Angle of Pull.

DISCUSSION OF EUTECTIC DIE BONDING

Eutectic die bonding is a process which is used to make an electro-mechanical connection of silicon or germanium to gold substrates, headers, or channels. The process utilizes the fact that when gold and silicon are alloyed in proper proportion, the melting temperature of the alloy is less than the melting temperature of either of its components. Thus, to eutectically bond, a silicon device is placed on a gold surface and scrubbing action and heat (approximately 380°C) are simultaneously applied. The scrubbing forms the alloy. The heat forms a melt. The solidified melt forms the bond. This process, at a different temperature, also allows mounting germanium devices.

During this development a Lindberg Hevi-Duty eutectic die bonder was purchased and evaluated. This bonder, with processes developed on this project, acceptably bonded to thick film conductors, transistor headers, and ceramic channels. The only problem occurred while attempting to bond several chips onto one substrate. The bonder heated the entire substrate to the bonding temperature (about 380°C) and the prolonged exposure to this heat caused the chips to continue melting, which ruined the devices. An attempt was made to refixture the bonder so that only a point source of heat would be applied to the substrate, but this attempt was unsuccessful. It is felt that the problem can be overcome by bonding two or three devices at a time; then removing the substrate from the heat and allowing it to cool; then replacing the substrate and bonding a few more devices, continuing in this manner until all devices are bonded. This method should work because it will require a higher temperature to remelt the bond.

Mounting chips directly to substrates is more reliable than channel-mounted devices because the need for an epoxy bond from channel to substrate is eliminated. A eutectic bond has better thermal conductivity than an epoxy bond. Direct die bonding to a conductor pattern eliminates the need for channel-mounted devices. This creates a better and more reliable circuit by reducing the number of wire bonds and increasing the device's thermal dissipation.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF EPOXY CHANNEL BONDING

In the fabrication of microelectronic devices which use chip-channel semiconductors, a bonding technique is required to attach channels to a thin film resistor-conductor network. The process used is epoxy gluing.

This technique includes the investigation of epoxies having the properties required for channel-substrate bonding. These same epoxies are also used for substrate-flatpack bonding. Such epoxies must have high thermal conduction, high strength, and high electrical resistance. Maximizing thermal conduction and electrical resistance is difficult and is best accomplished by minimizing the epoxy thickness. So the epoxy must be in the form of a solid thin film, or a viscous liquid or paste capable of being spread in a thin uniform layer. A thickness of less than 6 mils is acceptable. Secondary properties which are desirable, but not required, include a long shelf life, a long working time, a short cure cycle at low temperature, and ease in handling. Achieving as many of these properties as possible has been the goal of this investigation.

INVESTIGATION OF EPOXY CHARACTERISTICS

A total of five epoxies were investigated, two in paste form and three in film form. Table 5 lists these epoxies and their characteristics. Delta Bond 152 with ETC hardener is the system now in use. As a two component system, it requires mixing and has a limited working time. In application, these properties are particularly distressing because large quantities must be prepared to ensure an accurate mixture, and the major portion of this mixture must be discarded because such small quantities are required in circuit assembly that the epoxy working time is exceeded before a significant portion of the mixture has been used. This results in wasted material and time required for mixture preparation.

A new epoxy system to replace Delta Bond ideally should retain all the advantages and eliminate all the undesirable qualities of Delta Bond. Two systems have been investigated--a single component paste epoxy and a thin film epoxy. The paste apparently is the most promising system as a replacement for Delta Bond because of its very similar viscosity. However, attaching substrates to flatpacks has been a problem because of the lack of a suitable method of applying a paste epoxy. Improper application results in air gaps between the substrate and flatpack, or in excess epoxy squeeze-out or flow, or in both of these problems. The air gaps act as thermal insulators and cause heat dissipation problems, while the excess squeeze-out may damage other parts of the circuit and often leads to bonding difficulty. A film epoxy which could be precut to

Table 5. Epoxy Characteristics

Epoxy Type	Advantages	Disadvantages	Unknowns
Delta Bond 152 with ETC Hardener (Alumina Filled)	Adequate thermal conduction Adequate electrical resistance Adequate strength Reasonable cure cycle	Two component system (requires mixing) Short working time Component separation and flow	None
Bendix Single Component Paste (Alumina Filled)	Single component system Stable at room temperature (long working time) Reasonable cure cycle Good consistency for screening	None	Undetermined thermal physical, and electrical properties Undetermined separation and flow
Bendix Conductive Film (Epoxy Impregnated Silver Mesh)	No flow or separation problem Uniform thickness Good thermal properties Can be cut to size	Requires 50 psi during cure Conductive particles may enter system Long cure cycle	Undetermined physical properties
Bendix Nonconductive Film (Epoxy Impregnated Fiberglas Mesh)	No flow or separation problem Uniform thickness Can be cut to size	Requires 50 psi during cure Particles may contaminate system Long cure cycle	Undetermined physical and thermal properties
Duroseal Nonconductive Film	No flow or separation problem Uniform thickness Minimal pressure during cure Reasonable cure cycle Can be cut to size Can be ordered to preforms	Questionable strength Possible outgassing	Undetermined thermal properties

proper size would eliminate both these difficulties by yielding a uniformly thick bond between substrate and flatpack with no squeeze-out and practically no flow.

Investigations of the four possible substitutes for Delta Bond have reached various stages of completion. A review of the investigation of each epoxy system follows.

Bendix Single Component Paste

This 70 percent (by weight) alumina-filled epoxy was formulated at Bendix Kansas City. The first batch, completed in early December 1968, contained solvents used to introduce the curing agent to the resin and as a result had low strength. A second batch was prepared without solvents. This formulation compared favorably with Delta Bond in physical, electrical, and thermal properties and required no mixing. Shelf life should exceed six months. This formulation appears to be ideally suited for use with an epoxy printer, a technique preferred for precise deposition of epoxy.

Bendix Conductive Film

This epoxy--impregnated with silver mesh--was also developed at Bendix Kansas City, and is described in Electrically Conductive Film Adhesives, Bendix Kansas City Final Report E-288 (January 1968). Although this is a conductive film, it should be an excellent epoxy for placing substrates in flatpacks because of its high thermal conductivity. However, the pressure required during curing makes this material difficult to apply to microelectronic devices.

Bendix Nonconductive Film

This epoxy--impregnated with fiberglass mesh--was developed at Bendix Kansas City. Since this film is nonconductive, it could be used to place substrates in flatpacks; however, the film has a high cure pressure and particles of the film might contaminate the microcircuit system during cure. The film also has unknown thermal properties.

Duroseal Nonconductive Film

This nonconductive film is manufactured by Physical Sciences Corporation. Limited testing has indicated questionable strength. Thermal conductivity is unknown. The low pressure required during cure makes this product well worth investigating more thoroughly.

A specification, 1520416, defines the requirements of adhesive bonding and the epoxy used for such bonding.

INVESTIGATION OF HEAT DISSIPATION IN CHANNEL-MOUNTED TRANSISTORS

An investigation was conducted into the thermal dissipation of channel-mounted transistors epoxied to a flatpack. To determine the feasibility of channel-mounting power transistors in hybrid circuits, an experiment was devised to determine the thermal resistance of such a package. A General Electric 2N5150 power transistor¹ was mounted in a channel attached to an alumina substrate which was mounted in a flatpack. Delta Bond 152-ETC epoxy was used for all bonds with the exception of the chip-to-channel bond which was gold-filled epoxy. One-mil thermocouples were bonded to the chip, under the channel, under the substrate, and to the bottom of the flatpack. All four thermocouples were monitored as a function of transistor power level. The thermal resistance was found to vary with transistor power; however, for the range of power interest (up to 3 watts), the thermal resistance is less than 23°C per watt. Thus, the following pessimistic relationship may be stated.

$$T_C = HP + T_F,$$

where:

T_C is the chip temperature;

T_F is the flatpack temperature;

P is the power dissipated in the transistor; and

H is the thermal resistance (23°C/watt).

The problem reduces itself to one of heat sinking the flatpack.

¹The G. E. 2N5150 transistor is of particular interest. This transistor has a maximum operating temperature of 175°C and should be operated with 0.7 watts collector dissipation. Therefore, in keeping with the equation, $T_C = HP + T_F$ the flatpack must be held to a temperature less than 157°C to prevent "thermal runaway."

DISCUSSION OF SUBSTRATE SECTIONING

In the fabrication of thin or thick film microelectronic circuits, alumina substrates must be cut for packaging. Two methods were investigated for this work. Scribbling with a diamond pencil and then breaking proved to be inaccurate and left rough edges. A high-speed, water-cooled diamond saw was also investigated. A Bronwill thin-sectioning machine was purchased and modified for application to alumina sawing. The modification consisted of fabricating a mechanical chuck to hold and position substrates during cutting, and constructing a water circulating system to provide continuous cooling during cutting. With this modification, cutting time per substrate is approximately 15 minutes.

Alumina is a hard, brittle substance with a tendency to chip. Particles from the sawing operation contaminate the circuit. Since microelectronic devices must be clean for proper operation, a cleaning procedure has been developed and documented in Bendix Kansas City Procedure 1520884. The following steps define this procedure:

- Rinse substrates while still on chuck in running distilled water;
- Wipe substrates carefully with a soft, lint-free cloth saturated in distilled water;
- Remove substrates from the chuck;
- Boil the substrates in normal butyl alcohol for 5 minutes;
- Ultrasonically agitate the substrates in clean, warm, normal butyl alcohol for 5 minutes;
- Boil the substrates in clean, normal butyl alcohol for 5 minutes;
- Dip substrates in a 5-part "parlodion"-100 part amyl acetate solution and allow to dry;
- Ultrasonically agitate the substrates in amyl acetate; and
- Rinse the substrates in ethyl alcohol and blow dry.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF HERMETIC SEALING

The hermetic sealing of hybrid microelectronic devices was investigated. This investigation defined hermeticity, developed sealing techniques, and studied criteria by which sealing quality or hermeticity may be ascertained.

HERMETICITY DEFINITION

A true hermetic seal is one which entirely resists the flow of gas both into and out of a package. This is an idealized concept; thus the degree of hermeticity by which a seal resists gas flow is the usual measurement. For microelectronic devices, the hermeticity required is typically a seal which leaks at a rate no greater than 10^{-4} cubic centimeters per second of helium under a pressure drop of 1 atmosphere. In addition to the hermeticity requirement, microelectronic reliability requires that a sealed package contain little, if any, corrosive gases such as hydrogen, oxygen, hydroxyl, or water vapor. Therefore, studies were performed to determine the concentration of corrosive residual gases inside sealed packages.

SEALING TECHNIQUES

A sealing procedure was required for a variety of microelectronic packages consisting of ceramic, glass, and metal base materials. Three sealing techniques investigated were welding, soldering, and epoxy gluing.

Welding

In welding, current flows from one electrode to the lid of the flatpack and out the other electrode. The conduction of the flatpack frame contributes only a negligible amount to the conduction of current from electrode to electrode. Heat is generated by current flow because of the resistance (I^2R) between the electrodes and the outside lid corners. The current concentration in the lid is highest near these points, further increasing the localized I^2R heating. The temperature of the material at these points is sufficiently high so that the force of the electrodes causes a minor amount of material flow, leaving characteristic, parallel seam, electrode marks around the edge of the lid.

The standard flatpack has a 0.006-inch-thick Kovar window which facilitates sealing the lid to the flatpack. This window is sufficient for soldering techniques. But, for welding, the current distribution is such that the Kovar window overheats and fractures the window-to-flatpack glass seal. So, a new package has been designed with the same overall geometry as the present package but with a 0.060-inch-thick window.

Further investigation into welding was halted because of the success of solder and epoxy sealing. Metal packages or packages with metal sealing frames are solder sealed; others are sealed with epoxy. When the electronics in a package--or the package itself--cannot withstand solder temperatures or when the lack of sealing frame flatness (Figure 23) prevents solder sealing, epoxy is used.

Soldering

The development of solder sealing first required a machine that would provide a means for purging microelectronic packages and provide fixturing for holding the lid and packaging; and that would provide peripheral heating of the package. Such a machine was designed and built at BKC and is shown in Figure 24. It consists of a purging system, a fixturing system, and a heating system. The purging system (basically a vacuum pump with associated valves) is designed so a package to be sealed may be pumped down to 10^{-2} torr and then back-filled with an inert gas, which is typically a nitrogen-helium mixture. The fixturing system is composed of various clamps and a large aluminum heat sink. The heat sink is placed on the back of a package being sealed to ensure that the circuit is not exposed to a temperature which would cause drifting of its electrical characteristics. The heating system conforms to the edge of a package and consists of a peripheral filament through which a large current passes to provide joule heating. The current is controlled by a variable transformer, a thermostat, and a timer. The settings on these three controls then provide the required program for sealing a given package.

A procedure for solder sealing is as follows.

- Clean all soldering surfaces, including solder preforms, with trichloroethylene and rinse in isopropyl alcohol.
- Align the lid, solder preform, and flatpack on top of the heater.
- Position the aluminum heat sink and tighten so the back of the flatpack is in direct contact with it.
- Lower the bell jar over the system and pump down. Allow 10 minutes for pressure gradients to diminish. Back-fill the system with a mixture of 80 percent nitrogen and 20 percent helium to a positive pressure of 1 pound gage. Again, allow 10 minutes to diminish gradients.
- Activate the heater controls in accordance with a previously determined program.
- Allow the package to cool and then remove it from the sealer.

Figure 23. Failures in Hermetic Seals
Caused by Non-Flat Lids and
Ring Frames.

Figure 24. Flatpack Sealer.

An effective sealing program is one which provides sufficient heat to melt the solder at the sealing surfaces but does not heat the circuits or substrate above 150°C because higher temperatures might degrade the electronics. An example of a useful program is illustrated in Figure 25. To pick the time-temperature profile needed to establish a sealing program, eight thermocouples were used. Four of these thermocouples were spaced uniformly around the sealing surface, the other four upon the circuit to be sealed. The process was then cycled with various current and time settings with temperatures monitored. A second method verified that the substrate was not excessively heated by using temperature-sensitive paint. The paint will turn black when a specified temperature is reached.

Epoxy Sealing

The following procedure is used for epoxy sealing:

- All surfaces to be joined must be cleaned with trichloroethylene and rinsed in isopropyl alcohol.
- The packages to be sealed must be placed in a glove box, pumped down, and back-filled with inert gases as was done in the soldering procedure.
- The epoxy is mixed in accordance with Bendix Kansas City Standards 2140525 and 2201115.
- The epoxy is applied with a syringe to achieve a uniform continuous bead around the sealing area.
- The lid is placed on the package and 12 hours are allowed for curing.

TEST CRITERIA

Two criteria must be investigated to ascertain the quality of seals produced by any of the above processes: leak rate, and composition of the residual gases in the package.

Leak rate may be measured by a number of techniques. The glycerin bubble test, the fluorocarbon test, and the tracer gas test are techniques investigated during this study. The glycerin and fluorocarbon tests measure leaks of 10^{-4} atm.-cc/sec or above. The tracer technique measures leaks from 10^{-6} to 10^{-10} atm.-cc/sec.

The residual gas content is determined by pumping down a sealed package and measuring with a gas spectrometer the composition of the gases left in the vacuum system. This data provides a background calibration (Figure 26). After pumpdown and measurement, the package is punctured and the residual

Figure 25. Temperature Monitors in Flatpack During Sealing Cycle.

Figure 26. Calibration Run. (Background peaks are the result of hydrocarbon fractionation.)

gases in the vacuum system are again measured (Figure 27). Comparing this data to a calibration run indicates the gas composition in the sealed flatpack. The package was sealed in an argon-helium atmosphere. Note that Figures 26 and 27 reveal that very small quantities of corrosive gases are sealed into the electronic package. This technique is feasible for diagnostic work to determine the gas composition inside a flatpack.

CONCLUSIONS

Two techniques for hermetic sealing have been developed: solder sealing and epoxy sealing. Both of these techniques provide quality seals based upon the requirements of typical microelectronic networks. Solder sealing is used for packages up to 3/4 inch on a side that are made of metal or provide metal sealing frames. All other packages are sealed by the epoxy technique. Bendix Kansas City Specification 1520881 for hermetic sealing describes in detail the requirements for both of these sealing methods.

Figure 27. Flatpack Run. (Background peaks are the result of hydrocarbon fractionation.)

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF TOP HAT PACK

The investigation of a new packaging concept produced the following observations:

- Flatpacks are available from vendors in three basic styles: ceramic, metal, and glass. The packages are made from combinations of the three materials with the predominant material determining the name;
- Design criteria is the basis for the selection of the types of flatpacks used; and
- A study of the merits of each type of flatpack should yield a package best suited for the particular requirements.

For example, for service involving a severe thermal shock and centrifuge test, the ceramic package is better than the glass package. If an ohmic contact is needed to enable a common interconnection of devices, the metal flatpack is preferred. With cost being a prime consideration, the glass package is preferred. Where other factors are to be considered, compromises must be made in choosing the best package for a particular application.

Besides type, there are many sizes and configurations to consider. The number of leads may vary anywhere from 1 to 200. Some typical dimensions of packages are 1/8 inch by 1/8 inch, 3/4 inch by 3/4 inch, and 1 inch by 1 inch; round or rectangular packages also can be designed. A suitable flat-pack can be found for most dimensions.

Flatpacks are difficult to seal, expensive, and unreliable. Therefore, a new packaging concept known as the "top hat pack" (Figure 28) has been developed, which involves the complete elimination of wire bonds from hybrid circuits. The package uses the substrate as the bottom of the flatpack. A special cover has been designed to fit over the circuitry. Lead-outs are either deposited (thin film) or printed (thick film) onto the substrate. In an ordinary flatpack, wire connections are made between the substrate and the flatpack leads. The wire bonding is eliminated in top hat packs, thus substantially increasing reliability.

Hermeticity of the package can be obtained by two methods. In one method, an insulator film, which is either printed on with thick films or vacuum-deposited with thin films, is placed over the lead-outs and a metalizing layer is printed or deposited on top of the insulator and around the edge of the cover. The two metalized parts are then soldered together. The second method involves epoxy gluing the cover onto the substrate over the lead-outs.

Figure 28. New Top Hat Pack.

No insulator or metalizing layers are used. With this second method, the most vulnerable part of any flatpack--the glass seal around the leads--has been eliminated. The metal-to-ceramic seal of the ring frame has also been eliminated.

The top hat packs are much stronger and more reliable than conventional flatpacks. The top hat pack represents a significant cost savings (typical cost \$.50 versus \$8.00), and the all-ceramic construction gives added strength. Testing has shown this package to be very strong. The conventional flatpack in use failed at 20,000 g's. A 71 percent failure rate was found at 30,000 g's and an 85 percent failure rate at 35,000 g's. No further testing was done. The top hat pack had its first failure at 30,000 g's because of a cracked seal. At 35,000 g's the top hat pack had a 10 percent failure rate, all due to cracked seals. The first failure not caused by a cracked seal occurred at 45,561 g's. A cumulative total of all flatpacks up to 50,026 g's showed 40 percent of the packages failed because of cracked seals while 10 percent had failed because of the package failure. With a stronger epoxy sealing agent the reliability of the package can be improved.

The top hat pack can be connected externally the same as other packages by welding, soldering, or epoxying leads onto the lead-outs outside of the package. For added strength, an epoxy or borosilica film can be applied along the edge. In addition, the lead-outs can be directly soldered to a circuit board. The package can also be plugged into a socket like conventional circuits. Holes may be added to the substrate and pins placed through the holes. With this configuration the package can be plugged into a circuit board or receptacle as is done with conventional transistors or resistors.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF CENTRIFUGE EVALUATION

Integrity of hybrid microcircuits is verified in part by centrifuge tests. A specification for a centrifuge to spin hybrid microcircuits was written and a centrifuge purchased. A custom rotor was designed at Bendix Kansas City and fabricated by the vendor.

The main objectives of the evaluation were to determine the maximum g-loading to which a 1 inch by 1 inch flatpack could be subjected without a structural failure, and to evaluate the failures of hybrid microcircuits when they are subjected to a 10,000-g centrifuge test.

TEST PROCEDURE FOR 1 INCH BY 1 INCH FLATPACKS

This procedure was used for testing 1 inch by 1 inch flatpacks:

- A lid was temporarily attached to each test specimen using Mylar tape.
- The lead frame was clipped from each specimen.
- The test specimens were placed into the centrifuge rotor slots. They were oriented so the plane of the flatpacks was perpendicular to the accelerating force and the top of the flatpack was facing away from the center of rotation.
- Small pieces of foam rubber were placed in back of each flatpack in order to hold the flatpack in place while the rotor was stationary.
- Each specimen was first subjected to a 10,000-g test for a period of 2 minutes. It was then removed from the centrifuge rotor and inspected for structural damage. If damage was not detected, the specimen was then tested at the next higher g-level, 15,000 g's. The procedure was repeated in 5,000-g increments. The maximum g-loading to which any flatpack was subjected was 25,000 g's. Four types of flatpacks were tested and the results shown in Table 6:
- 1.0 inch by 0.945 inch, Kovar base and frame, glass side walls, made by Bendix Scintilla;
- 1.0 inch by 1.0 inch, ceramic base and side walls, made by American Lava;

- 0.967 inch by 0.896 inch, ceramic base, glass side walls on two sides, made by Tung-Sol; and,
- 0.967 inch by 0.897 inch, ceramic base, glass side walls, made by Philco-Ford.

Table 6. Results of Centrifuge Tests on 1 Inch by 1 Inch Flatpacks

Flatpack		Number of Specimens Failing Test at g's x 1000				Failure Mode
No.	Type	10	15	20	25	
16	Bendix Scintilla	0	16			Glass side wall fractured.
6	American Lava	0	0	0	0	None
9	Tung-Sol	0	0	5 (1)	4 (1 & 2)	1. Glass fractured 2. Lid fractured
4	Philco-Ford	0	4	0	0	Glass side walls fractured.

It was concluded from these results that flatpacks with the most glass used in their construction failed at the lowest g-levels; thus glass was the material limiting the structural strength of the packages. The Bendix and the Philco-Ford packages failed at the 15,000-g level. The Tung-Sol package failed at the 20,000-g level. The American Lava package which had all-ceramic side-walls passed all tests.

CENTRIFUGE TESTS ON HYBRID CIRCUITS

To evaluate the 10,000-g centrifuge test, 160 hybrid microcircuits were subjected to 10,000 g's for a period of 2 minutes. Failures are listed on the next page.

Type of Failure	Number of Failures
Wire bond	6
Slug capacitor separated from solder	2
Power transistor separated from flatpack	1
Flatpack fractured	<u>1</u>
Total	10

In the 160 circuits tested, there were 7165 fine wire bonds. The wire bond failure rate was calculated to be 0.084 percent. This low failure rate was expected because the centrifuge test is not considered an adequate aluminum fine wire bond test. A good 3 mil wire bond should have a 50-gram pull strength; however, a 10,000-g load applied to a 3 mil aluminum wire 0.125 inches long and bonded at one end subjects the bond to only a 0.15 gram force. The wire bonds that failed obviously were either of very poor quality or were not actually bonds. It is possible for a wire to appear to be bonded when it is merely contacting the surface of the bonding land.

The centrifuge test is considerably more useful in the detection of defective solder bonds and epoxy bonds. Components which are bonded into place using solder and epoxy typically have much more mass than 3 mil aluminum wire interconnect; so the centrifuge test is more meaningful in these cases.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF ANALYTICAL OPTICAL MICROSCOPY

Optical microscopic examination of specimens is important in all diagnostic work connected with microelectronic processes.

An extensive report entitled The Use of the Carl Zeiss Microscope for Microelectronics was written to provide instructions on the proper use of bright field or dark field illumination, reflected or transmitted light, Nomarski or regular optics, filtering, and polarizing techniques. The Zeiss microscope has a range of magnification available from 12.5 to 1750 diameters. The microscope itself has been improved by the addition of high intensity mercury vapor light source and a 2-inch-thick steel base to eliminate vibrations. The microscope has been valuable for post mortem analyses of circuits. It is also used for failure analysis and diagnostic analysis in all areas of microelectronic technology. Examples of pictures taken with a Polaroid camera attachment for the microscope are shown throughout this report. Figure 8 is of particular note.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION OF RESISTOR TRIMMING

Four methods of trimming thin film resistors on substrates were investigated. These involved removal of resistor material using mechanical, electrical, airbrasive, and ultrasonic probes. Three of the four methods are illustrated in Figure 29.

The method using a mechanical probe involved scratching a path in a resistor. This increased the path length of the resistor. A ragged edge and a very small separation was left between the resistor paths. Both effects were undesirable.

The electrical sparking method involved burning a path in the resistor. This was done by applying a potential to a probe and then using the probe to burn a path in the resistor.

The airbrasive method consisted of a high pressure stream of abrasive blowing through a small diameter nozzle. This method was unsuccessful because the position of the abrasive blast could not be controlled closely enough to avoid damage to 10-mil-wide resistors and the amount of trimming could not be accurately controlled.

The ultrasonic technique consisted of mounting a special tip in the Hughes ultrasonic bonder. Portions of the resistor were trimmed away by the ultrasonic scrubbing action of the tip. This type of trimming cut down the current carrying capability of the resistor.

The bonder provided a vacuum chuck to hold the substrate and resistance probes for measuring resistance during trimming. This resistor trim station was further automated through a circuit which removed the ultrasonic power when the desired resistance was achieved. This process is repeatable to ± 0.4 percent.

Since we do not require resistors of such a fine tolerance another method has been employed. This method involved the addition of trimming pads to the resistor. Small resistor segments which are connected by a conductor are added to the end of a resistor. If added resistance is needed the narrow portions of the conductor are cut by using an ultrasonic probe. Thus, the resistor value can be adjusted until the required tolerance is met.

Figure 29. Resistor Trimming Methods.

Appendix A

NOMARSKI INTERFERENCE CONTRAST

Appendix A

NOMARSKI INTERFERENCE CONTRAST

The Nomarski Interference Contrast principle may be described in this way:

Above the objective lens is a plate called a Wollaston prism. In cross-section, the prism looks like this:

The arrows indicate that the optical axes of the two parts of the prism are at right angles to each other. The light enters the prism and is plane polarized to an angle of 45° to match the polarization planes in the prism. The prism splits an entering ray of light into two rays which are spatially separated, and which are also polarized at right angles to each other. Schematically:

If the surface of the specimen to be viewed is flat, then the two rays will be reflected back on themselves and will combine, in phase, above the prism. If, however, the specimen has an irregular surface:

then there will be a difference in the time of the reflection of the two rays, and thus a difference in the time when they combine. Interference results from such a difference. In monochromatic light, the interference results

in a change of intensity, but in "white" light colors can appear, since certain light wavelengths can be cancelled out.

A color-change handle attached to the prism changes the relative distance of the light path by selecting the portion of the prism wedge to be used. Thus, it could be that for a situation like:

the path distance is the same for the two legs, even though the specimen has an irregular surface. With the prism so adjusted, that situation and this situation:

are different even though the amount of slope is the same. The former situation would give a white image with white light, while the latter situation would give a colored image with white light.

The prisms have been designed so that the spatial separation is less than the resolution of the objective lens used with it.

Appendix B

PROCESS SPECIFICATIONS AND MATERIAL STANDARDS

Copies of the following process specifications and material standards issued during the development of this report are available upon request.

PROCESS SPECIFICATIONS

Specification For Wedge Ultrasonic Fine Wire Bonding

1444391-000 Issue A July, 1969

Specification For Hermetic Sealing

1520881-000 Issue A August, 1969

Procedure For Sawing and Cleaning Substrates

1520884-000 Issue B March, 1970

Adhesive Bonding Specification

1520416-000 Issue B August, 1969

MATERIAL STANDARDS

Gold Wire, High Purity

8018050 Issue A November 17, 1969

Aluminum Alloy (1% Si) Semiconductor Wire

7461300 through 7461304 Issue A October 10, 1969

Gas, Pre-Mixed, 80 Nitrogen, 20 Helium, High Purity

4704011 Issue B October 6, 1969

Adhesive, Electrical, High Thermal Conductivity

2181005 through 2181007 Issue F October 22, 1969