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HERMETIC SEALING OF HYBRID MICROCIRCUITS: INITIAL CAPABILITY DEVELOPMENT

By J. H. Williams
and
W. A. Piper

Published December 1978

Topical Report

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Topical Report
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Communications Services Bendix Kansas City Division

HERMETIC SEALING OF HYBRID MICROCIRCUITS: INITIAL CAPABILITY DEVELOPMENT

BDX-613-1930 (Rev.), Topical Report, Published December 1978

Prepared by J. H. Williams and W. A. Piper

The capability to hermetically seal hybrid microcircuits has been established at Bendix Kansas City. Tests indicate that helium fine leak rates in the low 10^{-8} STP cm^3/s region and moisture content of less than 500 ppm are obtained with the 80 percent gold-20 percent tin solder sealing process being used. Initial production results indicate a yield of better than 90 percent for the process. Work is continuing to improve the capability to reseal packages that have been opened for rework. Future efforts will include evaluations of moisture sensors for use in hybrid packages, particle impact noise detection testing of sealed packages, and the use of laser welding as an alternate method for sealing packages.

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CONTENTS

Section	Page
SUMMARY	5
DISCUSSION	6
SCOPE AND PURPOSE	6
ACTIVITY	6
Process Description	6
Epoxy Bake, Cleaning, Vacuum Bake, and Sealing Procedures	8
Cleaning Method Prior to Sealing	12
Vacuum Bake Procedure	13
Leak Testing of Sealed HMC	13
Epoxy Bake	14
Substrate Temperature During Sealing	17
Moisture Content of Sealed HMC	17
ACCOMPLISHMENTS	17
FUTURE WORK	17
REFERENCES	21
DISTRIBUTION	22

ILLUSTRATIONS

Figure		Page
1	Flatpack (Upper), Cover (Lower Left), and Solder Preform (P-97909)	7
2	HMC in Flatpack (P-98143)	8
3	Hermetic Sealer	9
4	Sealing Chamber	11
5	Thermal Evolution Analysis of Epoxy A	15
6	Thermal Evolution Analysis of Epoxy B	16

TABLES

Number		Page
1	Substrate Temperature During Sealing	18
2	Analysis of Sealed Package Interior Environment	19

SUMMARY

Some new hybrid microcircuits require a hermetic seal capable of passing the test requirements of Mil. Std. 883A. Hybrid microcircuits built at Bendix have not been hermetically sealed. A sealer was ordered, but the required date to begin production sealing made it necessary to modify in-house equipment. The hermetic sealing process goals included a fine leak rate in the range of 1 x 10^{-8} STP cm^3/s and a moisture content in the range of 500 ppm. To realize these goals with the available equipment, it was necessary to install an existing solder sealer in a glove box with an attached vacuum oven. This provided the capability to vacuum bake the hybrids, move them directly into the glove box and seal them in a dry, low-oxygen environment. Exposure of the hybrid to room air between the vacuum bake and sealing would negate the possibility of obtaining the desired moisture content of less than 500 ppm. After the in-house sealer had been modified and tested, it was moved from the laboratory into the production area and characterized for production use.

Evaluations were performed to determine the effectiveness of various cleaning processes on the hybrid packages prior to solder sealing. Two of the processes, spray cleaning and abrasion, were found to give good results and to be harmless to the circuit.

To verify that the hybrid circuit would not be subjected to temperatures above 200°C during solder sealing, a test was conducted using various settings of the sealing equipment. For purposes of testing the packages both before and after sealing, a helium fine-leak detector was used and fixturing to provide the testing capability was designed and built. Another piece of equipment was built for helium pressurizing the sealed packages prior to testing.

Production sealing in the first five months of operation produced a yield better than 90 percent. A rework procedure for delidding packages that fail the hermeticity or electrical test was developed and effort is continuing to improve the process.

Future work will include an evaluation of moisture sensors to determine their suitability for use in monitoring moisture levels in sealed hybrid packages. The sealer will be characterized before production use, and sealing schedules for LSI circuits will be developed. A PIND (particle impact noise detection) tester, has been requisitioned and will be evaluated for testing of HMCs per Mil. Std. 883A. Finally, to permit resealing of packages that may no longer be in suitable condition for solder sealing and to provide an alternate to solder hermetic sealing, a laser welding capability is being established.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this work was to develop the capability at Bendix to hermetically seal hybrid microcircuits. The requirements for the sealed packages include a maximum fine leak rate of 1×10^{-7} cm^3/s. To test the hermeticity of sealed packages, it was necessary to develop the capability to fine leak test the packages.

ACTIVITY

Process Description

The hermetic sealing process developed to seal HMCs is a new capability for Bendix. The flat pack used (Figure 1) has leads on two sides with glass-to-metal seals. These packages are made from an alloy of iron, nickel, and cobalt and are electroplated with 2.54 μm of gold. A hybrid microcircuit (Figure 2) is attached inside the package with epoxy, and electrical connections are then made between the package leads and the circuit. The packages are then cleaned and vacuum-baked for 16 hours. At this time, the package is ready to be hermetically sealed.

Hermetic sealing is accomplished by soldering (without flux) a flat cover to the top of the package. The cover is made of the same material as the package. The solder used is a preform of 80 percent gold, 20 percent tin, eutectic alloy with a melting point of approximately 280°C (Figure 1).

The soldering process requires an inert atmosphere to prevent oxidation of the solder during heating. For this reason, all sealing is done in a dry nitrogen environment. The dry nitrogen provides an inert atmosphere with less than 50 parts per million oxygen and less than 20 parts per million moisture.

The sequence of the sealing operation is as follows (Figure 3).

1. Clean packages, covers, and solder preforms.

2. Vacuum bake packages in vacuum oven at 150°C and 10 μm for 16 hours. Covers are vacuum baked separately for 2 hours at 150°C. Solder performs are not vacuum baked.

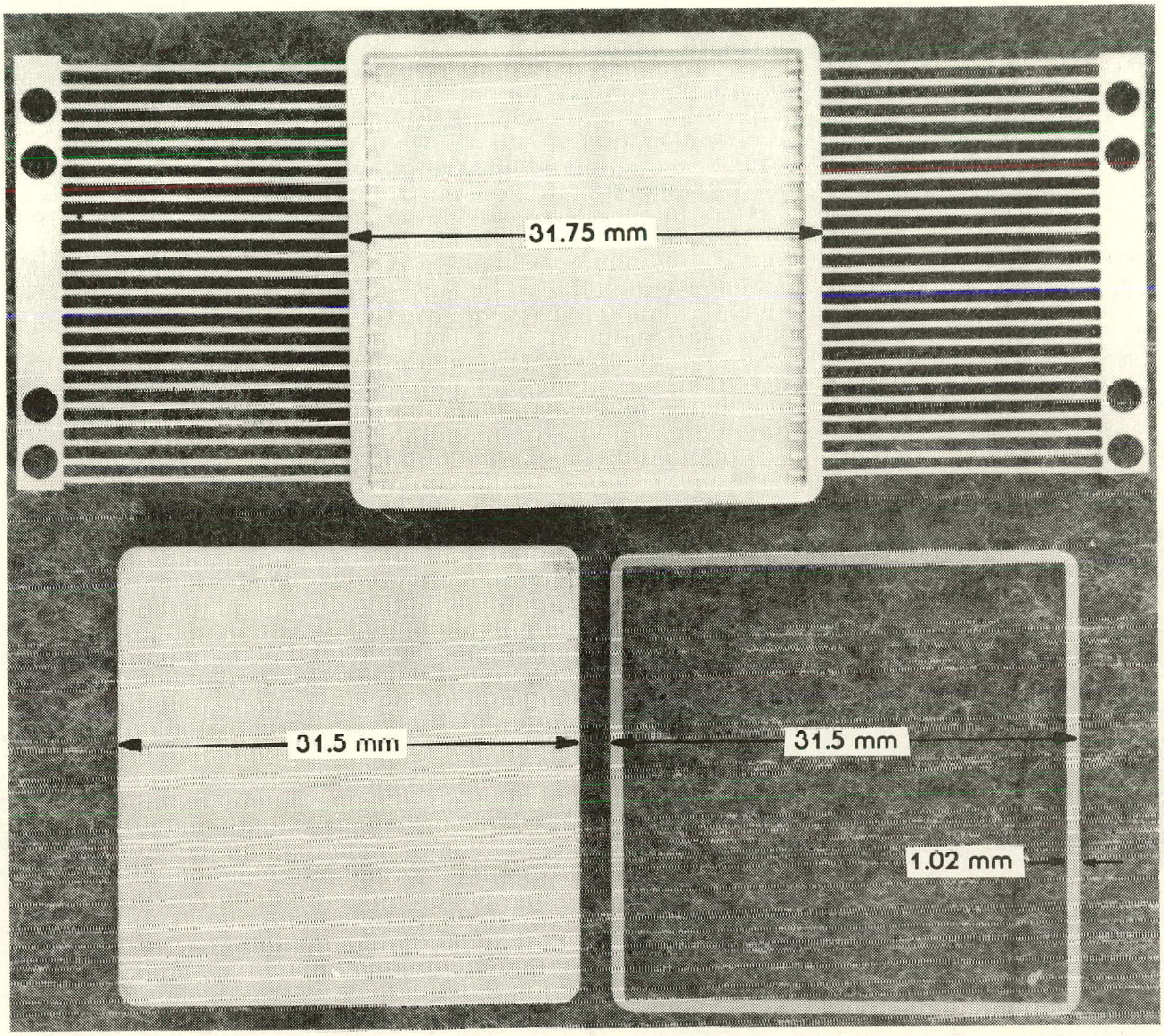

Figure 1. Flatpack (Upper), Cover (Lower Left), and Solder Preform (All three are square)

3. Move parts from vacuum oven into attached glove box, which contains the chamber where solder sealing is done.

4. Solder seal parts at set temperature for 30 seconds.

5. Remove parts from glove box and perform leak tests.

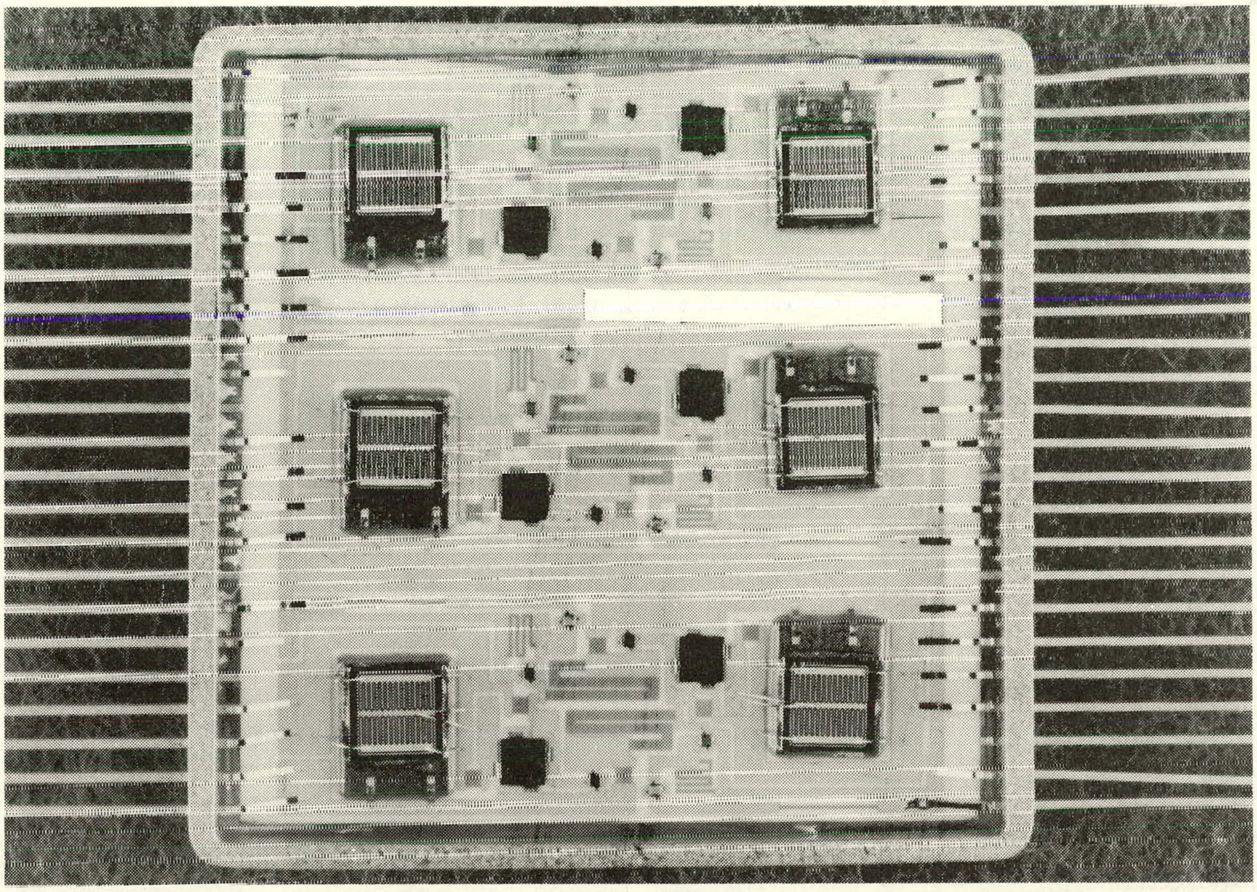

Figure 2. HMC in Flatpack (HMC is 28.19 by 21.21 mm)

Epoxy Bake, Cleaning, Vacuum Bake, and Sealing Procedures

In addition to the low oxygen levels required by the soldering operation, a low moisture content is required to insure reliability of the sealed circuit. To obtain a low moisture content, it is necessary to vacuum bake the HMC prior to sealing. The hybrid must not be exposed to air after vacuum baking, because the circuit would readsorb an excessive amount of moisture in less than one second;[1] thus, the vacuum oven must be directly attached to the glove box to provide a dry, inert atmosphere for the entire vacuum baking and sealing operation.

The process goal for moisture content was based on literature available on possible moisture-related failure mechanisms which could occur. Aluminum wire corrosion has been reported to require above 1 percent (1000 ppm) moisture by volume, and corrosion of aluminum metallization on a chip has been reported to require

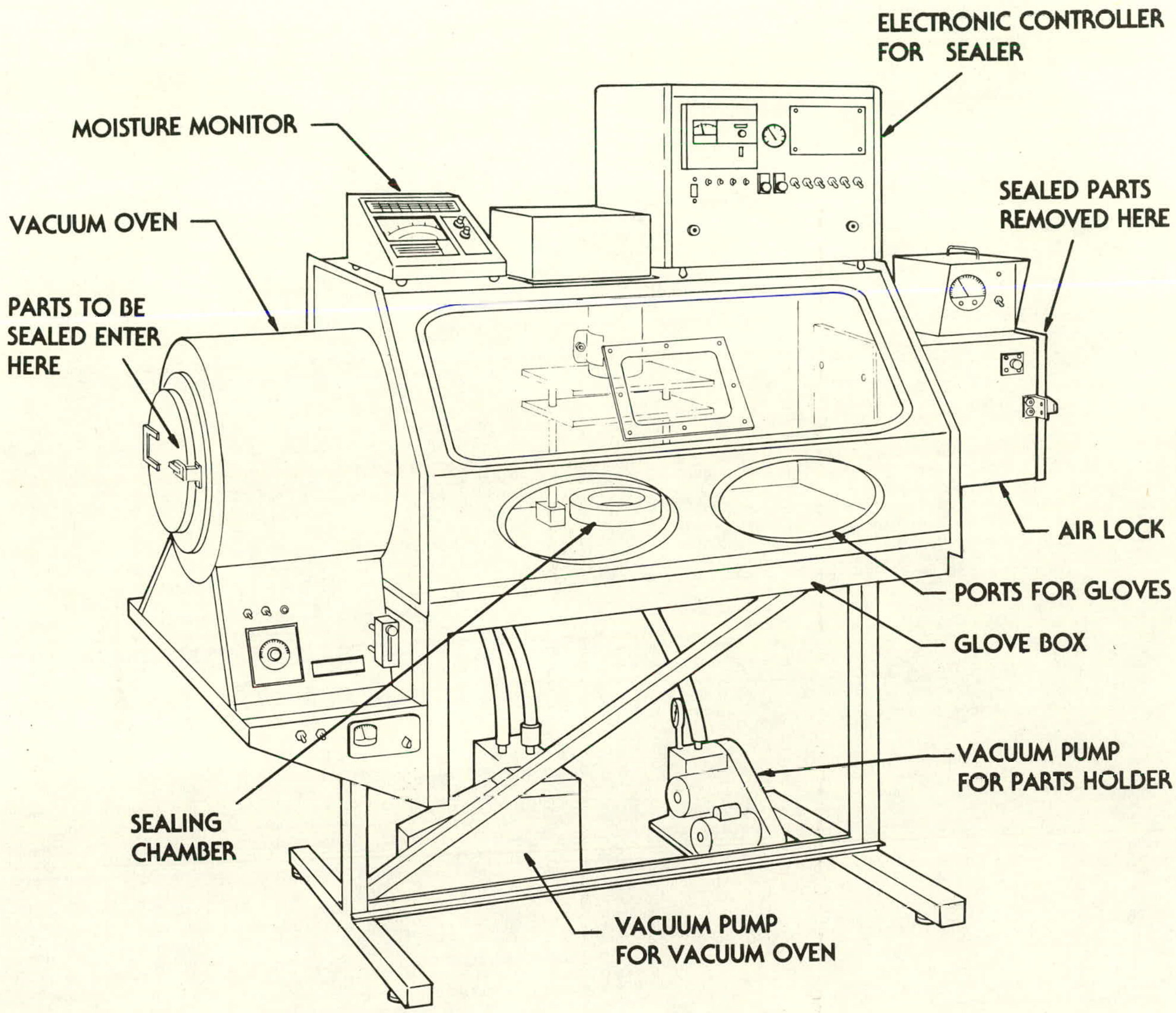

Figure 3. Hermetic Sealer

above 2 percent (2000 ppm) moisture by volume. Gold resistive leakage paths in nitride and silicon cracks in pnp beam-lead transistors and p+ silicon beam-lead zener diodes have been related to the presence of moisture and bias.[2] Condensation of moisture in cracks can occur at well below 100 percent relative humidity (6000 ppm at 0°C).[3] These reported failure mechanisms indicate that a moisture content of less than 1 percent by volume would assure long-term product reliability. Although no specific product requirement was established, the process goal was to achieve moisture content below 500 ppm.

The requirement for production hermetic sealing was specified by the design laboratory in September, 1976. Because of the long time required to obtain a sealer, existing sealing equipment was modified to provide a temporary production capability. The modification involved removing a solid state equipment seam welder from a glove box having an attached vacuum oven and installing a solder sealer in its place. In modifying the glove box (Figure 3) and sealer, stainless steel tubing was used throughout. The glove box was fitted with butyl rubber gloves. Butyl gloves pass much less moisture than do neoprene. A molecular sieve trap was added between the vacuum pump and the vacuum oven to protect the parts in the oven from oil that might backstream from the pump.

Moisture sensors in the glove box and air lock permit constant monitoring of the moisture levels of the interiors. The moisture sensor in the air lock provides a means of monitoring the moisture level after the air lock has been exposed to ambient atmosphere. The door between the glove box and air lock is not permitted to be opened unless the air lock moisture reading is below the level required by the process specification. Dry nitrogen flows continuously through the air lock.

After parts have been vacuum baked for the required time, they are moved into the attached glove box and assembled in the sealing chamber. The solder sealing cycle is initiated by pressing two switches. The top portion of the sealing chamber is lowered until a spring loaded ram contacts the package assembly and applies pressure which is maintained during the sealing cycle. The electronic controller has been preprogrammed to bring the heating element up to 650°C in 30 seconds, keep it at 650°C for 30 seconds, and then bring the temperature back down in 60 seconds. The rates for heating and cooling, as well as the sealing temperature, may all be manually set on the controller. After the parts have been sealed, they are moved into the attached air lock. They may then be removed from the air lock through the outside door. At this time, the parts are ready for leak testing.

To facilitate alignment of cover, solder preform, and package in the sealing chamber, five holes were drilled in the insulator base (Figure 4) and metal guide pins inserted. The pins are positioned around the perimeter of the heating element and provide the means for aligning the parts to be sealed. The cover, preform, and package are each placed on top of the heating element and positioned against the guide pins. In this manner, the sealing surface of the package touches nothing other than the solder preform. All positioning of parts is done with coated tweezers.

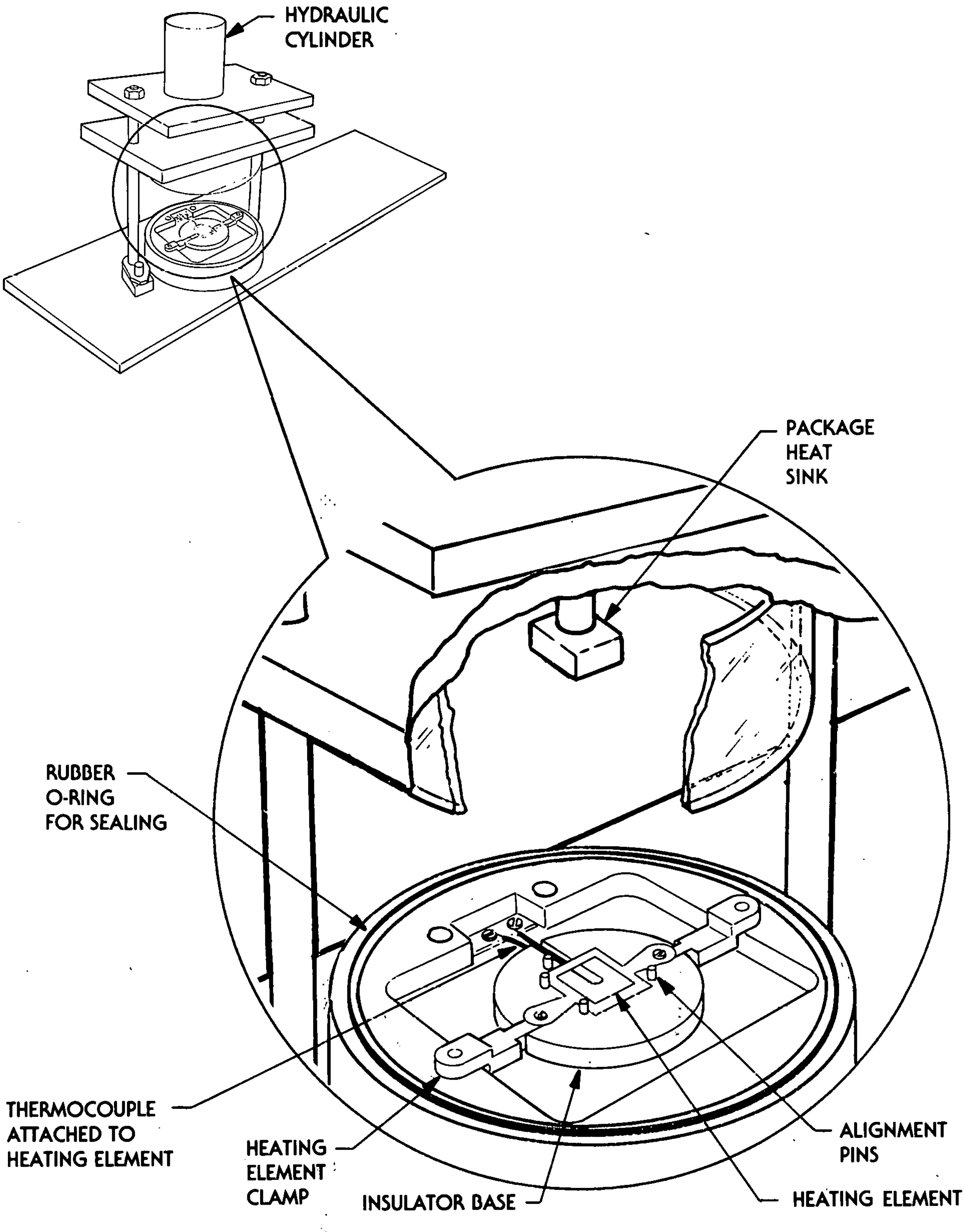

Figure 4. Sealing Chamber

The solder sealer uses a "skeleton" or ring type heating element to heat an area of the cover approximately equal to the area covered by the solder preform. Use of the skeleton heating element as received was found to cause insufficient heating in some areas of the solder joint. To improve the heat uniformity during sealing, an alumina plate, approximately 0.635 mm thick, was placed on top of the heating element. This plate also serves a second purpose. The manufacturer uses an insulative coating on the heating element to insure that the current will flow through the heating element and not the package. The main problem with this approach is that the outer coating tends to become brittle from the temperature cycling effects of 50 to 100 sealing cycles, and as a result, the coating begans to peel. This requires replacement of the heating element and recalibration of the sealer. Because the package being sealed is entirely metal, placing it on top of a bare heating element would cause the element to be shorted out. The alumina plate eliminates the need for insulation between the package and the heating element, thus allowing use of a bare metal heating element with a correspondingly greater life expectancy.

Cleaning Method Prior to Sealing

Two evaluations of cleaning methods were performed in an effort to determine which, if any, had distinct advantages over others. The first evaluation involved 12 packages as received from the manufacturer. The second used another 12 packages that had been intentionally contaminated with vacuum grease and then cleaned using the same procedure used on thin film networks prior to thermocompression bonding. In both evaluations, three cleaning methods were tested on four packages.

- Abrasion involves cleaning the sealing area of the package with a plastic eraser and then blowing dry nitrogen over the surface to remove eraser particles.

- Packages were etched in a 5 percent solution of hydrofluoric acid for 30 seconds, followed by five rinses in ultrasonic DI water, and then blown dry with dry nitrogen.

- Parts were immersed in a boiling fluorocarbon solution for 10 minutes and then a second bath for 5 minutes, after which they were blown dry with dry nitrogen.

After the parts had been cleaned, they were vacuum baked for two hours at 150°C and then sealed. There was no appreciable difference in the effectiveness of the three methods with regard to the hermetic sealing process. All eight packages cleaned by the abrasion method (numbers 3-1 through 3-4 and 22-1 through 22-4) passed the leak test, as did the eight cleaned by the hydrofluoric acid etch method (numbers 3-5 through 3-8 and 22-5 through 22-8). Of the eight cleaned with the boiling fluorocarbon solution (number 3-9 through 3-12 and 22-9 through 22-12), one as-received package 3-9) and one grease-contaminated package (22-12) failed the leak test.

The cleaning procedure specified for use prior to hermetic sealing was similar to the above cleaning procedure using the fluorocarbon solution. Trichlorotrifloroethane was used instead of fluorocarbon solution because it contains no acetone that might degrade the epoxy in the hybrid. There was some concern that the acetone in the fluorocarbon solution might have an adverse effect on the strength of the epoxies used in the hybrid. The parts are first immersed in room temperature solution for 1 minute minimum, and then suspended in boiling solution vapors for 1 minute minimum. These two steps are repeated three times. Cleaning procedure is the same for the covers and the solder preforms.

Vacuum Bake Procedure

After the parts have been cleaned, they must be vacuum baked (within 4 hours of cleaning) to achieve the required moisture level prior to hermetic sealing. The vacuum bake procedure is as follows.

- Place parts in vacuum oven.
- Evacuate oven to less than 20 μm.
- Back fill oven with dry nitrogen.
- Evacuate oven to less than 20 μm.
- Heat oven to 150°C and maintain temperature.

The packages are vacuum baked for 16 hours, and the covers are vacuum baked for 2 hours. The shorter time for the covers is permissible because epoxy is not present. The preforms are not vacuum baked because the solder will soften at the higher temperature and become deformed. When this occurs, the preform will either not fit or not lay flat. Therefore, the preforms are moved into the glove box through the air lock.

Once the parts are cool enough for handling, they may be moved into the attached glove box where they are kept until ready to be sealed.

Leak Testing of Sealed HMC

All HMCs that have been hermetically sealed are tested for both gross and fine leaks in accordance with the methods specified in Mil Std. 883A. To perform the fine leak test, the sealed packages are first placed in a vessel that is pressurized with 517 kPa (75 psi) helium for a minimum of 1 hour. After pressurization, the packages are loaded one at a time into the test chamber on the helium leak detector. The measured rate at which helium is flowing out of the package is recorded. The maximum allowable fine leak rate for a sealed package is 1×10^{-7} STP cm^3/s. The test procedure for gross leaks involves the use of a liquid that has been heated to 125°C. The parts are immersed one at a time in the liquid and observed for 30 seconds. The appearance of a stream of bubbles indicates a gross leak.

Epoxy Bake

The hybrid circuit is attached to the package with epoxy B. Epoxy A is used to attach some components to the hybrid substrate. Because these epoxies outgas during curing, it was desirable to know how long they would outgas considerable amounts of organic material, since this could have an adverse effect on hermetic sealing yields.

When the epoxy is being cured, it is in a forced air oven that allows the outgassed organic material to be removed by the flowing air. Prior to hermetic sealing, the packages are vacuum baked at 150°C for 16 hours. Any material outgassed in the vacuum oven may coat the surface of the package and interfere with solder wetting during the sealing operation. It is important, therefore, that the initial epoxy cure cycle be sufficiently long to prevent any contamination problems during the subsequent vacuum bake.

To determine the relative amounts of material outgassed during cure and then during vacuum bake, a Thermal Evolution Analysis (TEA) was performed on fresh samples of the two epoxies. The samples were of equal size and analysis of each sample was begun within one-half hour of removal from the storage freezer. Each sample was subjected to the same times and temperatures as used in building production hybrids.

The results of the analysis are shown in Figures 5 and 6. The samples were initially heated to 75°C (the cure temperature) for two hours, then the temperature was raised to 150°C (the vacuum bake temperature) for 14 hours. Comparison of the graphs reveals a much greater amount of hydrocarbon material being outgassed from epoxy B initially. When the temperature was increased to 150°C, additional outgassing of this sample occurred and continued for a period of 10 hours before returning to the base level. Epoxy A showed a negligible amount of outgassing at 150°C.

After reviewing the data, a postbake consisting of 24 hours at 150°C in a forced air oven was incorporated to reduce the possibility of epoxy contamination during vacuum baking.

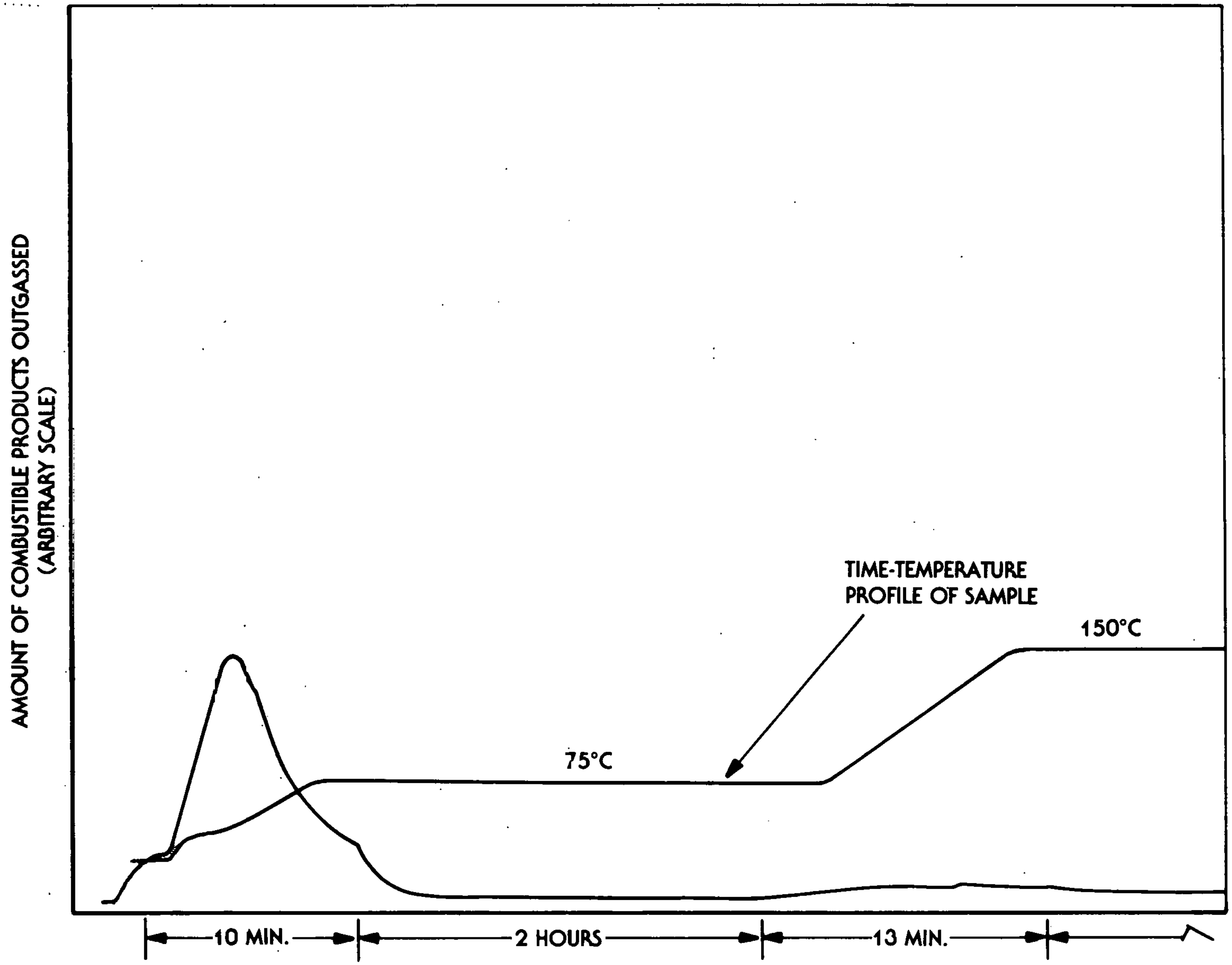

Figure 5. Thermal Evolution Analysis of Epoxy A

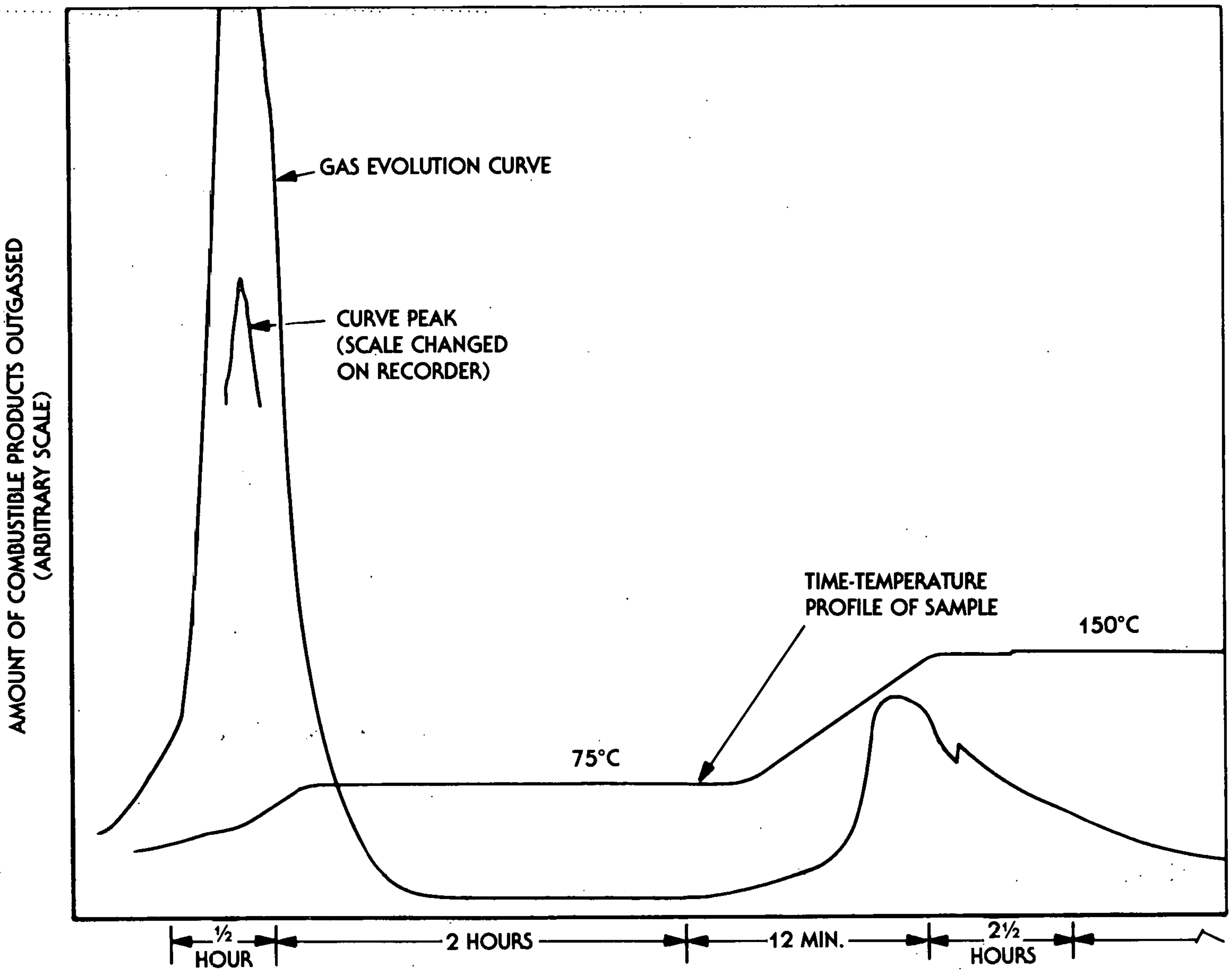

Figure 6. Thermal Evolution Analysis of Epoxy B

Substrate Temperature During Sealing

It is necessary to maintain the temperature of the HMC below 200°C to prevent chrome diffusion in the thin film and epoxy breakdown which could result in loss of substrate package adherence. To verify that this temperature is not exceeded during sealing, measurements were taken during the sealing cycle for various control settings (Table 1). The temperature set point determined the maximum temperature of the heating element. The solder interface is at a much lower temperature. The gain setting controls the time required for the heating element to reach the set temperature. The substrate remained well below the 200°C limit for all settings. After each sealing cycle (requiring approximately 2 minutes), the test package was allowed to cool down to the same temperature.

Moisture Content of Sealed HMC

Thirty flatpacks that had been sealed at Bendix were taken to Sandia Laboratories Albuquerque (SLA) to be opened on the mass spectrometer and analyzed for moisture and gas content. The results (Table 2) indicate a moisture level less than 500 parts per million for 25 of the 30 packages. Table 2 also lists the amounts of the various gases found in the packages.

ACCOMPLISHMENTS

The capability to hermetically package hybrid microcircuits has been established at Bendix. Initial sealing yields have been greater than 90 percent. Three packages containing substrates that had been sealed using the production process were found to have approximately 50 ppm moisture inside (the goal was less than 500 ppm).

FUTURE WORK

Future work on hermetic sealing includes the evaluation of moisture sensor chips for use in hybrid microcircuits. The chip is attached to the substrate with epoxy, and wires are connected from the sensor to the package. An electronic monitor may be connected to the package leads to read the interior moisture content of the sealed unit. The evaluation will determine suitability of the sensors for HMC use, based on their accuracy and stability when subjected to HMC product test requirements.

The new sealer will be characterized for production sealing and schedules will be developed for the LSI packages to be

Table 1. Substrate Temperature During Sealing

Heating Element Temperature (°C)	Gain	Maximum Substrate Temperature (°C)
550	150	142
550	150	149
600	150	157
600	300	146
600	600	154

used in FY1978. A new specification will be required for hermetic sealing of LSI circuits.

A particle impact noise detection (PIND) tester will be purchased and evaluated for testing of HMCs and LSI circuits in accordance with the proposed method 2020 of Mil. Std. 883A.

Additional work will be done to improve the rework capability of hermetically sealed units that must be opened for repair and then resealed. A glove box will be used to provide an inert atmosphere for opening packages. Possible methods of resealing packages, including resoldering and laser welding, will be evaluated. The laser welding capability will also provide an alternate to solder hermetic sealing.

Table 2. Analysis of Sealed Package Interior Environment

Unit	Water* (Volume ppm)	Gases (Volume Percent)				
		Ar	CO_2	CO	C_2H_6	He
2-1	100	0.09	0.04	0.0	0.0	0.37
2-2	0	0.01	0.05	0.0	0.01	0.0
3-1	100	0.0	0.01	0.0	0.0	0.0
3-2	900	0.06	0.05	0.0	9.48	5.86
3-3	300	0.0	0.01	0.0	0.0	0.0
3-4	0	0.0	0.01	0.0	0.02	0.0
3-5	200	0.0	0.01	0.0	0.02	0.0
3-6	0	0.0	0.01	0.0	0.02	0.0
3-7	0	0.0	0.01	0.0	0.02	0.0
3-8	0	0.0	0.01	0.0	0.03	0.0
3-10	300	0.0	0.0	0.91	0.0	0.0
3-11	700	0.0	0.01	0.93	0.0	0.0
3-12	0	0.0	0.01	0.91	0.0	0.0
22-1	200	0.01	0.0	0.90	0.0	0.0
22-2	0	0.0	0.0	0.91	0.0	0.0
22-3	100	0.10	0.0	1.62	0.0	0.0
22-4	300	0.0	0.0	0.78	0.0	0.0
22-5	1900	0.0	0.0	0.77	0.0	0.0
22-6	0	0.0	0.0	0.78	0.0	0.0
22-7	0	0.0	0.0	0.80	0.0	0.0
22-8	0	0.0	0.0	0.78	0.0	0.0
22-9	0	0.0	0.01	0.77	0.0	0.0
22-10	0	0.0	0.0	0.78	0.0	0.0
22-11	0	0.0	0.0	0.90	0.0	0.0
DPC-4**	36	0.0	0.01	0.01	0.0	0.0
DPC-1	9277	0.58	0.02	0.0	0.03	0.01
DPC-5**	27	0.0	0.11	0.0	0.0	0.0
EPC-7**	42	0.0	0.06	0.0	0.0	0.76
CLAY-4	0	0.0	0.01	0.0	0.0	0.0
DPC-9	324	0.80	0.03	0.0	0.03	0.58

Table 2 Continued. Analysis of Sealed Package Interior Environment

	Gases (Volume Percent)					
Unit	H_2	CH_4	N_2	O_2	C_2H_2	C_2H_4
2-1	0.01	0.01	97.45	2.02	0.0	0.0
2-2	0.0	0.0	99.87	0.04	0.0	0.02
3-1	0.02	0.01	99.94	0.0	0.0	0.01
3-2	0.0	0.0	82.38	1.43	0.65	0.0
3-3	0.05	0.01	99.90	0.0	0.0	0.0
3-4	0.02	0.01	99.94	0.0	0.0	0.0
3-5	0.05	0.01	99.89	0.0	0.0	0.0
3-6	0.03	0.01	99.93	0.0	0.0	0.0
3-7	0.02	0.01	99.94	0.0	0.0	0.0
3-8	0.13	0.01	99.82	0.0	0.0	0.0
3-10	0.01	0.0	99.05	0.0	0.0	0.0
3-11	0.03	0.01	98.85	0.0	0.0	0.10
3-12	0.01	0.0	99.07	0.0	0.0	0.0
22-1	0.03	0.0	98.85	0.18	0.0	0.01
22-2	0.01	0.0	99.08	0.0	0.0	0.0
22-3	0.0	0.0	95.85	2.41	0.0	0.01
22-4	0.01	0.0	99.18	0.0	0.0	0.0
22-5	0.0	0.0	99.04	0.0	0.0	0.0
22-6	0.01	0.01	99.18	0.02	0.0	0.0
22-7	0.0	0.0	99.11	0.0	0.0	0.09
22-8	0.01	0.0	99.21	0.0	0.0	0.0
22-9	0.01	0.0	99.21	0.0	0.0	0.0
22-10	0.0	0.0	99.22	0.0	0.0	0.0
22-11	0.0	0.0	99.10	0.0	0.0	0.0
DPC-4	0.0	0.0	99.98	0.0	0.0	0.0
DPC-1	0.0	0.0	84.61	13.82	0.0	0.0
DPC-5	0.0	0.0	99.86	0.03	0.0	0.0
EPC-7	0.0	0.0	99.03	0.15	0.0	0.0
CLAY-4	0.0	0.0	99.99	0.0	0.0	0.0
DPC-9	0.0	0.0	80.14	18.39	0.0	0.0

*Uncertainties in the volume percent for water may be 100 percent or higher.
**Packages with thin film networks inside.

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ELECTRICAL: HMC Sealing

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