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Thermal Shock Testing for Assuring Reliability of Glass-Sealed Microelectronic Packages

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Abstract

Tests were performed to determine if thermal shocking (Method 1011, MIL-STD-883) is destructive to glass-to-metal-seal microelectronic packages and if thermal shock step stressing can compare package reliabilities. Thermal shocking was shown to be not destructive to highly reliable glass seals. Pin-pull tests used to compare the interfacial pin-glass strengths showed no differences between thermal-shocked and not-thermal-shocked headers. A "critical stress resistance temperature" was not exhibited by the 14-pin DIP headers evaluated. Headers manufactured in cryogenic-nitrogen-based and exothermically-generated atmospheres showed differences in as-received leak rates, residual oxide depths and pin-glass interfacial strengths; these were caused by the different manufacturing methods, in particular, by the chemically-etched pins used by one manufacturer. Both header types passed thermal shock tests to temperature differentials of 646 °C. The sensitivity of helium leak rate measurements was improved up to 70% by baking headers for two hours at 200 °C after thermal shocking.

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Mr. Bruno Munoz, GSFC/Unisys Support Systems Group/Code 310, carried out the visual, thermal shock and hermeticity tests and Mr. Michael Fisher, GSFC/Unisys Support Systems Group/Code 310, prepared the metallographic specimens. Ms. Robin Sokoloski, Reeves Hoffman Division, Carlisle, Pennsylvania, performed the non-destructivity evaluation. Ms. Jillian Evans, GSFC Parts Branch/Code 311, analyzed and computed the thermal shock stresses. Ms. Diane Kolos and Mr. Mike Viens, GSFC Materials Branch/Code 313, provided their equipment to accomplish the metallographic evaluations and pin-pull tests. The authors appreciate these contributions, which were instrumental in completing this work.

INTRODUCTION

Package hermetic failures frequently cause environmental failure and subsequent electrical degradation of microelectronic devices.[1,2,3] Thermal shock testing[4] is one test employed for assuring the reliability of microelectronic packages, such as glass-to-metal seal headers* used for transistor and hybrid microcircuit packages. Headers are cycled between high and low temperature fluids to induce transient thermomechanical stresses in the glass seals and seal integrity is verified by subsequent leak testing.[5] This test qualitatively indicates package quality; however, it is only a "go/no-go" evaluation.

Our hypothesis is that thermal shocking is not destructive to highly reliable glass seals. The test has been used to screen out marginal packages in several NASA spaceflight programs. However, many device and package engineers regard the test as destructive and are reluctant to use it for screening headers. Thermal shock testing is classified as *conditionally* non-destructive in MIL-M-38510,[6] i.e., it initially is considered destructive until sufficient data is accumulated to indicate it is not destructive.** Proving the test to be non-destructive would establish its use as a viable package screening technique. Additionally, more quantitative information derived from thermal shock testing would be useful for comparing package performance and reliability.

The strength and thermal stress resistance behaviors of brittle materials have been evaluated using quench tests. Strengths measured on ceramics[7] and glasses[8] after they were subjected to increasingly large quench (thermal shock) temperatures showed a discontinuous decrease which occurred at a "critical quench temperature." Fracture mechanics theory related this critical temperature to the minimum temperature differential which would initiate and propagate cracks.[9] An analogous method could evaluate glass-to-metal seal headers. Thermally shocking them at increasingly large temperature differentials (step stressing) until they failed hermetically would establish a "critical stress resistance temperature" (ΔT_c) for the glass seals. The stress resistance depends on the glass-to-metal interface strength and on the extent and size of any existing flaws. Thermal shock stressing will propagate existing flaws or initiate and propagate cracks in weak interfacial bonds, causing eventual hermetic failures. Since the test temperature differential (ΔT) affects the magnitude of induced stresses, headers with weak interfaces or those having flaws will withstand less stress. The result is a lower measured ΔT_c. Factors affecting ΔT_c are glass and metal thermal and mechanical properties,

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* Headers are packages having no devices or lids mounted.

** MIL-M-38510, in effect when this work was initiated, has been superseded by MIL-H-38534 for hybrid microcircuits; non-destructivity requirements are identical for both specifications.

thermal shock test temperatures and fluid heat transfer coefficients, seal geometry,[10,11] and header manufacturing process variations. Measuring ΔT_c of similar glass seals under the same thermal shock conditions would compare their relative strengths; any variations could be related to design (materials and geometry) or manufacturing differences.

A cursory test differentiated glass seal quality by thermal shock testing.[12] Figure 1 shows results from identically-manufactured headers except that three different sealing glasses were used. There was a difference in the relative thermal shock resistance between the three glass types.

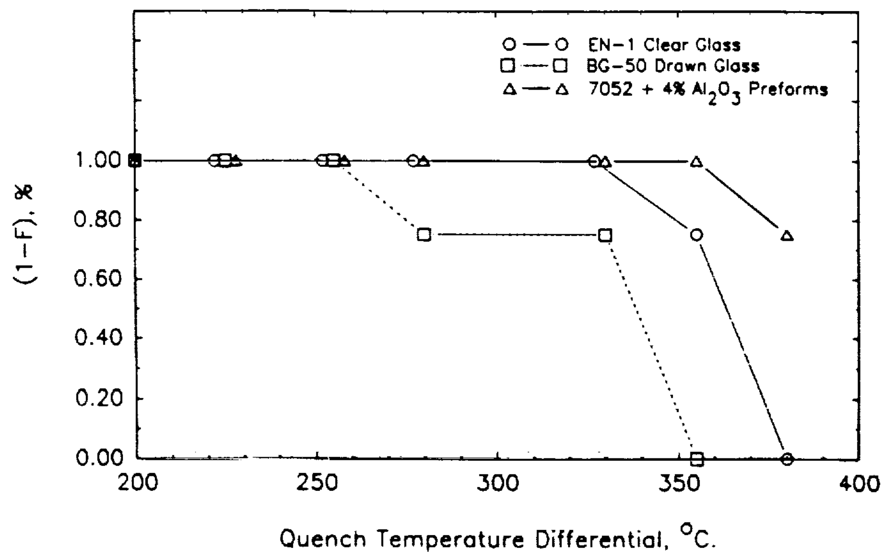


Figure 1. Comparative thermal shock tests on headers sealed with three glass types.

This research was performed to determine if thermal shock testing is destructive to the glass-to-metal seals and to evaluate using thermal shock step stressing for glass-seal header reliability comparisons.

EXPERIMENTAL PROCEDURES

Fourteen pin Dual In-line Package (DIP) matched seal headers were selected for study. These were manufactured from Fe-Ni-Co platforms and pins (ASTM F-15, Standard Specification for Iron-Nickel-Cobalt Sealing Alloy) sealed with borosilicate glasses. Two lots were procured. One manufacturer (A) produced headers using cryogenic nitrogen-based atmospheres and the other (B) manufactured them using exothermically-generated atmospheres. Both header lots were plated with electroless nickel after sealing.

All headers were numbered upon receipt: "A" headers were 0-99 and "B" headers 100-224. They were inspected visually and then tested for hermeticity in accordance with Method 1014 Condition A4[5] using a mass spectrometer helium leak detector (Spectron Model 3000S/3200, Edwards High Vacuum, Inc.). A Viton^{tm} gasket and vacuum grease (Apiezon Type M) were used to reduce leakage between the header and a custom-machined fixture. Leak rates were recorded for all measurements. All headers were cleaned in ultrasonic trichlorotrifluoroethane and alcohol baths before leak testing.

Header numbers 00, 06, 17, 90, 115, 116, 191, and 217 were selected as control samples. They were stored in a vacuum dessicator. Their leak rates were measured immediately before and after the thermal-shocked samples were leak-tested.

Thermal shocking was based on Method 1011;[4] the cold bath was Galden D-100 fluorocarbon fluid (Ausimont, Morristown, NJ) and the hot bath was Galden D-40 fluid (Ausimont) up to 200 °C. Above 200 °C a temperature-controlled box furnace (Model 056-PT, Heavy Duty Electric Co.) was used to heat the headers in air for 10 minutes of each hot soak cycle. (The hot air dwell time was twice the liquid bath dwell time to account for the lower thermal diffusivity of air.) Later testing used liquid nitrogen (-196 °C) as a cold bath. After thermal shock number 31 (test number 8 for control samples), the headers were oven-baked at 200 °C for two hours after thermal shocking and cleaning (per the above procedure) and before leak testing. Four of the eight control samples also were baked. Initial thermal shock tests were performed at -65 to +150 °C (Method 1011, Condition *C*, a 215 °C temperature differential); these were increased to -65+200 °C (Condition *D*, 265 °C), -65+350 °C (415 °C differential), -65+450 °C (515 °C), -196+400 °C (596 °C) and -196+450 °C (646 °C).

After all thermal shock testing was completed, the glass seals of several headers were examined under low (20X) magnification. Selected headers were mounted, ground, polished and etched and their pin-to-glass interfaces examined under high magnification (1000-1200X). Pin pull tests[13] were performed (Model 1113, Instron Corp.) to compare seal strengths.

Test non-destructivity was evaluated by thermal shocking 50 headers of group A and 45 of group B using Condition *C* (-65 to +150 °C) of Method 1011.[4] An automated thermal shock machine (Standard Environmental Systems, Model HCB/2075A) and Galden D02 fluid were used. Five headers of each group were control samples; these were not thermal-shocked and their leak rates were measured immediately before and after the test headers were measured. All headers were vacuum-baked at 80 °C for 90 minutes before being tested. Leak rates were measured on a helium mass spectrometer (Alcatel Model API 111B) after each 15 cycles of thermal shock. A total of 90 shocks was used; MIL-M-38510 requires a minimum of 75 shocks (five times 15 cycles) to verify test non-destructivity.

RESULTS

Four headers were rejected by the initial visual inspection: #9 had negative meniscus at pins 1 and 2, #88 had a void near pin 1, #101 had non-uniform wicking of its meniscus and #123 had a rejectable bubble in the glass at pin 8.

Normalized frequency distributions of the as-received helium leak rates are shown in Figure 2 for headers from each group. (Actual measurements are shown in Tables A-I and A-II.) No headers failed the Method 1014 Condition A4 criterion (1 x10^{-8} atm-cc/sec). Group A headers exhibited a narrower distribution.

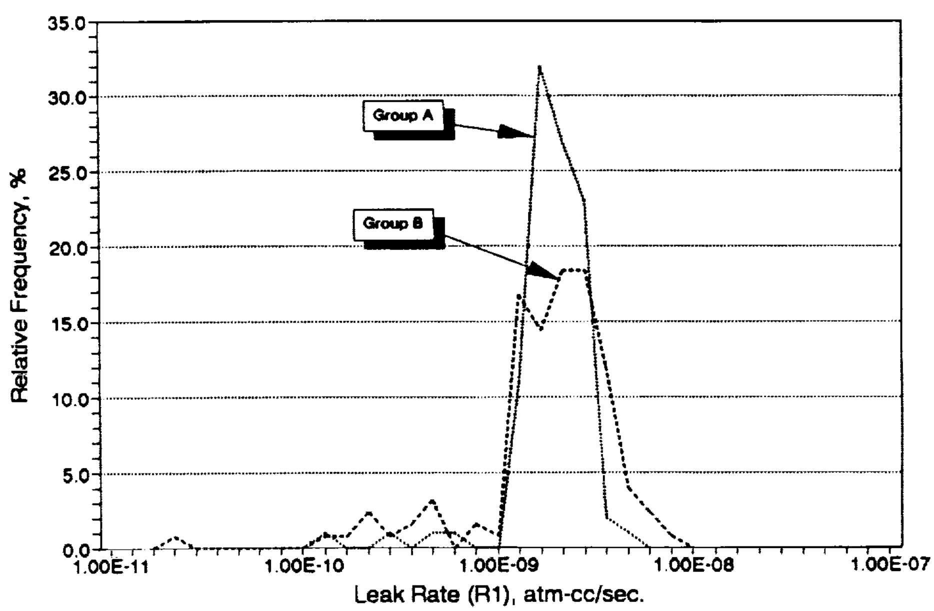


Figure 2. As-received helium leak frequency distributions.

Measured helium leak rate averages for the control samples are shown in Figure 3, below. (For the individual measurements see Tables A-III and A-IV and Figures A-1 through A-8, in the Appendix.) For most tests, "before" measurements (those taken before the thermal shock samples were measured) were less than "after" measurements. Statistical computations (t-test at 95% confidence) confirmed that "before" and "after" measurements were different for

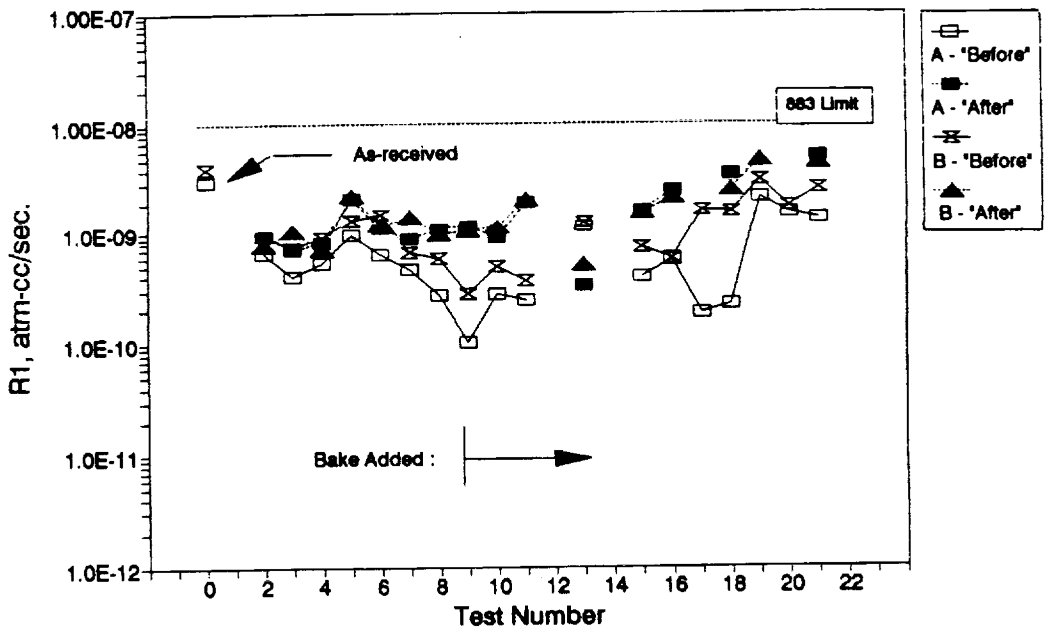


Figure 3. Control sample average leak rates.

groups A and B (within each group) and that group A was different from group B for "before" measurements but not for "after" measurements. The control sample measurements also exhibited a gradual increase over the duration of the test program.

The test method capability was evaluated by calculating 3-sigma control charts[14] on the "before" measurements. Table I (below) shows these results; they also are plotted on Figures A-1 through A-8. The test method was capable of detecting differences 1.7 to 3.4 times the initial leak measurements (t=0) for any one header during thermal shock testing.

Four control samples (SNs 6, 90, 116, 217) were baked out when this step was added after test number 8. (The bake-out erroneously had been omitted in the preceding tests.) The mean leak rates decreased for these four samples, as shown in Table I. For the thermal-shocked headers, average leak rates were compared for the three consecutive measurements before and after the bake-out was added. They decreased by 27 to 70 per cent (see Table A-V).

Table II and Figure 4, below, summarize leak test results on the thermally shocked headers; individual values are reported in Tables A-VI and A-VII. No group A headers failed; SN 52 had failed after thermal shock number 60 but passed when retested. Group B SNs 145 and 192 failed after thermal shock numbers 45 and 60, respectively; both failed upon retesting. Thermal shock test results were not significantly different between Groups A and B (when analyzed using a Chi-squared test at a 90% confidence level). Figures 5 and 6 show

TABLE I

Helium Leak Test Measurement Capabilities
(control chart calculations for individuals on "before" measurements)

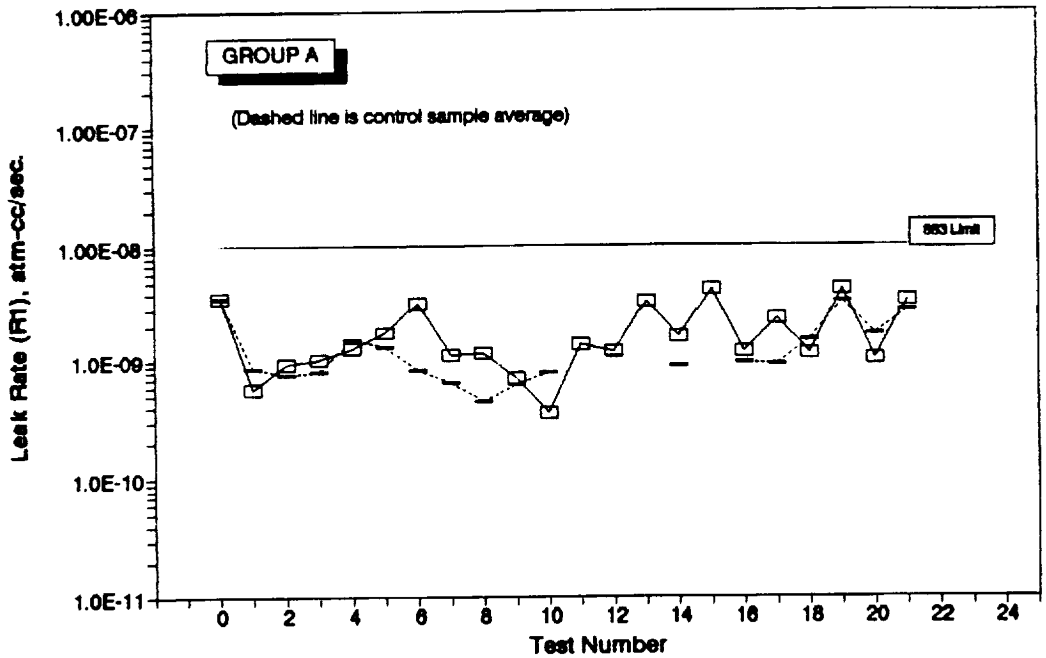
SN	Treatment	R_1 10^-10 atm-cc/sec n	x	UCL	UCL/x
00	No Bake	15	1.7	3.9	2.3
17	No Bake	16	4.2	14.1	3.4
06	Before Bake	8	5.9	12.7	2.2
	After Bake	7	2.6	7.1	2.7
90	Before Bake	7	8.6	14.4	3.4
	After Bake	7	3.7	12.0	3.2
115	No Bake	17	7.1	20.7	2.9
191	No Bake	14	6.7	14.9	2.2
116	Before Bake	7	10.9	21.0	1.9
	After Bake	7	5.5	13.7	2.5
217	Before Bake	7	15.0	34.1	2.3
	After Bake	7	7.6	19.0	2.5

TABLE II

Thermal Shock Test Conditions and Results

Shock Number	Temperature, C Cold	Hot	Diff.	Fluid Cold	Hot	Hot Dwell Time,min.	#Seals Failed/#Tested A	B
1-15	-65	+150	215	D-100	D-40	5	0/98	0/98
16-30	-65	+200	265	D-100	D-40	5	0/98	0/98
31-45*,**	-65	+350	415	D-100	Hot Air	10	0/98	1/98+
46-60	-65	+450	515	D-100	Hot Air	10	0/98++	4/98+++
61-75	-196	+400	596	LN_2	Hot Air	10	0/98	0/98
76-90	-196	+450	646	LN_2	Hot Air	10	0/98	0/98

* Bake-out added after shock #31.
** Leak measurements retested after shock #45.
\+ SN 145 (B) failed at pin 8 after shock #45; failed after retest; replaced with SN 193.
++ SN 52 (A) failed at 2 pins after shock #60; passed when retested.
+++ SN 192 (B) failed at four pins after shock #60; failed after retest; replaced with SN 194.



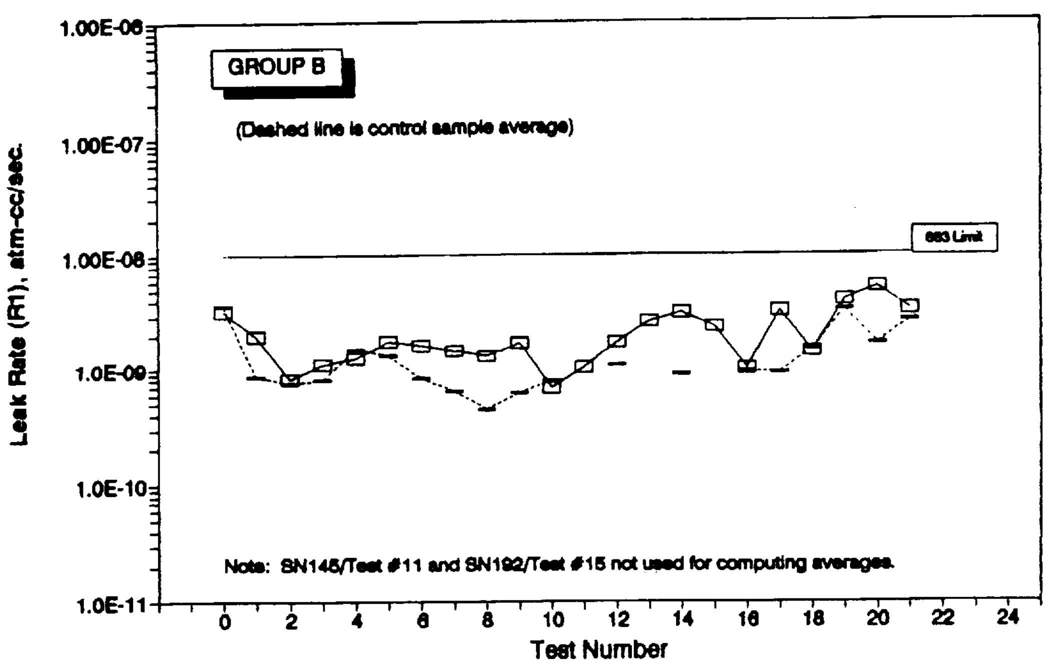
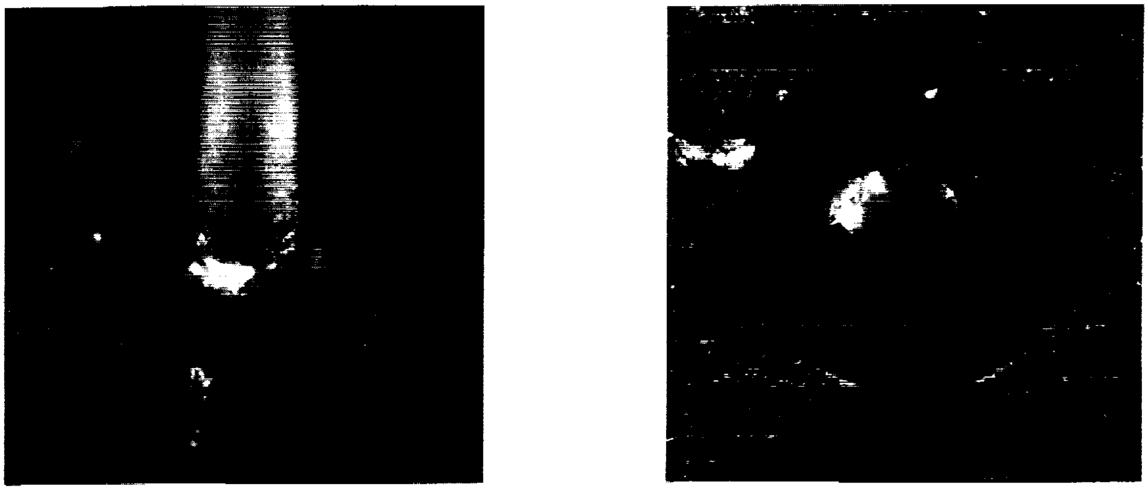
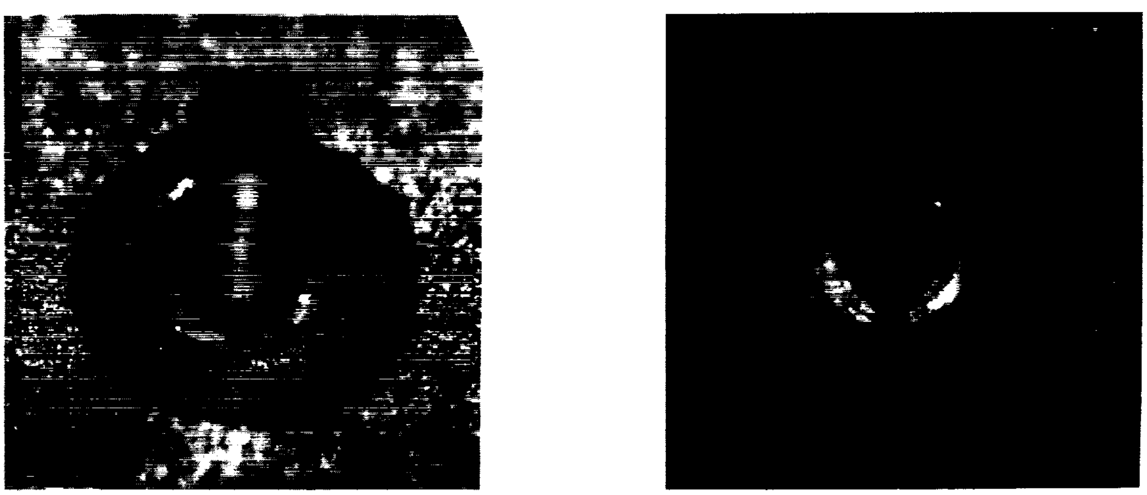


Figure 4. Average leak rates of thermal-shocked headers.



OBLIQUE VIEW PLAN VIEW

Figure 5. SN 145 pin failure; 15X reflected and oblique incident light.



OBLIQUE VIEW PLAN VIEW

Figure 6. SN 192 pin failure; 15X, reflected light.

cracks around the failed pin seals in SNs 145 and 192. Figure 7 shows cracks around a SN 52 pin; this header had not failed hermeticity.

The distribution of pin residual oxide depths grouped by header manufacturer is shown in Figure 8; individual data are shown in Table A-VIII. Two measurements on each of the six pins which had not been pull-tested were recorded for each header. Group A clearly had a higher mean and a narrower distribution of oxide depths; the average was 7.9 microns and the standard deviation 0.49 micron. Group B pins averaged 5.0 microns and had a standard deviation of 1.77 microns. As the two groups were produced by different manufacturing techniques, these differences are not unexpected.

Pin-to-glass interfacial strengths of the thermal-shocked and control headers were evaluated using pin pull tests. Nineteen headers from the two groups were tested. Each of eight pins on a header was loaded in tension at a strain rate of 1.0 cm/min until the pin-to-glass interface failed. Since the pin diameters were different for the two groups (mean diameters were 0.0185 inch for A and 0.0189 inch for B), nominal pin failure stresses were computed by dividing each measured failure load by the surface area calculated from the mean pin diameters and glass-to-pin interface lengths. Table III summarizes these results. (Individual failure loads are shown in Table A-IX and nominal failure stresses in Table A-X.) Analyses of variance

TABLE III

Average Pin-to-Glass Failure Stresses

		Controls	T-Shocked	
Group A	n =	32	46	
	x =	4900	5000	psi
	s =	190	130	psi
	CV =	3.9	2.6	%
Group B	n =	32	52	
	x =	5900	6000	psi
	s =	200	230	psi
	CV =	3.4	3.8	%

performed on the failure stress data showed no significant strength difference between the control (not thermal-shocked) and thermal-shocked headers for each group (A and B); however, group B showed a significant variance between headers whereas A did not. Strengths were significantly different between groups A and B for both control and thermal-shocked headers; this difference accounted for 93% of the total variance and error accounted for 6%. (See Table A-XI for the detailed analyses of variance results.)

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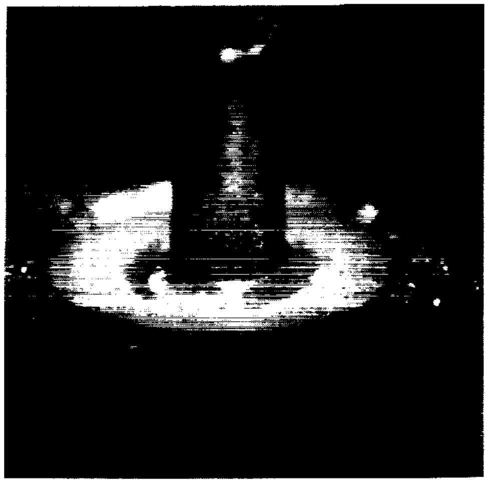
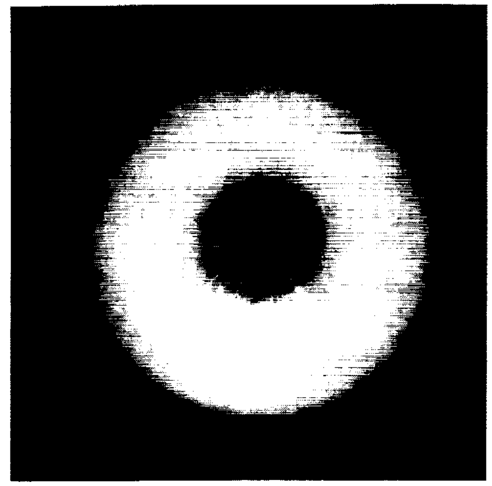




OBLIQUE VIEW

PLAN VIEW

Figure 7. Cracks around a SN 52 pin; 15X, reflected and oblique incident lighting.

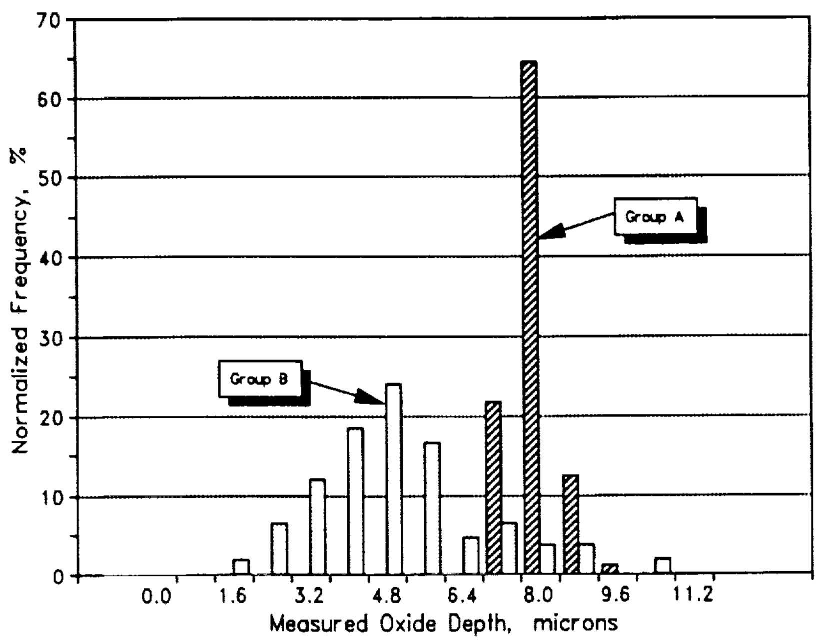


Figure 8. Residual oxide depths of pins.

Non-destructivity test results are shown in Table IV, below. No headers of either group failed after being thermal-shocked for a total of 90 cycles at Condition *C* (-65/+150 °C).

TABLE IV

Thermal Shock Non-destructivity Tests on 14-Pin DIP Headers

Cumul. # of Thermal Shocks[1]	Number of Seals Failed/#Tested		
	Cntrls[3]	Group A	Group B
0 [2]	0/140	0/700	0/630
15	0/140	0/700	0/630
30	0/140	0/700	0/630
45	0/140	0/700	0/630
60	0/140	0/700	0/630
75	0/140	0/700	0/630
90	0/140	0/700	0/630

[1] All thermal shocks per Method 1011, Condition C (-65/+150 °C).

[2] 0 = initial measurements before any thermal shock.

[3] Readings taken before and after thermal-shock measurements; controls were not thermal-shocked.

DISCUSSION

Since the open package leak test is used as the end-point measurement for thermal shock testing, we conducted extensive evaluations on the leak test itself. Statistical control calculations on measured headers showed our leak test method yielded mean leak rates of 1.7 to 15.0 x 10^{-10} atm-cc/sec. Variances (upper 3-sigma control limits) during the entire testing program were as great as 3.4 times the mean leak rate. Method 1014 requires a "sensitivity sufficient to read measured helium leak rates of 10^{-9} atm-cc/sec and greater."[5] Failure criteria established for this experiment were a leak rate greater than either 1 x 10^{-8} atm-cc/sec or 150% of the initial (t=0) leak rate. The test methods met these criteria.

Our technique used a "wand" to effuse helium over each header tested. Continuous testing caused the helium to diffuse into and accumulate in the test room. The room was relatively small (approximately 75 square feet) so the helium background level increased during continuous testing. When a period of time passed before a subsequent series of leak tests was run, the helium dissipated and the background level decreased. These accounted for control sample "before" measurements being less than the "after" ones, for A and B measurements being different for "before" but the same for "after" measurements, and for the gradual increase in measured leak rates over time. We also noted that the helium background leak readings dropped to approximately 10^{-10} atm-cc/sec several days after our test program was completed. The unusual behavior at test number 13, where the "before" measurements were greater than the "after" measurements, was caused by this series of tests being started one afternoon after the previous series (number 12) had been measured and then being finished the next morning. These observations suggest using closed containers ("cups") over the test fixture to allow helium to diffuse around the part but limit its diffusion into the test room.

Omitting the bake-out during the initial part of the test program was a fortuitous error. We were able to evaluate the bake-out effect on leak testing without harming the experiment. Our data, in Tables I and A-V, showed that a bake-out performed prior to leak testing clearly increased leak detection sensitivity by 50 to 57% for the control samples (which had not been immersed in the thermal shock fluids) and by 27 to 70% for the thermal-shock headers which had been immersed in the fluids. Ruthberg,[15] in fact, has recommended a bake-out prior to leak testing; its purpose is to remove any water or fluorocarbon plugging which would cause erroneous hermeticity measurements. This sample conditioning (bake-out) prior to leak testing currently is not required by Method 1014; it is, however, recommended for assuring accurate test results.

Thermal shock testing indicated no significant loss in thermal stress resistance for either group of headers, even at temperature differentials to 646 °C. There were no sharp decreases in failure rates for increasing ΔT, as was seen in Figure 1,. Figure 4 data showed that header leak rates after thermal shocking did not deviate significantly from the control sample (not thermal-shocked) average rates. Two failures did occur in Group B headers at ΔTs of 415 and 515 °C; however, they were not statistically different from the Group A results for the sample sizes used. (Detecting a 2% difference in failure rate, for example, would require testing up to 350 seals [25 headers] of each type.) These results did indicate, by inference, an improvement in header performance over several years; the Figure 1 data had been obtained on headers processed five years ago by one of the manufacturers who produced headers for this study.

Stresses generated in these headers during thermal shocking were computed for several temperature differentials, including Condition *C* , using Kokini's techniques[10]. These data are shown in the table on the next page:

TABLE V.

Computed Thermal Shock Stresses at Pin-Glass Interfaces for Fe-Ni-Co Alloy/Borosilicate Glass Seals in 14-Pin DIP Headers

		Stress, psi.			
		Cold Temp. Steady State	Cold->Hot Transient	Hot Temp. Steady State	Hot->Cold Transient
Condition *C*	(r)	-98	-4970	200	5070
ΔT = 215 °C	(t)	-1080	3400	2100	-2380
SN145 Failure	(r)	-972	-9410*	470	9780
ΔT = 415 °C	(t)	-1060	7460*	4990	-3530
SN192 Failure	(r)	-113	-13150*	680	13720
ΔT = 515 °C	(t)	-1230	10720*	7250	-4700
Max. Th. Shock	(r)	-280	-13675*	540	13930
ΔT = 596 °C**	(t)	-2975	9280*	5730	-6525

Notes: * See text.
** 596 ° ΔT used for calculations as 646 ° ΔT has hot temperature greater than glass strain point.
(r) are radial Stresses, (t) tangential; (+) tensile and (-) compressive.
Stresses computed for 0.0185 in. dia. pins; difference is less than 1% for 0.0189 in. dia. pins.

The computations showed the headers were subjected to stresses much larger than Kokini's experiments. Our Condition *C* stresses were approximately the same as his Condition *C* stresses. However, our headers withstood - without failure - calculated stresses three times those of Kokini's Condition *C*. Kokini's analysis assumed the heat transfer coefficient of the fluid contacting the glass seal is approximately the same as for the fluorocarbon liquid he had used. We did not measure the temperature response at the pins, so the actual heat transfer conditions using air as a "hot bath" are unknown and our calculated 415, 515 and 596 °C ΔT stresses may be in error. Kokini did analyze mean heat transfer coefficient (h) variances on his stress calculations: 40% variations in h caused less than a 10% variation in stress (500 psi) for his Condition *C* tests, and a coefficient one-tenth of h yielded a 48% smaller stress. The hot air h is on the order of 2% of that for fluorocarbon liquid,[16] so heat will be transferred less quickly going from cold liquid to hot air and the actual stresses then will be less than half of those (*) in Table V. A calculated first order estimate of h for liquid nitrogen[17] showed it to be greater than for the fluorocarbon cold fluid. The soak time in air was increased to ten minutes to attain steady state hot conditions; comparing thermal time constants and noting the furnace thermocouple response indicated they were attained. Thus, the hot-to-cold transient stresses are approximately correct.

Kokini[10] had assumed 5000 psi for the glass interface radial tensile (failure) strength. Typical "practical" strengths of glass are from 1,000 to 15,000 psi, the range being markedly affected by the surface condition of the glass.[18] Pin pull tests showed 5000 to 6000 psi failure stresses, but these are not directly comparable to the calculated thermal shock stresses. Pin pull testing creates shear stresses at the pin-glass interface whereas thermal shocking generates tensile and compressive stresses. Approximating the principle stress as twice the measured (shear) stress yields pin-glass failure stresses of 10,000 to 12,000 psi. As the glass-metal seal interface can be considered a relatively defect-free surface (i.e., not abraded or exposed to the atmosphere), the 13,000 to 14,000 psi stresses seen in our thermal shock tests seem reasonable. Using 5000 psi as a failure criterion may underestimate seal reliability.

The primary benefit of performing pin pull tests is that they delineate differences in pin-glass interfacial strength which thermal shock and hermeticity tests do not "see." For example, all fourteen pins of SN 52 and 192 headers were pull-tested. These results, displayed as probabil-ity plots in Figure 9, showed SN 52 (A) strengths were normally-distributed (except for the 5422 psi outlier) and SN 192 (B) strengths bimodally-distributed. The lowest pin-glass

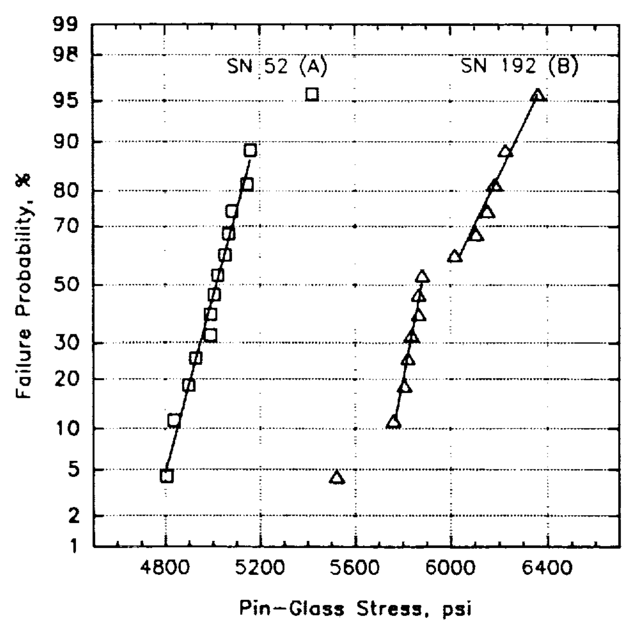


Figure 9. Probability plots of pin-to-glass failure stresses for two headers.

strength for SN 192 (5522 psi) corresponded to the pin which had failed hermeticity after thermal shock #55; it probably had been weakened since its strength was substantially less than the "lower" SN 192 distribution. (The fundamental strenght difference between groups A and B will be discussed later.)

Our non-destructivity evaluation (Table IV) yielded no hermetic failures for 1330 seals tested at Condition *C* for 90 thermal shocks. Only five seal failures were induced by thermal shock step stressing, at 415 and 515 °C ΔTs, and these were not statistically significant. One hundred ninety six seals withstood thermal shock stresses approximately 2.5 times those of Condition *C*. Furthermore, pin pull tests showed no significant differences in interfacial strengths between seals thermal-shocked and not thermal-shocked (Tables III and A-XI). Thus we conclude that thermal shock testing is not destructive to well-manufactured glass-to-metal seal headers and that the test can be used to "screen" poorly manufactured headers and packages. For seal geometries different from the coaxial configuration used here and for materials other than Fe-Ni-Co alloy and borosilicate glass, it would be prudent to evaluate[10,11] whether a proposed thermal shock will provide sufficient stresses to screen out marginal packages.

Visual examinations for seal cracks are not likely to yield accurate screens. The cracks illustrated in Figures 5 and 6 (thermal shock failures) are indistinguishable from those in Figure 7 (passed after retesting). Similar seal cracks were noted on several other headers which had passed thermal shock and hermeticity tests. Meniscus cracks, which usually result from handling damage, are allowable defects.[19] True meniscus cracks are confined to a plane perpendicular to the pin and thus do not penetrate down into the seal. However, a crack may appear as a meniscus crack, propagate into the glass and cause a hermetic failure.

Though not a primary objective of the study, group A and B headers were compared. Group A headers showed less variance in their initial (test #0) helium leak rates (Figure 2), pin-glass failure stresses and residual oxide depths (Figure 8 and Table A-VIII). These were caused by the different manufacturing techniques. Previous work [13] had shown that pin pull strengths are related to residual oxide depths; usually more oxide penetration (depth) yields greater strenghts because a greater degree of chemical bonding has occurred at the glass-metal interface. Group A clearly had greater and less variable oxide depths than Group B, yet the Group B strengths were 20% greater. Since the pin-glass strengths were the same for control and thermal-shocked samples, all data for each group were combined and graphed as probability plots, Figure 10. (Figure A-9 is a frequency distribution of the same data.) Except for the lower "tail"and the one upper outlier, Group A data fit a linear regression, exemplifying its normal distibution. The steep slope indicates its narrow distribution; with two data points

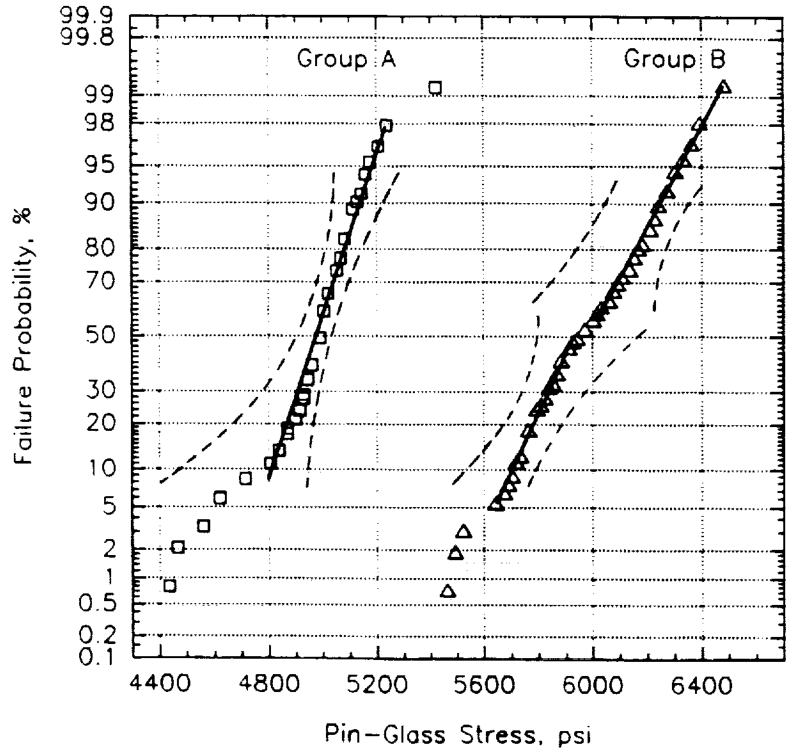
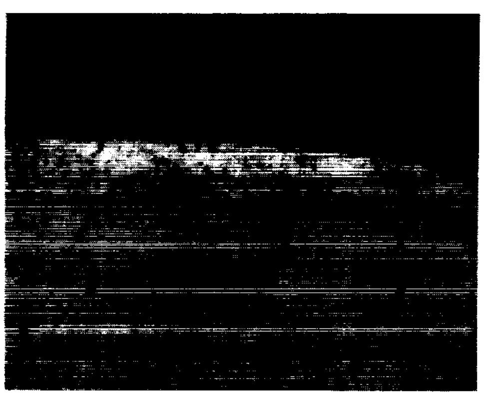
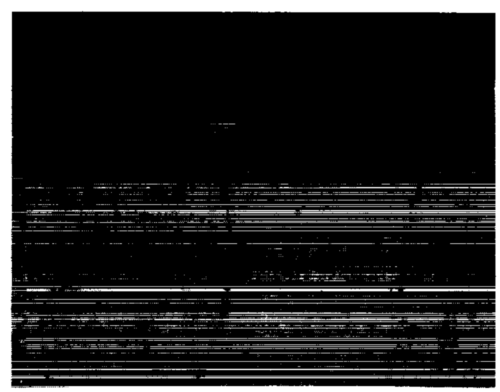


Figure 10. Probability plots of pin-glass strengths for all headers in each group.



Group A



Group B

Figure 11. Metallographic details of pin-glass interfaces; 1000X, reflected light.

removed using Chauvenet's criterion, the standard deviation was 144 psi (coefficient of variation 3.1%). Group B headers showed a bimodal distibution, as was seen for SN 192 in Figure 9, and their slopes were less than for A. The standard devation for B strengths was 220 psi (coefficent of variation 3.7%); Chauvenet's criterion showed all data to be within its distibution. An F-test (at 95% confidence) showed the A and B variances to be significantly different. The dashed lines in Figure 10 are regression fits for the maximum ranges among individual pin pull strengths for each group; B's wide range confirms the significant between-header variance detected in the analysis of variance. The "wide" distribution of B strengths follows from its wide residual oxide depth distribution. The reason why B headers had stronger pin-glass interfaces is shown in Figure 11. B headers were manufactured with pins which had been etched heavily. This chemical etching creates a mechanically rough surface which "locks" the glass onto the pin and effectively increases the pin surface area; a greater force is required to fracture the interface and pull the pin from the glass. However, the "points" on these rough surfaces may act as stress concentrators, causing premature fracture when compared to the morphology seen for Group A pins.

This example also points out why pin pull testing yields only comparative results. When pin tests are performed using statistically sufficient sample sizes and on seals for which all processing conditions are constant except those under study, relatively minor process differences can be detected. Tests on less-closely-controlled seals can yield valid comparisons; however, additional analyses may be required to ascertain any strength differences seen.

Our original intent had been to establish a ΔT_c behavior , i.e., a decrease in thermal stress resistance like that in Figure 1, and then use step stressing to compare reliabilities of other glass-sealed packages. We did not succeed in identifying a ΔT_c behavior using these 14-pin DIP headers. In retrospect, selecting 14-pin DIP headers for this this study may have been the "worst" choice because this package is very mature in its development and its geometry results in relatively minor thermal shock stresses. On the other hand, our results demonstrated its high reliability. It is known that packages in different configurations and produced by different manufacturers exhibit different reliabilities, e.g., reference [20]. Rectangular-leaded "flat packs," for example, most likely would show poorer thermal stress resistance because of the sharp lead corners (stress concentrators) and smaller glass seal volume. Step stressing may reveal this reliability difference if a ΔT_c behavior is seen. Pin pull testing also could compare any seal interface strength variances, but it will not indicate thermal stress resistance differences.

CONCLUSIONS

Thermal shock testing is not destructive to highly reliable (i.e., well-manufactured) glass-to-metal seal microelectronic headers and packages. No failures occurred in 1330 seals thermal-shocked for 90 cycles using Condition *C* ($\Delta T = 215\ ^{o}C$). Evaluations showed no significant differences in hermeticity and pin-glass seal strength between thermal-shocked and not-thermal-shocked samples. Thus thermal shocking can be used to screen marginal packages without degrading the reliability of good packages.

Visual inspections using the "appearance" of cracks to sort or screen for thermal shock failures are not likely to yield a useful sorting. Identically-appearing cracks were seen for both thermal shock failures and passes.

"Critical stress resistance temperature" (ΔT_c) behavior was not produced in the 14-pin DIP headers tested. Step stressing at ΔTs up to 646 °C caused only five failures in 198 seals tested, and these were not statistically significant for the sample sizes used. Maximum thermal shock stresses were computed to be as great as 13,000 to 14,000 psi for a 596 °C ΔT, and these approximately corresponded to the pin-glass pull (shear) stresses. Other package configurations or geometries and poorly-manufactured packages may exhibit a ΔT_c behavior in step stress tests, from which more definitive reliability comparisons could be made.

Pin pull tests are useful for supplementing thermal shock and other package evaluations. They indicate the relative interfacial bond strength between the pin and glass. However, the results are only comparative, since unknown or uncontrolled process variation may cause pin-glass strength variances.

The hermeticity test used for this study (Method 1014-A4) gave mean leak rates of 1.7 to 15.0 $\times 10^{-10}$ atm-cc/sec on the control headers. Using a "wand" to spray helium tracer gas during testing caused helium to accumulate in the test room; this suggests using a cup to contain the helium around the header being tested. Using a bake-out after thermal shocking and before leak testing increased the test sensitivity up to 70%.

Comparisons between the two groups of headers (A was manufactured in cryogenic-nitrogen-based atmospheres and B in exothermic atmospheres) showed significant differences. Group A had a lower mean pin-glass failure stress and a greater mean oxide depth than Group B; A had narrower distributions (less variance) for the initial measured leak rate, pin-glass strength and residual oxide depth. B headers exhibited significant between-header variances in pin-pull failure stresses; these were bimodally-distributed and were related to the wider distribution of residual oxide depths. The greater pin-glass strength of B was caused by chemical etching which roughened the pin surfaces.

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APPENDICES

TABLE A-I

Initial Helium Leak Rate Measurements
Group A

SN	Leak Rate atm-cc/sec	SN	Leak Rate atm-cc/sec	SN	Leak Rate atm-cc/sec
0	1.65E-10	34	4.05E-09	67	3.95E-09
1	6.95E-10	35	4.45E-09	68	3.20E-09
2	1.68E-09	36	4.35E-09	69	4.20E-09
3	2.45E-09	37	4.30E-09	70	2.75E-09
4	2.28E-09	38	4.20E-09	71	3.25E-09
5	3.20E-09	39	4.00E-09	72	2.65E-09
6	4.60E-10	40	4.75E-09	73	2.68E-09
7	1.20E-09	41	4.60E-09	74	1.55E-09
8	1.62E-09	42	4.40E-09	75	3.55E-09
9	2.18E-09	43	4.65E-09	76	2.15E-09
10	2.20E-09	44	5.00E-09	77	2.55E-09
11	3.55E-09	45	4.90E-09	78	1.78E-09
12	2.72E-09	46	4.70E-09	79	2.62E-09
13	2.60E-09	47	4.65E-09	80	2.80E-09
14	2.65E-09	48	4.35E-09	81	3.45E-09
15	2.75E-09	49	3.90E-09	82	4.00E-09
16	2.75E-09	50	3.60E-09	83	2.02E-09
17	6.65E-09	51	7.50E-10	84	1.98E-09
18	5.15E-09	52	1.20E-09	85	1.68E-09
19	2.22E-09	53	1.38E-09	86	2.40E-09
20	3.15E-09	54	2.25E-09	87	1.62E-09
21	3.00E-09	55	3.15E-09	88	1.22E-09
22	3.50E-09	56	2.20E-09	89	3.05E-09
23	3.55E-09	57	3.50E-09	90	5.20E-09
24	3.50E-09	58	3.45E-09	91	4.20E-09
25	3.55E-09	59	2.20E-09	92	3.35E-09
26	4.15E-09	60	2.45E-09	93	2.15E-09
27	4.25E-09	61	2.28E-09	94	2.28E-09
28	4.70E-09	62	2.45E-09	95	4.45E-09
29	4.90E-09	63	3.25E-09	96	2.62E-09
30	3.90E-09	64	2.60E-09	97	2.72E-09
31	3.80E-09	65	3.70E-09	98	3.20E-09
32	3.95E-09	66	4.30E-09	99	2.32E-09
33	4.15E-09				

TABLE A-II

Initial Helium Leak Rate Measurements
Group B

SN	Leak Rate atm-cc/sec	SN	Leak Rate atm-cc/sec	SN	Leak Rate atm-cc/sec	SN	Leak Rate atm-cc/sec
100	1.82E-09	132	4.70E-09	163	5.55E-09	194	5.10E-10
101	3.15E-10	133	6.30E-09	164	3.55E-09	195	6.85E-10
102	3.50E-10	134	3.25E-09	165	3.00E-09	196	1.05E-09
103	8.60E-10	135	5.30E-09	166	5.30E-09	197	9.05E-10
104	1.68E-09	136	5.75E-09	167	2.55E-09	198	1.65E-09
105	4.05E-09	137	5.40E-09	168	2.68E-09	199	1.45E-09
106	3.50E-09	138	5.85E-09	169	3.20E-09	200	2.52E-09
107	4.55E-09	139	3.55E-09	170	2.85E-09	201	2.98E-09
108	3.60E-09	140	5.50E-09	171	3.45E-09	202	2.35E-09
109	4.30E-09	141	4.50E-09	172	5.00E-09	203	4.10E-09
110	3.65E-09	142	3.25E-09	173	4.05E-09	204	4.00E-09
111	4.30E-09	143	5.55E-09	174	3.40E-09	205	2.48E-09
112	5.10E-09	144	3.50E-09	175	2.58E-09	206	1.48E-09
113	6.30E-09	145	3.55E-10	176	2.75E-09	207	1.42E-09
114	6.35E-09	146	3.70E-09	177	2.62E-09	208	1.75E-09
115	8.30E-09	147	4.10E-09	178	2.50E-09	209	1.95E-09
116	7.90E-09	148	3.50E-09	179	3.10E-09	210	1.85E-09
117	7.60E-09	149	3.35E-09	180	1.58E-09	211	1.82E-09
118	7.40E-09	150	4.05E-09	181	1.82E-09	212	2.08E-09
119	6.55E-09	151	5.75E-09	182	2.28E-09	213	5.35E-10
120	4.55E-09	152	4.95E-09	183	3.45E-09	214	6.15E-10
121	3.30E-09	153	5.65E-09	184	1.48E-09	215	6.25E-10
122	3.60E-09	154	4.95E-09	185	1.85E-09	216	6.40E-10
123	5.00E-09	155	5.60E-09	186	2.08E-09	217	1.02E-10
124	5.50E-09	156	4.50E-09	187	2.30E-09	218	8.05E-10
125	4.90E-09	157	5.40E-09	188	3.15E-09	219	1.08E-09
126	3.80E-09	158	4.45E-09	189	1.58E-09	220	1.18E-09
127	5.60E-09	159	4.50E-09	190	2.22E-09	221	1.42E-09
128	3.75E-09	160	4.15E-09	191	4.00E-11	222	1.08E-09
129	2.85E-09	161	3.25E-09	192	2.15E-10	223	1.35E-09
130	4.45E-09	162	4.40E-09	193	4.10E-10	224	4.10E-09
131	7.00E-09						

TABLE A-III

Control Sample Measurements
Group A

LEAK RATE (R1), atm-cc/sec

Test Number	Test [1] Conditions	"BEFORE" 0	6	17	90	"AFTER" 0	6	17	90
0	Initial	1.65E-10	4.60E-10	6.65E-09	5.20E-09	-	-	-	-
1	-65/150 1X	-	-	-	-	-	-	-	-
2	-65/150 5X	6.90E-10	7.75E-10	3.20E-10	7.90E-10	1.02E-09	4.25E-10	1.40E-09	9.40E-10
3	-65/150 10X	1.60E-10	5.90E-10	1.60E-10	6.95E-10	7.80E-10	6.30E-10	7.45E-10	6.50E-10
4	-65/150 15X	3.50E-11	7.00E-10	3.20E-10	1.05E-09	1.02E-09	7.70E-10	6.75E-10	8.00E-10
5	-65/200 1X	6.20E-10	1.08E-09	9.60E-10	1.18E-09	2.18E-09	2.28E-09	2.15E-09	2.05E-09
6	-65/200 5X	7.00E-11	1.12E-09	1.75E-10	1.18E-09	1.42E-09	9.15E-10	1.18E-09	9.35E-10
7	-65/200 15X	2.25E-10	6.10E-10	3.95E-10	6.50E-10	6.40E-10	9.20E-10	1.02E-09	1.02E-09
8	-65/350 1X	1.85E-10	3.60E-10	1.15E-10	4.45E-10	1.35E-09	1.18E-09	9.25E-10	9.50E-10
9	Add Bake	9.50E-11	1.15E-10	7.00E-11	1.35E-10	1.42E-09	7.25E-10	1.78E-09	8.15E-10
10	-65/350 5X	1.00E-10	3.50E-10	1.70E-10	5.10E-10	8.45E-10	8.75E-10	8.50E-10	1.05E-09
11	-65/350 15X	2.50E-10	2.25E-10	2.75E-10	2.45E-10	2.55E-09	1.98E-09	1.82E-09	1.55E-09
12	(Retest)	-	-	-	-	-	-	-	-
13	-65/450 1X	3.65E-10	2.08E-09	7.80E-10	1.45E-09	2.00E-11	5.25E-10	1.20E-10	6.65E-10
14	-65/450 5X	-	-	2.50E-09	-	-	-	-	-
15	-65/450 15X	2.10E-10	4.25E-10	2.80E-10	7.05E-10	1.42E-09	2.12E-09	1.28E-09	1.82E-09
16	-195/400 1X	2.20E-10	4.70E-10	1.05E-09	5.40E-10	2.70E-09	2.00E-09	3.30E-09	2.00E-09
17	-195/400 5X	1.15E-10	1.05E-10	4.15E-10	1.38E-10	-	-	-	-
18	-195/400 15X	7.00E-11	1.45E-10	3.50E-10	3.50E-10	3.45E-09	-	3.60E-09	
19	-195/450 1X	3.50E-11	4.45E-09	9.50E-10	3.35E-09	-	-	-	-
20	-195/450 5X	3.15E-10	2.92E-09	1.85E-09	1.12E-09	-	-	-	-
21	-195/450 15X	3.05E-10	-	2.45E-09	-	5.10E-09	-	5.05E-09	-

[1] Refers to corresponding thermal shock test; control samples were not shocked.

TABLE A-IV

Control Sample Measurements
Group B

LEAK RATE (R1), atm-cc/sec

Test Number	Test [1] Conditions	"BEFORE" 115	116	191	217	"AFTER" 115	116	191	217
0	Initial	8.30E-09	7.90E-09	4.00E-11	1.02E-10	-	-	-	-
1	-65/150 1X	-	-	-	-	-	-	-	-
2	-65/150 5X	6.15E-10	9.50E-10	8.85E-10	1.32E-09	9.05E-10	6.10E-10	8.90E-10	6.70E-10
3	-65/150 10X	4.75E-10	8.55E-10	6.25E-10	9.95E-10	8.25E-10	8.45E-10	9.80E-10	1.55E-09
4	-65/150 15X	3.95E-10	1.12E-09	8.35E-10	1.28E-09	6.55E-10	7.25E-10	7.10E-10	7.30E-10
5	-65/200 1X	1.05E-09	1.42E-09	1.20E-09	1.75E-09	1.98E-09	2.08E-09	2.80E-09	2.52E-09
6	-65/200 5X	4.10E-10	1.82E-09	9.20E-10	2.98E-09	1.12E-09	1.02E-09	1.38E-09	1.32E-09
7	-65/200 15X	3.65E-10	8.20E-10	4.25E-10	1.05E-09	1.15E-09	1.28E-09	1.72E-09	1.62E-09
8	-65/350 1X	2.15E-10	6.10E-10	4.05E-10	1.12E-09	1.18E-09	9.15E-10	9.65E-10	9.20E-10
9	Add Bake	1.05E-10	2.35E-10	2.60E-10	5.20E-10	1.35E-09	6.20E-10	1.18E-09	1.15E-09
10	-65/350 5X	3.85E-10	6.00E-10	4.30E-10	5.75E-10	9.40E-10	1.15E-09	1.15E-09	1.38E-09
11	-65/350 15X	2.45E-10	4.45E-10	2.25E-10	5.80E-10	1.68E-09	1.78E-09	2.32E-09	2.72E-09
12	(Retest)								
13	-65/450 1X	1.12E-09	1.95E-09	1.22E-09	8.45E-10	2.60E-10	6.00E-10	5.80E-10	6.25E-10
14	-65/450 5X	-	5.00E-09	-	-	-	-		
15	-65/450 15X	3.50E-10	7.85E-10	6.80E-10	1.18E-09	1.32E-09	1.68E-09	1.72E-09	1.62E-09
16	-195/400 1X	7.50E-10	4.50E-10	5.60E-10	5.80E-10	2.45E-09	2.20E-09	7.00E-10	3.40E-09
17	-195/400 5X	9.80E-10	2.62E-09	7.75E-10	2.25E-09	-	-	-	-
18	-195/400 15X	1.65E-09	8.00E-10	3.05E-09	1.05E-09	2.75E-09	-	2.35E-09	-
19	-195/450 1X	2.55E-09	3.35E-09	1.78E-09	4.83E-09	4.90E-09	-	4.55E-09	-
20	-195/450 5X	4.55E-10	1.90E-09	8.40E-10	4.00E-09	-	-	-	-
21	-195/450 15X	2.85E-09	-	2.35E-09	-	5.35E-09	-	3.60E-09	-

[1] - Refers to corresponding thermal shock test;
control samples not shocked.

TABLE A-V

Bake-out Effect on Helium Leak Tests

Test Number	SN	Mean Leak Rate, x10^-10 atm-cc/sec.						
		01	07	18	29	44	51	52
6,7,8		33.5	21.7	16.4	17.3	12.5	15.0	14.3
9,10,11		9.7	10.7	10.3	8.9	9.1	3.9	4.7
% Change		-71.0	-50.8	-37.5	-48.8	-27.1	-74.2	-67.4
		101	102	117	118	131	145	192
6,7,8		14.2	18.7	13.8	15.0	18.8	10.7	11.5
9,10,11		4.9	8.0	9.2	10.5	12.6	9.9*	24.7
% Change		-65.6	-57.3	-33.2	-30.3	-33.0	-8.1	114.5#

* SN 145 failed during #11; only #9 and #10 used to compute average.

Value ignored; latent defect which eventually failed at test #15.

TABLE A-VI

Leak Measurements After Thermal Shock
Group A

Test Number	Test Conditions		Cumul # T/S	LEAK RATE (R1), atm-cc/sec 1	7	18	29	44	51	52
0		Initial	0	6.95E-10	1.20E-09	5.15E-09	4.90E-09	5.00E-09	7.50E-09	1.20E-09
1	-65/150	After 1X	1	4.45E-10	3.55E-10	3.35E-10	4.25E-10	5.75E-10	7.65E-10	1.12E-09
2		4X more	5	1.58E-09	1.62E-09	1.08E-09	2.50E-10	7.75E-10	5.90E-10	6.10E-10
3		5X more	10	7.90E-10	9.80E-10	1.02E-09	1.10E-09	1.22E-09	1.05E-09	1.02E-09
4		5X more	15	7.00E-10	1.40E-09	1.25E-09	1.28E-09	1.28E-09	1.65E-09	1.32E-09
5	-65/200	After 1X	16	1.82E-09	2.22E-09	1.78E-09	1.52E-09	1.58E-09	1.52E-09	1.85E-09
6		4X more	20	7.88E-09	4.00E-09	2.82E-09	2.38E-09	2.32E-09	2.02E-09	1.82E-09
7		10X more	30	1.15E-09	1.35E-09	1.05E-09	1.45E-09	3.50E-10	1.42E-09	1.08E-09
8	-65/350	After 1X	31	1.02E-09	1.15E-09	1.05E-09	1.35E-09	1.08E-09	1.05E-09	1.38E-09
9		Add Bake	31	6.65E-10	7.55E-10	7.25E-10	7.70E-10	6.60E-10	7.25E-10	6.80E-10
10		4X more	35	5.70E-10	4.65E-10	2.70E-10	2.65E-10	4.95E-10	2.70E-10	2.05E-10
11		10X more	45	1.68E-09	1.98E-09	2.08E-09	1.62E-09	1.58E-09	1.65E-10	5.10E-10
12		Retest	45	2.00E-11	9.35E-10	1.02E-09	1.78E-09	1.68E-09	2.28E-09	7.25E-10
13	-65/450	After 1X	46	5.00E-09	7.10E-09	3.05E-09	1.82E-09	1.98E-09	2.48E-09	2.15E-09
14		4X more	50	7.50E-11	6.30E-10	6.45E-10	5.85E-10	1.62E-09	4.70E-09	3.10E-09
15		10X more	60	1.42E-09	3.60E-09	1.45E-09	2.25E-09	1.55E-09	1.65E-09	1.78E-08*
16	-195/400	After 1X	61	1.35E-10	1.65E-10	1.60E-09	1.50E-09	3.60E-09	1.40E-09	3.50E-11
17		4X more	65	1.22E-09	1.35E-09	4.30E-09	2.82E-09	1.45E-09	2.52E-09	2.35E-09
18		10X more	75	6.75E-10	6.55E-10	1.15E-09	1.72E-09	1.25E-09	9.30E-10	1.62E-09
19	-195/450	After 1X	76	4.35E-09	4.55E-09	4.25E-09	4.40E-09	3.95E-09	4.60E-09	3.65E-09
20		4X more	80	2.60E-10	4.50E-10	1.80E-10	4.60E-10	3.70E-10	2.25E-09	3.30E-09
21		10X more	90	2.18E-09	4.55E-09	3.35E-09	3.90E-09	3.55E-09	3.25E-09	3.20E-09

* SN 52 retested; R1 = 2.92E-09 atm-cc/sec.

TABLE A-VII

Leak Measurements After Thermal Shock
Group B

Test Number	Test Conditions		Cumul # T/S	LEAK RATE (R1), atm-cc/sec 101	102	117	118	131	145	192
0		Initial	0	3.15E-10	3.50E-10	7.60E-09	7.40E-09	7.00E-09	3.55E-10	2.15E-10
1	-65/150	After 1X	1	1.25E-09	2.02E-09	1.78E-09	1.85E-09	2.80E-09	1.98E-09	2.05E-09
2		4X more	5	6.60E-10	9.60E-10	4.55E-10	1.32E-09	7.30E-10	7.90E-10	8.40E-10
3		5X more	10	1.08E-09	1.62E-09	9.10E-10	1.28E-09	1.12E-09	8.25E-10	8.45E-10
4		5X more	15	1.02E-09	1.52E-09	1.32E-09	1.45E-09	1.48E-09	1.05E-09	8.55E-10
5	-65/200	After 1X	16	2.22E-09	1.52E-09	1.30E-09	1.40E-09	1.30E-09	2.60E-09	2.18E-09
6		4X more	20	1.72E-09	2.52E-09	1.58E-09	1.58E-09	1.75E-09	1.18E-09	1.15E-09
7		10X more	30	1.12E-09	1.65E-09	1.38E-09	1.68E-09	2.45E-09	9.15E-10	9.80E-10
8	-65/350	After 1X	31	1.42E-09	1.45E-09	1.18E-09	1.25E-09	1.45E-09	1.12E-09	1.32E-09
9		Add bake	31	1.02E-09	1.75E-09	2.08E-09	2.05E-09	1.12E-09	5.90E-10	3.25E-09
10		4X more	35	1.25E-10	1.10E-10	6.00E-11	1.40E-10	1.68E-09	1.38E-09	1.30E-09
11		10X more	45	3.20E-10	5.40E-10	6.25E-10	9.55E-10	9.85E-10	1.28E-08	2.85E-09
12		Retest	45	1.65E-09	1.52E-09	2.02E-09	2.65E-09	2.62E-09	FAIL	1.68E-09
13	-65/450	After 1X	46	3.70E-09	2.72E-09	2.05E-09	2.48E-09	2.32E-09		2.68E-09
14		4X more	50	3.90E-09	3.60E-09	1.28E-09	4.15E-09	3.30E-09		2.58E-09
15		10X more	60	3.50E-09	2.05E-09	1.82E-09	1.85E-09	2.80E-09		1.75E-05 FAIL
16	-195/400	After 1X	61	2.00E-10	4.85E-10	7.00E-10	1.80E-09	1.90E-09		
17		4X more	65	9.20E-10	1.22E-09	3.30E-09	6.15E-09	4.80E-09		
18		10X more	75	3.15E-09	1.20E-09	1.09E-09	7.60E-10	1.02E-09		
19	-195/450	After 1X	76	4.05E-09	3.90E-09	3.55E-09	4.70E-09	4.15E-09		
20		4X more	80	6.65E-09	6.45E-09	3.73E-09	2.85E-09	6.51E-09		
21		10X more	90	3.15E-09	4.55E-09	3.45E-09	2.28E-09	3.50E-09		

Replacements:

Test Number	Test Conditions		Cumul # T/S = 193	194	LEAK RATE 193	194
0		Initial	0	0	4.10E-10	5.10E-10
13	-65/450	After 1X	1	-		
14		4X more	5	-	3.00E-09	-
15		10X more	15	-	5.10E-09	-
					1.62E-09	-
16	-195/400	After 1X	16	1		
17		4X more	20	5	1.90E-09	1.50E-09
18		10X more	30	15	3.50E-09	3.90E-09
					3.55E-09	2.89E-09
19	-195/450	After 1X	31	16		
20		4X more	35	20	4.35E-09	3.80E-09
21		10X more	45	30	4.55E-09	2.65E-09

TABLE A-VIII

Pin Residual Oxide Depth Measurements

OXIDE DEPTHS - microns (µ)

SN	0	6	17	90	1	7	44	51	101	115	116	117	131	145	191	192	217	
Pin # 2	8.0	7.6	8.0	7.6	8.0	8.0	8.0	7.2	10.4	4.0	4.0	4.8	7.2	6.4	5.6	8.0	2.4	
	7.6	8.0	8.4	7.2	8.0	8.8	8.0	8.0	5.6	4.8	3.2	4.8	8.8	5.6	3.2	4.8	5.6	
4	8.4	8.0	8.0	7.6	8.0	8.8	8.0	8.0	5.6	4.8	7.2	7.2	4.8	4.8	3.2	4.8	5.6	
	8.0	8.4	8.0	8.0	8.8	8.0	7.2	7.2	8.8	4.0	4.8	8.0	4.0	4.0	4.8	4.0	3.6	
6	8.0	8.0	8.0	8.0	8.0	7.2	8.0	8.0	8.8	3.2	4.0	5.6	4.8	7.2	5.6	3.2	5.6	
	7.6	8.0	8.0	7.2	8.0	7.2	8.0	8.0	4.8	2.4	5.6	4.8	8.0	4.0	4.0	2.4	6.4	
9	8.0	8.0	9.6	8.0	8.0	8.0	8.0	8.8	6.4	2.4	3.2	4.0	4.8	4.8	5.6	3.2	2.4	
	7.2	8.8	8.0	8.0	8.0	8.0	8.0	8.0	3.2	7.2	4.0	5.6	4.8	4.8	3.2	4.0	4.8	
11	7.2	8.8	8.0	7.2	8.8	8.0	7.2	8.8	7.2	8.0	4.8	10.4	2.4	2.4	7.2	5.6	3.2	
	8.0	8.0	7.2	7.2	7.2	7.6	7.2	8.0	6.4	4.8	4.0	4.8	5.6	4.8	4.0	4.0	5.6	
13	7.2	8.0	8.0	8.0	8.0	8.0	8.8	8.0	4.8	4.0	1.6	3.6	5.6	5.6	4.8	4.0	6.4	
	7.2	7.2	8.0	7.2	7.2	8.0	8.0	7.2	8.8	4.8	1.6	4.8	4.0	3.2	3.2	3.2	5.6	
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	
n =	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
x =	7.7	8.1	8.1	7.6	8.0	8.0	7.9	7.9	6.7	4.5	4.0	5.7	5.4	4.8	4.5	4.3	4.8	µ
s =	0.42	0.45	0.54	0.38	0.48	0.50	0.46	0.53	2.12	1.68	1.56	1.93	1.81	1.32	1.29	1.46	1.47	µ
min =	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	3.2	2.4	1.6	3.6	2.4	2.4	3.2	2.4	2.4	µ
max =	8.4	8.8	9.6	8.0	8.8	8.8	8.8	8.8	10.4	8.0	7.2	10.4	8.8	7.2	7.2	8.0	6.4	µ
CV =	5.5	5.5	6.7	5.0	6.0	6.2	5.9	6.7	31.4	37.1	39.1	33.9	33.5	27.5	28.5	34.2	30.8	%

TABLE A-IX
Measured Pin-Glass Failure Loads

Failure Load, lbs.

CONTROL SAMPLES	SN	GROUP A				GROUP B			
		0	6	17	90	115	116	191	217
Pin#	1	16.40	16.80	14.80	16.20	19.55	19.55	19.50	19.60
	3	15.00	16.00	16.70	16.20	18.90	20.70	19.20	19.90
	5	14.80	16.40	15.60	16.50	20.00	20.10	19.20	19.00
	7	15.70	16.10	16.20	15.60	20.30	20.90	19.20	19.40
	8	15.90	16.60	16.10	14.40	20.20	21.30	20.20	20.20
	10	16.00	15.80	16.10	16.05	20.25	18.80	18.95	19.75
	12	16.20	16.00	16.05	16.50	20.00	20.80	19.05	19.30
	14	16.20	16.30	14.50	16.25	19.70	20.35	18.30	19.80

THERMAL -SHOCK SAMPLES	SN	1	7	44	51	52	101	117	131	145	192	194
Pin#	1	16.30	16.90	16.50	15.80	16.70	20.50	19.90	19.20	-	19.55	19.60
	3	17.00	16.10	15.80	16.20	16.25	20.60	20.75	19.40	20.30	20.05	19.00
	5	16.20	15.30	16.30	16.25	15.90	21.00	20.45	19.50	19.10	20.60	-
	7	16.50	16.50	15.90	16.00	16.75	19.70	21.60	20.90	19.10	19.45	20.20
	8	16.25	15.00	16.20	16.30	16.45	20.90	21.10	20.45	18.40	19.55	19.70
	10	16.25	16.65	16.00	16.10	15.70	18.20	20.70	20.55	19.20	20.50	19.90
	12	16.10	16.50	15.95	16.05	16.50	20.70	20.30	20.05	19.80	21.20	20.00
	14	16.30	16.40	16.40	16.40	16.40	20.50	19.20	19.60	19.40	19.20	19.20
	2					17.60					19.60	
	4					16.00					20.35	
	6					16.30					19.40	
	9					16.20					20.75	
	11					15.60					18.40	
	13					16.20					19.35	

TABLE A-X
Pin-Glass Failure Stresses

Failure Stress, psi

CONTROL SAMPLES	SN	GROUP A				GROUP B				
		0	6	17	90	115	116	191	217	
Pin#	1	5053	5176	4560	4991	5867	5867	5852	5882	
	3	4621	4929	5145	4991	5672	6212	5762	5972	
	5	4560	5053	4806	5083	6002	6032	5762	5702	
	7	4837	4960	4991	4806	6092	6272	5762	5822	
	8	4899	5114	4960	4436	6062	6392	6062	6062	
	10	4929	4868	4960	4945	6077	5642	5687	5927	
	12	4991	4929	4945	5083	6002	6242	5717	5792	
	14	4991	5022	4467	5006	5912	6107	5492	5942	
		----	----	----	----	----	----	----	----	
	X-bar =	4860	5006	4854	4918	5961	6096	5762	5888	psi
	s =	167.9	97.4	215.9	199.5	131.8	228.2	149.5	106.1	psi
	CV =	3.5	1.9	4.4	4.1	2.2	3.7	2.6	1.8	%

THERMAL -SHOCK SAMPLES	SN	1	7	44	51	52	101	117	131	145	192	194	
Pin#	1	5022	5207	5083	4868	5145	6152	5972	5762	-	5867	5882	
	3	5237	4960	4868	4991	5006	6182	6227	5822	6092	6017	5702	
	5	4991	4714	5022	5006	4899	6302	6137	5852	5732	6182	-	
	7	5083	5083	4899	4929	5160	5912	6482	6272	5732	5837	6062	
	8	5006	4621	4991	5022	5068	6272	6332	6137	5522	5867	5912	
	10	5006	5130	4929	4960	4837	5462	6212	6167	5762	6152	5972	
	12	4960	5083	4914	4945	5083	6212	6092	6017	5942	6362	6002	
	14	5022	5053	5053	5053	5053	6152	5762	5882	5822	5762	5762	
	2					5422					5882		
	4					4929					6107		
	6					5022					5822		
	9					4991					6227		
	11					4806					5522		
	13					4991					5807		
		----	----	----	----	----	----	----	----	----	----	----	
	X-bar =	5041	4981	4970	4972	5029	6081	6152	5989	5801	6006	5899	psi
	s =	81.1	193.8	73.4	54.9	148.2	258.6	205.9	174.7	166.5	195.6	119.9	psi
	CV =	1.6	3.9	1.5	1.1	2.9	4.3	3.3	2.9	2.9	3.3	2.0	%

TABLE A-XI

Analysis of Variance Tables for Pin-Glass Failure Stresses

Control vs. Thermal-shocked: Group A

Source	Sum Squares	df	Mean Square	F	E.M.S.	C.Var
Treatment	65,600.0	1	65,600.00	3.443	$32\phi_T + 8s_H^2 + s_E^2$	6.1%
Header w/in Treat.	114,329.0	6	19,054.83	0.852	$8s_H^2 + s_E^2$	0
Error (w/in Header)	1,252,638.0	56	22,368.54		s_E^2	93.9
Total	1,432,567.0	63				100.0

Control vs. Thermal-shocked: Group B

Source	Sum Squares	df	Mean Square	F	E.M.S.	C.Var
Treatment	103,684.0	1	103,684.00	0.619	$32\phi_T + 8s_H^2 + s_E^2$	0 %
Header w/in Treat.	1,004,273.2	6	167,378.87	5.721****	$8s_H^2 + s_E^2$	37.1
Error (w/in Header)	1,638,391.8	56	29,257.00		s_E^2	62.9
Total	2,746,348.9	63				100.0

Controls: Group A vs Group B

Source	Sum Squares	df	Mean Square	F	E.M.S.	C.Var
Treatment	16,542,874.0	1	16,542,874.00	166.26****	$32\phi_T + 8s_H^2 + s_E^2$	92.7%
Header w/in Treat.	596,992.0	6	99,498.67	3.074**	$8s_H^2 + s_E^2$	1.5
Error (w/in Header)	1,812,506.0	56	32,366.18		s_E^2	5.8
Total	18,952,372.0	63				100.0

Thermal-shocked: Group A vs Group B

Source	Sum Squares	df	Mean Square	F	E.M.S.	C.Var
Treatment	20,330,270.0	1	20,330,270.00	288.06****	$40\phi_T + 8s_H^2 + s_E^2$	93.5%
Header w/in Treat.	564,614.0	8	70,576.75	2.316*	$8s_H^2 + s_E^2$	0.9
Error (w/in Header)	2,133,136.0	70	30,473.37		s_E^2	5.6
Total	23,028,020.0	79				100.0

* - Significant at 95%.
** - Significant at 97.5%.
*** - Significant at 99.0%.
**** - Significant at >99.5%.

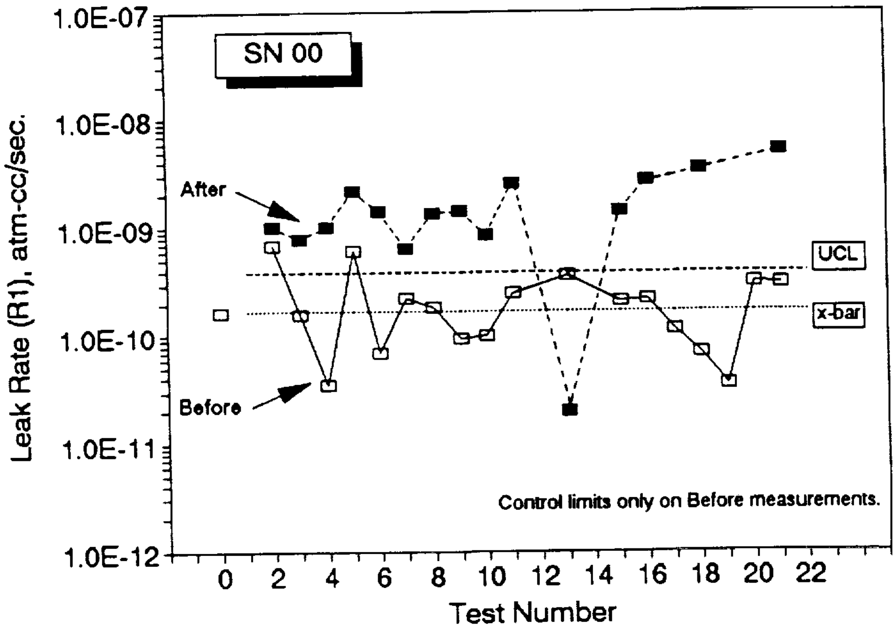

Figure A-1. Control sample helium leak measurements, SN 00.

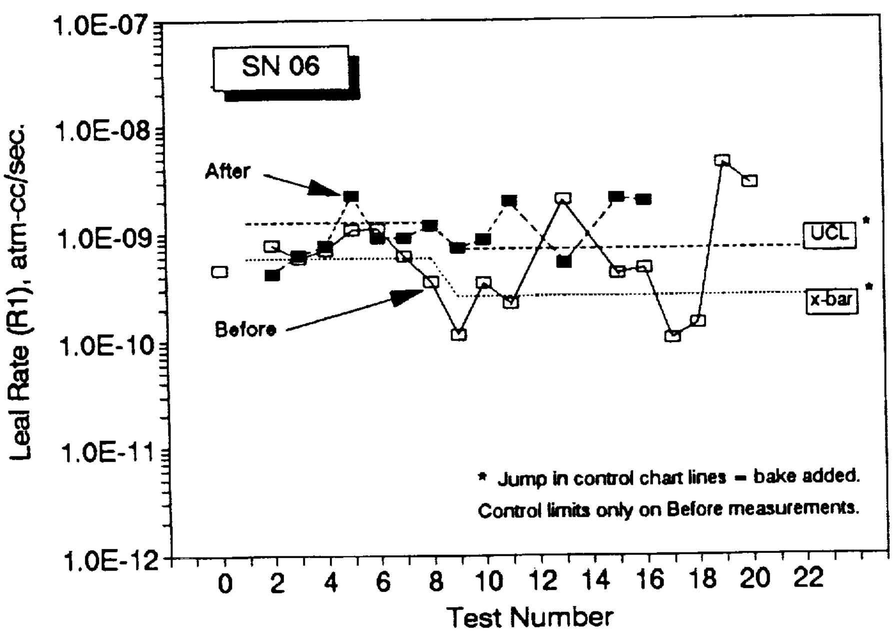

Figure A-2. Control sample helium leak measurements, SN 06.

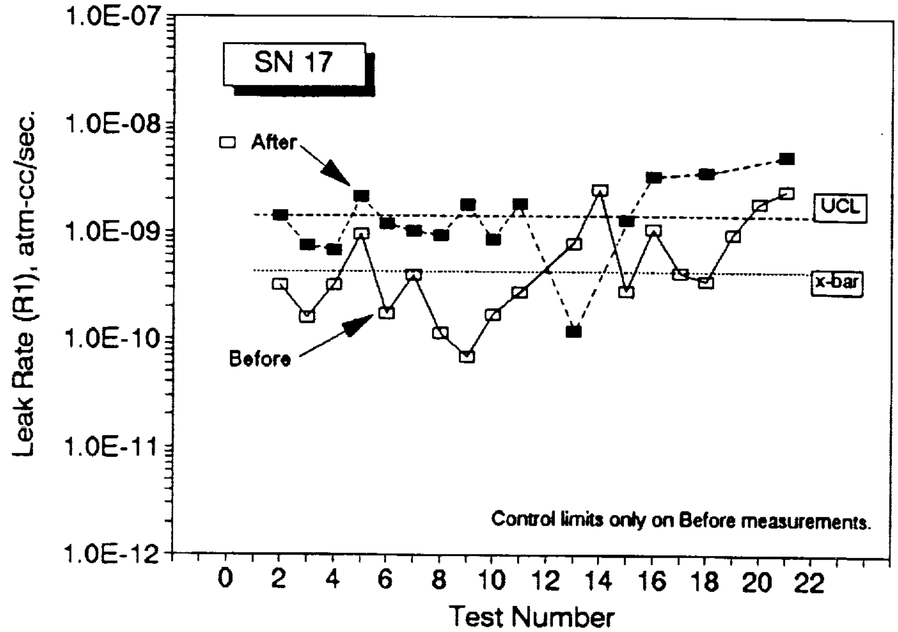

Figure A-3. Control sample helium leak measurements, SN 17.

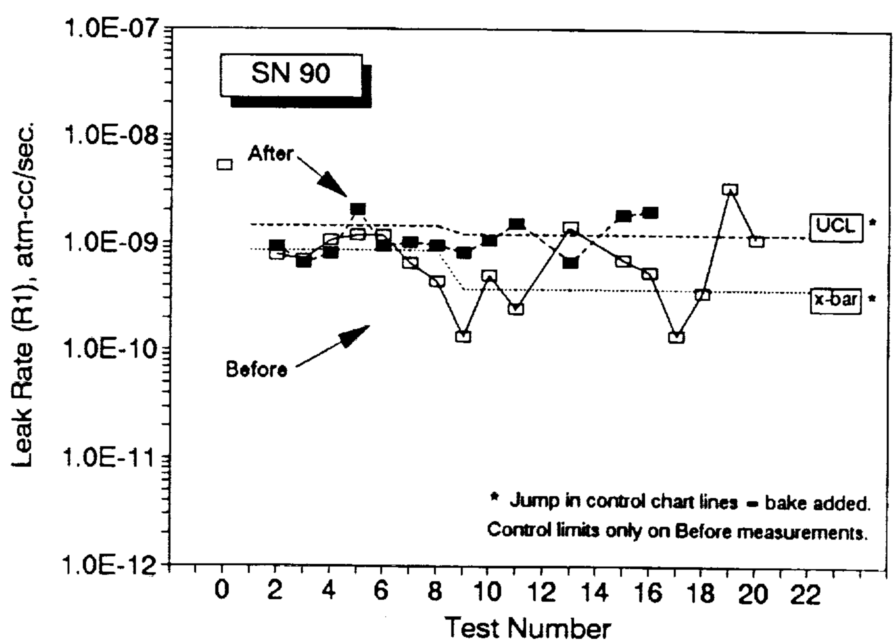

Figure A-4. Control sample helium leak measurements, SN 90.

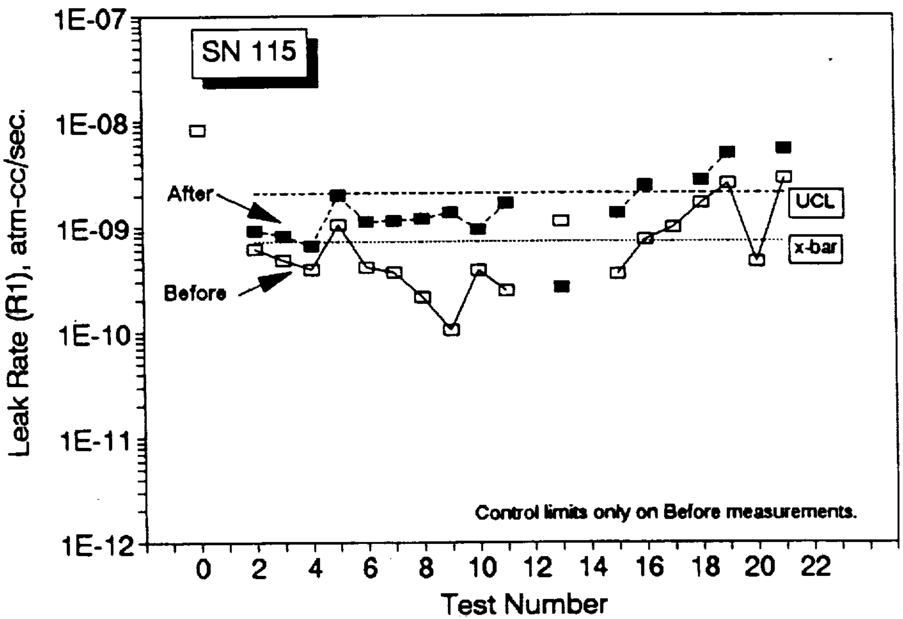

Figure A-5. Control sample helium leak measurements, SN 115.

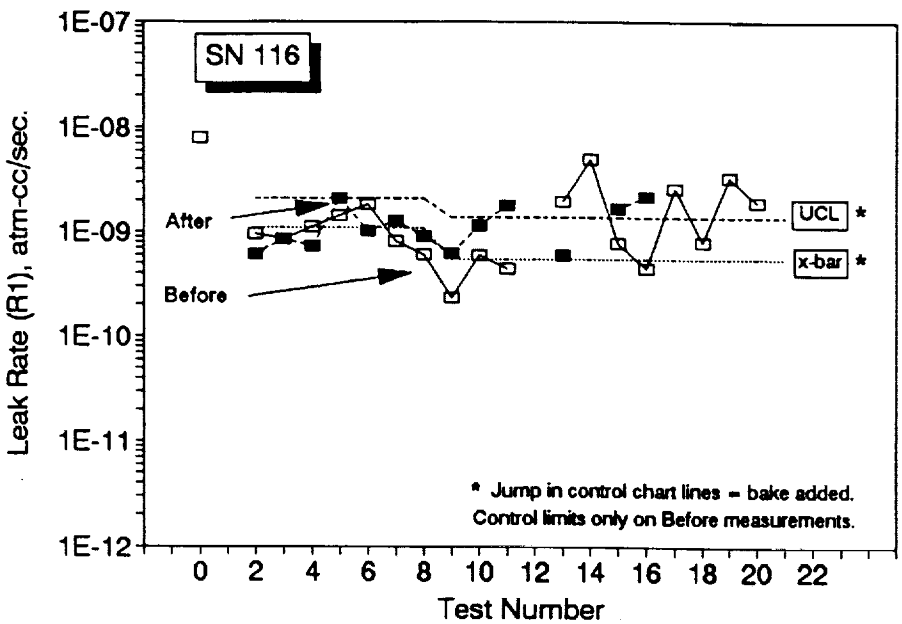

Figure A-6. Control sample helium leak measurements, SN 116.

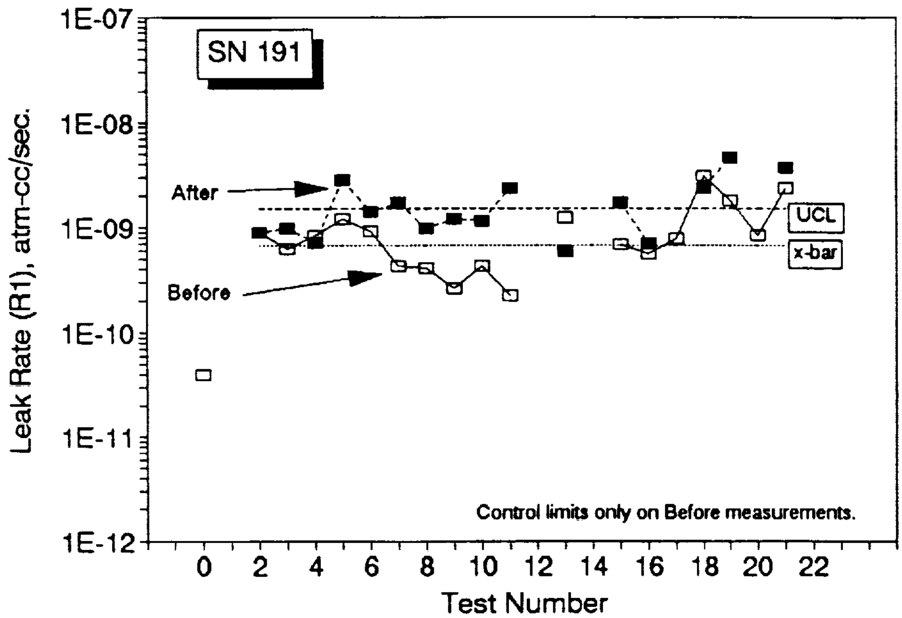

Figure A-7. Control sample helium leak measurements, SN 191.

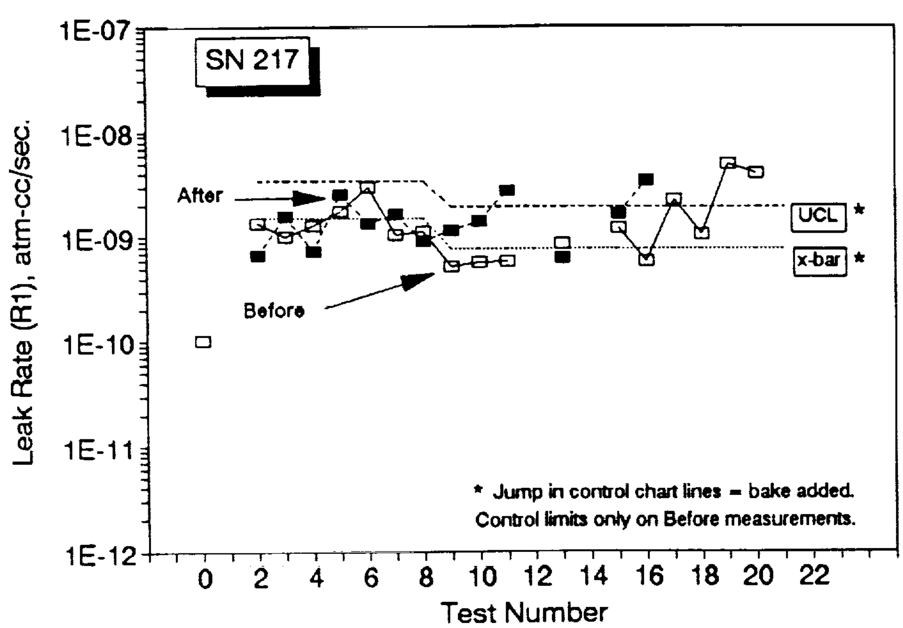

Figure A-8. Control sample helium leak measurements, SN 217.

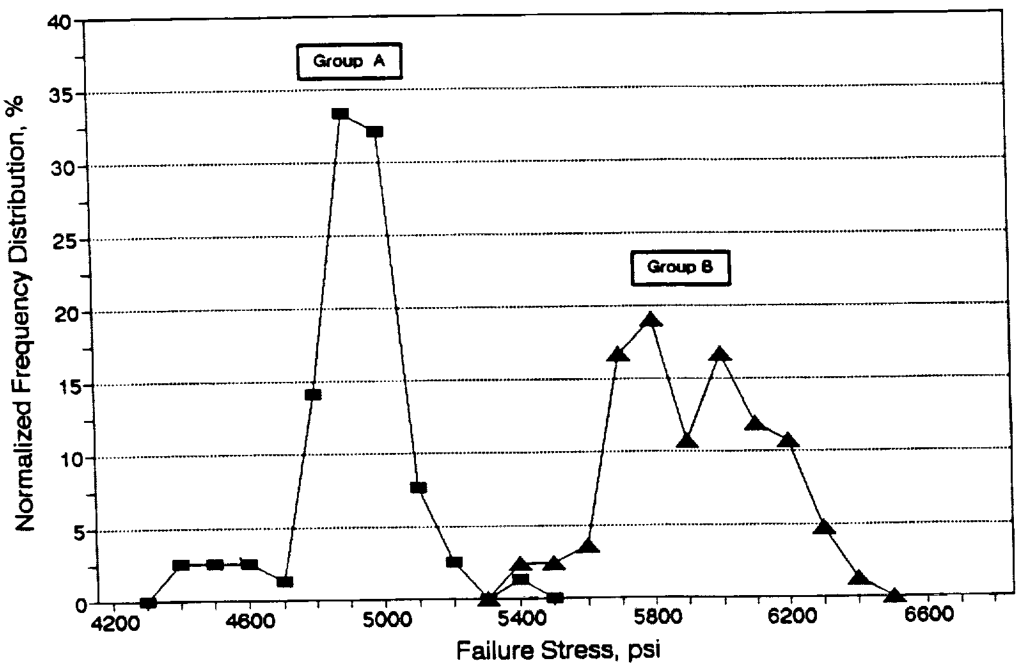

Figure A-9. Pin-glass failure stress distributions.

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16. Abstract

Tests were performed to determine if thermal shocking (Method 1011, MIL-STD-883) is destructive to glass-to-metal-seal microelectronic packages and if thermal shock step stressing can compare package reliabilities. Thermal shocking was shown to be not destructive to highly reliable glass seals. Pin-pull tests used to compare the interfacial pin-glass strengths showed no differences between thermal-shocked and not-thermal-shocked headers. A "critical stress resistance temperature" was not exhibited by the 14-pin DIP headers evaluated. Headers manufactured in cryogenic-nitrogen-based and exothermically-generated atmospheres showed differences in as-received leak rates, residual oxide depths and pin-glass interfacial strengths; these were caused by the different manufacturing methods, in particular, by the chemically etched pins used by one manufacturer. Both header types passed thermal shock tests to temperature differentials of 646°C. The sensitivity of helium leak rate measurements was improved up to 70% by baking headers for two hours at 200°C after thermal shocking.

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