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Metallographic Cross Sectioning Techniques for Performance of Destruct Physical Analysis of Glass Encapsulated Diodes

The purpose of Destruct Physical Analysis (DPA) is to determine if workmanship defects or process changes are present, or if changes have occurred in the constituent materials of a new production lot. The procedure used by the analyst to make these determinations must be detailed enough to prevent, to the degree possible, the generation of artifacts which would result in erroneous conclusion and unwarranted lot rejection. Unfortunately, it has been Microsemi's experience that DPA cross sectioning is often performed using techniques that do not meet this criteria.

General Background

There are three classifications of glass body axial leaded double slug diodes that are mainly distinguished from each other by the method employed for attachment of the die surfaces to their respective contacts or heat sinks. As techniques or findings may vary by construction they will be noted herein. The definitions of these categories appear in MIL-PRF-19500 Appendix A.

Typical DPA Observations

Void damage: Voids may be induced or exaggerated at the die to heat sink (slug) interfaces during initial grinding when micro fracturing of silicon silicides at interface areas occur due to the composition in the type of the abrasive, the resiliency of the paper or film, grinding direction, lubricant or grinding pressure applied to the sample. The problem of assessment becomes compounded by the decision to accept as finished, a cross section that appears to be free of grinding damage but may not, on closer examination, be free of the artifacts of that grinding. This can occur to some degree in all diode sample preparation. Category I signal diodes made with the Microsemi Epi Pad process used in fast recovery switching diode manufacturing such as those types listed in MIL-PRF-19500/578 and /609 are particularly susceptible to damage of the Anode side contact button when adequate precautions are not observed. See Figure 1 for a typical rendition of a properly sectioned device.

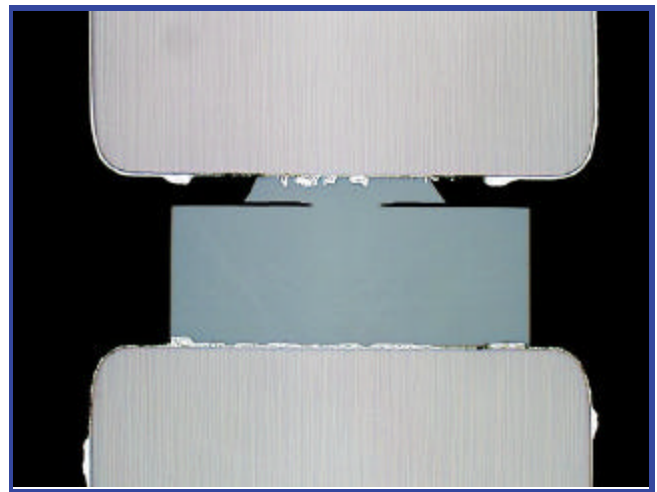


Figure 1

Figure 1 depicts a properly rendered Epi Pad cross section performed by using all recommended methods described in this Application note

The contact button on the Epi construction is composed of poly silicon grown out of the junction area over the die passivation. It is highly granular in crystal composition and will precipitate a silicide reaction with the nickel plating from the slug, resulting in a very brittle material. When bonding, silver and silicon will melt together at our high temperatures and penetrate into the button along the silicon grain boundaries, more so than into the bulk single crystal substrate. Cross section residual-grinding damage will not necessarily be evident on a polished section unless mild silicon etching is performed. The etch will help by uncovering microcracks and damage left by rubble being dragged across the section surface. It will also delineate the poly silicon nature of the contact button. Damaged areas may have material inadvertently removed by polishing pull out, water flushing or air blowing, thus leaving voids behind which are then mistakenly considered as construction faults rather than grinding artifacts. See Figures 2 and 3.

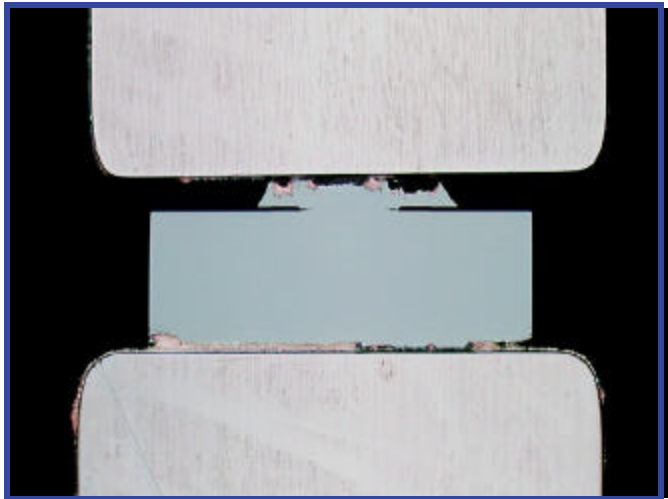


Figure 2

Figure 2 represents a cross section performed by a customer contracted test house. The damage to the brittle button region is evident. This device would not have survived Thermal Impedance testing. Nor Power burn-in if manufactured in this condition. At this plane there is no die material contacting the anode slug. The section was touched up by Microsemi to allow for photography. As received, there were rough grinding scratches and feathered edges present interfering with resolution of details.

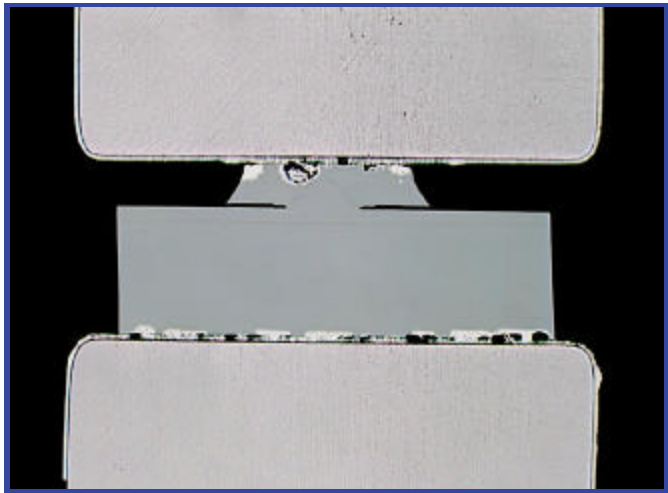


Figure 3

Figure 3 is representative of a device with back contact voids as well as damage to the EPI button. The bottom side voids are an artifact of the grinding. This can be determined by a viewing the die and noticing the eutectic material penetrating into the die. This would not be present in the silicon if there initially was a void to bridge in the die bonding phase.

2. Crack damage: Microsemi non-cavity diodes are compression sealed at high temperatures in a highly pressurized nitrogen environment. This pressure acts to drive the softened cylindrical sealing glass into the temporary void area around the die between the heat sink slugs. This glass then entraps the die providing a solid glass structure that acts as a trap to prevent foreign particles from drifting about looking for electrically isolated areas to bridge. This intrusion of the glass into the die area is the reason for the slight hour-glass appearance of the finished device. As the glass cools, compressive forces are locked into the encapsulating glass.

Scribe and break techniques when employed as an alternative to cross section may cause Silicon to totally disappear in the violent reaction of glass shattering, leaving behind nothing but the metal footprint of the contact metal alloyed to the slug. This alloy area can be recognized and measured by observing the slug surface with a high power microscope (200x or greater) and measuring the change in focus required to analyze the die contact residual metal. This metallization step is usually best observed when using an oblique side light source to produce distinctive shadows rather than a flat light vertical illuminator. The step change can be measured with a calibrated Z axis stage focus control knob. The combination of silicon and metal left on the slug will provide a good indicator of the total bonding area that was present.

In the non-cavity construction die crack damage may be induced when the diode glass encapsulation is partially ground away leaving a weakened structure that can suddenly decompress. Neither the die nor the specimen holding media, can by itself, prevent the decompression of a sufficiently weakened diode package. If Category I or II devices (bonded die) are involved, the silicon, being the weakest mechanical link, may crack upon decompression. Decompression can also be accompanied by glass encapsulation cracks. This of course makes the decompression action easy to identify.

Decompression bond cracks will leave unsupported edges along the cracks that can become progressively more prominent as grinding and resulting microcracking effects remove more of the edge materials. This will often leave the appearance of ragged separation across the entire die to slug interface in a very fine line requiring 200 times or more magnification to notice.

Initial Sample Evaluation

1. Thermal impedance evaluation: By performing thermal impedance testing on devices before subjecting them to Cross-sectioning, valuable information will be obtained that will be useful in disposition of the analysis. For instance: Attachment voids may be encountered at the interfaces as an artifact of the grinding process. If voids are large enough to cause a rejection decision by the DPA analyst they should also cause a non-

typical thermal impedance value. If they did not, then the probability is high that they were not present initially and were induced in cross-section. Thermal impedance can also be used to help validate die-to-slug interfaces when the scribe-and-break technique is performed. It is possible in some instances to have a large amount of silicon remaining on a slug after break while voids remain unseen under this silicon residue. Again having the thermal impedance data beforehand can lead one to a more accurate conclusion.

2. Reverse Voltage Trace Analysis: If the potential for die cracking in the sectioning process is a concern, it may be useful to perform a reverse-voltage-trace analysis on a curve tracer to characterize the device before mounting the sample and then performing the same reverse-trace analysis at intervals as the die material is removed. Curve tracing a cross-sectioned die should be preceded by a careful polishing and cleaning of the die to remove scratch damage and rubble caused by grinding. Practice on non-critical samples is recommended to get this technique mastered. The sudden appearance of an unstable reverse trace will help identify when a crack has been induced if the crack has crossed the semiconductor junction. This procedure is a useful tool when cross sectioning our larger devices made with .030 inch diameter leads or larger where there is a greater tendency for the device body to crack as its strength is reduced by sectioning.

3. Device preparation: The body paint should be removed from the device with a sharp tool such as an Exacto knife while taking precautions to avoid gouging the glass. When all paint is removed a visual inspection should be performed, preferably with the device suspended in a Methanol solution to improve the ability of the optics to resolve detail through the curved glass body. Removing the paint allows the analyst to backlight the specimen and view the glass body characteristics and observe for possible light penetration through die to slug interfaces if voids are present at the interfaces. If transparent specimen mounting materials are used, the analyst can continue to view the cross-section in backlight as cutting progresses. This backlighting technique should be done using a metallurgical microscope with sub-stage illumination capability; a sub-stage condenser is also of benefit in controlling and lens flare. A sub-stage mirror when used alone is inadequate.

Microsemi Cross-Section Techniques

It is presumed that the techniques being presented herein are for general use by a technical person already familiar with cross-sectioning procedures. The techniques are described for manual operations but do not preclude the use of mechanical holding devices, although the frequent progress inspections required may prove manual operation more efficient.

1. Grinding and polishing: The mounting medium for diodes of hard glass and tungsten slug construction should have hard-

ness and shrinkage properties comparable to the sample being mounted along with the capability to provide back-filling of construction voids. Buehlers transoptic thermoplastic resin is adequate for this purpose. For cavity devices such as DO-7 with straight-through or arrow-head construction, backfilling is particularly important as soon as the cavity is exposed to ensure satisfactory results before further grinding into the active die element region.

When mounted specimens are harder and much smaller in size than the surface area of the mount, different wear rates will occur. It is helpful to place Tungsten slugs or a similarly hard material around the perimeter of the mount to maintain flatness in the upcoming grinding operations. For devices using dumet plugs or straight-through leads for internal contact, this added material around the perimeter of the mount can also be dumet leads or slugs to ensure comparable wear rates when grinding through the sample. When mounting is completed, begin grinding the sample on an automatic grinder with 180 grit paper.

Struers Rotopol-15 operating at 400 rpm and 20 N force with water is one of many ways grinding can be performed. With this particular operating setting, 180 grit SiC paper will be spent in 30 to 45 seconds. Grinding with 180 grit SiC papers should continue until the plane of interest is reached, which will obviously depend on the size of the sample. With the same grinding settings, the sample will be ground with 600 grit SiC paper. The 600 grit SiC papers usually are spent in 15 to 20 seconds. Two applications of 600 grit SiC paper is typically performed after 180 grit SiC paper grinding. After two applications of 600 grit SiC papers in rough grinding, fine grinding begins. Fine grinding uses Struers Allegro grinding pad with 6 μ m monocrystalline diamond as the abrasive. With the same grinding machine settings (400 rpm and 20 N force with water), the sample is ground for 10 minutes. Further fine grinding is performed with Struers Largo grind pad with 6 μ m monocrystalline diamond as the abrasive. The sample will be ground on the Largo for one minute. Polishing is performed after fine grinding using a nylon cloth and 3 μ m monocrystalline diamond abrasive. With the same machine settings used for grinding (400 rpm and 20 N force and reduced water flow), the polishing lasts for 30 to 60 seconds. Final polishing is performed next using Buehler's vibratory polisher operating with a nylon cloth and 0.10 μ m polycrystalline diamond abrasive. Final polishing lasts for two hours or more.

This DPA procedure works well, but under unpredictable circumstances some deviation may be needed. For example, during rough grinding a possible void in the sample may have to be backfilled. Or, grinding damage on the silicon die needs to be removed before continuing to final polishing.

These special circumstances need special immediate attention before continuing. If they are not addressed, section induced defects maybe created.

2. Sample etching: A slight etch will help delineate the sample surface for better interpretation of results if questions remain about the source of any voids which may have appeared despite the precautions taken to prevent them. A solution of 20ml Nitric, 5ml Hydrofluoric, and 75ml Acetic acid is used to swab the sample for 10 seconds. Wash in DI water and Methanol.

Microscope Evaluation

Select a metallurgical microscope with a magnification range of 50 to 500 times. It should have both darkfield and brightfield illumination capability. A substage illumination and condensing system will be of use in certain situations. The vertical (Z axis) focusing mechanism should be calibrated if depth measurements are to be taken. The illuminating light path should contain a variable aperture to allow for increasing contrast and resolution.

Extended depth of field also becomes useful when detail is required in the rendering of microcracks. It is necessary to maintain side to side focus at high magnifications when the sample is not absolutely perpendicular to the optical axis of the microscope. Maintaining focus on mounted specimens is not problematic if the analyst has access to an inverted stage microscope. Quality work cannot be done if the objective lenses are scratched, dirty, or if the microscope shakes when photographing.

For photography a yellow or green light filtration system for black and white film will produce superior contrast images although too much can obscure detail in the shadows: Experiment for best results. For color, a Polaroid film type 64 for tungsten light is used to maintain color balance.

Observation should begin at low power using brightfield illumination. Scan the encapsulation glass for cracks caused in sectioning. There should be no scratch marks on the sample. If there are, they may need to be factored into any analysis that results in unfavorable findings in the area of the scratch. Look for slug misalignment; if this is present there is a strong likelihood that the die will be also. The misalignment may result in a wedge shaped void between elements if the slug or die metallization cannot bridge the resulting gap. Wedge type voids described above can often be verified by turning off the top illumination and switching on the substage illuminator. This lighting technique in combination with the substage condenser and its aperture diaphragm will allow light to appear through the gaps providing an indisputable finding. The use of quality optics is a prerequisite for this method since light is being projected straight at the microscope lens that will cause varying degrees of flare and contrast loss, even in the best equipment.

Using appropriate magnification, observe the slug to die interfaces and determine if voids are present. Voids caused in assembly in category I bonds are usually recognized by the fact that no evidence of alloying can be found at the void periphery as would be the case if metals were not in contact.

Category I optical analysis

It is normal in Microsemi hard glass product to see locations where a small die to slug interface void will appear as a result of material removal in the sectioning process. Many analysts will presume a specimen has been properly prepared if no evidence of scratches appear in their finished product. The problem with this assumption is that deep voids are often an artifact of the grinding process. If these voids are greater in depth than the grinding scratches that may have been carefully polished out, they may be thought to have been there initially. Great care is required in the analysis of the section to reach the proper conclusion.

Larger voids are possible if less care is used in the sample preparation. To determine if missing material has been removed by sectioning, observe the silicon at the perimeter of the void at high power and inspect for microcracks. These, when observed, are regions where more silicon is ready to pull out if additional sample grinding were to occur. Also observe the silicon to metallization interface. The appearance of ragged edges on the die may be the result of metal penetration into the silicon in the bonding process. If a void appears at the die to slug interface, notice if the slug metallization is still present. Alloy formed by the bonding process will have consumed some of the slug silver, thus if the slug silver is missing or reduced at the void it may be because it was wicked into the silicon when the bond was made.

Another useful inspection technique is to switch the microscope illumination to darkfield. In this mode, the light path is not coaxial with the optical path and does not require a mirror-flat specimen to reflect light back into the lens as required in the brightfield mode. Void areas scanned with this lighting technique will allow you to penetrate into the void and observe if metal-

lization remains just below the polished plane. When metal is observed below the surface, the depth can be measured by switching to the highest useful power on the microscope, changing the focus from the deepest part of the void to the surface of the section, then reading the depth from the stage elevation knob which is usually calibrated in microns.

Voids which are an artifact of the sectioning process are usually in the area of 5 to 10 microns deep, just enough to appear as black holes in the brightfield mode.

Another frequently observed sectioning fault found in the brightfield mode is the appearance of dark interfaces and obscured detail caused by the rounding of hard edges or the tapering of constituents of dissimilar hardness. This can be the result of improper choice of mounting material, failure to support mount edges (as mentioned earlier), fine grinding with paper, long polishing times, long nap polishing cloths, or too much pressure being applied to the sample when grinding. Detail can usually be found in these darkened regions by increasing the magnification or switching to darkfield illumination. This is a clue that improper sample processing has occurred.

Lastly, scan the void region for silicon or metallization rubble. Where microcracking has occurred there are often silicon particles entrapped in the void itself. These are easy to see at 200X to 500X magnification. The use of the aperture control will often render these quite clear. The silicon particles in themselves are proof of sectioning damage.

Category II and III optical analysis

The optical techniques employed for Category I types also apply to these constructions. Category II types will be viewed to determine if solder or braze preform metals have properly flowed to fill the die to slug interface. As with type I construction, the bonding media will flow to fill surface irregularities. Severely cocked slugs or die may create wedge type spaces that the preform material cannot bridge. For Category III bonds, irregularities in the slug surface or cocked slugs may create voids that cannot be bridged by the die contact metals alone. The sufficiency of contact area for this and all constructions may be resolved by review of the thermal impedance data, as well as considerations for the power burn-in with end-point electrical measurements if also performed.

Conclusion

There are certainly many instances when the DPA has uncovered situations needing immediate correction by a manufacturer, but this paper has been directed at correcting those situations where relevant details and procedural artifacts are being co-mingled leading to faulty conclusions. Automatic disposition of "lot failure" to samples representing component shipments that are urgently required for the contractors programs is a disservice to all involved. We recommend that lot failure disposition be withheld until the device manufacturer has been consulted and provided with the opportunity to attach a comment to the contracting party if disputes with the laboratory cannot be resolved. This action combined with greater attention to the techniques of sectioning and analysis will go a long way towards improving the present situation.