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CONTAMINATION CONTROL IN HYBRID MICROELECTRONIC MODULES

INDENTIFICATION OF CRITICAL PROCESS AND CONTAMINANTS
FINAL REPORT – PART I

APRIL 1975

AEROSPACE GROUPS
HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

CONTAMINATION CONTROL IN HYBRID MICROELECTRONIC MODULES

FINAL REPORT - PART 1

IDENTIFICATION OF CRITICAL PROCESSES AND CONTAMINANTS

Contract No. NAS 8-30876

April 1975

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Prepared for
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FOREWORD

This document presents a description of work performed by the Hughes Aircraft Company, Culver City, California, under NASA Contract No. NAS8-30876. The work was sponsored and administered by the George C. Marshall Space Flight Center, Huntsville, Alabama, with Mr. S. V. Caruso serving as the Technical Manager. The Hughes Program Manager was R.Y. Scapple and the Principal Investigator was R.P. Himmel. The report was prepared by F.Z. Keister with assistance by A. Koudounaris.

This report, Part 1 (of 3 parts) of the Final Report, covers the work described in Task I of the Statement of Work. The objective of Task I was to "identify the process steps, handling procedures, and other critical parameters that could contribute to internal contamination of hybrid microcircuit packages." Parts 2 and 3 of the Final Report will cover work described in Tasks II, III, and IV of the Statement of Work. The final draft of Parts 2 and 3 will be issued April 30, 1975.

This report covers work performed from May 1974 through April 1975.

There have been no inventions, discoveries, improvements, or innovations made under this contract.

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INTRODUCTION AND SUMMARY

A significant problem in the manufacture of hybrid microcircuits is the prevention of contamination within a hybrid package. Contamination is one of the important causes of reduced reliability and reduced life in hybrids. Its prevention is especially important in hybrids used in space applications or other critical missions in which the in-flight hardware may not be repairable or replaceable and a failure can jeopardize an entire mission. The objective of the work reported here was to examine the various hybrid processing steps, handling procedures, and materials in an attempt to:

- Identify the critical process steps in which contamination is most likely to occur
- Identify the particular contaminants associated with these critical steps
- Propose methods for the control of these contaminants.

Some of the information presented in this report was obtained from a search of the technical literature and from conversations with other hybrid manufacturers. However, a large portion of the data was obtained from practical experience at the Hughes Aircraft Company, gathered during the last decade in the manufacture of both thin film and thick film hybrid microcircuits for a variety of government applications.

From the analyses and experiments performed, it was found that three processing steps are especially susceptible to contamination: assembly (including parts mounting and interconnect bonding), package sealing, and rework. The various potential contamination sources and types of contaminants were tabulated, each problem was analyzed, and photomicrographs were taken of typical contaminants. Moisture and loose particles were identified as two of the worst contaminants.

The points at which contaminants were most likely to enter the hybrid package were also identified, and both general and specific methods for their detection and control were evolved. In general, three of the most effective controls for contaminants are: clean working areas, visual inspection at each step of the process, and effective cleaning at critical process steps. Specific methods suggested by this study include the detection of loose particles by a pre-cap visual inspection, by pre-seal and post-seal electrical testing, and by a particle impact noise (PIN) test. Moisture is best controlled by sealing all packages in a clean, dry, inert atmosphere after a thorough bake-out of all parts. The atmosphere in the dry box should be monitored, and all packages should be given a thorough leak test after sealing to insure a hermetic seal.

1.0 CONTAMINANTS AND SOURCES OF CONTAMINATION

1.1 HYBRID PROCESSING STEPS

The fabrication of a hybrid consists of a rather lengthy sequence of independent operations. Mainly, these operations serve to bring together a number of components (substrates, devices, etc.) which when assembled with the use of materials such as wires, epoxy, preforms, etc., will become a functional unit ready for hermetic sealing. Every time a component is added to the assembly and every time an operation is performed, foreign materials potentially can be added to the assembly. While cleaning operations are generally practiced throughout the assembly operation, it is important that these operations be based on knowledge of the contaminants introduced during the preceding steps so that the cleaning operations can be designed to remove those specific contaminants.

Figure 1 shows the process flow used at Hughes for hybrid assembly. It is a typical flow followed by many manufacturers with minor modifications to accommodate their particular designs or processes.

1.2 CONTAMINANTS AND SOURCES OF CONTAMINATION

The sources of contamination (Table 1) can be divided into two categories: 1) the contaminants brought into the assembly by the parts and materials added to the hybrid, and 2) assembly contaminants introduced by processing the hybrid through the various steps until it becomes a hermetic package. The latter category includes general environmental contaminants. Detailed listings of the various potential contaminants are contained in Tables 2, 3, and 4.

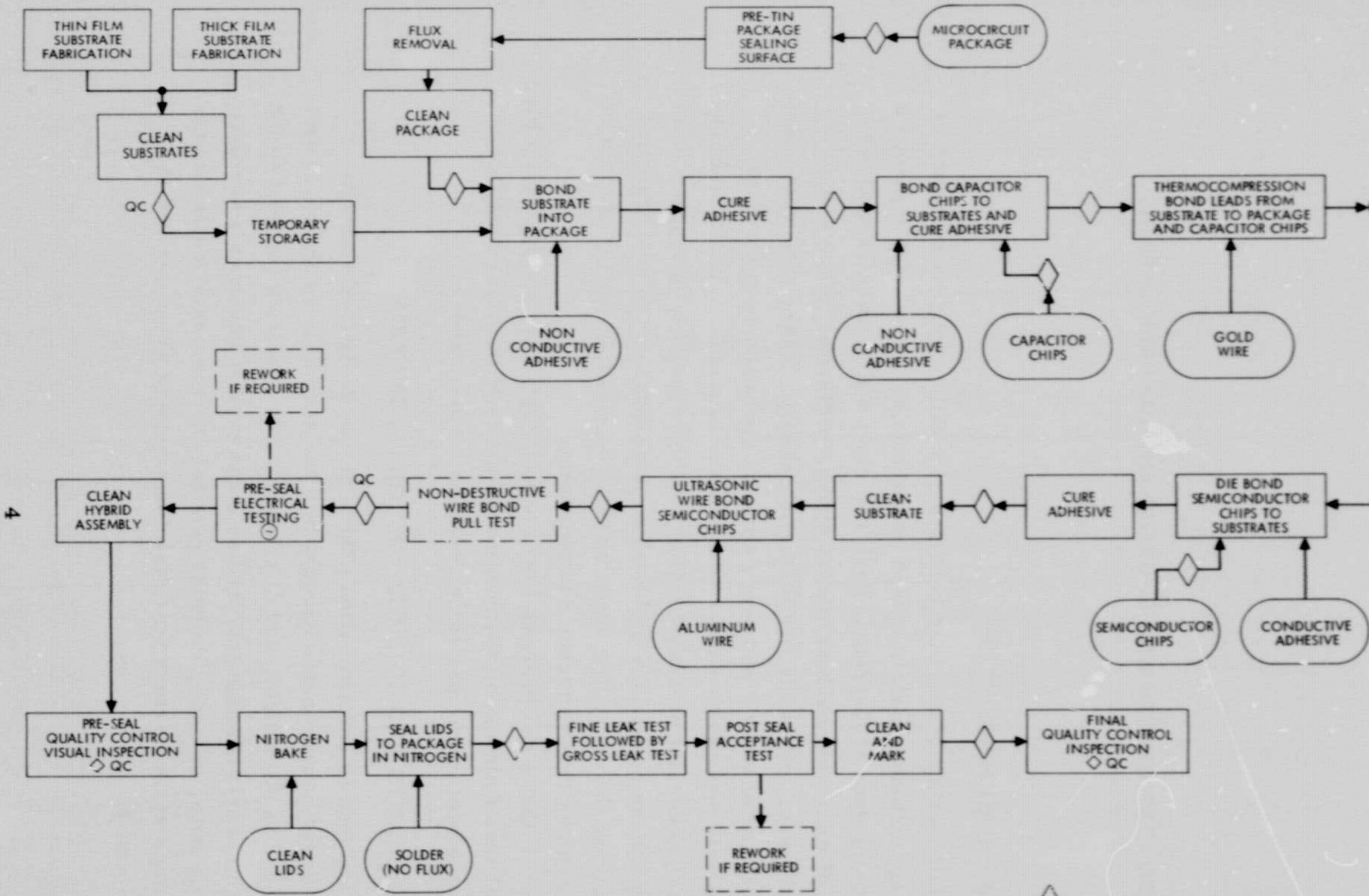

Figure 1. Process flow for hybrid microcircuit fabrication showing manufacturing and quality-control inspection and test operations.

TABLE 1. SOURCES OF CONTAMINANTS AFFECTING HYBRIDS

Parts and Materials Contaminants		Assembly Contaminants	
Parts	Materials	Process	Environment
Thin film substrates Thick film substrates Active devices Passive devices Hybrid package Packages and headers	Wire and ribbon Epoxy adhesives Organic coatings Solvents and cleaning agents Solder and eutectic alloys Flux Packaging materials, such as plastic boxes and anti-static bags	Substrate attachment Device attachment Wire bonding Test Rework Inspection Sealing	Atmosphere Operator Equipment

Certain categories of potential contaminants are not unique to any particular fabrication operation but are common to those in which the part is handled, operated on, or merely exposed to ambient conditions. This group includes airborne particulate matter in the form of dust and lint as well as human-associated products such as dandruff (skin flake), hair, fingermarks, and cosmetic makeup. Another potential contaminant common to inspection or operation steps is projectile spittle (sputum). Airborne particulate matter may be reduced by such general practices as limited access areas, smoking and eating prohibitions, and special protective garb. Particularly sensitive steps may be performed under laminar flow stations. Careful handling in covered containers is of course essential in all areas outside the laminar flow stations. Operator sputum can be intercepted at work stations by the use of properly located shields.

Airborne particulate matter is also common to all curing or baking steps, which are performed in ovens. This matter takes the form of heater element oxide particles and outgas products of the materials being cured. Air circulating ovens are preferred to exhaust outgas products during curing, but covering of open devices is essential with this type of oven. Even the most scrupulous preventive measures are unlikely to prevent all airborne particulate contamination, and the use of visual inspection and liquid or vapor condensation cleaning steps is essential. In all steps in which

TABLE 2. CONTAMINANTS THAT ARISE FROM THE VARIOUS PARTS USED IN HYBRID FABRICATION

Part and Process	Type of Contamination
1. <u>Thin Film Substrates</u>	
a. Substrate cleaning	– Residual surface contaminants from shipping, packaging, inspection, handling.
	– Bake-out environment
	– Solvent contaminants
b. Film deposition	– Residual chamber contaminants
	– Gas contaminants
	– Metal impurities
	– Outgassing
	– Oxidation
	– Backstreaming
	– Leakage
c. Film build-up plating	– Bath impurities
	– Deposit impurities
	– Anode impurities
	– Rinse impurities
	– Drying contaminants
d. Photomask	– Mask contamination, imperfections
	– Resist impurities
	– Resist drying contamination
	– Developer impurities
	– Rinse impurities
	– Bake/dry oven contamination
e. Etching	– Etchant impurities
	– Rinse impurities
f. Resist removal	– Residual resist
	– Stripper impurities
	– Rinsing and drying impurities
g. Film stabilization	– Chamber residuals
h. Resistor trimming	– Splatter, flaking
	– Oxidation
i. Substrate cutting	– Sawing contaminants
	– Scribe and break or Laser cutting ceramic chips, flakes, dust
i. Final cleaning, packaging, storing	– Cleaning contaminants
	– Package contaminants
	– Identification materials
	– Storage environment
2. <u>Thick Film Substrates</u>	
a. Substrate cleaning	– Same as for thin film
b. Paste preparation	– Paste contaminants
	– Thinner impurities
	– Mixing/blending tool and container contaminants
c. Printing	– Printer lubricants
	– Squeegee contaminants, residual pastes
	– Screen contaminants, residual pastes
	– Pneumatic air system contaminants
d. Drying	– Oven residual contaminants
e. Firing	– Furnace contamination, adjacent paste poisoning, belt contamination
	– Environmental gas impurities
f. Resistor trimming	– Splatter, dust, flaking, static damage
g. Final cleaning, packaging, storing	– Same as for thin films
3. <u>Active Devices</u> Dice, beam leads, flip chips, LIDs packaged (plastic or hermetic) diodes, transistors, ICs, FETs, MOS chips, etc.	– Surface contaminants (organic and inorganic) – Packaging material contaminants – Shipment damage
4. <u>Passive Devices</u> Capacitors, resistors, inductors, transformers	– Inspection (shipping and receiving) contaminants – Solvent residues, flux residues, absorbed gases
5. <u>Hybrid Packages</u> Kovar, glass, and ceramic bases and covers	– Plating residues, flaking, outgassing, peeling, oxides – Marking paints

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TABLE 3. CONTAMINANTS THAT CAN RESULT FROM THE VARIOUS HYBRID ASSEMBLY PROCESSING STEPS

Assembly Processing Step	Type of Contamination
Substrate attachment to package	– Package residuals – Flux residues, solder splatter – Adhesive particles, void entrapment
Attachment of chips to substrate	– Epoxy or eutectic alloy contaminants – Tool and equipment contaminants – Chip contaminants, chip fragments – Adhesive migration, adhesive fragments – Eutectic flakes or balls
Interconnect bonding	– Wire contaminants – Wire fragments – Oxidation, water condensation – Chip fragments
Pre-seal electrical testing and rework	– Probe contaminants – Wire fragments, chip fragments – Adhesive and eutectic solder fragments
Hermetic sealing	– Bake chamber residuals and backstreaming – Sealing chamber residuals – Purge gas impurities – Sealing material contaminants – Solder balls – Flux – Moisture – Weld splatter

TABLE 4. CONTAMINANTS THAT ORIGINATE WITH THE ENVIRONMENT OR THE OPERATOR

Source	Type of Contamination	
Atmospheric	Dust	Dessicator contaminants
	Lint	Sulfur dioxide
	Moisture	Solvent volatiles
	Smog	Miscellaneous airborne particles
	Smoke	Outgassing products
Operator	Perspiration	Skin flakes
	Hair	Food particles
	Sputum	Clothing particles
	Makeup	Finger prints
Equipment	Grease	Fumes
	Oil	Loose particles

cleaning is required, the potential exists for contamination from residual cleaning solvents. Figure 2 shows the effect of such contamination (in this case, chlorine-water) on a 0.0025 cm (0.001-inch) aluminum wire. This type of contamination can be avoided by the use of degreaser-type final rinses.

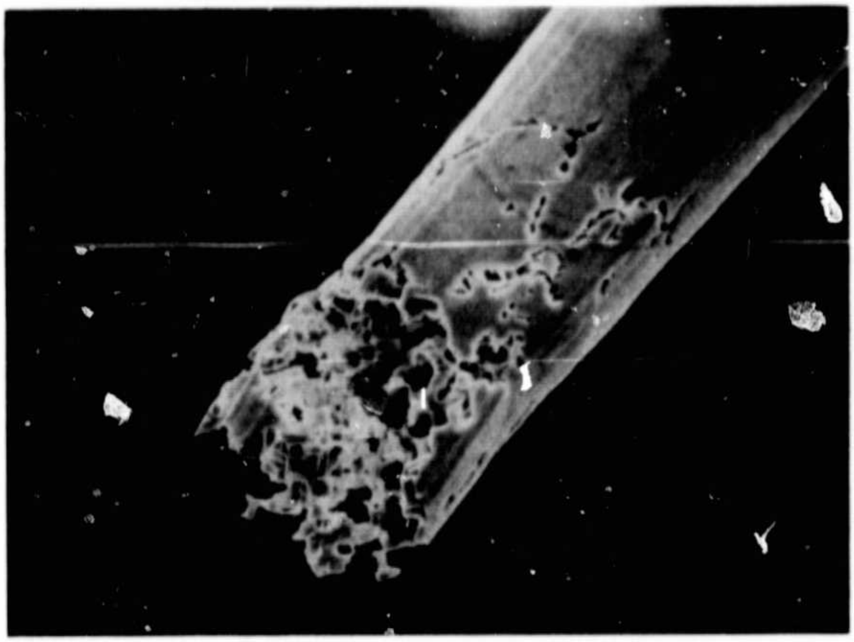

Figure 2. Scanning electron microscope (SEM) photo showing corrosion of aluminum bonding wire caused by chlorine-water contamination. (1400x.)

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2.0 POTENTIAL CONTAMINATION PROBLEM AREAS

2.1 COMPONENT CONTAMINANTS

The components that enter the hybrid are generally manufactured outside the control of the hybrid manufacturer. They are subsequently packaged, shipped, received, unpackaged, counted, and inspected by personnel who are generally non-technical and lack awareness of the contamination possibilities. In some cases irreparable damage can result from inappropriate handling of parts, for example fingerprints on porous nickel, solder, or gold plating (on packages) or on silicon dice which can permanently etch these surfaces. It is therefore necessary that personnel be instructed to use gloves or tweezers in handling hybrid parts and materials. Flux residue may be present on parts that have been soldered or solder coated. Plating residues are another source of contaminants. While the range of contaminants can be quite broad, it is generally conceded that a thorough cleaning with solvents for the organic contaminants and with a deionized water rinse for the ionic contaminants, coupled with a visual inspection for particles, can be quite satisfactory in diminishing this type of problem.

An example of contamination that is not only outside the hybrid manufacturer's control, but that can easily go undetected by him as well, is cited by Gutherie.[47]

He finds that the silver metallization of barium titanates contains, in addition to silver and the usual bismuth oxide and borosilicate glasses, micron-size contaminants that are primarily silver chloride. These can be detected only by scanning electron microscopy. However, their presence results in bond degradation of ultrasonically welded aluminum wires. The source of this contamination is traced to the manufacturer but is of unknown origin, and the author implies that its appearance is erratic. It can be eliminated by ultrasonic cleaning in a 50-percent solution of ammonia followed by a vacuum bake at 800°C.

2.2 PROCESS RELATED CONTAMINANTS

Various investigators agree that contaminants can enter the hybrid during all processes. Beall[1] speaks of surface contamination from abrasive trimming of thick film resistors causing decreases in bond strength. Hof[2] mentions flux residues from soldering affecting tantalum nitride resistors. Holloway[3] talks about surface chromium oxide contaminant interfering with TC bonding. Their thin film substrates were of tantalum nitride-chromium-gold. The chromium had migrated through the gold, forming the oxide. Autonetics[4] discovered fingerprint contamination causing damage to thin film resistors. In a survey of the effect of air pollutants on electrical components, ITT[5] found gaseous sulfur compounds (namely sulfur dioxide) accounting for most of the damage. Manufacturers, however, disagreed with the ITT results and blamed particulate matter for most malfunctions. These are just a few typical examples. Figures 3 and 4 are typical photographs of the effect of unknown residual surface contaminants.

In the following discussion, each microcircuit processing step will be reviewed for potential sources of contamination.

2.3 SUBSTRATE FABRICATION

As indicated in Figure 1, substrate fabrication occurs early in the fabrication sequence. The substrate fabrication steps are compressed in that diagram because the emphasis of this study lay in the assembly operation. <u>Thin film</u> substrate fabrication in itself involves numerous steps, generally in the following sequence:

1. Vacuum deposition of the metallic layers
2. Coating with photosensitive resist
3. Exposure, development, and bake of resist

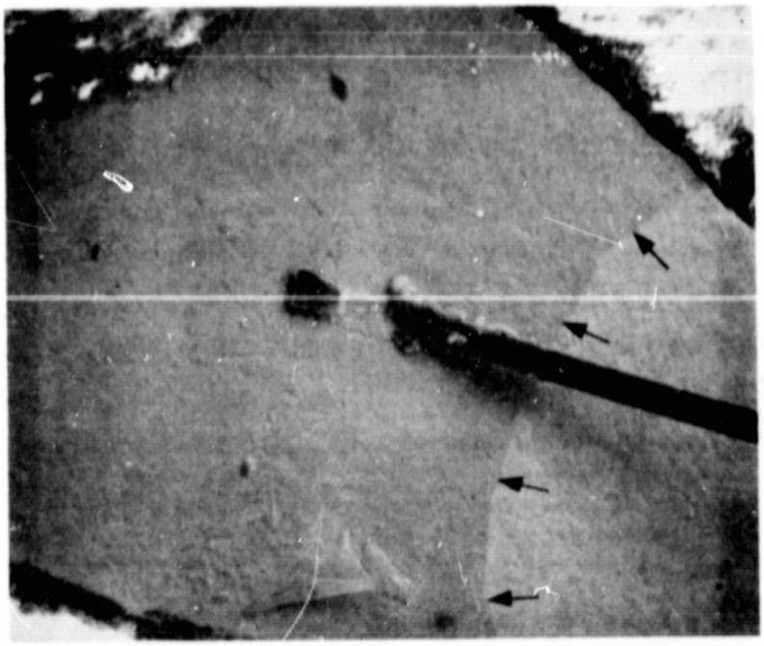

Figure 3. SEM photo showing degradation of aluminum wire bond due to residual contaminant (180X). (Edge of the stain shown by arrow)

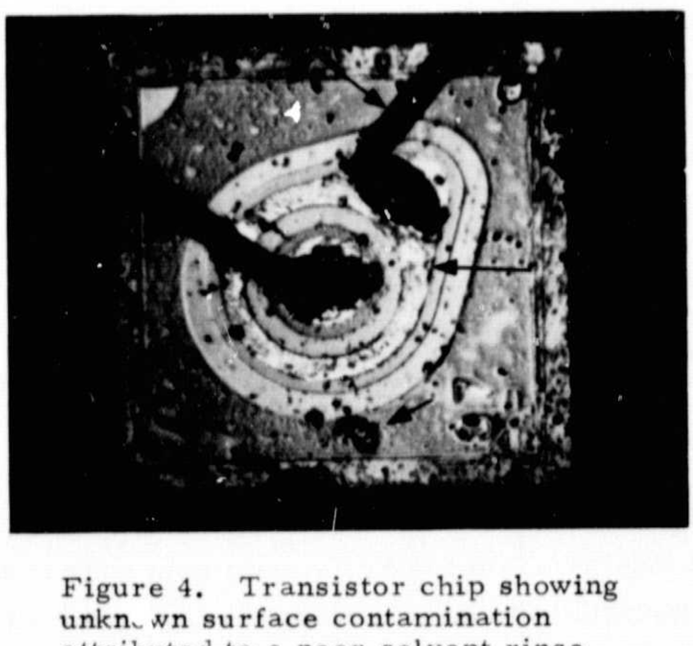

Figure 4. Transistor chip showing unkn..wn surface contamination attributed to a poor solvent rinse. (120X)

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4. Selective etching of metallic layers
5. Stabilization of the resistive film
6. Laser adjustment of resistors.

Organic contamination of the substrate before deposition is easily prevented by effective cleaning procedures. Detection of such contaminants after deposition is also easily accomplished by visual inspection because of the blistering or discoloration of the deposited film in the region of the contaminant. Photo resist, chemical etchant, and cleaning solvent residuals are also easily detected after resistor film stabilization because of the temperature-induced visual effects of the contaminants on the metalization. A potential contaminant during laser trimming is "splatter," or redeposition of evaporated film on areas adjacent to the resistor being trimmed. This splatter may be reduced by careful laser power adjustment and may be removed in a subsequent cleaning step.

Thick film fabrication ordinarily proceeds by the following general process steps:

1. Screen printing of conductor layer and firing
2. Screen printing of crossover dielectrics/conductors and firing
3. Screen printing of resistors and firing
4. Screen printing of resistor overglaze and firing
5. Trimming of resistors to value.

As is true for thin films, contamination is readily apparent after high temperature processing; the problem areas for thick film fabrication occur mainly after overglaze firing. Resistor trimming is accomplished by either airbrasive or laser machining. Airbrasive trimming is inherently a dirty process: a large volume of resistor material is removed and redeposited and a large volume of ambient air is required to exhaust the spent alumina powder. Although ultrasonic cleaning is required after airbrasive trimming, there is evidence that such cleaning can degrade the adhesion of glass-containing conductors; therefore, a maximum time in the ultrasonic cleaner should be established and enforced as a process control. Residual contamination can be identified by visual inspection. The potential problem of "splatter" due to laser trimming of thick films is greater than that for thin films because of the greater volume of resistor material removed. It has been reported that one way to avoid the effects of splatter is to coat the substrate (before trimming) with an easily removed organic coating. A subsequent cleaning step could then remove this film, along with all traces of the splatter.

Substrates are often packaged and stored before release to the assembly area. Because the storage bags present a potential contamination source at this stage, a thorough cleaning step before actual assembly is required.

2.4 MICROCIRCUIT ASSEMBLY

2.4.1 Package Preparation

To insure hermeticity when a hybrid package is sealed by solder, the package ring frame (solderable region) requires a well tinned surface. To achieve such a coating, the package ring frame is tinned (with a non-activated flux) and cleaned before assembly of any circuit elements. Potential contaminants at this assembly stage are solder splatter and flux residue. Both can be minimized by careful tinning. Process specifications covering this step must include cleaning to remove the flux and careful visual inspection to uncover residual flux or solder splatter.

These suggestions apply primarily to packages that are to be hand soldered. Machine soldering generally does not require pre-tinning, although it is sometimes used. Welding does not require tinning, but does require meticulously clean surfaces.

2.4.2 Substrate Attachment

This step is often accomplished with non-conductive epoxies. Careful application of the adhesive to achieve a void-free bond (for good thermal transfer) and even spreading of the film must be carefully controlled to prevent contaminants. To achieve a complete outgassing of this layer, curing is done in two steps, the final curing for a longer period of time. The adhesive itself should be controlled by a material specification to avoid contaminants.

Excess adhesive in the periphery of the substrate, which could later be dislodged and become a free particle, is another potential problem. It may be easily avoided by in-process control over the amount of adhesive and a thorough visual inspection.

2.4.3 Discrete Component Attachment

Passive chip components such as capacitors, inductors, and resistors are generally attached to the substrate by means of either non-conductive adhesive or reflow soldering. One area of potential contamination at this stage is the cleanliness of the chips themselves. Chip cleanliness is normally controlled by component specifications but may be further insured by a thorough visual inspection and cleaning of such components before use. An area of concern when adhesives are used is surface contamination, due to adhesive spreading, of the area adjacent to the chip mounting area. For example, an adhesive layer over a wire bond location might, if bonding was successfully accomplished, endanger the reliability of such a bond. The tendency to spread after application is a common characteristic of adhesives. Such spreading might be due to inherent rheological properties of the adhesive or to the use of excessive quantities in application. Rheological properties can be controlled by materials specifications. Spreading due to the use of excessive adhesive can be prevented by an appropriate in-process monitor. For solder reflow attachment, the risk of excess solder can also be avoided by control of the quantity of solder at the joint.

The basic problem areas in this part of the hybrid operation are flux residues, adhesive spreading, adhesive particles, and possible contaminants from the oven used to cure the non-conductive epoxy. A thorough cure of the epoxy is necessary to prevent possible outgassing after the package is subsequently sealed and submitted to a high temperature environment.

2.4.4 Semiconductor Chip Attachment

Active chips may be attached by means of conductive adhesive or eutectic bonding. As with components received from outside vendors, the possibility of contaminated chips as received from the vendor, due either to his processing or to careless handling/packaging steps en route to the hybrid assembly area, is not unlikely. An example of such contamination is seen in Figure 5. Use of contaminated chips is probably best avoided by visual inspection and rejection before attachment. The cleaning of semiconductors in chip form is considered difficult and the added risk of damage to the chips makes this possibility less attractive as an in-process control step.

The use of adhesive to secure chips is inherently risky because of the possibility of excess adhesive spreading to adjacent areas, as with passive chips. Control of the amount of adhesive used, by means of controlled dispensers, screen printing, or the use of "tape" epoxies for example, can provide adequate in-process control over this step.

The basic contaminants introduced during the semiconductor chip attachment operation are occasional loose chips of the conductive silver epoxy or eutectic die bonding alloy and small loose chips of silicon from the transistors, diodes, and integrated circuits. Both types of contaminants are in the form of loose particles. A thorough visual inspection and cleaning operation should always be performed immediately after this step. Wire bonding to the chips is the next operation and, if the chip surfaces are not clean, there is a strong probability that the bonds will have a lowered strength.

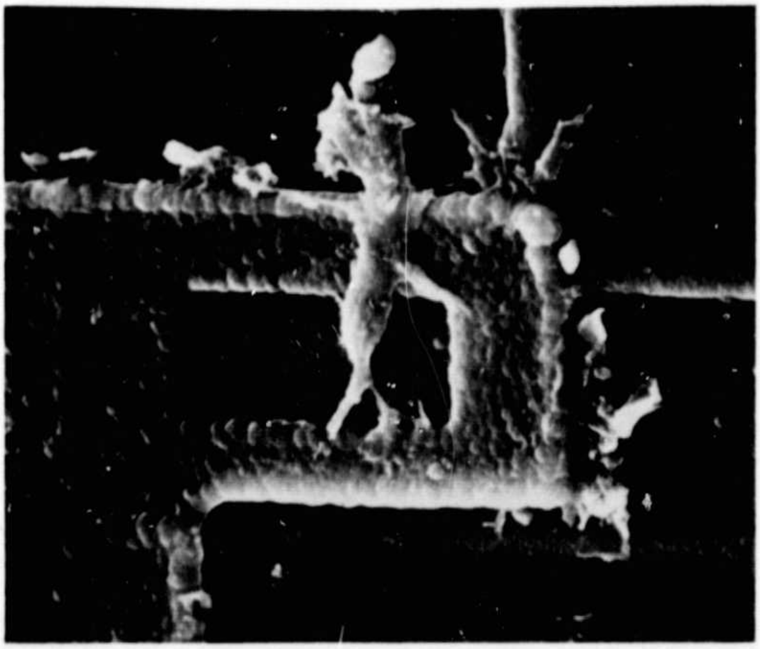

Figure 5. SEM view of contamination of semiconductor chip surface (1800X).

2.4.5 Thermocompression Wire Bonding

Gold wire, 0.005 cm (0.002 inch) in diameter, is often used to interconnect passive components and provide exit wiring to package leads. Wire cleanliness is an important consideration because no cleaning of the wire is normally done in-process. Since the gold wire is covered by a materials specification, it is possible to utilize a sampling plan for contamination detection. A more serious potential problem is the presence of loose bits of gold wire as a result of the bonding operation.

Contamination might also occur during thermocompression wire bonding as a result of the "flame-off" routine, in which a hydrogen flame is used to form the "ball" before bonding. Under certain conditions it is possible that water may condense on the substrate from the hydrogen cut-off flame. This water can be quite detrimental to nichrome resistors if a voltage is applied to the resistor; the resulting electrochemical reaction causes the resistor to "disappear" (Figure 6). Such a combination of factors is unlikely during the initial fabrication of the hybrid device but has been observed to occur in a rework situation. In-process controls over the bonding procedure can reduce the likelihood of water condensation, but an additional bake process before retest (to evaporate the water) is an effective preventive step.

2.4.6 Ultrasonic Wire Bonding

Bonding of the aluminum wire to interconnect active chips carries the same risk of loose wire fragments as gold wire in thermocompression bonding, but there is another potential problem inherent in ultrasonic bonding. In the process of ultrasonic wire bonding there is a scrubbing action that sometimes forces bits of metal from under the bond area. These pieces may be loose but are more likely to adhere with unknown adhesion. Such particles present a potential failure mechanism if they come loose after the microcircuit is assembled. It is felt that proper operation of the bonder will avoid the generation of such particles. A nitrogen blow-off operation following the ultrasonic bonding operation can be useful in the removal of loose particle contaminants.

Another control that is sometimes used after wire bonding is an impact shock test at a 1000 to 2500 g level. This is a simple drop test and

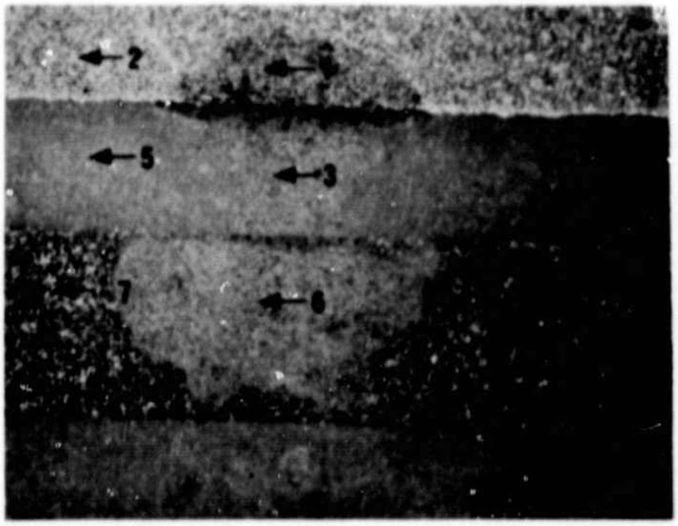

Figure 6. Contaminant residue and damage to nichrome resistor by electrochemical action (176X).

can be helpful in dislodging or uncovering loose particles and even in revealing loose wire bonds.

2.5 PRE-SEAL ELECTRICAL TESTING AND REWORK

Pre-seal electrical testing introduces problems other than those in the "human associated" category (dandruff, hair, etc.). The test technician is frequently required to manually probe the hybrid in the course of troubleshooting. In probing, the risk of probe scrapings, chip damage, and wire fragments is not inconsequential. Another category of potential contaminants is introduced in the event of electrical overstress in the preseal electrical tests.

This testing operation should either be done in a controlled area or under a laminar flow hood to assist in controlling airborne contaminants. A thorough visual inspection and cleaning operation should always follow this step. Inspection and cleaning are particularly important because chips and wire bonds frequently need replacement. This rework cycle is especially hazardous because of the added handling of the hybrids and because chip replacement again introduces the possibility of loose particles.

2.6 PACKAGE SEALING

Microcircuit packages for military and space applications are usually hermetically sealed, with an innocuous atmosphere inside the package. In Hughes microcircuits, the atmosphere is dry nitrogen, and the hermetic seal is made by manual reflow soldering, peripheral soldering, resistance welding, or parallel seam welding, depending on the type of package.

Before sealing, the packages and lids are baked in a dry nitrogen atmosphere to remove absorbed and adsorbed water. The actual sealing is done in a sealed chamber, again in a dry nitrogen atmosphere. One potential problem in this sealing operation is excessive humidity. Trapped moisture in a hermetic package can have many deleterious effects on the components inside. Fortunately, it is relatively easy to monitor the dew point of the dry box atmosphere. Process specifications should emphasize this critical parameter.

Solder fragments, weld splatter, or balls present possible problems in package sealing, whether by soldering or welding. While careful package design and controlled sealing techniques reduce this risk, only a subsequent particle detector insures lack of contamination at this stage. The problem of moisture in the package and of a particle impact noise test will be discussed later, because moisture and loose particles are probably two of the worst contaminants which plague hybrid microcircuits.

2.7 POST SEALING

It would appear that, after the final package seal is made, the danger of contamination would be over. Because the package is hermetically sealed, however, any outgas products of materials contained in the package will remain in the package. For this reason it is important that any materials included in the package (especially organic materials) be thoroughly tested for compatibility[48] before their use, and that the baking and adhesive curing steps be more than adequate.

In addition, if rework is required, the lid may have to be removed. Lid removal can be particularly hazardous, especially if the lid has been welded on or sealed on with 80 Au/20 Sn eutectic and has to be removed by grinding or machining. The fine particles created by grinding or other methods of lid removal can easily find their way inside the package. There are some methods of removing a lid which minimize the entrance of particles. These include: 1) remove the lid with the package inverted; 2 if machining is used to remove the lid, position a vacuum nozzle adjacent to the tool bit to suck up the particles as they are generated; 3) lift up a corner of the lid with a sharp edged instrument and then peel off the lid with pliers, similar to opening a can of sardines. Since none of these methods is guaranteed to keep out all the particles, the inside of the package should always be blown out with dry nitrogen and the package recleaned after lid removal.

3.0 CRITICAL CONTAMINATION TYPES AND PROCESSES

3.1 INTRODUCTION

The previous section of this report delineated a multiplicity of contaminants and the problem areas where these contaminants generally occur. This was followed by a brief discussion of each.

The following section is primarily concerned with defining which of the many contaminants are the most critical, which of the many processing steps are the most critical, and with suggestions for detecting and controlling these contaminants.

3.2 CONTAMINANTS OF GREATEST CONCERN

There are three processing steps that are especially susceptible to contaminants:

1. Assembly
2. Package sealing
3. Rework

From a thorough literature survey, it appears that the two predominant contaminants of most concern are: loose particles and moisture.

3.2.1 Importance of Loose Particles

Slaughter[9], in analyzing data from 200,000 hybrids over a 5-year period, found numerous instances of loose particles, such as gold and aluminum particles. He emphasized a pre-cap visual inspection. Vaccaro[11] also emphasized a pre-cap visual inspection to reveal surface contamination and foreign particles. Goddard Space Flight Center[10] found conductive gold/tin particles in sealed packages during post-vibration electrical tests. These particles came from either substrate bonding or from the lid sealing process. Arinc Research Corp.[13] mentions numerous instances of loose particles, such as broken pigtails and sealing materials, that have caused shorts, intermittent shorts, mechanical damage, etc.

The sketches in Figure 7 and the photographs of hybrids in Figures 8, 9, 10, and 11 illustrate the loose particle danger. Not all particles such as these are conductive and not all particles are dangerous. However, the hazard is always present, especially with conductive particles.

3.2.2 Detection and Control of Loose Particles

Loose particles enter the hybrid primarily during the assembly, rework, and sealing operations. Many are not detected until the hybrid is given a functional electrical test and found inoperable. Early detection can be accomplished by several methods, the most important of which are pre-cap visual inspection, pre-seal and post-seal electrical testing, and particle impact noise test.

Other detection methods for loose particles include X-ray and monitored shock testing. Radiographic (X-ray) inspection is limited in picking up small particles. Cleaning will remove most of the particles, and visual inspection will reveal many others. However, there may still be particles that escape detection and many others that are introduced only during sealing (such as solder balls, weld splatters, etc.). Thus, there is a need for particle detection method after sealing. One of the better detection methods appears to be the particle impact noise test.

The particle impact noise test is known under various names:

PIN - particle impact noise
PIND - particle impact noise detection
PINT - particle impact noise test
ALPD - acoustical loose particle detection

The test has been used as far back as 1966 by Lockheed[16] and is currently in use by a number of hybrid companies, including Hughes, TRW, General

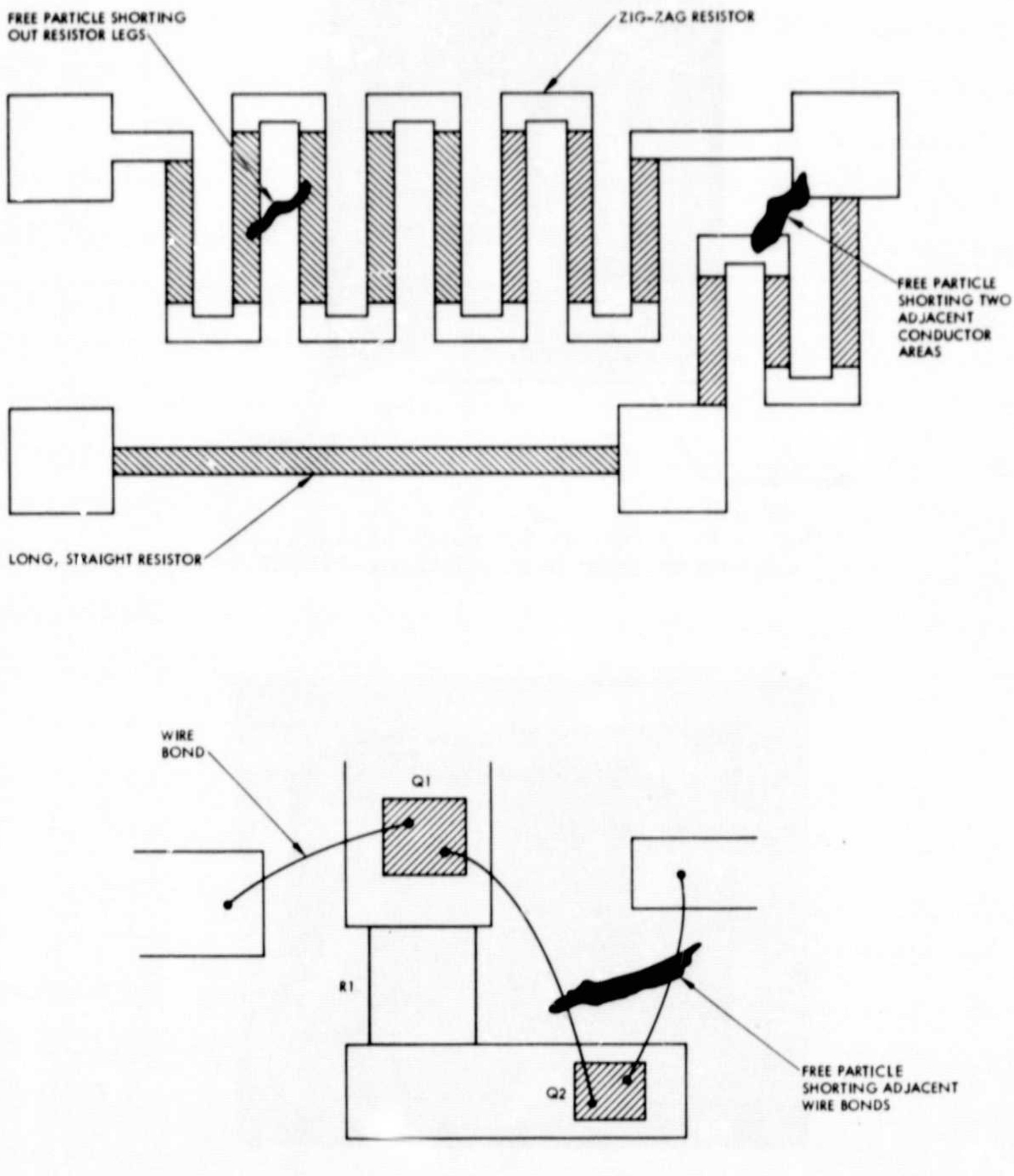

Figure 7. Sketches illustrating how free conductive particles can short circuit resistor/conductor paths (top sketch) and wire bonds (bottom sketch).

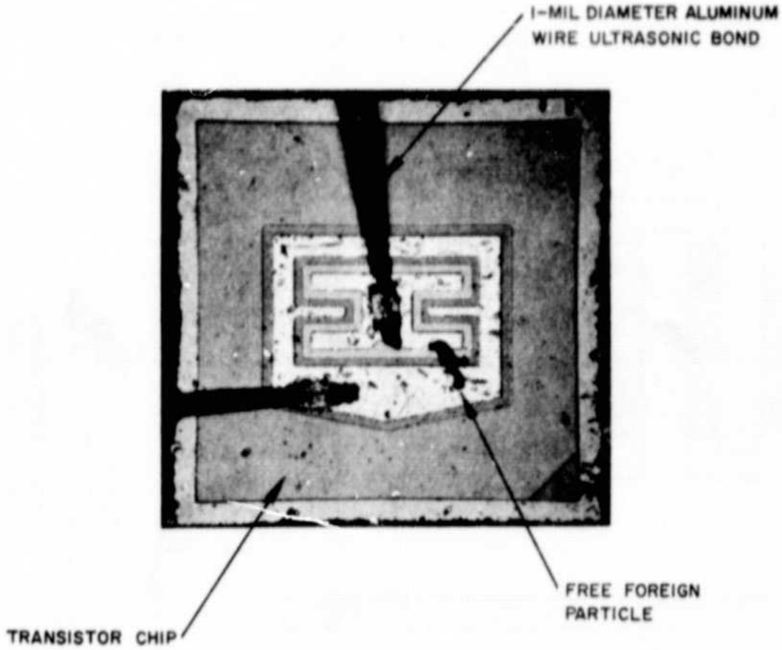

Figure 8. Free foreign particle that could cause a transistor chip failure (110X).

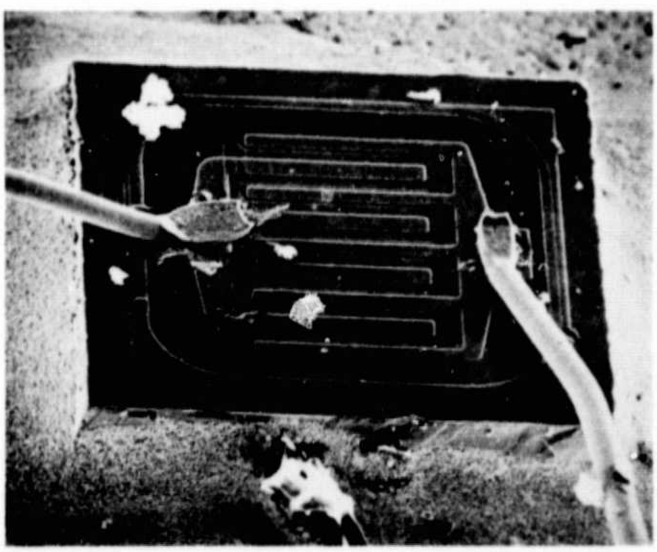

Figure 9. SEM photo at 180X showing unidentified particles on the surface of a transistor chip and an ultrasonic wire bond posing a potential short.

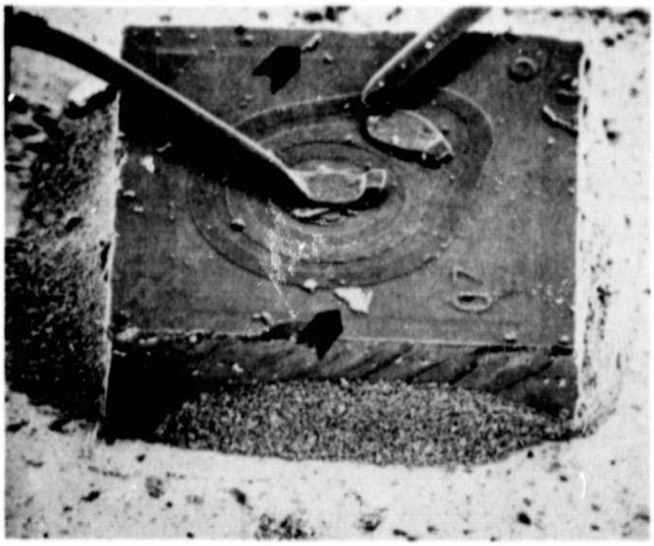

Figure 10. SEM photo at 180X showing unidentified particulate contaminants on a transistor chip and a wire bond with partially severed heel.

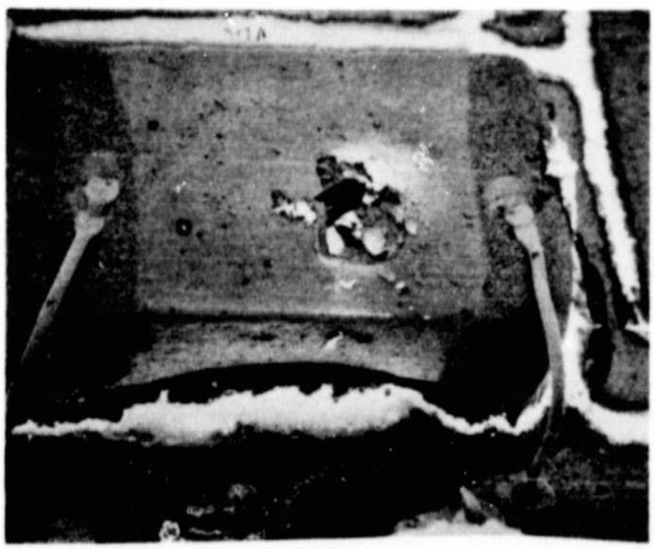

Figure 11. SEM photo at 47X showing a damaged capacitor chip. The particles resulting from the damage could easily become free agents and cause subsequent failure on another part of the hybrid circuit.

Dynamics, and Martin-Marietta. It has been shown to be non-destructive and has been the subject of numerous recent articles in the technical literature.[17, 18, 19]

Shown schematically in Figure 12, the PIN test is basically a low level vibration technique (30 to 65 Hz at 5 to 8g) by which loose particles are detected by ultrasonic emissions due to particle collisions within a vibrated hybrid package. Particles with diameters less than 0.0025 cm (0.001 inch) and with masses of only 1 microgram have been detected. Both visual and audible displays are used by the operator. The test is currently being proposed in a revision of MIL-S-19500 for HI-REL space hybrids.

While the PIN test is very useful for in-process detection of particles, it suffers two shortcomings as a product acceptance test. It cannot detect particles which are mechanically lodged, and it does not discriminate between non-conductive particles (which may never cause failures) and conductive particles.

3.2.3 Importance of Moisture

Moisture may be the worst hybrid contaminant of all, especially since it can be sealed into the package during the sealing operation and is

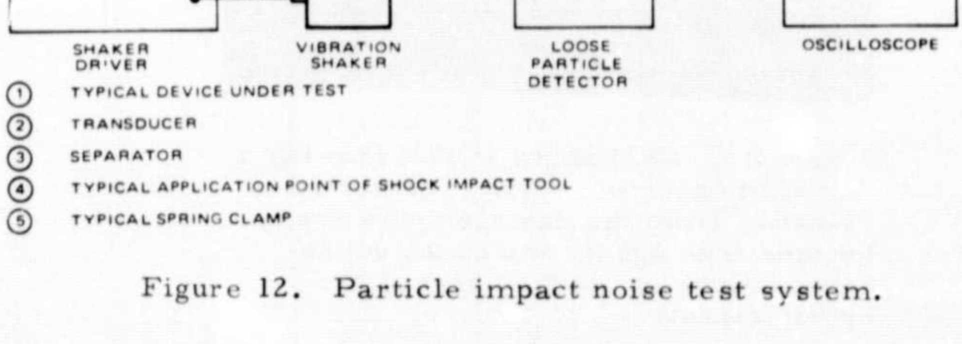

Figure 12. Particle impact noise test system.

difficult to detect in sealed packages. It has been estimated that 20 percent of semiconductor and hybrid module failures are directly or indirectly related to moisture contamination. Investigators at Hughes and elsewhere (Lane[20], Bart[21], Zatz[23], and Trautretter[22]) have shown that enclosed water vapor can cause corrosion of nichrome thin film resistors. Peattie[12] talks about moly-gold metallization being corroded by moisture that caused bond strength problems and gave nonohmic contacts. He recommends that the package contain less than 10 ppm of water. Meyer[24] mentions package moisture around 1000 ppm causing chemical reactions leading to corrosion of wire bonds and interconnect metallization. Moisture can also cause charge spreading, which can lead to inversion layer formation and surface leakage of semiconductor chips. Agnew[27] points out that the aluminum metallization on semiconductor chips is susceptible to corrosion from moisture resulting in unbondable surfaces, weakened bonds, open circuits, destroyed metallization, and surface leakage. Thomas[28] states that the presence of water vapor appears more closely associated with device failure than any other gas inside the package. He recommends an upper limit of 500 ppm of water vapor inside packages, with more sensitive devices (MOS devices) needing even a lower limit. Thomas[46] recommends a sealing chamber moisture level of no more than 10 ppm to obtain "dry" packages.

3.2.4 Detection and Control of Moisture

The best way to prevent moisture from entering the package is by insuring that all package sealing is done in a clean, dry, inert atmosphere. The normal atmosphere in hybrids is dry nitrogen, and sealing is usually accomplished in a dry box with the atmosphere monitored by means such as a dewpoint indicator. There are a number of commercial package sealing machines. Many, such as the GTI/DIX sealer and Research Instrument sealer provide their own sealing atmosphere; others, such as the Solid State Parallel Seam sealer, must be mounted in a dry box. A bake-out should always precede the sealing operation.

To insure a hermetic seal, the hybrid packages must always be fine and gross leak tested afterwards. MIL-STD-883, Method 1014, provides several adequate leak detection techniques, such as helium, radioisotope, fluorocarbon, and penetrant dye methods. Unless the package is truly hermetic, moisture will eventually find its way inside.

Two methods for moisture detection in sealed packages have been researched: cavity gas analysis and moisture detectors. Meyer[24] and Thomas[28] have proposed placing a very small moisture sensor inside the package. Zatz[23] describes the development of such a moisture sensor, and RADC has a contract with Texas Instruments[29] to develop such a sensor. Thomas[28] and Long[26] have both developed elaborate gas analysis systems that accurately measure the concentration of water vapor inside a package. However, cavity gas analysis is destructive because the package must be cracked. Thus, it could only be used as a process control on a sample basis to check a sealing vendor's process. Both the gas analysis and the moisture detector methods are "after-the-fact." The best control is to take all precautions possible to prevent moisture from being sealed inside the package in the first place.

3.3 GENERAL CONTAMINANTS

Other general contaminant types, such as airborne particles, etching residues, etc., can be controlled in various ways. For example, airborne particulate contamination can be controlled by clean rooms, proper air filtering, laminar flow hoods, air showers, smocks for personnel, etc. These techniques have been thoroughly researched by Sandia[6] and others. Residues from various processes can usually be detected by thorough visual inspection and can be controlled by proper cleaning.

Cleaning is an art by itself. Each hybrid manufacturer has his own methods and cleaning solutions. For example, cleaning can be done by rinsing, ultrasonic, immersion soak, spray, vapor, etc. Jackson[7] and Kennedy[8] have researched the various cleaning solvents suitable for electronic equipment. Even the cleaning solvents must themselves be clean (i.e., filtered, distilled, purified, electronic grade) and must be of the proper type to remove the oils, greases, resist, flux, etc., under suspicion.

Thus, it should be emphasized that three of the most effective controls for general contaminants are:

1. Clean working area
2. Visual inspection
3. Cleaning at critical process steps.

3.4 PROTECTIVE COATINGS AS A SOLUTION TO THE CONTAMINATION PROBLEM

One method of contamination control not yet discussed is by the use of a protective coating applied to the hybrid microcircuit. Hughes recently completed two programs, one for MSFC[14] and one for Goddard[15], specifically directed at methods for protecting hybrid microcircuits from contaminating particles. In these studies a Parylene coating was investigated. Such coatings can potentially serve to immobilize loose particles and to passivate otherwise unprotected hybrid surfaces.

Organic coatings for microcircuits have been given increased emphasis since 1962, both as conformal coatings and as encapsulants (see References 30 through 43). However, coatings themselves, unless carefully selected, can be yet another source of contamination. White[44] speaks of the corrosion of chip metallization due to ionic impurities in an epoxy encapsulant, principally sodium chloride. Eisenmann[25] found evidence of BF_3 activation in most epoxy systems that could cause corrosion, especially in accelerated high temperature, high humidity environments. Although few hybrids ever see such conditions, it is none-the-less a threat ~~treat~~. Spriggs[45] mentions failures occurring when organic adhesives were used to mount components in hybrid devices. These failures were caused by electrochemical reactions between constituents of the epoxy materials and the substrate's aluminum metallization. Moisture and excess hardener in the epoxy accelerated the failures. Thus, whenever an organic is used inside the package, whether as an adhesive or as a protective coating, its properties must be thoroughly researched from a potential contamination standpoint (e.g., outgassing, purity, etc.).

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