THE DEVELOPMENT AND QUALIFICATION OF AN IMPROVED GLASS SEALING SYSTEM FOR KOVAR HYBRID PACKAGES

by

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Abstract

Existing matched sealing glass formulations were found to be inadequate for meeting military quality requirements. The paper outlines the deficiencies of present 7052-based conventional sealing glass compositions, primarily in the areas of radial and meniscus crack resistance. Based on an actual case study, a mechanical model for the generation of radial and meniscus cracks is developed. The paper then goes on to discuss the development and qualification testing of an improved nonproprietary glass system that solves the cracking problem and is readily adaptable to existing glass sealing processes.

Keywords

Aluminum oxide, cracks, glasses, glass-to-metal seals, Kovar™, MIL-M-38534, MIL-STD-883, MIL-STD-1772, packaging, sealing.

Introduction

Many high-reliability hybrid microcircuit contracts require that final external visual inspection of the packaged circuits be performed in accordance with MIL-STD-883C, Method 2009.8. Attempts by the hybrid industry to fully enforce these inspection criteria have generally resulted in unacceptable final visual inspection (FVI) yields for the product. The problem is that when the inspection is performed using high-intensity lighting at the maximum specified magnification, small radial cracks are commonly detected in some of the glass-to-metal package seals. The majority of such cracks violate the requirements of Method 2009.8.

The presence of such cracks in the glass seals of microcircuit packages is not a recent discovery. The phenomenon has been studied by Honeywell, and other companies, for many years. The results of these studies have generally indicated that, so long as the packaged part met the contractual hermeticity requirements, visual defects of this type in the glass seals did not represent a significant product reliability threat. Many manufacturers, including Honeywell, have in place internal FVI specifications that allow such glass defects. At least in the case of Honeywell, products produced using these amended requirements have had an excellent field reliability record.

With the advent of MIL-STD-1772 line certification requirements for hybrid manufacturers, waivers to baseline military inspection requirements are increasingly difficult to obtain. Recent, new contracts being accepted by Honeywell do not allow exceptions to the MIL-STD-883C, Method 2009 requirements. Customers want full compliance to contractually committed military specifications. Unfortunately, the enforcement of a specification does nothing to alter the continued reality of the problem. Cracking in sealing glass on microelectronic packages continues to be an endemic problem for the entire electronics industry[1,2].

Every major hybrid manufacturer we have contacted has privately admitted to producing product that does not meet the Method 2009 requirements. Most of these companies regard the problem as not solvable using the commonly specified sealing glasses and have either obtained waivers, resorted to interpretation of the magnification and lighting conditions so as to not see the cracks, and/or instituted costly and questionable repair procedures. Many of these same companies have commented that if they were to use the lighting and magnification conditions presently being enforced by Honeywell for FVI, they would ship no product. Indeed the military and JEDEC inspection requirements go to great lengths to describe acceptable cracks, whose shapes and location are such that it appears quite unlikely that they will ever propagate through the seal. These specifications were developed of necessity in order to be able to build hardware[1].

Though much field reliability data supports the use of helium leak rates as an arbitrator of seal quality, no rational argument can be made that radial, or other cracks in the hermetic sealing glass, are a good thing. The balance of this report details the steps taken to understand the crack producing mechanism and develop and qualify an improved glass sealing system that allows true compliance to the specification requirements.

Background

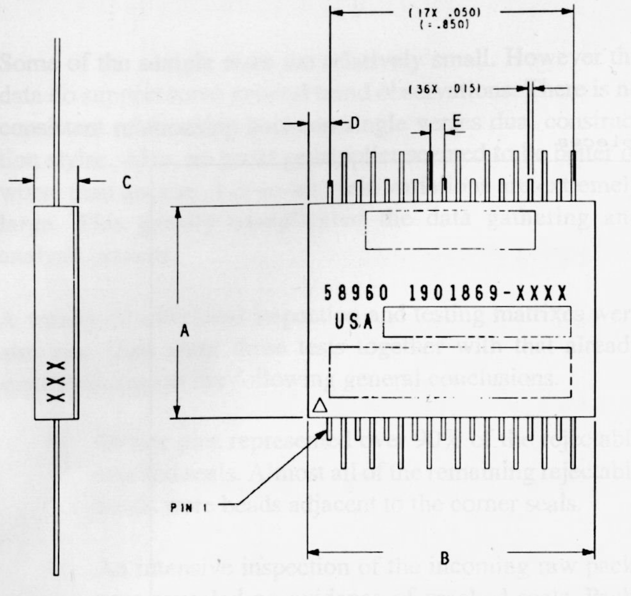
In order to solve this problem, it was necessary to first develop a rational mechanical model for the cracking mechanism. This was important not only for addressing the potential solution, but also in assessing whether already effected product posed a reliability risk.

Four configurations of a single style package were evaluated (Figure 1). The package styles were all flat packs. Body material was Fe/Ni/Co (Kovar), and the sealing glass was Corning 7052 (or equivalent) matched-glass. The configurations ranged in size from 1.27 x 2.54 in^2 (0.5 x 1.0 in^2) to 3 x 3 cm^2 (1.18 x 1.18 in^2)[3].

Nominal glass seal diameter is 1.016-mm (0.040-in) for all configurations. Two manufacturing styles are in use for these packages. Single-piece, where the case body is stamped as a single-extrusion, and two-piece, where a rectangular ring frame is brazed to a flat base. (Figure 2)

Both styles of packages were evaluated. Several different package suppliers were also involved in the various evaluations. These package outlines are very common configurations and have been in volume production at Honeywell for many years.

A major point requiring clarification is the specific nature of the defect under investigation. There have been many different interpretations of what constitutes a crack in sealing glass. The cracking phenomenon observed here is visible only under high magnification (10x and above) and with intense incident lighting. It is manifest by the appearance of a single,



DIM.	PACKAGE CONFIGURATIONS			
	-1	-2	-3	-4
A	0.500	0.750	1.00	1.18
B	1.00	1.00	1.00	1.18
C	0.170	0.170	0.170	0.170
D	0.075	0.075	0.075	0.115
E	0.050	0.050	0.050	0.050
Leads	36	36	36	40

Figure 1. Package configurations.

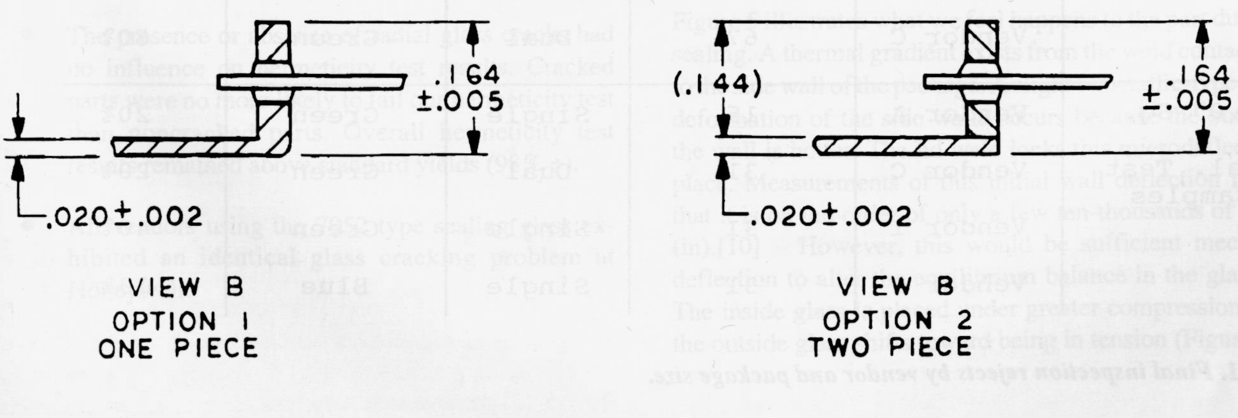


Figure 2. Glass metal seals.

or occasionally double, radial crack. These cracks originate at or very near the corners of the rectangular lead and propagate toward the case. Excluded from this study are meniscus chip-outs and seal damage resulting from obvious mishandling of the parts. The military external visual inspection requirements defining rejectable cracks are somewhat vague. Method 2009 allows a wide magnification range for glass seal inspection, 1.5 to 10x[4]. The specification also requires that the inspection equipment have a field of view sufficiently large to contain the entire device[5]. This proviso generally leads most hybrid manufacturers to employ a large 1.5x magnifying glass for external visual inspection. Inspected in this manner, the radial cracks discussed here would not be visible.

Even using the best microscopes and lighting conditions, a considerable amount of training was required for our QC inspectors to be able to consistently identify the defect. This uncertainty in inspection at first greatly complicated the task of isolating the problem. We were able to ameliorate this only by restricting inspection to a few specially trained individuals. In addition, all inspections involving sequential engineering evaluations were done by the same inspector.

Even after limiting the interpretive variability, large lot-to-lot reject rates were still observed. However, as can be seen in Figure 3, based on a large sample population, a definite package size trend emerges. As will be discussed shortly, this trend observation formed the basis for developing a hypothetical mechanical model for the cracking phenomenon.

We also looked at the relationship of package supplier and package design style. The following table shows some early data from an actual hybrid program grouped by package size and vendor. Also included is some additional inspection data derived from earlier package supplier qualification tests. Suppliers A,B, and C, were qualified suppliers, while data for suppliers 1 and 2 were derived from qualification package lots (Table 1).

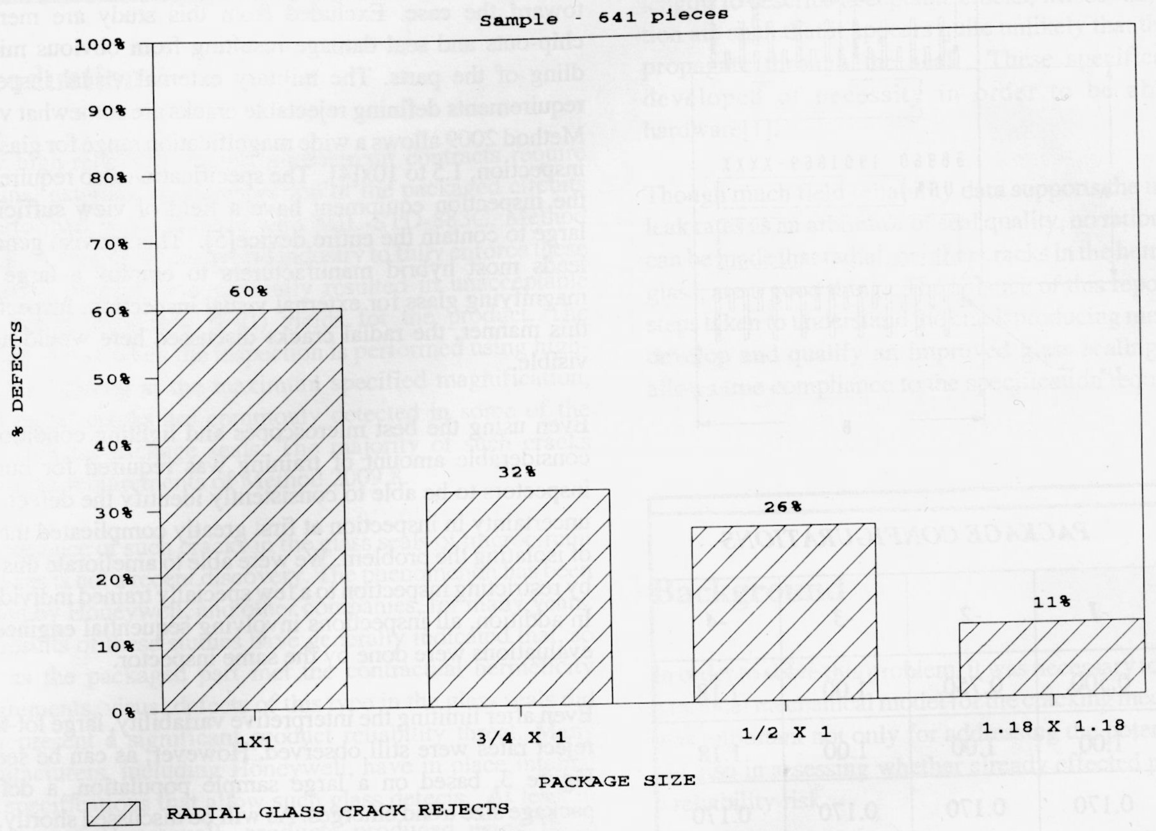


Figure 3. EMDM reject rate at final inspection.

Package size	Vendor	Sample size	Type	Bead Color	% Reject
1/2" x 1.0"	Vendor A	18	Single	Green	6%
	Vendor B	131	Single	Green	49%
3/4" x 1.0"	Vendor B	53	Single	Green	55%
1.0" Sq.	Vendor A	209	Single	Green	66%
	Vendor B	100	Dual	Green	19%
	Vendor C	67	Dual	Green	60%
1.0" Sq.	Vendor A	15	Single	Green	20%
Qual. Test Samples	Vendor C	31	Dual	Green	20%
	Vendor 1	31	Single	Green	40%
	Vendor 2	31	Single	Blue	13%

Table 1. Final inspection rejects by vendor and package size.

Some of the sample sizes are relatively small. However the data do support some general trend observations. There is no consistent relationship between single verses dual construction styles. Also, no package supplier seemed to be better or worse than another. Lot-to-lot yield variations are extremely large. This greatly complicated the data gathering and analysis process.

A variety of additional inspection and testing matrixes were also run. Data from these tests together with that already presented support the following general conclusions.

- Corner pins represented over 90% of the rejectable cracked seals. Almost all of the remaining rejectable beads were beads adjacent to the corner seals.
- An intensive inspection of the incoming raw packages revealed no evidence of cracked seals. Packages were not being received with cracked seals.
- No seal cracking was observed after assembly operations prior to lid attach (seam seal).
- Some cracks were seen immediately after the lid seal operation. However, their occurrence rate was far less than observed in the same product lots by the time they had reached final inspection.
- Crack occurrence was slowly cumulative through each subsequent assembly operation after seal. We were not able to isolate a single responsible process step.
- Processing operations which caused the flexing of the lid resulted in the largest increase in cracks.
- Handling damage was not related to the formation of radial cracks. Mishandling of the parts caused meniscus chip-outs and other damage but could not be made to induce the type of radial cracks being observed.
- The presence or absence of radial glass cracks had no influence on hermeticity test results. Cracked parts were no more likely to fail our hermeticity test than noncracked parts. Overall hermeticity test results remained above standard yields (98% +).
- All vendors using the 7052 type sealing glass exhibited an identical glass cracking problem at Honeywell.

The general direction of the qualitative information collected thus far strongly suggested that the cracking problem was the result of a combination of the mechanical design of the packages, the tensile strength/fracture resistance of the glass, and the manufacturing and testing stresses applied to the hybrid during its assembly. In the next section, a hypothetical mechanical model is developed and tested to explain the observed behavior of the cracking parts.

Mechanical Model

Microdeflection Model

The glass seal under discussion is a matched-type seal. The case body material is ASTM F-15-78 alloy, 29% nickel, 17% cobalt, balance iron and trace elements (Kovar). The sealing glass is a hard borosilicate glass with structural properties similar to Corning 7052[6]. These materials are used because of their closely matched coefficients of thermal expansion. In the manufacture of this type of seal, the metal components must be carefully preoxidized prior to the melting of the glass. This ensures that the glass forms a strong mechanical bond to the metal surfaces. A critical amount of residual intergranular oxide at the metal-to-glass interfaces must exist in order to have a strong and hermetic bond between the glass and metal[6]. The matched-type seal is characterized by a glass that is not only chemically bonded to the metal but also in a state of slight compression with it.

Figure 4 shows what we believe to be a reasonable mechanical model for a matched seal in an equilibrium state. Compressive forces are equally balanced along the cross section between the glass and metal. The glass is strongly bonded to the lead and case metal by the presence of a thin oxide boundary layer between the glass and metal[7].

Figure 5 illustrates what we feel happens to the part during lid sealing. A thermal gradient exists from the weld contact point to the side wall of the package. A slight bimetallic-type inward deformation of the side walls occurs because the outside of the wall is hotter. The lid weld locks this microdeflection in place. Measurements of this initial wall deflection indicate that it is on the order of only a few ten-thousands of an mm (in).[10] However, this would be sufficient mechanical deflection to alter the equilibrium balance in the glass seal. The inside glass is placed under greater compression, while the outside glass shifts toward being in tension (Figure 6).

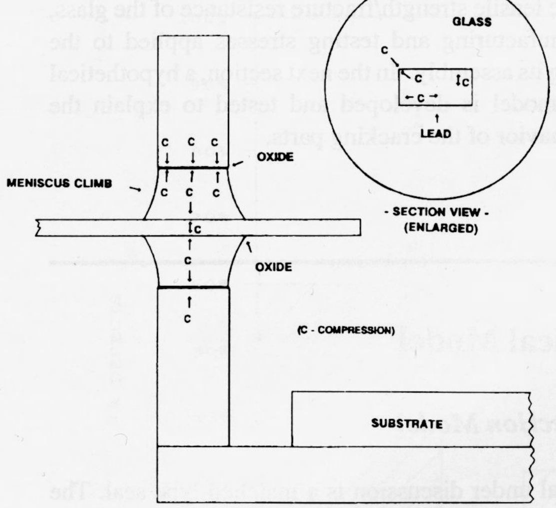


Figure 4. Normal match seal at equilibrium.

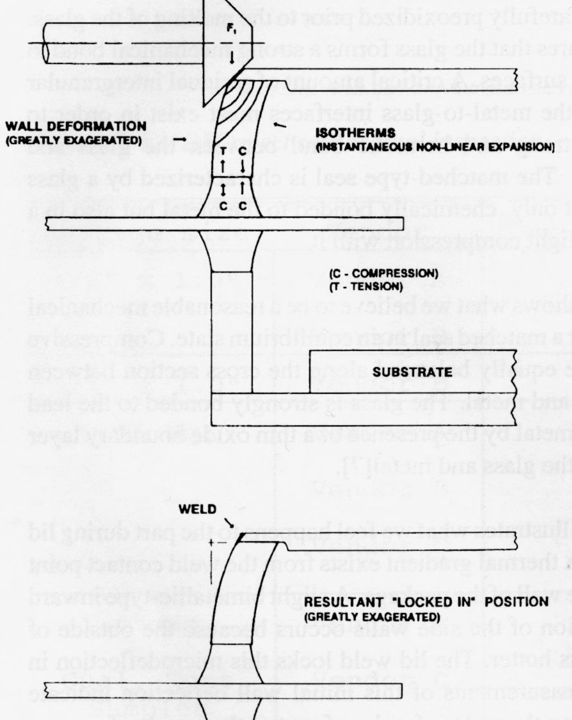


Figure 5. Lid seal microdeflection model.

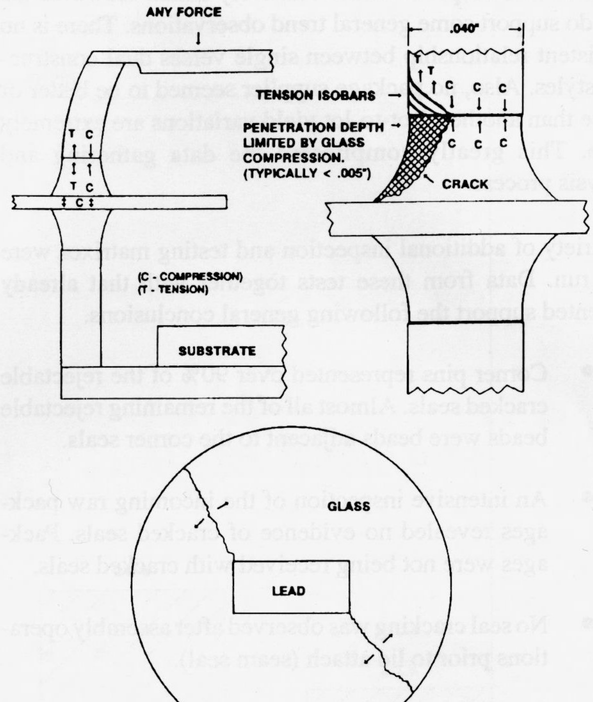


Figure 6. Mechanical deflection of the glass seal.

Glasses are generally much stronger under compression than when in tension. The exterior glass surface, being under a tensile stress, would now be prone to stress relief cracking. The cracks could appear immediately after the sealing operation or after any operation that produces further deflection of the package side walls resulting in the tensile load limit of the glass being exceeded. Since the interior glass structure in this model is being put under increasing compression, stress-relieving cracks that propagate from the outside should be self-limiting as to depth of penetration into the glass. With this model, exterior seals could crack, maintain hermeticity, and not propagate further after the initial tensile stress is relieved.

Experimental Procedure

The data presented in Figure 3 show that the 2.54 x 2.54 cm^2 (1.0 x 1.0 in^2) package by far exhibits the highest crack formation rate. Accordingly, this part was selected to test the crack formation hypothesis. Two test groups of 30 pieces each were assembled. Group A were empty packages with no substrates attached. Group B had substrates with Au/Ge solder attached into the packages per our normal assembly process. The two groups were further divided;that is, half of each group (S/N:1-15) were vendor A samples consisting of single-piece constructed packages, and the remaining half (S/N:16-30) were vendor B samples consisting of two-piece constructed packages. Test Matrix 1, shown in Figure 7, was developed to reflect every process step which we believed might contribute to the generation of cracks. A 40x optical inspection was performed on the glass after each operation. In order to minimize inspection uncertainty, the same person performed all inspections. The location and size of any observed cracks were recorded on an individual part basis. All parts were run through all of the assembly operations and tested at precisely the same time. Both groups were inspected carefully immediately before sealing to ensure that no prior cracks were present. None was observed.

Results and Discussion

Figure 8 shows the observed crack formation rate for Group B - Au/Ge-attached substrates.

The lower hatched bars are radial glass cracks which extended more than 50% from the lead to the case. The upper bars are all other cracks regardless of their severity. The rejectable crack occurrence rate is clearly cumulative through the processing flow. The expected operations (seal, centrifuge, and the fine and gross leak pressure bombing) all increased the number of cracks. Almost all of the packages in the sample exhibited the beginnings of minute cracks, which in many cases could be seen to grow into rejectable cracks as processing continued. Ninety-three percent of the rejectable radial cracks occurred in one or more of the four corner pins of the package. These are the same type of results seen in actual production product.

Figure 9 shows the crack formation (actually nonformation) rate for Group A, empty packages.

No radial cracks were seen in this group. In addition, meniscus chip-outs and other glass damage related defects were essentially absent.

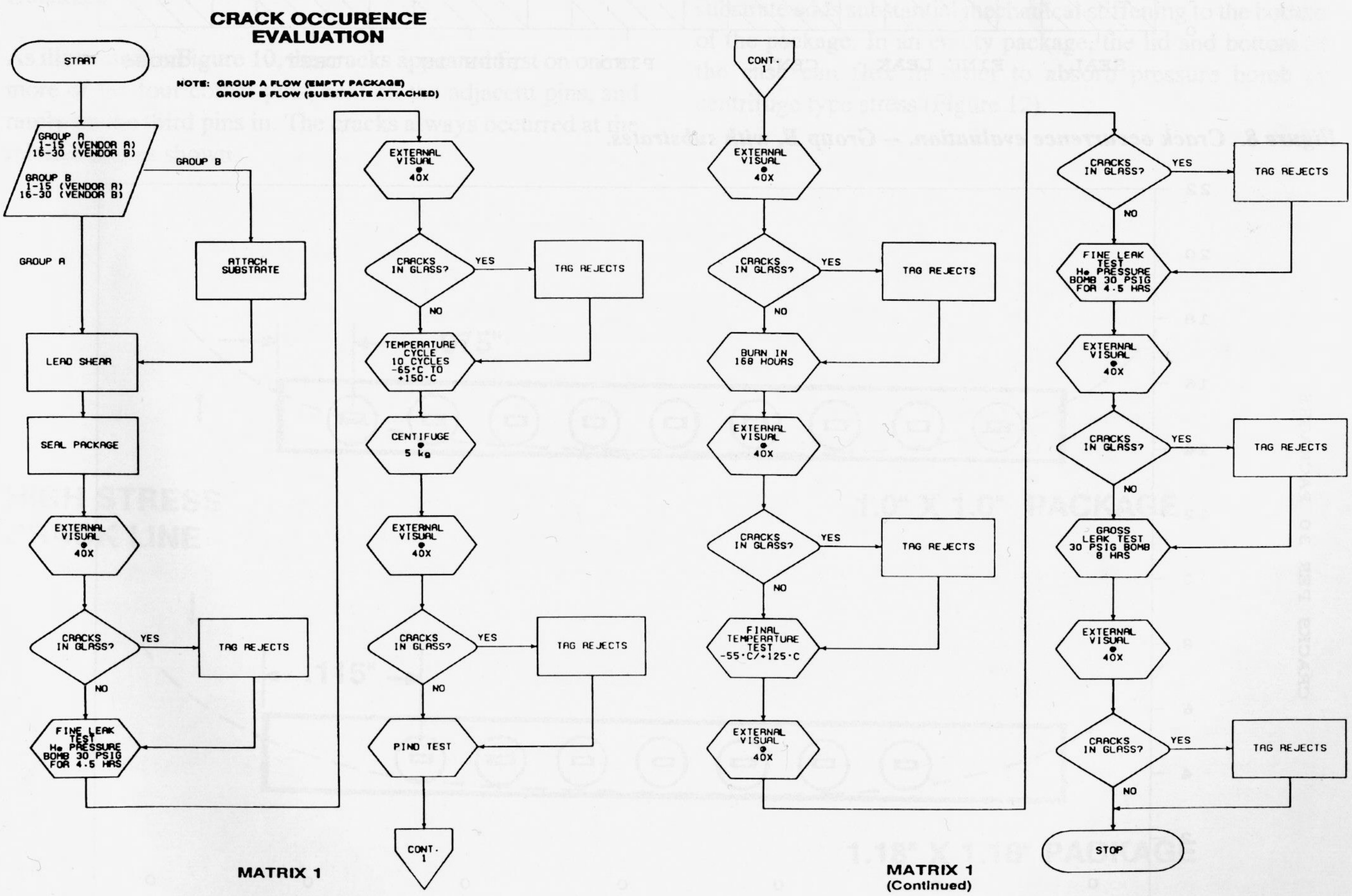


Figure 7. Test matrix 1.

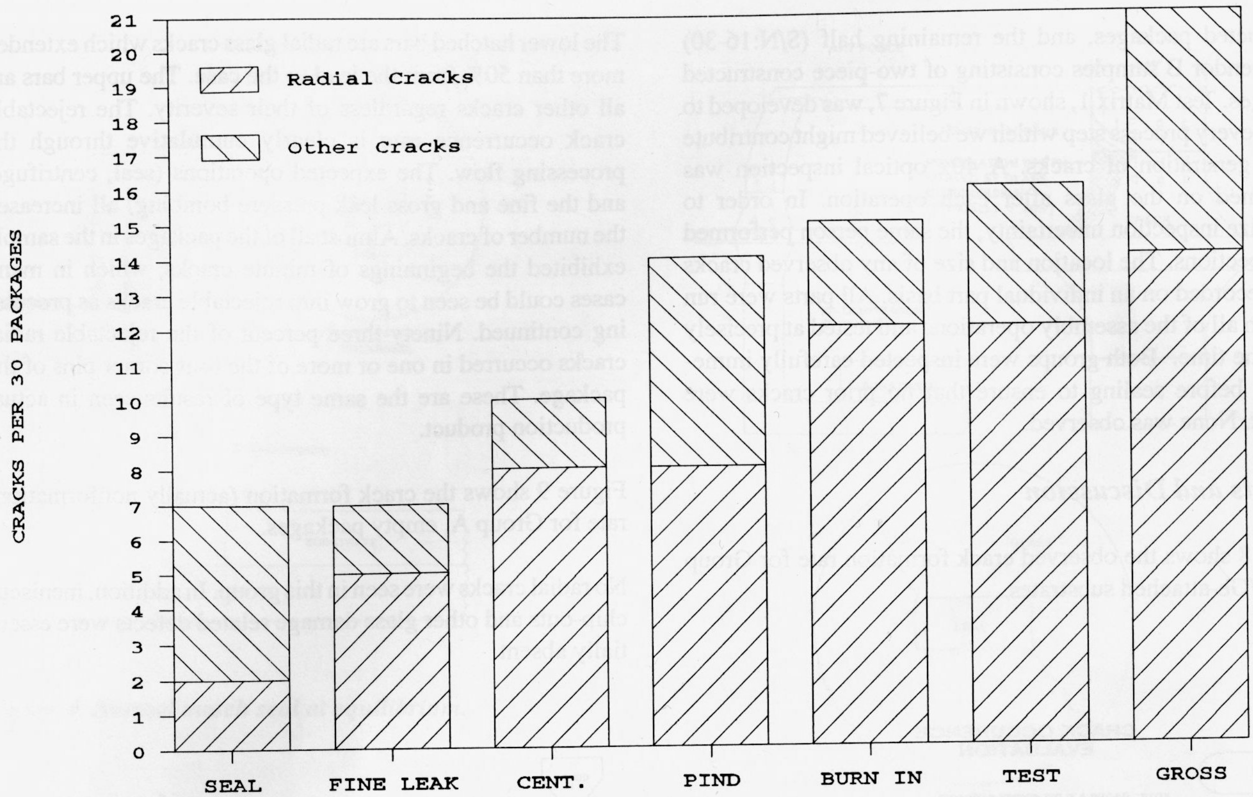


Figure 8. Crack occurrence evaluation. -- Group B, with substrates.

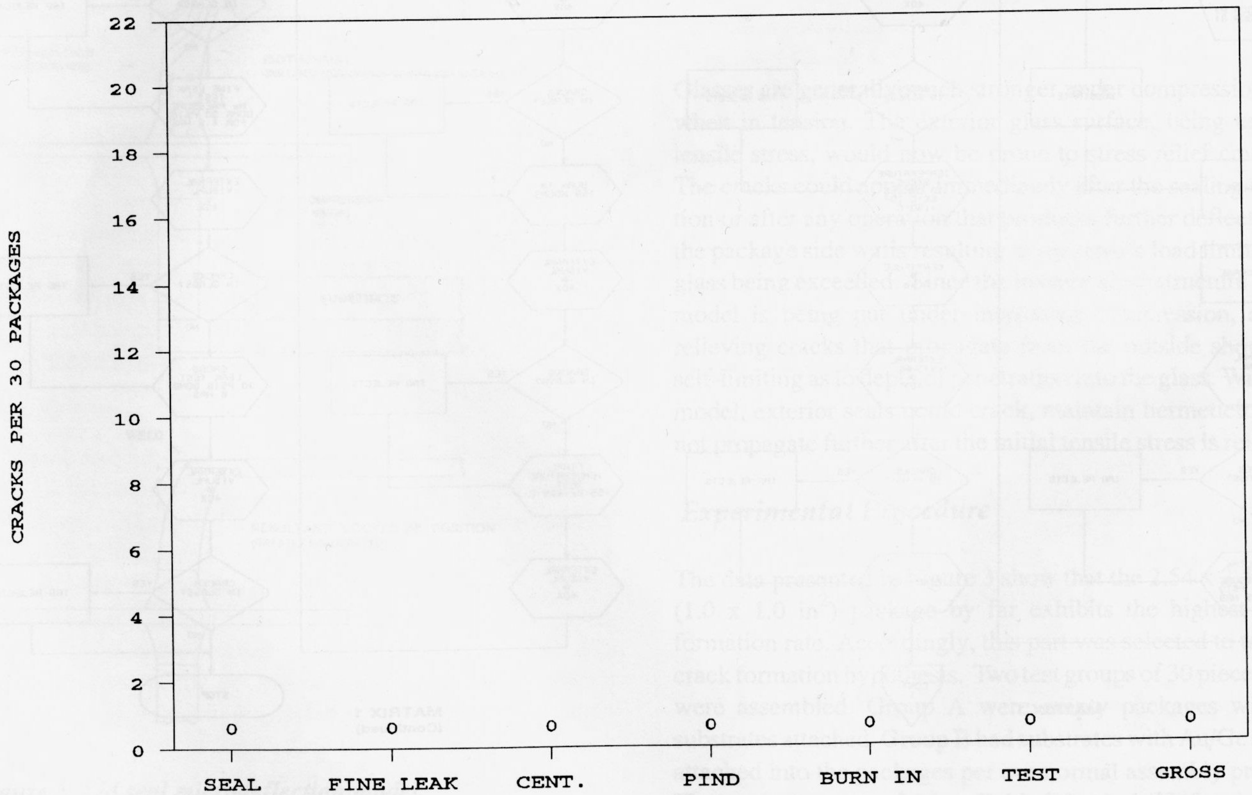


Figure 9. Crack occurence evaluation -- Group A, without substrates.

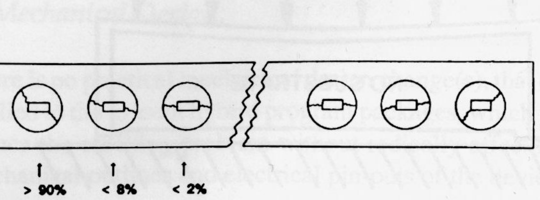


Figure 10. Crack types.

Another key observation, which was noted in both the controlled Group B evaluation and in the production population at large, was a repeatable and specific pattern to the radial cracking.

As illustrated in Figure 10, the cracks appeared first on one or more of the four corner pins, next on the adjacent pins, and rarely on the third pins in. The cracks always occurred at the relative angles shown.

The tensile cracks followed the maximum stress lines in the package.

Stress is highest near the package corners, thus the corner pins are affected first. The much lower occurrence rate of cracks in the 2.997 x 2.997 cm^2 (1.18 x 1.18 in^2) package is due primarily to the fact that the holes for the corner leads are physically spaced farther from the package corners 2.921-mm (0.115-in) than those for the three smaller sizes 1.905-mm (0.075-in) shown in Figure 11.

Mechanically the three smaller size packages, 2.54 x 2.54 cm^2 (1.0 x 1.0 in^2), 2.54 x 1.905 cm^2 (1.0 x 0.75 in^2), and 2.54 x 1.27 cm^2 (1.0 x 0.5 in^2), are identical, varying only in width. The 2.54 x 2.54 cm^2 (1.0 x 1.0 in^2) package will, owing to its greater surface area and mass, be subject to the most stress during centrifuge and pressure bombing. This would account for the observed defect rate differences between the three smaller packages, shown earlier in Figure 3. The proposed mechanical model is further supported by the observation that cracks do not occur in empty packages. The presence of the substrate adds substantial mechanical stiffening to the bottom of the package. In an empty package, the lid and bottom of the case can flex in order to absorb pressure bomb or centrifuge type stress (Figure 12).

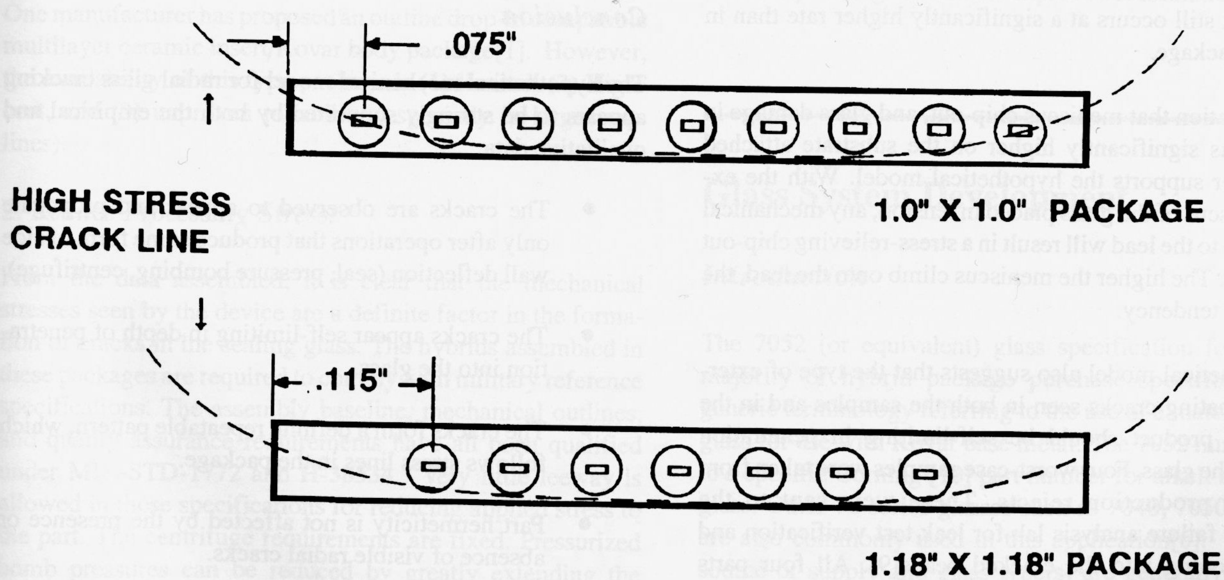


Figure 11. High stress distribution in two type of packages.

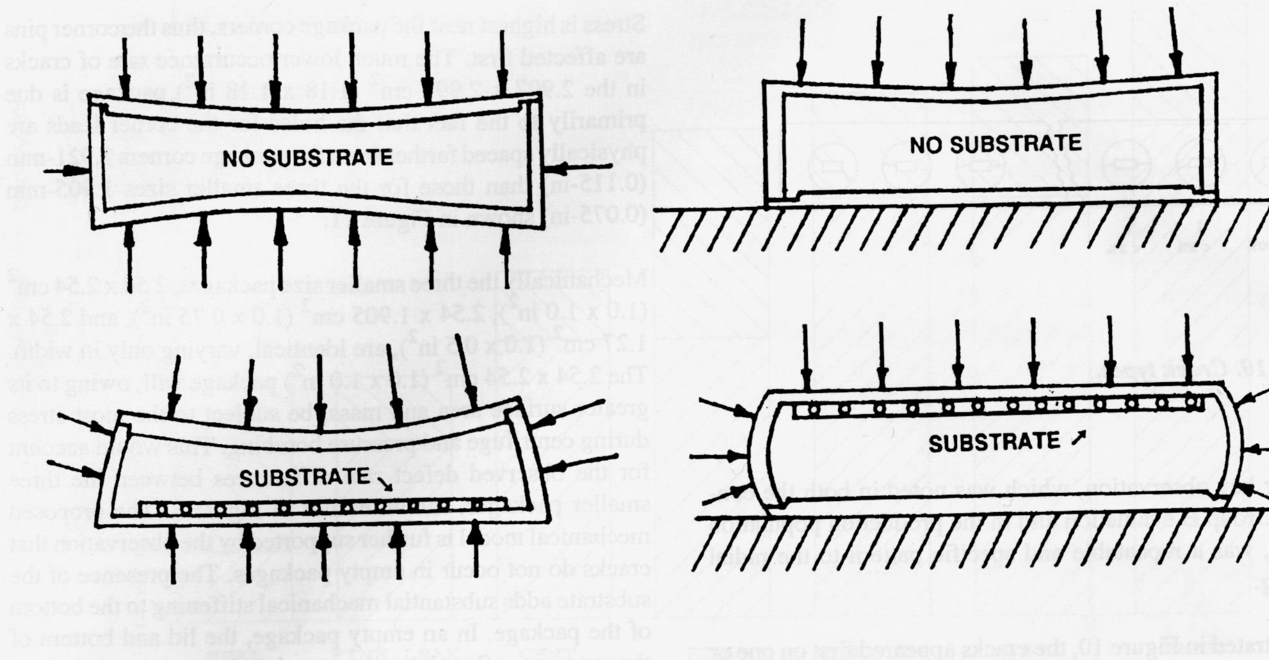


Figure 12. Physical effects of pressure and centrifuge testing on packages.

With the substrate present the base is prevented from flexing. The applied forces now result in side wall flexure. Additional testing done using an epoxy substrate attach in place of the hard eutectic solder has shown that the cracking frequency is reduced but still occurs at a significantly higher rate than in an empty package.

The observation that meniscus chip-out, and glass damage in general, was significantly higher on the substrate attached parts further supports the hypothetical model. With the exterior meniscus of the glass placed in tension, any mechanical disturbance to the lead will result in a stress-relieving chip-out of the glass. The higher the meniscus climb onto the lead, the greater this tendency.

The hypothetical model also suggests that the type of externally originating cracks seen in both the samples and in the production product should be self-limiting in penetration depth into the glass. Four worst-case samples were taken from the actual production rejects. These were sent to the Honeywell failure analysis lab for leak test verification and cross sectioning into the cracked beads[9]. All four parts passed the military hermeticity requirement. Microsectioning showed that the worst-case crack extended 0.2794-mm (0.011-in) into the glass. This is approximately 1/4 of the glass thickness available 1.016-mm (0.040-in). Typical crack depths were 0.1016-mm (0.004-in). The failure analysis report concluded that the cracks were superficial in nature.

Conclusion

The hypothetical mechanical model for radial glass cracking appears to be strongly supported by both the empirical and qualitative data.

- The cracks are observed to appear and propagate only after operations that produce some form of side wall deflection (seal, pressure bombing, centrifuge).
- The cracks appear self-limiting in depth of penetration into the glass.
- The cracks form a definite repeatable pattern, which follows stress lines in the package.
- Part hermeticity is not affected by the presence or absence of visible radial cracks.

For the package outlines and processing involved in this study, the conclusion can be reached that standard 7052-type sealing glass is not structurally strong enough to meet the visual requirements being imposed on the product. We do not believe that the reliability of this specific product is in jeopardy. However, cracks in hermetic sealing glass are certainly not a desirable thing. The data generated thus far suggest three possible means of reducing or eliminating glass cracking:

1. Mechanical Design:

There is no practical mechanical design change(s), that can be applied to the present hybrid program packages, which would reduce the cracking problem without radically affecting the mechanical outlines and electrical pin-outs of the devices.

The present 1.27-mm (0.050-in) lead pitch hybrid package is a maximum pin-out per unit area design. Unfortunately, this produces a package side wall centerline that is almost 80% glass[1]. Increasing the lead spacing to 2.54-mm (0.100-in) would greatly reduce wall flexure and cracking. However, the density advantage of hybrid packaging would be negated.

As the yield data show in Figure 3, for the 40 lead 2.997 x 2.997 in^2 (1.18 x 1.18 in^2) package, increasing the distance between the corner leads and the package edges reduces the incidence of bead cracking. However, an average 11% fallout at final inspection was still seen for this part, which is certainly unacceptable for any rational production situation.

Repackaging the devices in a combination cofired ceramic/metal package is technically feasible. However, the readily available ceramic base/kovar ring type package must be designed significantly larger for an equivalent pin out. Also, thermal dissipation and electrical shielding are affected. One manufacturer has proposed an outline drop-in compatible multilayer ceramic insert/Kovar body package[1]. However, the availability of this type package is (1) limited, (2) High-cost, and (3) unproven reliability (especially in larger outlines).

2. Reduce Processing Stress:

From the data assembled, it is clear that the mechanical stresses seen by the device are a definite factor in the formation of cracks in the sealing glass. The hybrids assembled in these packages are required to comply with military reference specifications. The assembly baseline, mechanical outlines, and quality assurance requirements have all been qualified under MIL-STD-1772 and H-38534. Very little leeway is allowed in these specifications for reducing applied stress to the part. The centrifuge requirements are fixed. Pressurized bomb pressures can be reduced by greatly extending the required dwell times. However, the data indicate that pressure bombing is not the only process step that produces cracks.

The effect of varying the weld schedule for lid sealing of the part was extensively evaluated. It was found that using weld temperature settings well above those considered optimum increased the number of cracks observed immediately after seal. However, we were unable to develop a statistically significant relationship between the radial cracks observed immediately after seal and the final number observed after all subsequent processing. It was concluded that the mechanical act of sealing up the package was the primary precursor to the glass-cracking phenomena.

3. Improved Sealing Glass:

The common element in all of these evaluations is the use of 7052 soda borosilicate sealing glass. Though there undoubtedly exists a myriad of other variables governing whether the glass beads crack or do not crack, the central material issue remains the sealing glass itself. Finite element stress analysis performed by other companies experiencing similar glass fracture problems indicates that tensile stress in the glass due to flexing of the lid, from operations such as pressure bombing, can easily generate stresses 2 to 3 times greater than the tensile strength of the glass[1]. The sealing glass is clearly the weak link in the package design.

Increasing the tensile strength and crack resistance of the glass would be the most comprehensive solution to the problem. Glass formulations with superior mechanical properties to the generically specified 7052 materials are now available. The following section of this report details the selection and reliability testing of such an improved formulation.

Glass System Development

Introduction

The 7052 (or equivalent) glass specification found in the majority of hybrid package purchase specifications is a generic terminology referring to the use of a matched sealing glass for use with Kovar base metal. The 7052 number refers to a specific Corning [10] part number for alkali borosilicate glass. Other 70 series glasses such as 7040, 7050 and 7056, are also commonly used in this application[6]. The actual source of supply and glass type(s) are generally left to the package manufacturers discretion, based on what seems to work best in their process. Generically, these glasses all conform to the basic Corning specifications.

Package manufacturing companies are, for a variety of reasons, extremely reluctant to change their glass types or processes. Only a handful of the companies claiming to build hermetic metal packages really has any detailed technical knowledge of their glass-sealing processes. A glass material change that required significant modifications to the basic process parameters would be a major undertaking for many companies. The microelectronics package industry is also very customer driven. No matter how many problems there are with the established glass, customers do not want to risk having additional problems with new and improved material. In the world of microelectronic packages, this is perhaps not an ungrounded fear[2].

Package manufacturers have begun offering some new material types in response to customer demands[11]. The most widely marketed type uses a standard 7052 bead with a high level of refractory alumina powder distributed on the surface of the glass[11]. Another approach has been to place a small ceramic washer around the lead so that it fuses into the outer surface of the glass. These methods yield some degree of improvement in chip and crack resistance, though none substantially improves the intrinsic strength of the glass[1].

With these and other proposed solutions comes the problem of single source. Many are proprietary products, available only from specific manufacturers. Hybrid circuit producers are wary of dependency on a single source for the supply of a critical part; e.g., the hermetic package. There is also a great deal of reluctance to qualify new materials. Many times this requires lengthy customer(s) approvals and often awkward explanations concerning difficulties with the present material that need improvement.

It was our objective to evaluate a substitute glass material that would not only have improved tensile strength and fracture resistance but also be compatible with a variety of glass-sealing processes and be available as a nonproprietary product. To this end, we entered into a development program with our largest hybrid package supplier, vendor A (Xeram/Pechiney, Site Industrial de St-Pierre-de-Senos 84500, Bolléne, France.), to evaluate an improved sealing material. This vendor was selected based on his quality record and demonstrated expertise in glass-sealing process control.

Glass Selection

The most direct way of improving the fracture resistance and tensile strength of a glass is to dope it in some manner or form with finely divided alumina (Al_xO_y) particles. In the past, there have been certain technical problems in doing this. Attempts to dope straight 7052 glass in this manner have met with only limited success. There were problems related to maintaining an even dispersion of alumina in the glass and maintaining good glass to metal adhesion. It has also been reported that the doping percentages normally needed to significantly improve the glass properties can result in prefired beads that are too fragile for the package manufacturer to handle. Vendor A had prior experience in successfully working with variations of alumina-doped glasses and was willing to work with us, and his glass supplier, to improve this technology further.

The glass material finally selected for testing was assigned the code name ACN after alumina chargé noir. The glass itself is a newly developed, but not proprietary, product. The specific processing employed by Vendor A to successfully use the ACN glass is believed to employ some proprietary steps. A prototype group of parts to our 1.27 x 2.54 cm^2 (0.5 x 1.0 in^2) flat pack configuration was initially furnished to Honeywell for evaluation. Results of our preliminary testing on this group were so promising that a preproduction order for 200 packages in our 2.54 x 2.54 cm^2 (1.0 x 1.0 in^2) configuration [12] was placed. The bulk of the subsequent formal qualification testing was done on this preproduction group of parts.

Qualification - Testing and Discussion

The important characteristics that Honeywell has identified for the evaluation of package quality are as follows:

- Intergranular oxide quality/glass chemistry,
- Lid seal for hermeticity,
- Temperature cycling at 100-cycles (Air-to-Air),
- Residual gas analysis (RGA),
- Electrical characteristics,
- Salt atmosphere testing for corrosion resistance, and
- Visual.

Microsectioning was done on samples of vendor A standard 7052 and ACN glass seals[13]. Oxide boundary dissolution into the 7052 glass was found to be greater than with the ACN glass. The ACN interface was characterized by a concentration of very dense residual oxide, 3-μm thick, in the boundary area. Some literature suggests that this is the ideal glass/oxide/metal boundary condition[7]. The oxide layer on the 7052 glass showed more dissolution into both the glass and base metal. This condition promotes a maximum amount of adhesion and wetting of the glass to the metal[6]. These microsection observations were supported by the physical

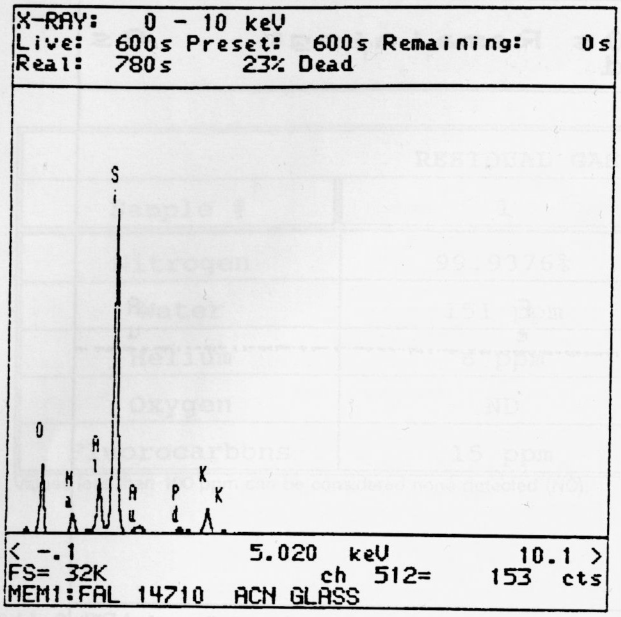


Figure 13. ESXA scan of ACN glass.

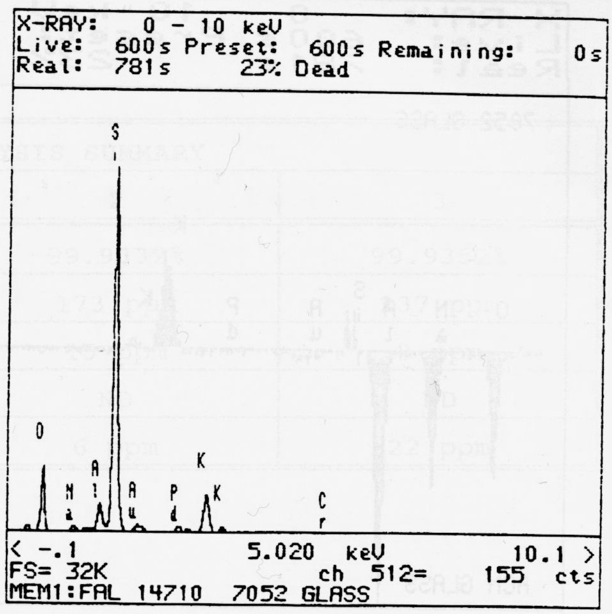


Figure 14.ESXA scan of 7052 glass.

examination of the seals themselves. The ACN seals show a near-zero meniscus condition. There is almost no glass climb up the lead. This is a highly desirable condition relative to meniscus-related damage, as it greatly reduces the tendency for the glass to chip due to flexing of the lead. The 7052 seals had definitely more glass climb up the leads 0.0508-mm (0.002-in) to 0.1016-mm (0.004-in), consistent with a greater wetting of the glass to the metal. Both of the noted conditions may be the result of the glass composition, the specific processing conditions, or a combination of the two. Both the ACN and 7052 seals exhibited a high degree of lot-to-lot consistency characteristic of a high level of control in the glass-sealing process.

A qualitative chemical analysis was performed on each glass type using EDXA. The EDXA scans shown in Figures 13 and 14 are for the ACN and 7052 glasses.

These scans were not very informative. The presence of chromium as a coloring agent in the 7052 glass is evident as well as higher levels of aluminum and sodium in the ACN glass. In order to highlight the composition differences between the two samples, a subtracted spectra scan was done.

The differential spectra (Figure 15) clearly shows the higher levels of aluminum and oxygen in the ACN glass, as would be expected from the alumina loading. Also present in the ACN glass is sodium. This probably indicates that the base glass for the ACN material is a soda potash composition, similar to Corning 7040. The 7052 glass is a soda borosilicate composition that does not contain significant amounts of sodium.

The package qualification test plan, Matrix 2, is shown in Figure 16. This is a standardized qualification sequence used by Honeywell to qualify package suppliers. The test sequence far exceeds the minimal requirements of military reference specifications, such as Method 5008. Thirty samples of 2.54 x 2.54 cm^2 (1.0 x 1.0 in^2) ACN glass packages was run through the series of Matrix 2 tests. The parts attached with Au/Ge eutectic solder to substrates and lid-sealed were subjected to thermal shock, 100 temperature cycles, intermediate and final fine and gross leak testing, and external visual inspection at 40x magnification. Upon completion of these tests, three pieces were sent out for internal gas analysis. The remaining samples were run through a lid removal/reseal test loop and were again inspected and leak-tested. Six parts were also solder-reflowed to circuit cards. A five-piece sample from the ACN lot was also subjected to salt atmosphere testing per MIL-STD-883C, Method 1009.8, condition A.

The qualification sample passed all of the environmental tests. Visually, there was no glass cracking or other rejectable damage noted at any point in the test flow. Hermeticity performance of the parts was outstanding. Through the first three fine leak tests, none of the parts exhibited a leak rate above the detection limit of our test equipment (1.0 x 10^{-9}

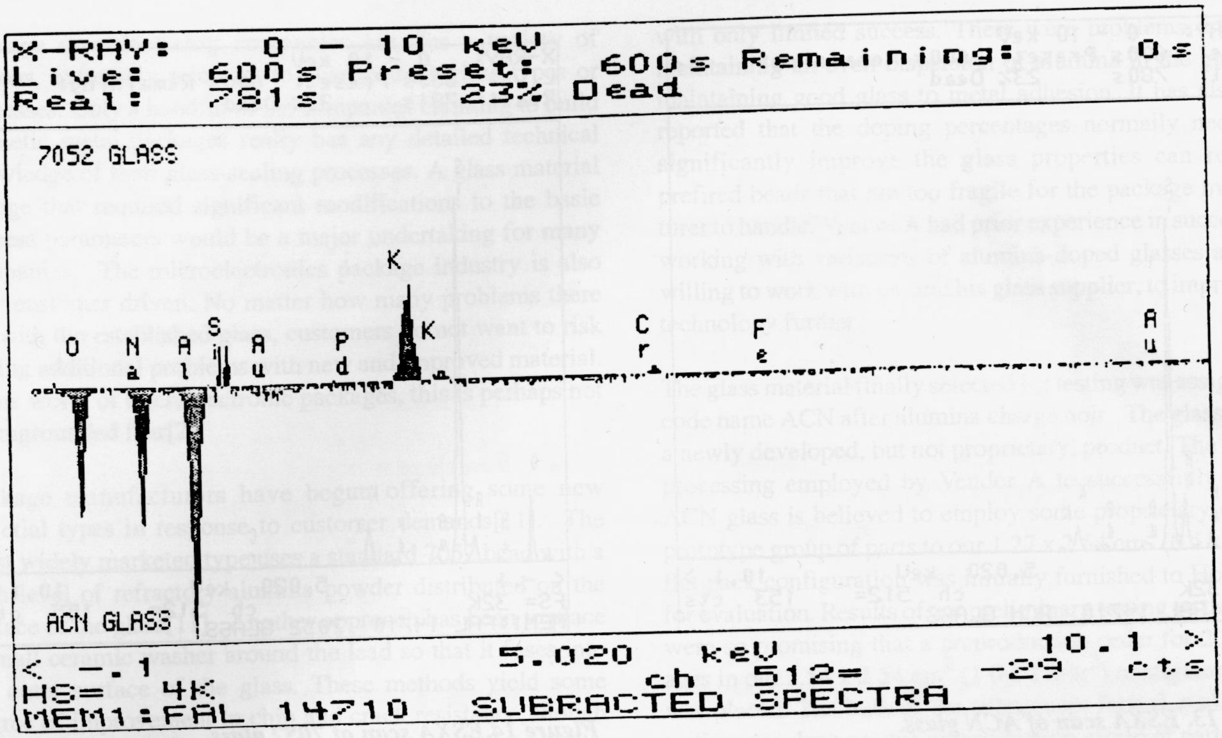


Figure 15. Subtracted spectra ACN vs 7052 compositions.

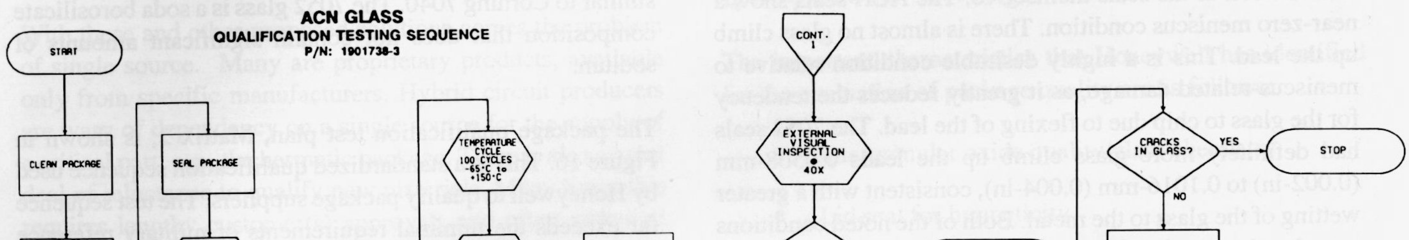


Figure 16. Matrix 2: ACN glass qualification testing sequence.

RESIDUAL GAS ANALYSIS SUMMARY			
Sample #	1	2	3
Nitrogen	99.9376%	99.9332%	99.9352%
Water	151 ppm	173 ppm	237 ppm
Helium	6 ppm	15 ppm	8 ppm
Oxygen	ND	ND	ND
Fluorocarbons	15 ppm	6 ppm	22 ppm

Values less than 100 ppm can be considered none detected (ND).

Table 2. RGA summary.

atm-cc/s-He). There was one reject in the delided/resealed group, and it was a leak in weld. The solder reflow test units showed no evidence of cracking or other glass damage.

The RGA test results (shown in Table 2) confirmed the excellent hermetic performance of the ACN parts. The RGA test is used as part of our package qualification plan to determine whether the packages outgas during temperature cycling and/or pressure bombing. Situations have been encountered where the hermetic enclosures appear to pass the room temperature hermeticity test but are actually becoming transiently nonhermetic at hot and cold temperatures. This condition can generally be revealed by RGA data that show significant levels of helium, air, and/or fluorocarbons in the package. (The parts were sealed in 99.99% nitrogen.) As can be seen in the following table, no such problem existed with these parts. Even after 100 temperature cycles and three helium pressure bomb cycles, the internal package atmospheres show virtually no ingress of external gases.

Five ACN packages were also sent out for salt atmosphere corrosion resistance testing per MIL-STD-883C, Method 1009.8 condition A. A common problem associated with passing this test with flat pack style packages has been corrosion occurring at the lead-to-glass interface. Glass meniscus chip-outs in this area result in the exposure of small areas of unplated base metal. The salt solution promotes localized anodic corrosion at this point. This frequently results in the separation of the lead from the case body. The five ACN packages passed the corrosion resistance requirements of Method 1009.8. Some corrosion was still evident at the glass/lead interfaces. However, the amount of corrosion was significantly less than equivalent 7052 glass seals subjected to the same test conditions. This improved corrosion resistance can be attributed primarily to the lack of meniscus climb/chip-outs previously noted. Some authors have also suggested that the presence of aluminum in the glass provides some level of cathodic protection for the lead[11].

Capacitance, dissipation factor (DF), dielectric-withstanding voltage, and insulation resistance were all measured for the ACN glass. Capacitance and dissipation factor were measured using an HP 4284A LCR meter from 1-kHz to 1-MHz. A four-wire bridge mode was used to minimize test fixture interaction. Eighteen leads were measured in parallel to enhance sensitivity.

The capacitance values for the ACN glass are slightly lower than for the 7052, indicating a slightly lower dielectric constant (Figure 17). This would be consistent with the hypothesis that the ACN glass is 7040 series based. The dielectric constant for 7040 glass is 4.8 versus 5.1 for the 7052 glass[10]. The dissipation factor is also slightly lower, on average, for the ACN glass (Figure 18). The noted differences in capacitance and dissipation factors are not large enough to be significant in most circuit applications.

Dielectric withstanding voltage was tested using an ESI Model 5300 flash tester. Eighteen leads were tested in parallel. At the maximum available test voltage of 1250-Vdc, there was no evidence of dielectric breakdown on either glass type.

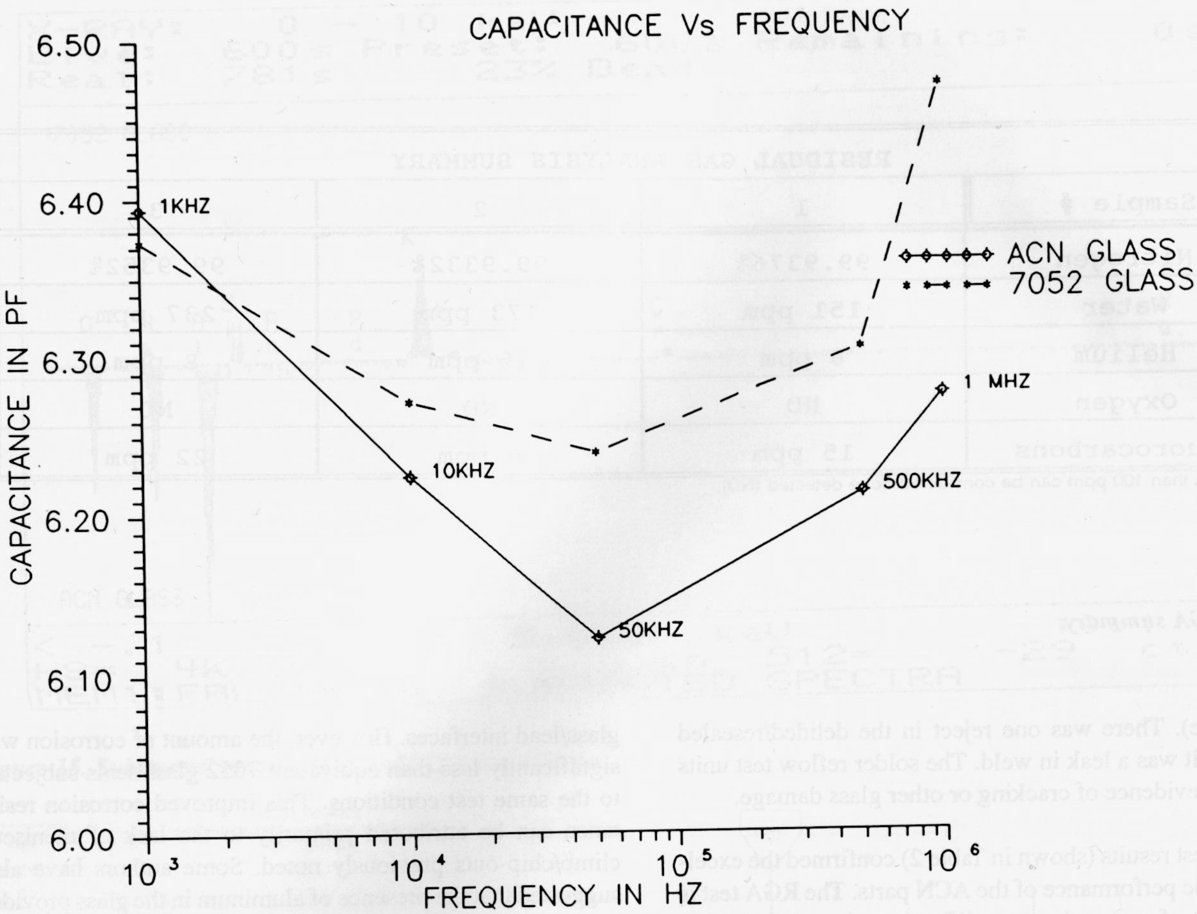


Figure 17. Capacitance of ACN vs 7052 compositions.

Insulation resistance was measured per MIL-STD-883C, Method 1003 at 600 Vdc. For this test, all 36 leads were measured in parallel relative to the case. Leakage for both glass types was less than 10-nA (test limit 100-nA).

Emulation Testing

The test results assembled thus far indicate that the ACN glass composition is significantly stronger than the standard 7052 glass. However, it was not possible using standard environmental processing to readily produce radial type glass cracks in the 7052 glass. A way was needed that could consistently demonstrate the strength and fracture resistance difference between the standard and improved glass formulations.

During the problem characterization phase of this investigation, detailed in Section II, it was noted that the 5000-G centrifuge step produced some radial cracks. It was found that increasing the centrifuge G-force above 5 kg rapidly increased the number of radial cracks. At G-forces between 15-kg and 20-kg, it was possible to consistently induce large numbers of easily visible, severe, radial, and other cracks in the standard 7052 glass. Subjecting the same size ACN glass parts to this test produced no visible anomalies in the glass. To confirm this observation, centrifuged-parts independently verified by our failure analysis laboratory using metallurgical grade microscopes[13]. The absence of cracks and general crack resistance of the ACN glass was verified by the failure analysis laboratory. Alumina-filled ACN glass is demonstratively stronger than standard 7052 sealing glass.

Glass Identification

Vendor A was somewhat reluctant to identify the supplier for its ACN glass. However, we were able to determine quickly that the material is a product of Elan Technology. Elan is a major supplier of technical glasses to the electronics package industry. The ACN material is Elan 88 series, 4 to 6% α-

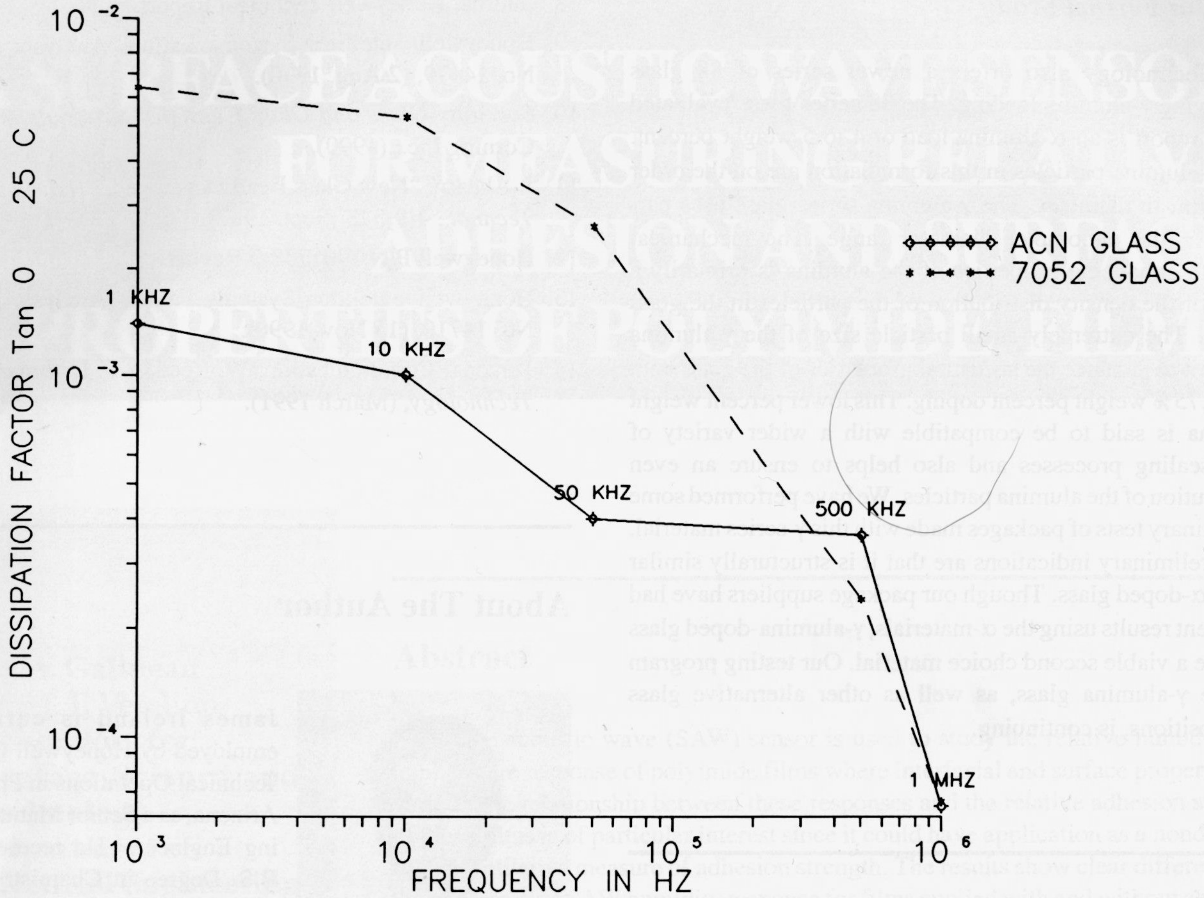


Figure 18. DF of ACN vs 7052 compositions.

alumina-loaded glass (Elan P/N 88-046). The 88 series glass is an improved alumina-loaded glass composition featuring improved flow and strength characteristics[11]. This material is readily available in a variety of configurations.

Conclusion

The Elan 88 α-alumina-doped glass system is a major technical breakthrough for the manufacture of high-reliability hermetic metal packages. The material appears to have many redeeming qualities for both the package manufacture and customer. For the manufacturer, the material has proven to be adaptable to their glass-sealing operation with only minimal process changes. Its enhanced structural properties and controlled flow characteristics should result in improved manufacturing yields when compared to 7052 glass. For the package user, the material offers greatly improved structural strength, excellent hermeticity, reduced corrosion potential, and the ability to fully comply with all military external visual inspection requirements.

Honeywell would not normally specify sources of supply for subcomponents used to manufacture hybrid packages. In this case, the overwhelming superiority of the Elan 88 series glass, at least in our application, argues otherwise. We believe that the 7052 (or equivalent) sealing glass found in the majority of package procurement specifications is too generic. The composition and source of the glass material used in the manufacture of hermetic packages is critical to the performance of the part. Its selection should not be at the whim of the package manufacturer. Changes in glass source or composition should be seriously managed by both the package supplier and consumer. Based on the results of this report, and our experience with subsequent large production volume use, Honeywell is in the process of changing its procurement documents to require Elan #88-046 glass for all of its Kovar packages. We advise other hybrid manufacturers to study carefully the requirements of their package procurement specifications.

Area for Further Study

Elan Technology also offers a newer series of 88 glass employing γ-alumina loading. The 88 series glass evaluated in this report is an α-alumina load of 4 to 5 weight percent. The α-alumina particles in this formulation are on the order of 40-μm in diameter. The γ-alumina series glass uses particles in the nanometer diameter range. The mechanical strength enhancing properties of the alumina is primarily a result of the density distribution of the particles in the glass matrix. The extremely small particle size of the γ-alumina allows it to enhance the structural properties of the glass with only 0.75% weight percent doping. This lower percent weight alumina is said to be compatible with a wider variety of glass-sealing processes and also helps to ensure an even distribution of the alumina particles. We have performed some preliminary tests of packages made with this γ-series material. The preliminary indications are that it is structurally similar to the α-doped glass. Though our package suppliers have had excellent results using the α-materials, γ-alumina-doped glass may be a viable second choice material. Our testing program on the γ-alumina glass, as well as other alternative glass compositions, is continuing.

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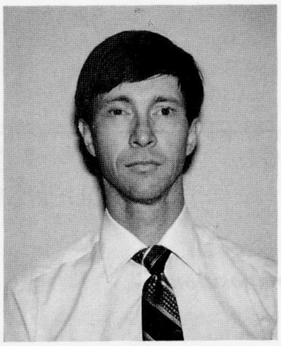
About The Author



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