

# **Three-Dimensional Computed Tomography as a Method for Finding Die Attach Voids in Diodes**

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***September 2010***

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## **LIST OF ACRONYMS**

CT	computed tomography
EEE	electrical, electronic, and electromechanical
3DCT	three-dimensional computed tomography



## TECHNICAL MEMORANDUM

### THREE-DIMENSIONAL COMPUTED TOMOGRAPHY AS A METHOD FOR FINDING DIE ATTACH VOIDS IN DIODES

#### 1. INTRODUCTION

NASA analyzes electrical, electronic, and electromechanical (EEE) parts used in space vehicles to understand failure modes of these components. Engineers use this knowledge to avoid failures that impact safety, cost, and schedule. Diodes are but one example of such a part that serve critical functions throughout typical flight avionics. Figure 1 shows a diode of the type that was analyzed in this study. Past research and test data have shown that diodes cannot serve their purpose if there is excessive voiding in the die attach, typically a silver-based material that bonds the cathode and anode plugs to the die. One technique that has been used for determining die attach integrity is metallographic preparation. This is a time-intensive process whereby mechanical grinding and polishing of the diodes reveal voiding and other anomalies in the die attach. However, it is a destructive process and the results are sometimes inconclusive due to observations being limited to one plane at a time and the ease of damaging the brittle die in the harsh grinding procedure. A quick, veritable, and nondestructive method for finding voids in the die attach of diodes is desirable.



Figure 1. The Keyence VHX-600 optical microscope was used to collect this magnified image of a 1N5550 diode.

Three-dimensional computed tomography (3DCT) is a promising alternative to metallography because it is a nondestructive and expeditious technique. The most notable advantage of three-dimensional x-ray inspection is that it results in a complete picture of the area of concern.<sup>1</sup> While the cross sectioning of a diode typically requires many hours, a computed tomography (CT) scan of the same diode can be completed in less than an hour. The purpose of this study was to verify that CT scans of die attach accurately represent the die attach structure.

Figure 2 shows the nanome|x 160 NF manufactured by phoenix|x-ray (nanome|x) used to x-ray and CT scan the diodes in this study. Verification was accomplished by comparing several physical cross sections of three diodes to the corresponding cross-sectional plane in the tomographs of those diodes. The three diodes used for this study were manufactured by Unitrode (now Texas Instruments). Diodes 1 and 2 have part number 1N5550 and lot date code 8516. Diode 3 has part number 1N4942 and lot date code 8413. Unitrode diode construction is typical of other manufacturers' diodes with the same part number and similar lot date codes.



Figure 2. The nanome|x 160 NF manufactured by phoenix|x-ray creates x-ray images of aerospace components using two-dimensional x-rays and 3DCT data sets.

Figure 3 is an optical bright field image of a cross section of a nonmesa 1N5550 diode taken at 2.5X objective showing the typical construction of one of these diodes. Nonmesa diodes are characterized by a cathode side that maintains the same dimensions as the anode side. Mesa diodes typically have the junction edges ground or laser etched to promote a larger breakdown voltage.

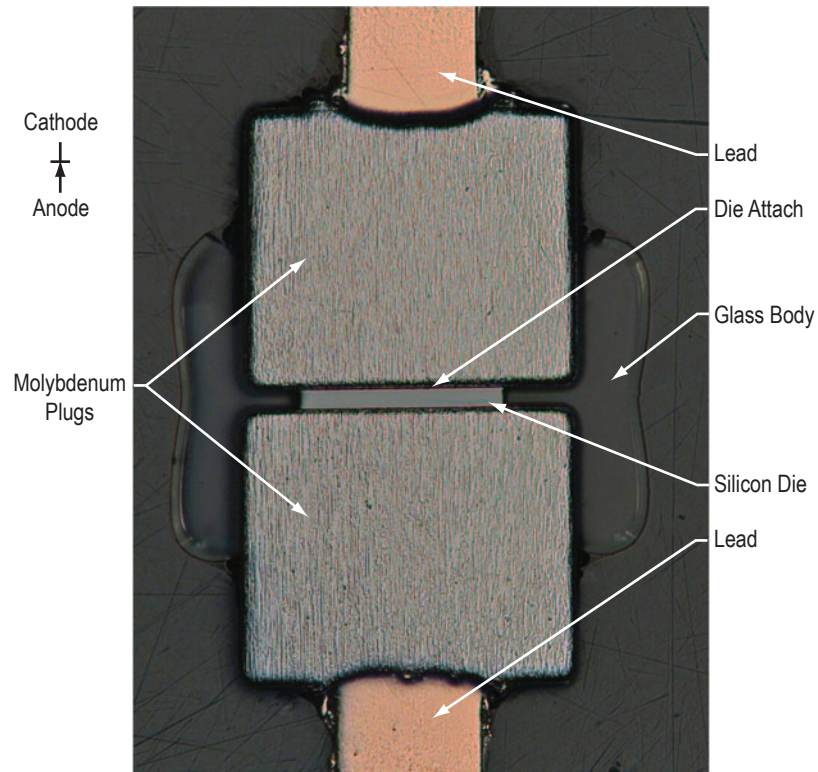


Figure 3. The nonmesa 1N5550 diode cross section shows typical construction of a diode and was photographed with a Leica CTR-6000 metallograph with 2.5× objective magnification.

## **2. BACKGROUND ON EQUIPMENT**

Unlike two-dimensional x-ray imaging, 3DCT enables the user to penetrate beneath the surface and virtually slice into the target object without physically dissecting it. The digital volume model created by the 3DCT scan can be used to view a full interior plane of a diode, including substructures like die attach. A traditional x-ray system produces two-dimensional images by collecting the x-rays transmitted through the target object.<sup>2</sup> A CT scan creates a three-dimensional representation with gray values proportional to the x-ray density of the object using a computer algorithm to compile a series of two-dimensional radiographs collected as the object or detector is rotated 360 deg.<sup>3</sup> The CT images for this Technical Memorandum were created with the phoenix datos|x, version 1.2.1.7 (datos|x) software reconstruction of images from the nanome|x. The three-dimensional rendering software package VGStudio MAX, version 2.0 (VGStudio MAX) was used to view the images and create the digital planes for comparison to the physical cross sections.



### 3. PROCEDURE

The first step in verifying the 3DCT technique was to find diodes that exhibited significant spatial variation in the die attach volume. For example, a thick coating of die attach exhibiting large voids makes clear the boundary between the die attach and voids in the CT scan, so these diodes were chosen for this study. To find a diode with die attach that was suitable for conclusive analysis, a large collection of diodes was two-dimensionally x-rayed with the nanome|x to identify those with prominent die attach.

Figure 4 shows the two-dimensional radiograph of diode 1 with a mottled cathode die attach plane between the plugs. The mottled appearance suggests a large number of voids, the reason this diode was selected for this study. The two-dimensional radiograph also illustrates that the viewing angle must be extremely oblique to just see the die attach only vaguely. The lack of clarity is the primary reason that two-dimensional imaging is not preferable as a die attach analysis technique. After screening over 100 diodes, the three selected diodes were notched on the cathode lead for digital to physical orientation purposes. The paint was also scratched off the body of the diode with a scalpel to facilitate optical microscopic observation.

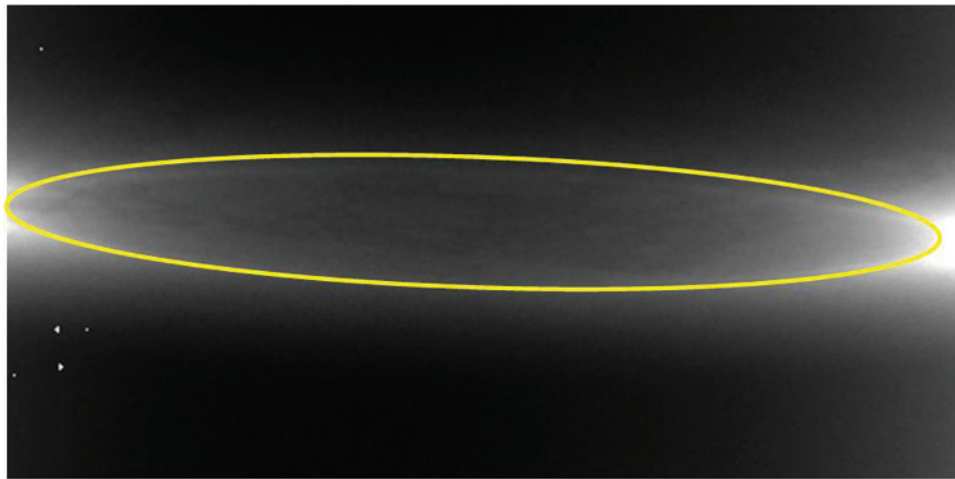


Figure 4. This oblique, two-dimensional x-ray of diode 1, part 1N5550, shows the mottled 'prominent' die attach (yellow ellipse) that made this diode a good candidate for analysis.

Although these two operations can be considered destructive, they were only implemented in this study to ensure the orientation could easily be correlated between physical and digitized cross sections and are not necessary procedures. The diode was then positioned as straight as possible in the CT sample holder, which spins the part, and as close to the x-ray source as possible to

obtain the highest resolution image achievable.<sup>4</sup> The typical resolution reported by the software was 9  $\mu\text{m}$  for each of the three diodes. The x-ray images were then imported into datos|x to create the volumetric data file. The subsequent volume file was loaded into VGStudio MAX for three-dimensional viewing and image creation.

Figure 5 is the three-dimensional view of diode 1 in VGStudio MAX after the gray values of air and other similar density materials were set to transparent. The image shows the leads on the left and right, the notch in the cathode lead, the dark glass body in the center, and the plugs between the leads and glass body. The dark area on the cathode side plug is due to the green paint that is used to mark the diode when it has passed screening. The clipping tool in the VGStudio MAX software was used to digitally section into the diode until the entire plane of the cathode die attach was visible. Figure 6(a) shows the square die attach plane, surrounded by the circular plug that is enclosed by the dark circular glass body in the digitally sliced 3DCT scan of diode 1.

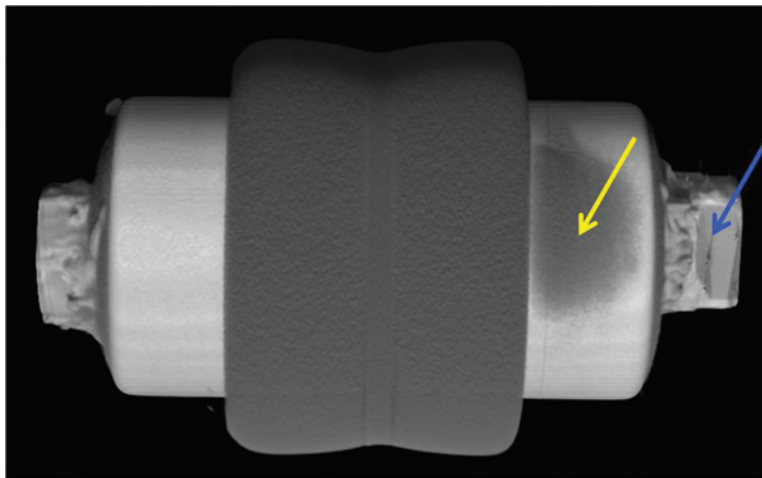


Figure 5. The leads, plugs, and glass body are visible in this image of the 3DCT volume of diode 1. The notch made with the scalpel (blue arrow) and the paint on the cathode side plug (yellow arrow) are detectable by x-ray.

After digital volumetric modeling, the diode was prepared for mechanical grinding and polishing. The first step in this process was to place the sample in  $\approx 40$  mL of epoxy formed from the mixture of five parts Buehler epoxide resin to one part Buehler epoxide hardener by weight. The diode leads were mounted in plastic specimen support clips to keep the body of the diode as level as possible in the epoxy. Using the notch in the lead as a fiducial, the diode was positioned so that each cross-sectional plane could be easily mapped back to the digital planes created with CT. The support assembly was placed in a SamplKups® mold cylinder and covered with the epoxy. To remove air bubbles formed while mixing the epoxy, the mold cylinder was placed in a  $1 \times 10^{-2}$  torr (1.3 P) vacuum chamber for 5 min, then allowed to cure overnight without heat or pressure.

The potted diode was removed from the mold cylinder and labeled with the diode number and a mark indicating the location of the cathode for orientation purposes by etching the hardened

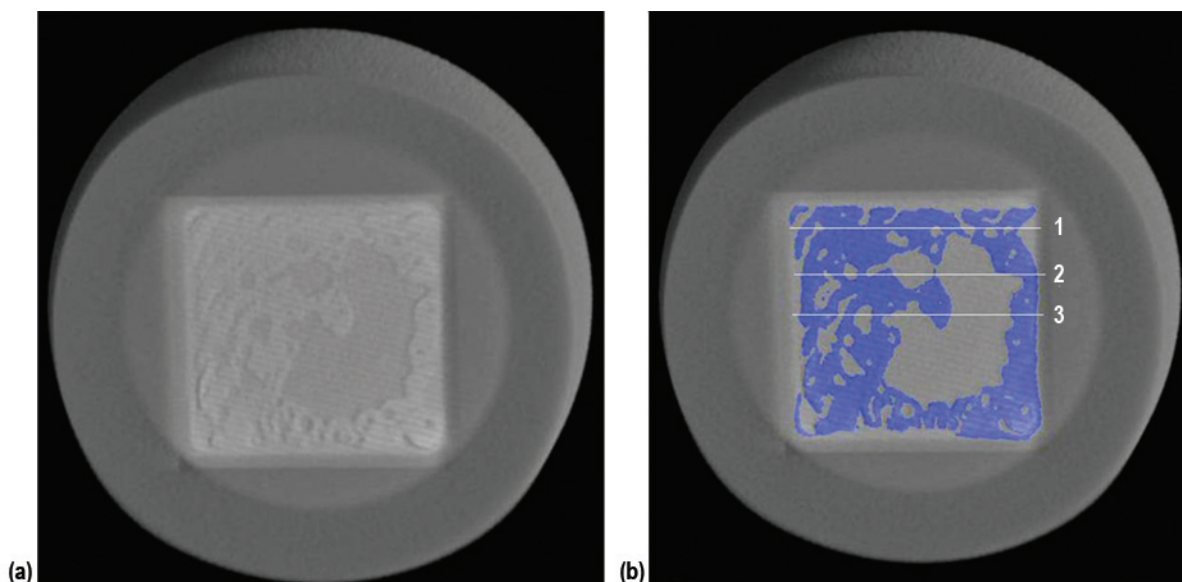


Figure 6. The 3DCT scan of diode 1, part number 1N5550, was digitally sectioned so that the entire plane of cathode die attach was visible: (a) The unenhanced 3DCT scan shows the mottled die attach plane, and (b) The highlighted 3DCT scan shows the remaining die attach in blue with white lines indicating locations of the physical cross-section planes 1 to 3 shown in figures 7–9, respectively.

epoxy with an electric engraver. To obtain a cross section, the potted diode was abrasively cut on an 8-in-diameter Buehler EcoMet® 3 variable-speed grinder-polisher (EcoMet) until the desired depth into the die was reached. The cross-sectioning regimen consisted of a progression of grinding steps starting with 320-, 400-, and 800-grit, 8-in Buehler Carbimet® paper discs or Allied High Tech Products, Inc. (Allied) silicon carbide paper discs at 420 rpm. A different EcoMet was used for each grit size to avoid cross contamination. Rough polishing was accomplished using 6-grit diamond suspension on an Allied Gold Label polishing cloth at 900 rpm followed by 1-grit colloidal silica on an Allied White Label polishing cloth at 900 rpm. Final polishing consisted of 0.05-grit colloidal silica on an Allied Final Red C polishing cloth at 500 rpm. A typical polished cross-sectional plane is illustrated in figure 3.

The diode cross sections were photographed using a Leica CTR6000 metallograph under 5×, 10×, and 20× objective magnification in bright field view. The entire die did not fit in the field of view for the 10× (diodes 1 and 2 (1N5550) only) and 20× objective magnifications, so pictures were taken of the die and die attach in overlapping sections. The 10× segments for diodes 1 and 2 were then merged to create a panorama of the entire die using the Photomerge™ Panorama feature of the Adobe® Photoshop Elements, version 5.0 program. The potted diode was sectioned and photographed several more times, each time grinding deeper into the diode to obtain additional reference planes. Images of each cross-sectional plane were then matched to the two-dimensional digital plane of the cathode die attach from the volumetric data of that diode. Comparisons were made between the digital and physical representations of die attach and voiding.

## 4. DATA AND ANALYSIS

The accuracy of the 3DCT scan in representing the presence and voiding of the cathode die attach in diodes was verified by ensuring that the die attach appearance in the physical cross sections confirmed the die attach appearance in the 3DCT scan. After several physical cross sections were obtained, the exact position of each physical cross-section plane in the CT scan was determined by matching the locations and sizes of the voids appearing in the cross sections to the locations and sizes of the voids appearing in a line in the die attach plane of the CT scan. To verify these cross-section positions, cross-section lines were drawn on the printed CT scan die attach planes to ensure that the cross-section planes were parallel. Next, it was verified that the ratios between the lengths of the die attach and the distances between several pronounced voids were consistent between the printed pictures of the cross sections and the CT scan. The 5× optical magnification pictures were used for 1N5550 diodes in these tests because the entire die could be viewed in one frame. The 10× optical magnification pictures were used for the smaller 1N4942 diode in these tests because the entire die was visible in a single frame.

### 4.1 Diode 1

Figure 6(a) shows the cathode die attach plane in the virtually sectioned 3DCT scan of diode 1, part number 1N5550. The die attach is the porous square in the center with the voids appearing darker than the remaining die attach, the result of using a special lighting algorithm provided in the VGStudio MAX software. The die does not appear in the 3DCT scan due to its much lower x-ray density. To facilitate finding the exact locations in the 3DCT scan that corresponded to the physical cross sections, Jasc® Paint Shop Pro, version 8.10 was used to highlight the cathode die attach in blue. Figure 6(b) shows the highlighted CT scan of diode 1. The white lines in the image correspond to the three physical cross-section planes made of diode 1. The physical cross sections, locations designated 1 to 3 in figure 6(b), are shown with their 3DCT counterparts in figures 7–9, respectively.

The cathode die attach is on the top, mesa side of the die in each physical cross section. The cathode side glass body, cathode plug, and die attach are depicted in the sliced digital volume. The physical and digital cross sections are oriented so the left and right correspond as shown.

Figure 7 depicts cross section 1 of diode 1, in which  $\approx 10\%$  of the die has been ground away. The five small, dark voids in the die attach on the right half of the physical cross-section plane and the two tiny voids on the left edge of the plane in figure 7(a) correspond to the five small, dark voids on the right and two tiny voids on the left edge of the digital 3DCT model of the physical cross-section plane in figure 7(b).

Figure 8 depicts cross section 2 of diode 1, in which  $\approx 30\%$  of the die has been ground away. Both figures 8(a) and (b) depict six voids of increasing size from left to right, separated by very



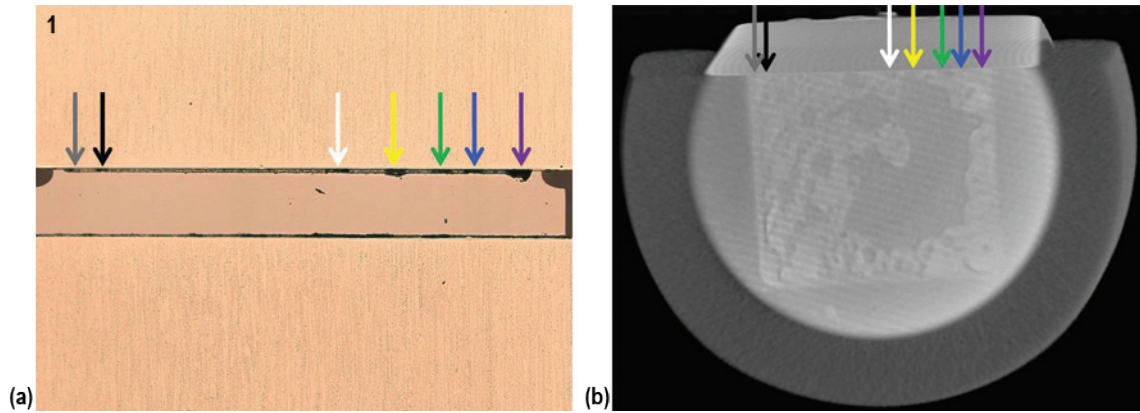


Figure 7. The die attach and voiding in physical cross section 1 of diode 1 parallels the die attach plane in the 3DCT scan equivalent: (a) The first physical cross section of diode 1 was optically imaged at 10 $\times$  objective magnification in bright field, and (b) The 3DCT scan of diode 1 was virtually sectioned 10% of the way through the die to represent the portion of the diode remaining after the first physical cross section was made. The five very small voids on the right half of the cross-section plane (white, yellow, green, blue, and purple arrows) and the two very small voids on the left edge (gray and black arrows) are present in both the physical cross section and its 3DCT model.

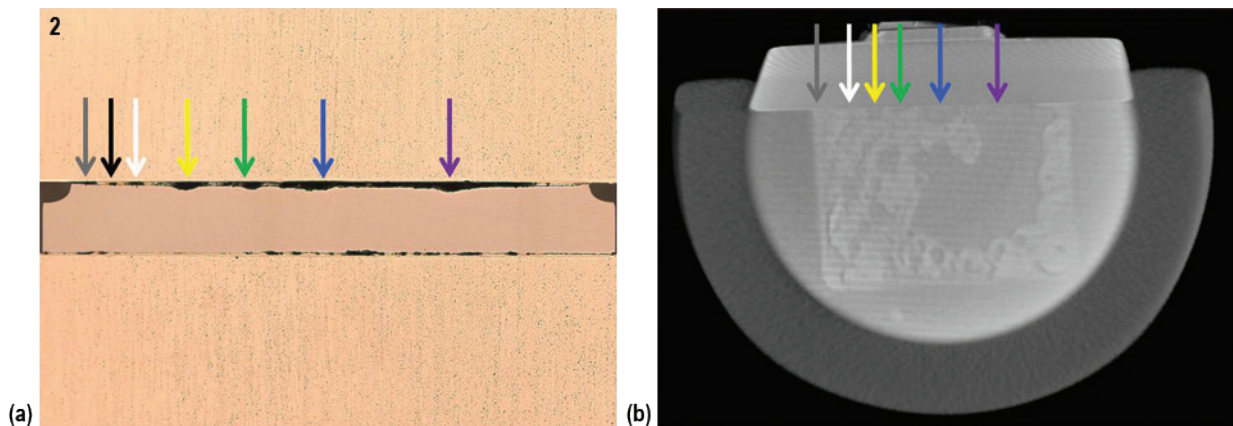


Figure 8. The die attach and voiding in the physical cross section 2 of diode 1 parallels the die attach plane in the 3DCT scan equivalent: (a) The second physical cross section of diode 1 was optically imaged at 10 $\times$  objective magnification in bright field, and (b) The 3DCT scan of diode 1 was virtually sectioned 30% of the way through the die to correspond to the second physical cross section. Both the physical cross section and its 3DCT representation have six voids of increasing size moving from left to right across the cross-section plane (gray, white, yellow, green, blue, and purple arrows). The CT model does not show the tiny void on the left (black arrow).

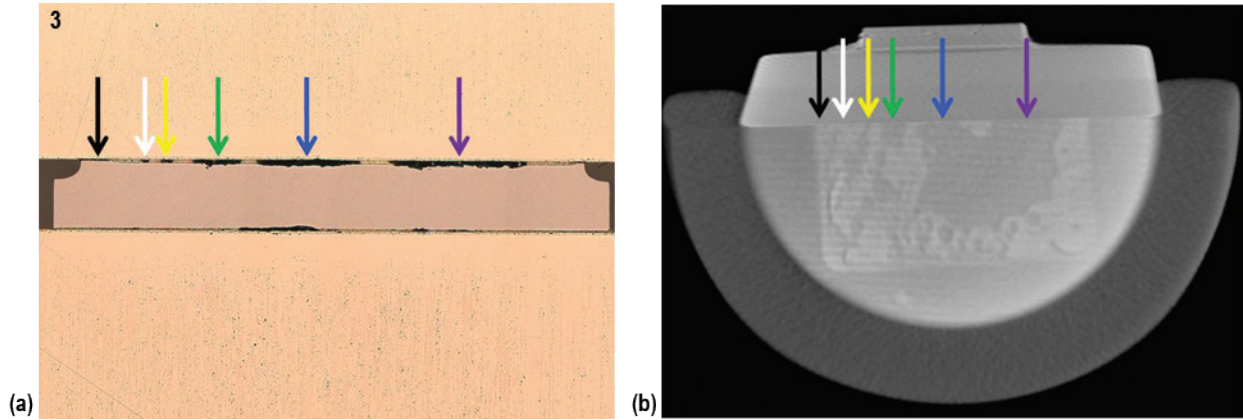


Figure 9. The die attach and voiding in the physical cross section 3 of diode 1 parallels the die attach plane in the 3DCT scan equivalent: (a) The third physical cross section of diode 1 was optically imaged at 10X objective magnification in bright field, and (b) The 3DCT scan of diode 1 was virtually sectioned 50% through the die to correspond to the third physical cross section. The physical cross section confirms the 3DCT cross section in that both have a very small void on the left edge (black arrow), two tiny voids on the left (white and yellow arrows), followed by three voids of increasing size from left to right (green, blue, and purple arrows).

small bits of die attach and ending with a small piece of die attach on the right edge. However, the physical cross section in figure 8(a) shows a tiny void to the right of the first void on the left edge that does not appear in the 3DCT version of the section. This discrepancy is due to ‘pull-out’ as the silicide is visible, bonded to the cathode plug where the die attach is missing.

Figure 9 depicts cross section 3 of diode 1, in which  $\approx 50\%$  of the die has been ground away. Figures 9(a) and (b) show a very small void on the left edge followed by five voids of increasing size from left to right with the most distinct die attach present on the right half of the plane. Figure 9 illustrates that a 3DCT scan can also differentiate between thick and thin die attach. The die attach is thin on the left of the plane in both representations. Thin die attach in the 3DCT scan is not as emphasized as thicker die attach and often appears mottled, possibly leading to missed correlation between the physical and digital cross sections when highlighting with grayscales. The die attach in the physical cross sections and the digital die attach in the 3DCT scan for diode 1 were in nearly exact congruence for each section.

## 4.2 Diode 2

Figure 10 shows the cathode die attach plane in the virtually sectioned 3DCT scan of diode 2, part number 1N5550. This particular diode is viewed at an angle so that the lighting algorithm in VGStudio MAX makes the die attach more distinct. Figure 10(a) shows the unenhanced die attach plane. Figure 10(b) shows the die attach colored blue with white lines across the die attach area corresponding to the three physical cross sections made of diode 2. The cross sections, locations designated 1 to 3 in figure 10(b), are shown with their 3DCT counterparts in figures 11–13, respectively.

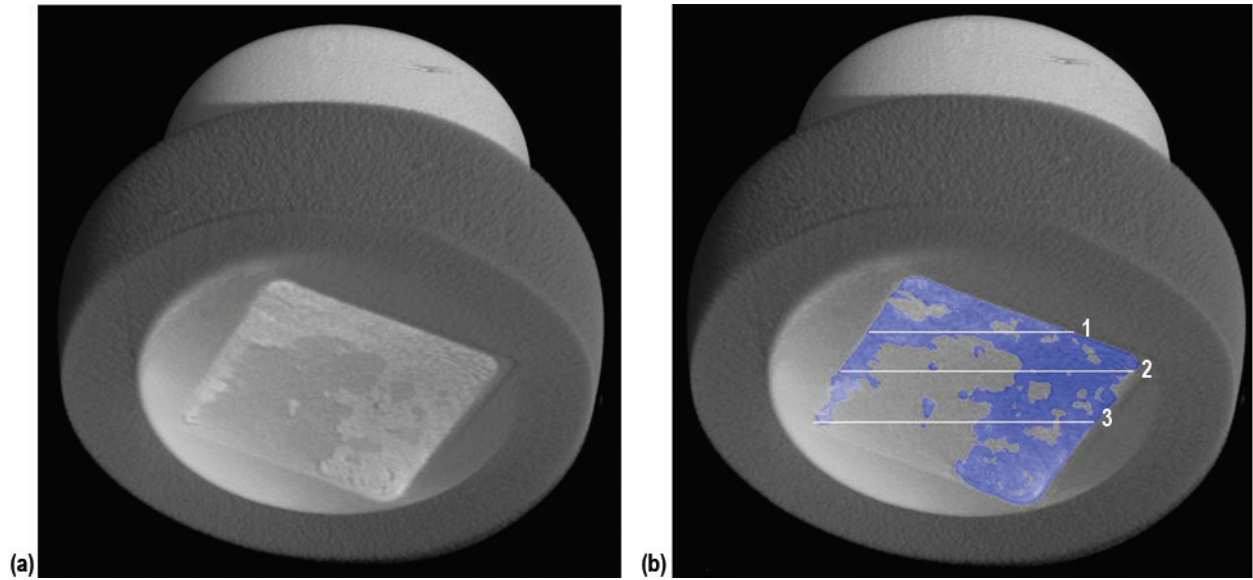


Figure 10. The 3DCT scan of diode 2, part number 1N5550, was digitally sectioned so that the entire plane of die attach was visible: (a) The unenhanced 3DCT scan is tilted forward so the glass body and plug on the cathode side are visible, and (b) To contrast the die attach from the plug in the 3DCT scan of diode 2, the die attach was highlighted blue, and the three cross-section locations are shown in white and labeled 1 to 3.

Figure 11 depicts cross section 1 obtained from diode 2, in which  $\approx 25\%$  of the die has been ground away. Notice that both the physical cross section in figure 11(a) and the digital cross section in the 3DCT scan in 11(b) have solid die attach in the cross-section plane except for a small void slightly right of center and several tiny voids on the far right of the die attach plane. In the 3DCT scan, the tiny voids on the right appear as a dappled area in the die attach.

Figure 12 depicts cross section 2 of diode 2, in which  $\approx 40\%$  of the die has been ground away. Figure 12(a), the physical cross section, and 12(b), the 3DCT representation of the cross section, show a voided left half of the die attach plane except for a small bit of die attach on the left edge of the plane. There is also a tiny void just to the right of the large void, a tiny void approximately three-fourths across the plane from the left, and very small void near the right edge in both representations.

Figure 13 depicts cross section 3 of diode 2, in which  $\approx 65\%$  of the die has been ground away. The left half of the die attach plane is voided except for a small piece of die attach on the left edge in both the physical cross section in figure 13(a) and the 3DCT cross section in 13(b). Figure 13(a) and (b) both show thick die attach to the right of the large void followed by a small void on the right side of the die attach. The 3DCT and physical cross section die attach were in nearly perfect agreement for each slice of diode 2.



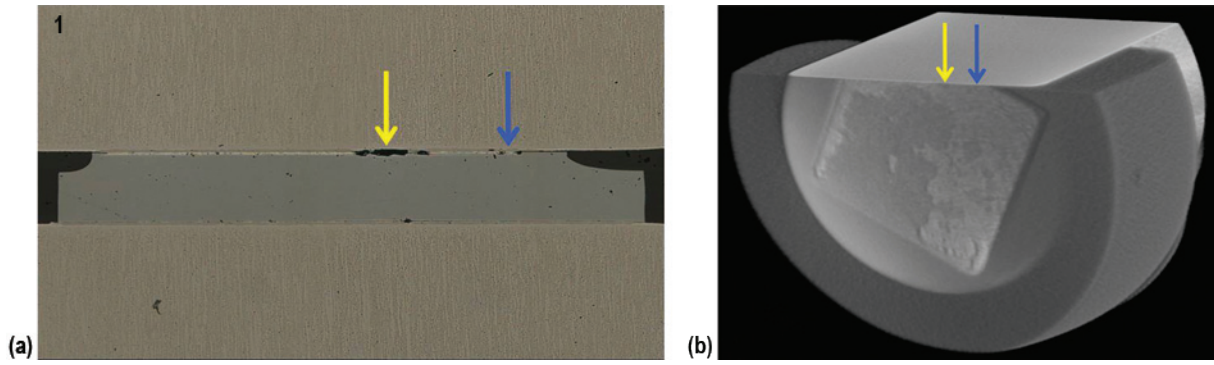


Figure 11. The die attach and voiding in the physical cross section 1 of diode 2 parallels the die attach seen in the 3DCT scan equivalent: (a) The first physical cross section of diode 2 was optically imaged at 10X objective magnification in bright field, and (b) The 3DCT scan of diode 2 was virtually sectioned 25% of the way through the die to correspond to the first physical cross section. Both representations have thick, solid die attach in the cross-section plane except for a void right of center (yellow arrow) and thin die attach with spotty voiding on the right (blue arrow).

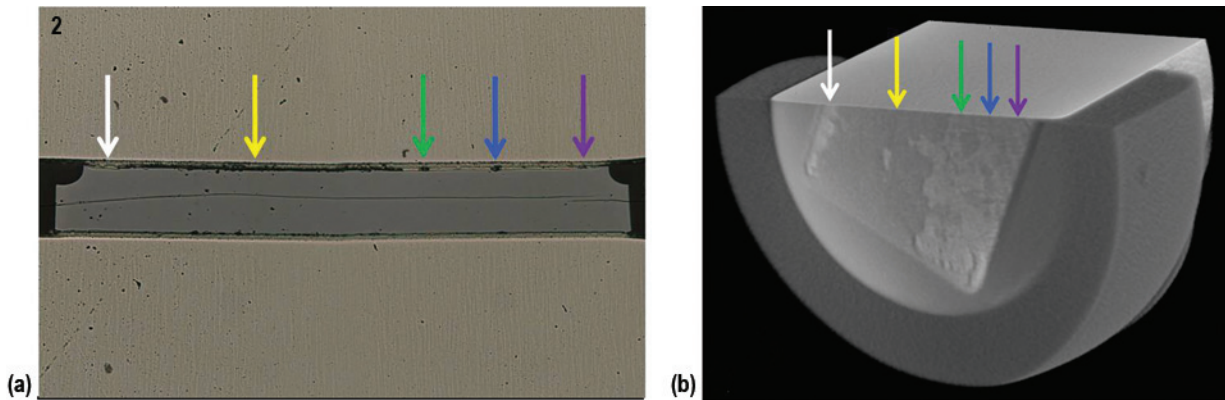


Figure 12. The die attach and voiding in the physical cross section 2 of diode 2 parallels the die attach plane in the 3DCT scan equivalent: (a) The second physical cross section of diode 2 has a cracked die and was optically imaged at 10X objective magnification in bright field, and (b) The 3DCT scan of diode 2 was virtually sectioned 40% through the die to correspond to the second physical cross section. The physical cross section and its digital 3DCT model both show a void stretching across the left side of the plane (yellow arrow) except for a small section of die attach present on the left edge (white arrow). The two tiny voids on the right (green and blue arrows) and the very small void near the right edge (purple arrow) also coincide exactly between the two representations.



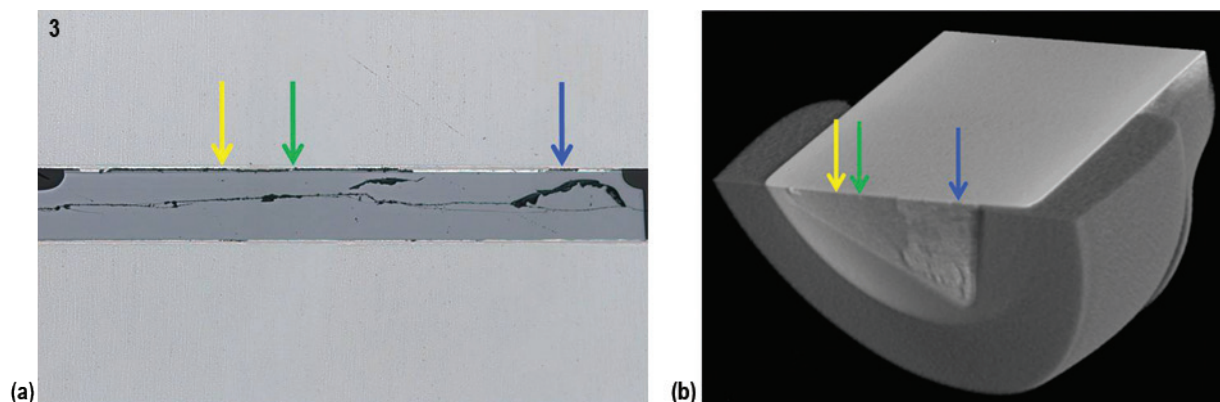


Figure 13. The die attach and voiding in the physical cross section 3 of diode 2 parallels the die attach plane in the 3DCT scan equivalent: (a) The third physical cross section of diode 2 has a cracked die and was optically imaged at 10× objective magnification in bright field, and (b) The 3DCT scan of diode 2 was virtually sectioned 65% of the way through the die to correspond to the third physical cross section. Both the physical and the digital representation have a large void on the left half of the cross-section plane (yellow arrow) with a tiny piece of die attach right of center (green arrow) and a small void near the right edge (blue arrow).

### 4.3 Diode 3

The die and glass body of diode 3 were fractured upon removal from the mold cylinder, so the grinding progression used for diode 3 was augmented to avoid exacerbating the condition. Mechanical grinding began with 600-grit, then 800-grit, followed by rough and final polishing as described in section 3. Starting with a smaller grit ensured milder abrasive cutting which, in turn, minimized die damage that can lead to extensive die attach pull-out.

Figure 14(a) shows the cathode die attach plane in the 3DCT scan of diode 3, part number 1N4942. Whereas diodes 1 and 2 had relatively solid die attach along the edges and large voids in the center, diode 3 is voided around the edges with the die attach centrally concentrated. The edges of the die attach in diode 3 also appear more marked in the 3DCT volumetric model than in the former diodes, so there is little to no areas of mottled, thin die attach. Figure 14(b) shows the enhanced CT scan of diode 1. The die attach is highlighted in blue to delineate the precise boundary of the die attach. White lines across the die attach area correspond to the locations of the four physical cross sections made from diode 3, designated 1 to 4 and pictured in figures 15–18, respectively. The 10× objective magnification, bright field metallograph pictures of the four cross sections and their 3DCT counterparts are shown in figures 15–18. Diodes of the 1N4942 variety are significantly smaller than 1N5550 diodes. The maximum width for a Unitrode 1N4942 diode is 2.16 mm, while the maximum width for a Unitrode 1N5550 diode is 3.68 mm. This is why the 3DCT images of diode 3 are pixelated when displayed at the same size as diodes 1 and 2.

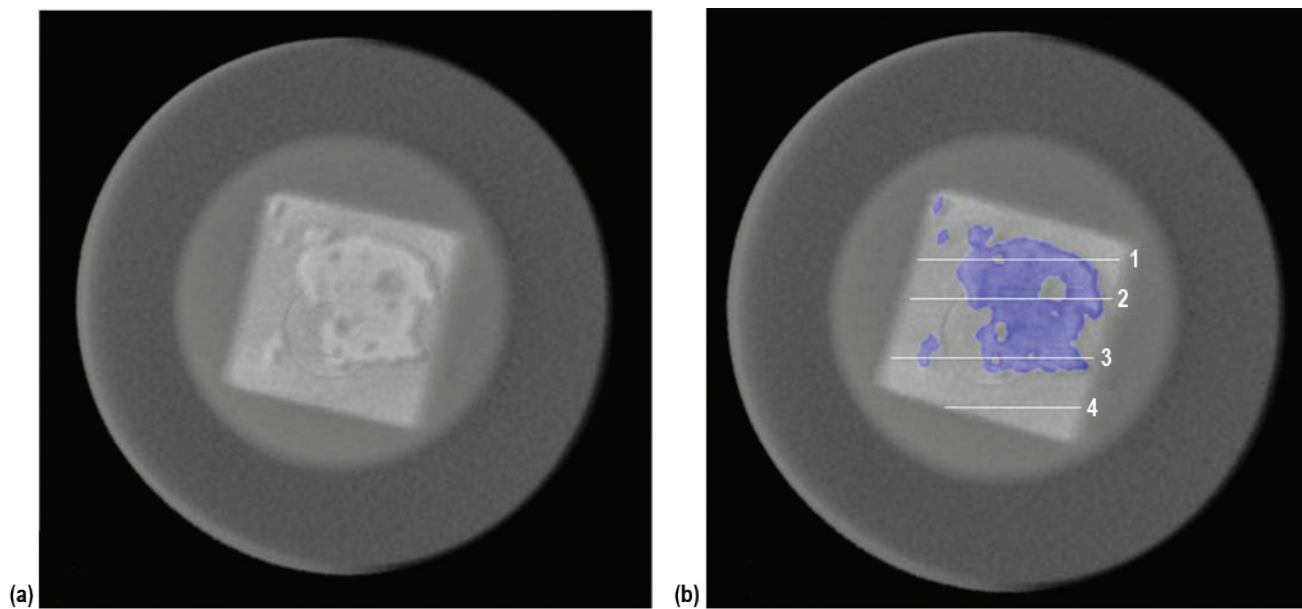


Figure 14. The 3DCT scan of diode 3, part number 1N4942, was digitally sectioned so that the entire plane of die attach was visible: (a) The unenhanced 3DCT scan shows the cathode die attach in the square of the footprint of the mesa of the die, surrounded by the plug and the glass body, and (b) To contrast the die attach from the plug in the 3DCT scan of diode 2, the die attach was highlighted blue, and the four cross-section locations are shown in white and labeled 1 to 4.

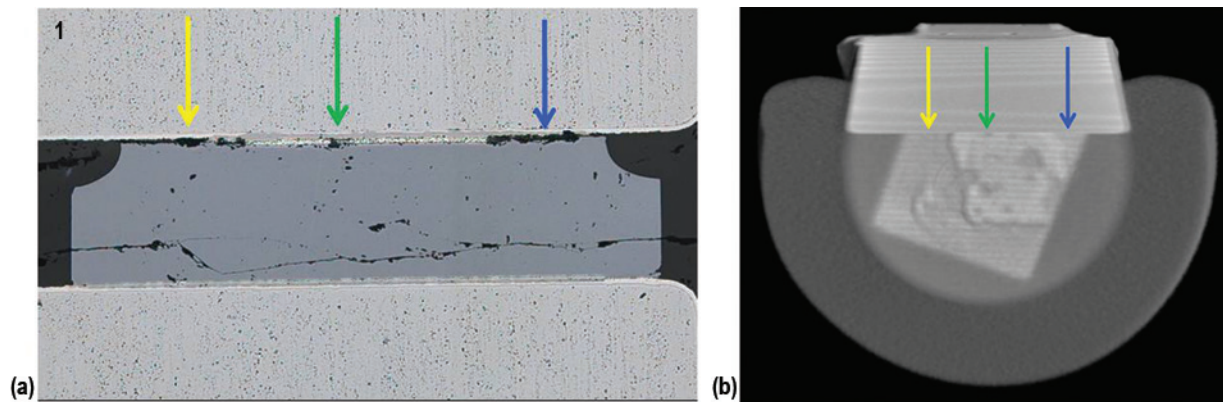


Figure 15. The die attach and voiding in the physical cross section 1 of diode 3 parallels the die attach plane in the 3DCT scan equivalent: (a) The first physical cross section of diode 3 has a cracked die and was optically imaged at 10 $\times$  objective magnification in bright field, and (b) The 3DCT scan of diode 3 was virtually sectioned 25% of the way through the die to correspond to the first physical cross section. Both the physical and the digital representation have voids of approximately equal size on the left and right of the center die attach (yellow and blue arrows) and a tiny void left of center (green arrow).

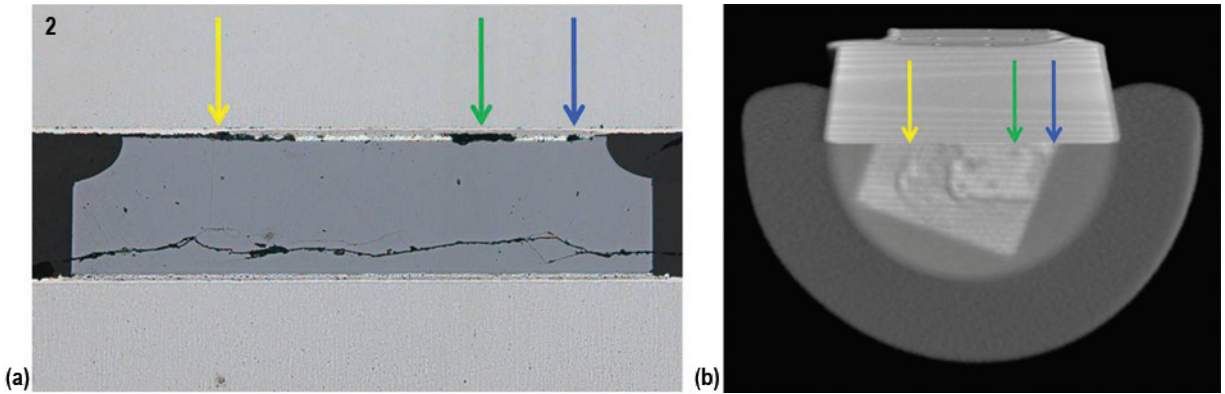


Figure 16. The die attach and voiding in the physical cross section 2 of diode 3 die parallels the die attach plane in the 3DCT scan equivalent: (a) The second physical cross section of diode 3 has a cracked die and was optically imaged at 10× objective magnification in bright field, and (b) The 3DCT scan of diode 3 was virtually sectioned 40% of the way through the die to correspond to the second physical cross section. The large void on the left edge (yellow arrow), tiny void on the right edge (blue arrow), and small void 70% of the way across the die attach plane from the left (green arrow) are all seen in both cross sections.

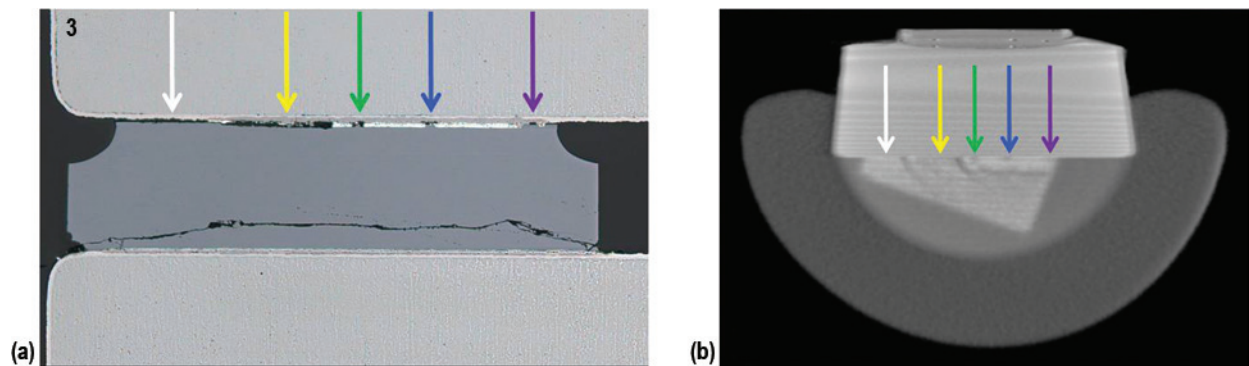


Figure 17. The die attach and voiding in the physical cross section 3 of diode 3 parallels the die attach plane in the 3DCT scan equivalent: (a) The third physical cross section of diode 3 has a cracked die and was optically imaged at 10× objective magnification in bright field, and (b) The 3DCT scan of diode 3 was virtually sectioned 65% of the way through the die to correspond to the third physical cross section. Both representations of the cross section 65% of the way through the die show a large void on the left edge (white arrow), a void of the same size after a small bit of die attach (yellow arrow), two tiny voids in the die attach on the right half of the plane (green and blue arrows), and a tiny void on the right edge (purple arrow).

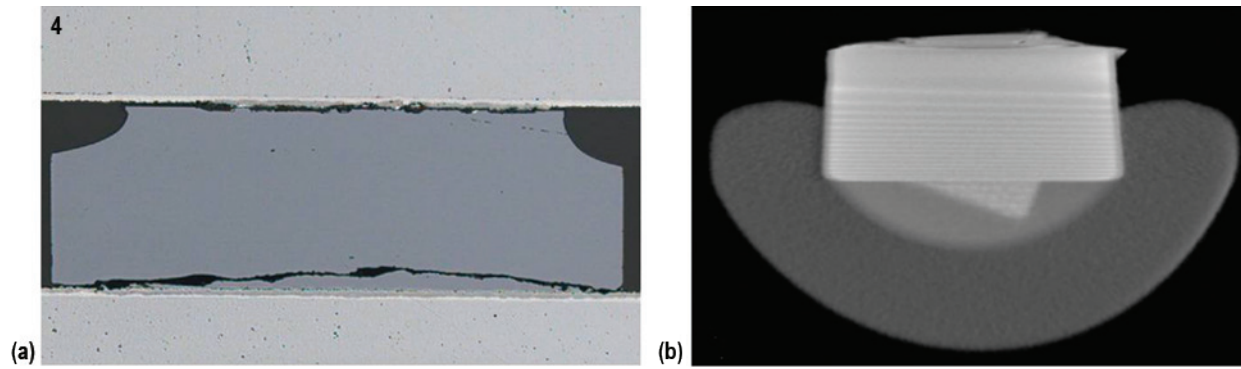


Figure 18. The die attach and voiding in the physical cross section 4 of diode 3 parallels the die attach plane in the 3DCT scan equivalent: (a) The fourth physical cross section of diode 3 has a cracked die and was optically imaged at 10 $\times$  objective magnification in bright field, and (b) The 3DCT scan of diode 3 was virtually sectioned 85% of the way through the die to correspond to the fourth physical cross section. Neither representation of the fourth cross section shows any significant die attach.

Figure 15 depicts cross section 1 of diode 3, in which  $\approx 25\%$  of the die has been ground away. The 3DCT cross section in figure 15(b) parallels the physical cross section in 15(a) in that both show die attach only in the center of the plane and a tiny void left of center in the die attach. The voids on the left and right edges are of approximately equal size in both depictions.

Figure 16 depicts cross section 2 of diode 3, in which  $\approx 40\%$  of the die has been ground away. There are three voids in both the physical and the digital representation of the cross section in figure 16(a) and (b), respectively. There is a large void across the left third of the die attach plane, a small void in the right third of the plane, and a tiny void on the right edge. The small void may be difficult to see in the 3DCT cross section in figure 16(b) because the cross section cuts through the bottom of the void, so most of the void has been sliced away. In the 3DCT cross sections, it is difficult to distinguish the voiding on the edge of the slice because the contrast between the voids and die attach is not as clear as in the physical cross sections. One must evaluate the entire die attach plane in the CT scan to draw hard conclusions about small voids. The voids must be significant enough in size to be clearly visible in the 3DCT scan. Very small voids, especially those smaller than the CT scan resolution of 9  $\mu\text{m}$ , are almost indistinguishable from the pixelation and variance in gray values in the CT scan. This tiny void and other voids that are cut through at the bottom are easier to see in the full plane 3DCT depictions in figure 14 where the entire void is visible.

Figure 17 depicts cross section 3 of diode 3, in which  $\approx 65\%$  of the die has been ground away. Both representations of cross section 3 agree that the left half of the die attach plane is voided except for a tiny patch of die attach present a quarter of the way across the plane. There are two tiny voids in the die attach on the right of the plane on the left and in the center of the remaining die attach. Both physical and digital cross sections also show a tiny void on the right edge.



Figure 18 depicts cross section 4 of diode 3, in which  $\approx 85\%$  of the die has been ground away. There is no significant presence of die attach at this depth. The location of cross section 4 of diode 3 was determined by equating the scale between the metallograph pictures and the CT view of the die attach plane that was established by the previous cross sections. Die attach voiding in the 3DCT scan and the physical cross sections matched well for diode 3.

## 5. ADDITIONAL OBSERVATIONS

Figures 12, 13, and 15–18 show a fractured die. The die of diode 2 (figs. 12 and 13) was fractured during the abrasive grinding, one of the potential consequences of this harsh technique. The die of diode 3 was fractured during its removal from the SamplKups® mold cylinder. Elimination of fractures is sometimes outside the control of the operator because fractures are exacerbated by the voiding in the die attach.

Pull-out is a consequence of abrasive grinding that can lead an operator to incorrect die attach conclusions. The die attach is softer than most of the other materials in the diode, so the abrasive grinding cuts away at the die attach faster. This can lead to chunks of die attach coming out and leaving a hole that resembles a void in the die attach plane. To differentiate between pull-out and voiding of the die attach in the physical cross section, the plug was checked at the location of the missing die attach for the presence of silicides. The presence of silicides without die attach indicates pull-out as seen in the second section of missing die attach in figure 8(a). Because the other cross sections in this study, including those with fractured dies, had no significant pull-out, one can conclude that the physical cross sections match their digital CT equivalents.

Mistakes in accenting the die attach in blue in the 3DCT scan and in slicing the digital diode in VGStudio MAX are possible sources of error for incongruities between the physical cross sections and the 3DCT scans. The die attach in the 3DCT scan was colored blue through an imprecise combination of selecting the die attach by gray values and by hand in Photoshop. Therefore, there are likely small errors in the highlighting, especially for small voids and where the die attach is thin and indeterminate. The sectioning tool in the volume rendering software, VGStudio MAX, is inexact and presents difficulties when attempting precise clipping. The result is that CT cross-section planes may not correspond exactly to their physical counterparts. The notch cut into the diode is effective for general physical to digital orientation, but there could be slight differences between the two. The small size of the diode also amplifies any small errors in the placement of the lines indicating the locations of the cross sections in the CT scans in figures 6, 10, and 14.

There is another technique available to study die attach voiding, the scribe and break technique (MIL-STD-750E, Method 2101.1, 5.2).<sup>5</sup> This technique is typically used to complement cross sectioning, and it requires scribing the glass packaging and fracturing the die intentionally. Unfortunately, this technique does not work well sometimes because the glass packaging may cause the silicon to fracture in undesired locations. This can complicate interpretation of the results and, like cross sectioning, the technique renders the diode unusable.

## 6. CONCLUSIONS

Cross sectioning is not an optimal method for examining die attach in diodes because it is time consuming, is a destructive technique, and can yield questionable results. It takes several hours to days to sample enough cross sections to compile an extensive picture of the die attach in a diode, and even then, slices of the die attach plane cannot provide a comprehensive assessment of the voiding. Additionally, the brittle silicon die is highly susceptible to cracking, and voids in the die attach increase the possibility of pull-out during the abrasive sectioning. This renders failure analysis conclusions questionable in many instances. Slightly angled or uneven polished cross-section planes render it nearly impossible to capture a sharp picture in high magnification due to the low focal length of most high-magnification optical objectives. Potting and sectioning the diode in the cross-section process destroys it.

Despite the errors discussed in the previous section, results from this study show that 3DCT scanning is a superior method for failure analysis of the diode die attach as compared to cross sectioning in terms of time efficiency, retention of diodes, and definitiveness of evaluation. A CT scan yields a complete portrayal of the die attach in less than an hour, and because the technique is nondestructive, the diode is still operable after testing. Because the diode is intact after the scan, 3DCT can be repeated if additional tests on the diode need to be performed. Die attach voiding is clearly visible in the virtual volume model, and, unlike in cross sectioning, the voids cannot be attributed to pull-out. The thickness of the die attach is also discernable from the CT scan. The three-dimensional scan is preferred over the two-dimensional x-ray because the plugs on either side of the die obstruct the view of the die attach and the picture is less distinct and less detailed in two dimensions.





## REFERENCES

1. Maur, F.: “X-ray Inspection for Electronic Packaging Latest Developments,” *Electronic Packaging Technology Proceedings*, ICEPT 2003, Fifth International Conference on Electronic Packaging Technology, pp. 235–239, 2003.
2. “Basics of Tomography,” European Synchrotron Radiation Facility, 2008, <<http://www.esrf.eu/UsersAndScience/Experiments/Imaging/ID22/Applications/Imaging/TomoBasics>>, cited July 8, 2010.
3. Kropas-Hughes, C.V.; and Neel, S.T.: “Basics of Computed Tomography,” American Society for Nondestructive Testing, Back to Basics, 2000, <<http://www.asnt.org/publications/materialseval/basics/may00basics/may00basics.htm>>, cited July 8, 2010.
4. Pacheco, M.; and Goyal, D.: “X-ray Computed Tomography for Non-Destructive Failure Analysis in Microelectronics,” *Reliability Physics Symposium (IRPS) Proceedings, 2010 IEEE International*, Garden Grove (Anaheim), CA, pp. 252–258, 2010.
5. MIL-STD-750E, Method 2101.1, 5.2.1, Department of Defense Test Method Standard, Test Methods for Semiconductor Devices, November 20, 2006.

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14. ABSTRACT  NASA analyzes electrical, electronic, and electromechanical (EEE) parts used in space vehicles to understand failure modes of these components. The diode is an EEE part critical to NASA missions that can fail due to excessive voiding in the die attach. Metallography, one established method for studying the die attach, is a time-intensive, destructive, and equivocal process whereby mechanical grinding of the diodes is performed to reveal voiding in the die attach. Problems such as die attach 'pull-out' tend to complicate results and can lead to erroneous conclusions. The objective of this study is to determine if three-dimensional computed tomography (3DCT), a nondestructive technique, is a viable alternative to metallography for detecting die attach voiding. The die attach voiding in two-dimensional planes created from 3DCT scans was compared to several physical cross sections of the same diode to determine if the 3DCT scan accurately recreates die attach volumetric variability.					
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