COMPUTED TOMOGRAPHY ON ELECTRONIC COMPONENTS BETTER WAYS TO DO FAILURE ANALYSIS PLUS 4D CT THE NEW FRONTIER

Wesley F. Wren
North Star Imaging
Rogers, MN, USA
wwren@4nsi.com or wrenwesley@hotmail.com

ABSTRACT

In the decade past, Computed Tomography has been anunderutilized modality. With the exceptions of failure or quality issues related to safety critical or very expensive components, CT was seldom used. Use of computed tomography systems in the industrial market continues to rise. This recent Shift in paradigm has been attributed to the technologic advances made in digital detectors, new scintillators, better resolution, faster frame rates, and improved bit depth. Most crucial to the growth of computed tomography systems have been the evolutions of better computers, utilization of graphic processing units, along with user friendly software. The
proliferation of technology and popularity has allowed the cost of equipment to go down while the acquisition and scan times have dramatically improved.

The new detector technology and computers have allowed for scanning of low density martials inside denser packages that have been almost impossible in the past. This has really opened some doors on what can be done to monitor and understand the integrity of bond wires and via's in electrical components that are being manufactured with aluminum.

The combination of improved computers, detectors, and new software has even allowed the addition of a fourth dimension to a computed tomography data set. Now days a Computed tomography scan on low density material can be done so fast that it allows the element of time to be added in. Making it possible to do a scan of certain parts and watch components move or fluid flow once the 4D computed Tomography scan is reconstructed.

INTRODUCTION

Over the past few decades, Computed Tomography has undergone a significant period of evolution. As recent as five years ago, CT was viewed by many as a slow and cumbersome imaging modality [3]. However, as computational power and speed continue to improve, that perception has begun to change. The ever increasing power of computers has led to faster scan times and reconstruction speeds, as well as more powerful analytical tools. Today, CT has become a proven choice for many applications including failure analysis, metrology, and reverse engineering applications.

The growth in computed tomography has been complemented well by the development of image evaluation software tools. Many of these software tools aid in the process of getting useful data such as volumetric analysis or void calculation. Other software packages paired with quality CT scan data will help cut down on the time to reverse engineer parts. As advancements in computational power continue, 3D software applications and detector technology continue to evolve. These advancements have allowed for inspection of lower density and smaller high density materials that were not previously possible [see figure 6 and 7]. It has also allowed more studies to be performed through reduced scan times and improved accuracy without damaging the integrity of the test specimen. The evolution of 4D CT makes it possible for us to not only study static components, but motion versus time as well. This dynamic volume imaging opens up endless opportunities for expanding our knowledge of product and processes to levels never previously understood or previously proven. This technology has immediate applications in failure analysis and design, and will rapidly be applied in development testing, and inspection areas.

Key words: 4D CT, Computed Tomography, Contrast Sensitivity, and CT

THE SPEED OF COMPUTED TOMOGRAPHY

The first computed tomography system was introduced in 1972 by Godfrey Hounsfield, five year after he had first conceived the idea [1]. Early medical CAT scanners used supper computers where almost a whole room was filled with clusters of central processing units (CPU's) in order to compute the data that was collected, but it was not fast enough for most industrial applications. The lack of speed and great expense were cost prohibitive for most manufactures. However over the last 10 years the return on investment has gone up with the capability of single chassis computer with multiple graphic processing units (GPU's) computing things at speeds that continuing to accelerate. System now days are being used in line with automatic defect recognition on certain parts where data is being collected, reconstructed and software is making the call out in less than 6 seconds [2].

ELECTRONIC COMPONENTS GETTING SMALLER

Electronics components are evolving into smaller packages. This is one of the reasons why high resolution computed tomography images are even more important. With smaller electronic components it is critical that we are able to see inside of the chips and look at the boards before they are destroyed. This allows us to preserve the data and better understand where to look if cutting the part for inspection is even necessary. Figures 1 through 4 show computed tomography results of large and small parts, demonstrating how a CT scan can reveal useful data on a variety of different sized components. As components get smaller they are still being integrated into lager end products. This makes it essential to have the flexibility in the equipment to scan larger and smaller parts with optimum precision, because this allows industrial companies to see faster returns on their investment into this technology by being able to utilize it in a broad array of applications. Figures 1 through 4 are examples of scans that are being performed in less than an hour on various parts when optimized for resolution and contrast. This increase in through put along with the continued improvement of resolution and contrast is making CT technology something that most industrial companies will be able to benefit from now and into the future. These benefits will be realized in reverse engineering, failure analysis, finite element analysis, metrology, CAD to actual comparisons, as well as other areas

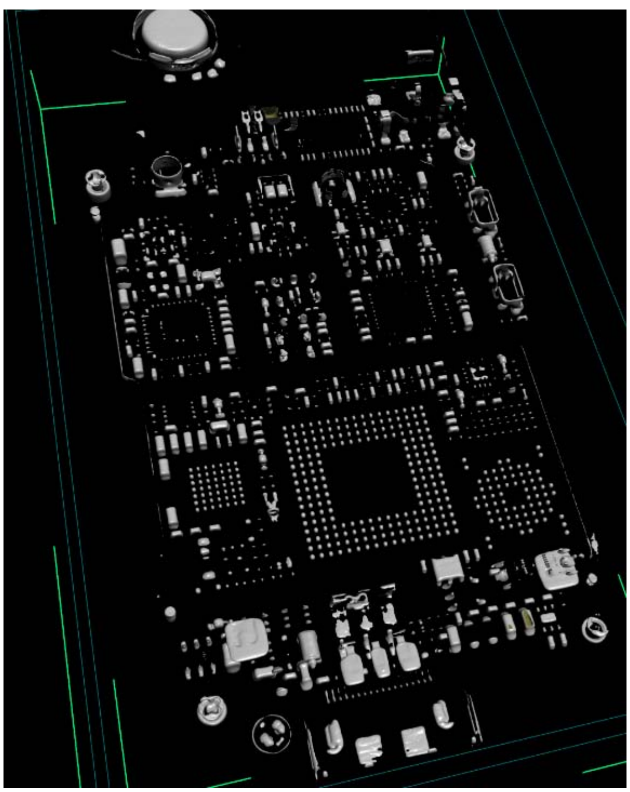

Figure 1. Cell Phone CT Images

Production CT inspection of some components has begun and will continue to utilize CT technology as scan times continue to accelerate [2]. With continuous scanning and faster computers results can be produced in a few seconds on smaller less dense products. When the speed begins to increase down to this level the result will be a loss of some resolution and contrast sensitivity. How ever the data is often times more than adequate as shown in figure 5 on and IC chip that was scanned in under a minute. This makes optimization of a production system product, and criteria dependent, which means most fully automated inline CT application will entail a certain level of software customization.

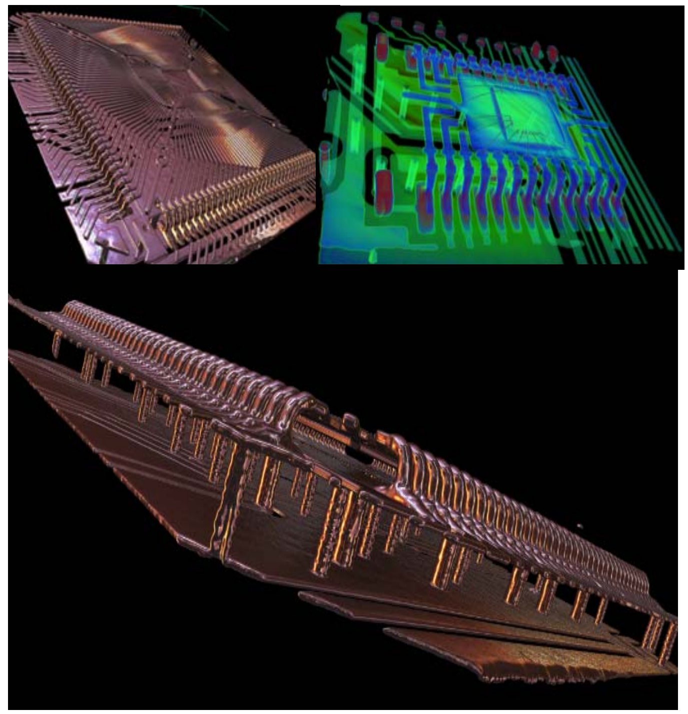

Figure 2. Component Level CT Images

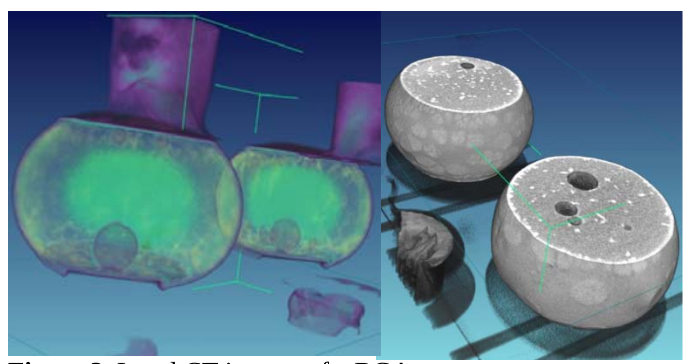

Figure 3. Local CT images of a BGA

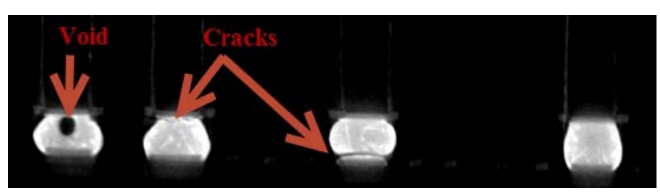

Figure 4. CT Slice Showing a Void and Cracks on BGAs with Enough Senility to also show the vias and pads

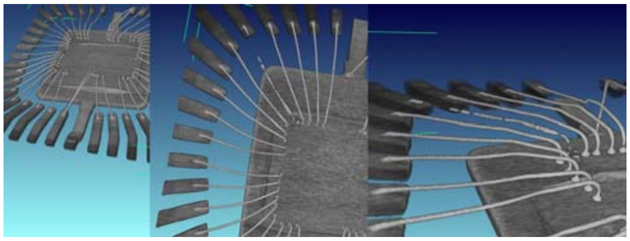

Figure 5. CT Scan Done in Under One Minute Showing a Failure on one of the Bond Wires

Images 2 through 4 illustrate the resolution that can be achieved when imaging smaller objects or local areas with optimum settings. Accomplishing this is possible through increasing the amount of geometric magnification, along with improved contrast sensitivity due to less material being penetrated. Contrast sensitivity and geometric magnification are critical variables in discerning many features of interest.

CONTRAST SENSITIVITY

There are a number of variables that contribute to improved contrast sensitivity in a sample:

1. Material thickness is a vital part in determining what the contrast sensitivity will be. Taking two data sets of the same material, and scanning them at the same resolutions it is clear that the thinner sample would show better contrast sensitivity on a similar void then the thicker sample.

2. Density of material is a key factor in determining whether the contrast sensitivity will be great, average, or poor. Less dense materials show better contrast sensitivity than higher density materials. Highly dense materials require higher energies resulting in a larger percentage of density change in the material in order to see a difference. Whereas low density material like composite or plastics can see subtle changes in the density of the materials.

3. Scanning energy is also a key factor. The lower energy utilized for scanning the sample while still pulling the proper grey scale values the better the contrast will be [5]. One key factor in this is the ability to move the detector closer to the tube, because the numbers of photons that make it to the detector increase by a factor of four. The inverse square law applies to the tube to detector distance [4]. For example if you have 20 inches versus a 40 inch tube to detector distance it will get 4 times the photon count to the detector. Giving the CT technician the chance to either decrease the scan time, or lowering the energy. Lowering the energy will produce better contrast sensitivity. Figure 4 above is a great example of what can be detected when utilizing tube to detector distance reduction to increase contrast. Samples similar to this are often done with a 40 inch or longer tube to detector distance. However, the example shown in figures 6 and 7 were done with less than a twenty inch tube to detector distance.

4. Pixel Pitch is another variable that can affect the contrast sensitivity. The larger the pixel size, the more photons it is able to collect. This results in better contrast resolution while giving up some resolution.

5. Many other variables can play a role in the contrast sensitivity such as BIT depth and scintillators as well.

A technician must consider all of these variables when optimizing a scan for contrast. This is a skill that requires fair amount of training, and practice to optimize your results full potential.

OPTIMIZING CONTRAST FOR ALUMINUM BOND AND TRACE WIRE INSPECTION

When optimizing for the detection of Aluminum Bond wires all of the things discussed our vital in being able to inspect them for failures. Due to the low density of aluminum versus gold wires it is more critical to understand, and utilize all the variables discuss above for superior results. Below in figures 6 and 7 you will find some images of an IC that has aluminum bond wires in it. The bond wires were detectable with longer scan times, shorter tube to detector distance, cesium scintillator was used, and the energies where kept as low as possible while achieving good grey scale values.

The data below clearly demonstrates that utilizing Computed Tomography data in imaging Aluminum Bond wires is possible, but the likelihood of success will depend heavily on the size of the package and density of the outer material. In Figures 6 and 7 you will see that one is illustrated utilizing a black and white histogram and the other was done with a color histogram. Taking a close look at the images one will see how utilizing color can help improve the visualization process.

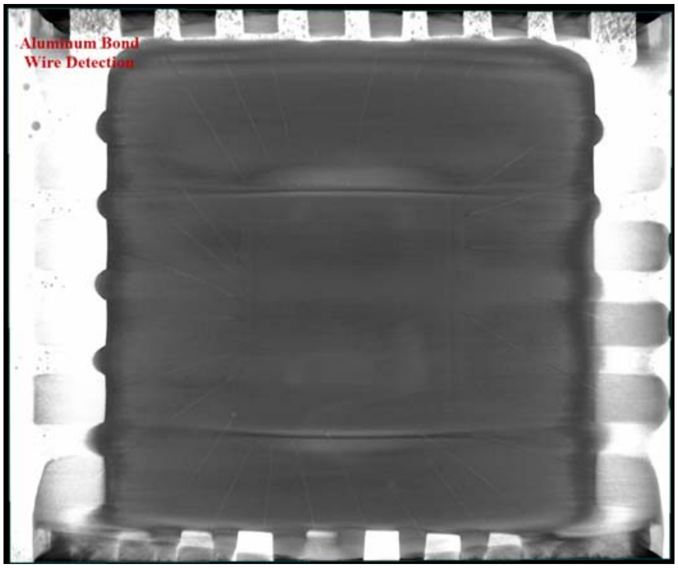

Figure 6. CT Image Showing Aluminum Bond Wires Inside a Package Utilizing the Black and White Histogram

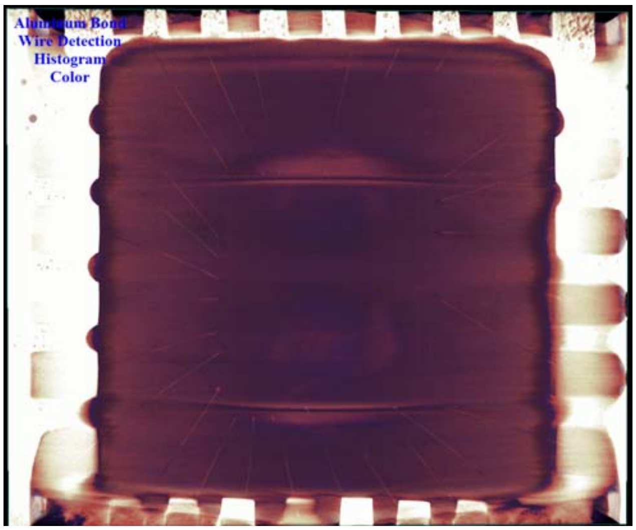

Figure 7. CT Image Showing Aluminum Bond Wires Inside a Package Utilizing a Color Scale Histogram

When you compare the data from the aluminum bond wire scans in Figures 6 and 7 to the scan of the IC with the gold bond wires in figure 5. It is definitive as to how simple it is to create a good data set on gold bond wires versus aluminum bond wires. The gold bond wires in figure 5 as stated were scanned in under a minute versus the Aluminum Bond wires being scanned in just over an hour.

The IC with the gold bond wires due to the easy of detection could be scanned utilizing the continuous process. The continuous process is when images are collected and the part continually moving versus a step scan were the part will turn, stop, acquire. This allows for some frame averaging which makes for cleaner x-ray images. Better x-ray images with more contrast will help improve the CT scan data. This makes it imperative that components with aluminum bond wires be scanned utilizing the step scan process to obtain optimum results.

This proposes a big question to the industry when it comes to safety critical components. Does it make more sense to build these components with a material that allows their integrity to verified, or is there an advantage of designing components to be manufactures out of aluminum? Building Chips out of aluminum will help ensure that the chips are more difficult to reverse engineer. This could help reduce the number of counterfeit components finding their way to market, which is problem that continues to grow.

4D COMPUTED TOMOGRAPHY

4DCT is a process that takes a number of scans consecutively on a product or sample as some variable of movement is applied. Examples range from fluid being dispersed through a product, a component moving in a part at a relatively slow rate, or a male and female connector being merged together.

As an example application two connectors could be merged together while acquiring the multiple data sets. Most 4D applications require a fair amount of preparation as in this example we may have to manufacture a device to help marry the male and female connectors together at a rate that would be slow enough to gather adequate data as the part is continually. This will ensure the results will be useful and one can see the change occurring upon reconstruction, and the video being made. Once you have the device set up and you begin scanning the connectors as they are slowly being merged you will do multiple scans in arrow. Once the scans are done the reconstruction software allows you to play this in a video format, so you can visualize the interaction or changes occurring in the part or specimen.

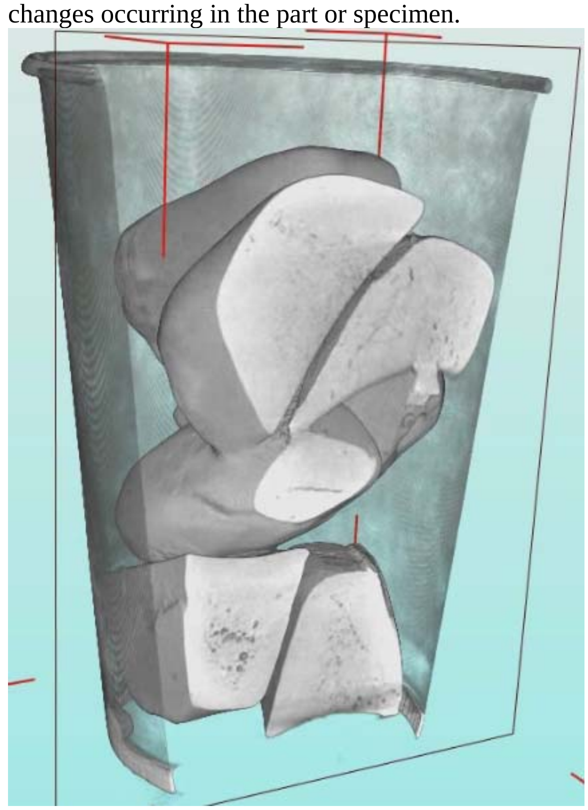

Figure 8. Ice at the Beginning of the 4D CT Scan.

Figure 9. Ice at the Halfway Point of the 4D CT Scan.

4D CT is in its infancy, but could be very useful tool in helping us better understand how certain products interact. Products that lend its self well to 4D CT our typically lower in density and the components of interest usually move at a slow speed. Some application that fit the build would be a slowly occurring chemical reaction, fluid distribution at a controlled rate, switches, or any small component with moving parts. As this technology continues to evolve, so will the possibilities and ideas for new applications.

Figure 8 and 9 above show a plastic cup filled with ice that is being scanned while it was melting. The images only give you part of the story. To really understand how valuable this data can be one must see it in a video where you can witness the ice melting.

In figure 10, 11, and 12, you will see one more sample of 4D CT that demonstrates the versatility of the various applications. In this component it is easy to see how monitoring the interaction of parts could be useful in understanding ways to improve products and resolve issues that are related to failure.

FORESEEN ADVANCEMENTS IN TECHNOLOGY

Two advancements that appear to be coming down the road that will further the capabilities of computed tomography are faster computers and detector improvements. With the advancements in detectors having better resolution, bit depth, and speed there is a growing need for more storage space and faster computation. Luckily computational speeds and storage devices continue to grow. Presently, it is not uncommon for a single high resolutions data set to be more than 50 gigabyte in size. This will continue to be a big concern due to some of this data needing to be saved for the life cycle of the part. This current environment we work in storage capabilities do not be seems to be growing fast enough to keep up.

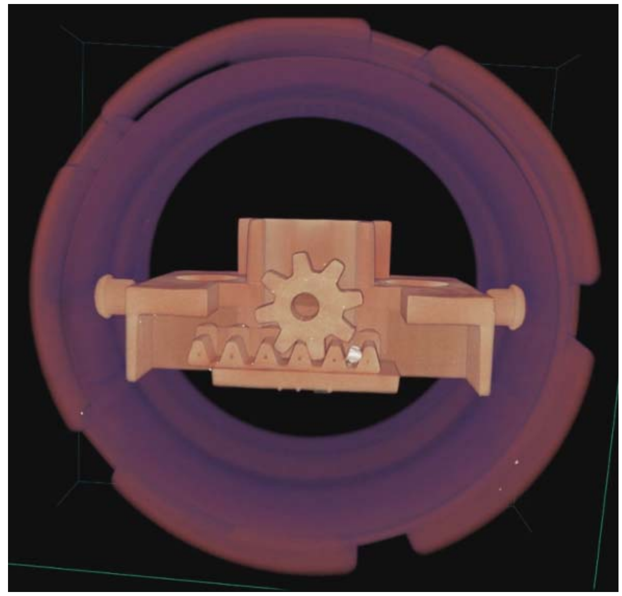

Figure 10. View 1 of 3.

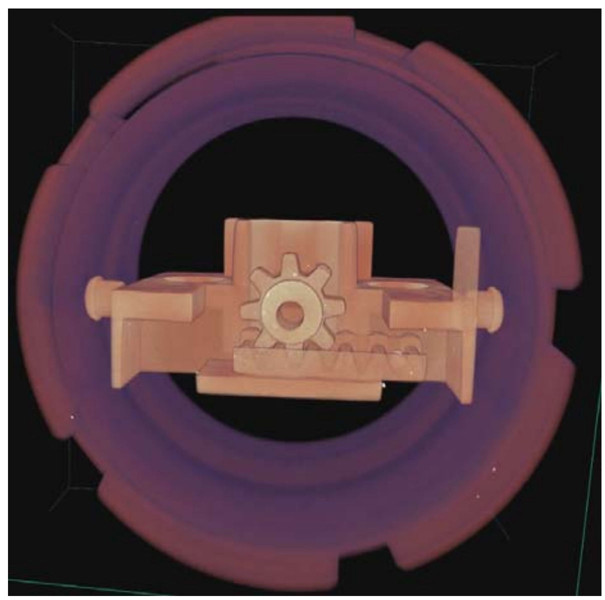

Figure 11. View 2 of 3.

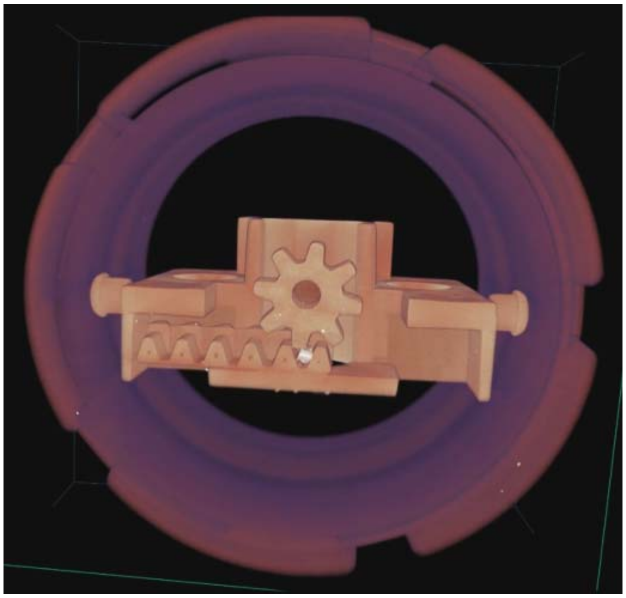

Figure 12. View 3 of 3.

CONCLUSIONS

Computed tomography is a valuable tool that is growing in use and functionality for many applications. With the ever increasing capabilities of computers and the advancements of the detector technology it is clear that CT will continue to see increases in speed, contrast sensitivity, and special resolution. These improvements will allow for better imaging of smaller products with a faster through put time. Do to this many industries and companies will be looking into CT technology as the return on investment improves with more and better data.

4D CT will begin to play a much larger role in the learning more about the functionality of parts, and different processes. Applications in areas never thought of before will begin to be explored with this technology.

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