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Automating C-SAM® Process Control - From the Lab to the Fab and Back-End

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ABSTRACT

Acoustic Microscopy (AM), and specifically C-SAM®, has been utilized by labs within the microelectronics industry for failure analysis and quality assurance testing of front-end and back-end for many years. As manufacturing processes have become more critical, more costly and higher yields desired there has been a push toward more integrated process control systems.

Initially standard C-SAM lab systems were utilized with skilled operators trained to inspect and interpret the results. As volume increased improvements to the through put were made by simplifying the operator handling of devices/parts to be screened in trays for modified laboratory systems. Eventually the increases in the volume of device/parts lead to operator fatigue, leading to poor interpretation of the data and miss-handling.

Initially full automation of a C-SAM system was done for front-end processes, such as the bonded wafers, for all handling, staging, scanning, drying and analysis functions. An application engineer sets-up the scanning and analysis recipes upon installation. Technicians load the systems, if AGV/OHT is not implemented, and based on the lot information the proper recipe is downloaded from the Host and data for the lot is sent back via the SECS/GEM protocol.

As the push for process control into the back-end and mid-end has increased an automated C-SAM had been developed for those manufacturing processes, too. Controls have been added to monitor and compensate for small variations and to match systems from site to site for consistent, reliable data for total process control.

This paper will discuss the development of the C-SAM systems and controls that can be integrated into a microelectronics manufacturing process to ensure your control limits and higher yields.

Key words: Acoustic Microscopy, AM, C-SAM, process control, front-end, mid-end, back-end.

BACKGROUND

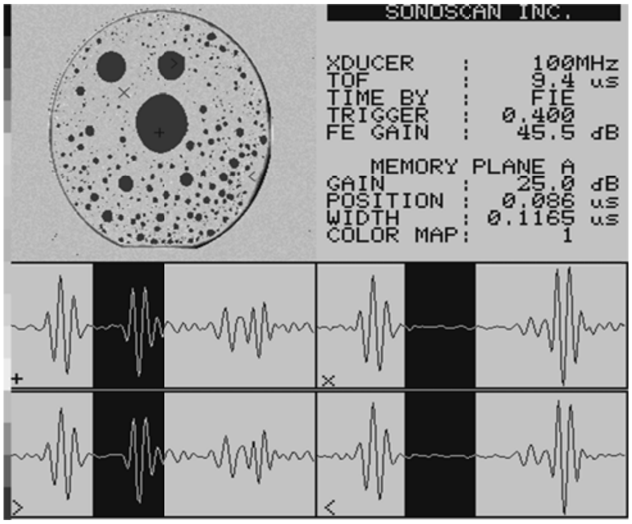
C-SAM and Acoustic Microscopy (AM) in general are a form of ultrasonic testing that typically utilizes sound waves with higher frequencies, in the mega-hertz (MHz) range. The higher frequencies have smaller wave lengths providing more detail and are more sensitive to material properties.

All reflection mode based AM systems start off with one basic piece of AM information called the A-Scan. The A-Scan is obtained by sending a pulse of acoustic energy from a transducer and into the sample under investigation at a specific X-Y location and then looking for the return of any echoes. Depending upon the construction of the sample/device, there can be multiple echoes or a single echo from the backside, assuming a solid, defect free material. The returned echoes make up the A-Scan and are typically displayed on a digital oscilloscope.

The echoes can be interpreted, since any interface between two materials within a device will cause some of the acoustic energy to reflect back (echo) to the transducer. The amount (amplitude) and form (polarity) of the returned energy is dependent upon the differences between the acoustic properties of the materials, in particular the acoustic impedance (Z) mismatch.

Acoustic impedance (Z) is a physical property based on the velocity of sound and density of the material. When two materials are bonded together, the amount (amplitude) of energy reflected is based on the difference between the two materials' acoustic impedances. A large difference will cause most of the energy to be reflected back to the transducer and a small difference will allow most of the energy to be transmitted to the next material. This data is obtained from the amplitude of the A-Scan at that interface.

The polarity of the A-Scan tells additional information. If the polarity is positive, we know that the first material has a lower acoustic impedance than the second material. If the polarity is negative, we know the first material has a higher acoustic impedance than the second. A simple example would be two silicon wafers bonded together, as shown in Figure 1.



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     SONOSCAN INC.

XDUCER    :   100MHz
TOF       :    9.4 us
TIME BY   :    FIE
TRIGGER   :  0.400
FE GAIN   :   45.5 dB

   MEMORY PLANE A
GAIN      :   25.0 dB
POSITION  :  0.086 us
WIDTH     : 0.1165 us
COLOR MAP:       1
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Figure 1. A-Scans and a C-Mode image of a bonded wafer pair. Two A-Scans marked "+" and ">" indicate no bonding between the wafers at those locations. The other two A-Scans, marked "X" and "<" show no reflection from the interface between the two wafers and only from the back surface of the second wafer.

Two properly bonded silicon wafers would not have any reflection from the interface, since they are the same materials; most of the energy is transmitted to the second silicon wafer. If the first wafer is not bonded to the second, some gap exists, which could contain air or be a vacuum. In either case, most of the energy would be reflected back and would have a negative polarity. It would be negative since silicon has a high acoustic impedance and air/vacuum is low, practically zero. [1]

With this information collected at all X-Y locations of a device, you can image the locations of defects in the X, Y and Z directions within the device. The most common image type is called a C-Mode, an X-Y plane at a particular depth Z within the part. Further processing of the data can provide non-destructive cross sectional information and other forms of images/data for evaluation, too. Most of the automated systems utilize C-Mode images captured at a specific depth for analysis purposes.

Initial C-SAM Lab Systems

The first system was developed as part of the "Star Wars" program under then President Reagan in 1984. Sonoscan developed a reflection, C-Mode scanning acoustic microscope (C-SAM) to inspect the bond of a 4 foot diameter, conically shaped mirror.

The mirror consisted of a layer of copper bonded to a molybdenum base that had cooling channels running throughout it. Those cooling channels did not allow through transmission of ultrasound, so the current Scanning Laser Acoustic Microscope (SLAM)® technology could not be utilized. A new, reflection mode technology was designed with a contour following water squirter system to slowly image the full surface of the 4 foot bowl shape for any non-bonded areas of the copper to molybdenum. Small non-bonded regions would cause the mirror to overheat and melt when hit with the laser intended to knock out a missile in space.

Approximately one year later the first commercially available C-SAM lab system was introduced by Sonoscan. It was mainly a hardware driven technology, since computing power was fairly novel and limited in the mid-1980s. Scan areas were limited to about a 3 x 3 inch scan area, the A-Scan was displayed on an analog oscilloscope and images were displayed on a CRT screen. There were no color digital printers, only Polaroid® instant film or 35mm cameras mounted to a hood over the CRT screen to capture the color mapped images of defects within a device. C-SAM was a technology waiting for other technologies to catch up.

Over the years CPU and memory chips evolved, along with microelectronics in general. The development of these chips and microelectronics provided a market for C-SAM lab systems, provided the technologies to improve the capabilities of the lab systems and eventually allowing them to evolve into process control systems, too.

Fast Automated C-SAM Tray Scanning System (FACTS^2 ™)

The first commercial automated version of C-SAM was introduced in 1997 to scan devices in trays, JEDEC or metal, at a rapid rate as the trays passed along a conveyor belt system from an unloader into the acoustic scanning section, to a dryer section and then back out to a loader. Turning a lab technology into an automated inspection system required several innovations before it became practical. One of the key innovations was the WaterFall Transducer™.

With a typical C-SAM lab system a device under investigation was immersed in a tank of DI water. While this technique was adequate for handling loose devices, it was not practical for trays of devices since they would simply float out of the tray as it entered the tank of water. Sonoscan had experimented with several methods of submersing a tray of devices into the water and even offered an autoloader mechanism for inserting a single tray of devices into a laboratory C-SAM system. The autoloader also included a function to help shake away the air bubbles that commonly formed on a surface as it entered the water tank.

A better solution was needed to provide the water coupling needed for acoustic imaging without submersion, so Sonoscan went back to its reflection mode roots, a water squirter system that was now above and perpendicular to the surface of the device being imaged. A falling water acoustic imaging technique, now known as a WaterFall Transducer.

A special housing is placed around a standard immersion transducer that provides water coupling between the transducer and the device under test via a steady stream of water as the transducer was scanned over a tray of devices, as shown in Figure 2. This technique worked well for most devices, since they would stay in the trays and not float. However, some trays would have pockets without cutouts, so those areas were not initially populated. As devices became smaller and/or lighter a specially slotted plate was developed that allowed a part to be imaged while still held in place outside the area of the WaterFall Transducer movement.

Figure 2. Example of the WaterFall Transducer™ used in C-SAM® automated systems. It provides acoustic imaging without immersion into a water bath.

A second advantage of the WaterFall Transducer technique was the elimination of the air bubbles that commonly clung to a device when it is immersed in DI water. Many of our lab system customers have experienced this and are taught to use small paint brushes to gently wipe away the bubbles from the device surfaces. Those people may have also used a water squirt bottle to push those bubbles out of the way with the stream of water coming from that bottle. Well, the WaterFall Transducer has that same affect, washing away any bubbles with the stream of water coming from it and touching the device.

Another innovation was the drying of devices in the trays once they were wet. While the use of the WaterFall Transducer did reduce the amount of water present after scanning, they were still wet. So a three (3) stage drying section was added into the automated system. It included stages of air knifes and vacuum to push and suck the water from the carrier trays. Obviously some tray designs are inherently designed to dry easier, while others had deep pockets that would still retain some. If allowed based on the temperature limits of the carrier tray, the addition of heated air to the air knifes helped remove the remaining water from those pockets.

With an automated system you would also expect automated analysis of the acoustic images. At first operators were used to make judgment calls of acceptable or not based on the AM images of the device. However, operators do not consistently make the same judgment and prone to fatigue.

Since there are a large variety of device types, simple analysis functions, such as a percentage (%) of an area were provided initially. This data could then be saved into a common data file format called CSV, which is still used today, and imported into spreadsheets or other programs for statistical analysis. Naturally users wanted more sophisticated analysis methods and accept/reject criteria added to make the automated C-SAM system even simpler to use, to eliminate operator to operator variances and poor judgment calls.

These requests led to the development of specialized analysis techniques, such as one for Flip Chip devices. An Automated Image Analysis (AIA) function was developed to determine not just percentage (%) of bond area, but to determine good and bad cells and enclosed bumps within the pattern of the flip chip bumps. The full technique was presented at a Toronto SMTA symposium [2] several years ago. In brief, the technique included finding the bump locations, making a “cell” based on four (4) of those bumps, determined if a cell was “bad” or “good” based on the amount of voiding in that cell and then determining if a bump was enclosed enough or not, as shown in Figure 3. This worked well for a bump region of regularly spaced solder bumps.

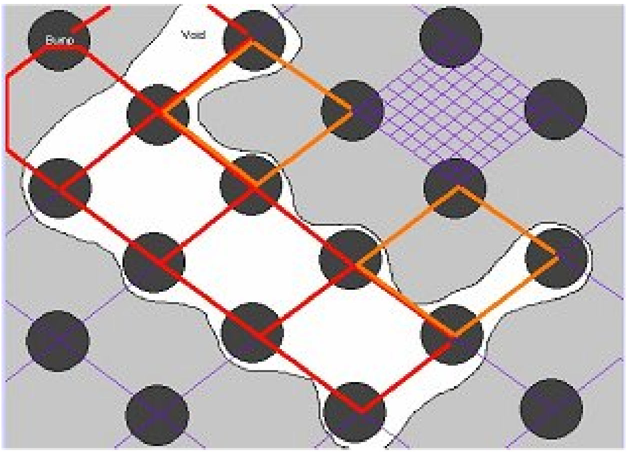

Figure 3. Diagram of how a “cell” was defined by four (4) solder bumps and how bad cells determined if a solder bump was being supported or not.

Additional requests over the years have led to more specialized automated C-SAM systems and capabilities to screen a variety of devices and sub-assemblies with more consistency, eliminating operator intervention and variances.

FRONT & MID END PROCESS CONTROL

The automated C-SAM systems have evolved into two (2) versions of systems, a more sophisticated version of FACTS Systems (FACTS^2 ™) and an Automated Wafer (AW Series™) system. The AW Series is designed specifically as a parallel processing system for handling wafer level products or similar form factors. This includes, but limited to; unpolished wafers, polished wafers, bonded wafers, chip-on-wafer, MEMS cavity seals, multi-layer LEDs, sensors and ceramic discs. Virtually anything that you can put into a FOUP, FOSB, SMIF or Cassette wafer carrier and the wafer is 100 to 300mm in diameter. For the purpose of this paper the word ‘wafer’ will be used generically for any of the wafer level products.

The wafer level products are docked to the AW via a BOLTS compatible loadport for the various types of carriers. From that point forward the parallel processing of an AW system is fully automated with a dry wafer out and back into the carrier process. Figure 4 shows a typical layout of an AW system status window.

Wafers are located within the carrier and removed individually by a robot with a vacuum assisted end effector that will alarm if the wafer cannot be properly handled due to a poor vacuum, perhaps due too much warpage, etc. Once properly gripped by the robot the wafer is aligned for scanning on one of two scan platforms in the Acoustic Imaging Module (AIM) section of the system. The first set of wafers is placed directly on to each of the two vacuum assisted platforms and scanning starts per the selected recipe.

While the first set of wafers are being scanned, the second set are removed from the carrier, aligned for the scan platform and placed in a pre-stage area.

Upon completion of the scan of the first set of wafers, an air knife blows off the bulk of the DI water on the top surface, then wafer #1 is removed from its scan platform and placed into a spin dryer, where the rest of the water is removed. While wafer #1 is drying, wafer #3 from the pre-staged second set is placed on the open scan platform. Then wafer #2 from the first set of wafers is placed in the staging area. Wafer #4 is taken from the pre-stage area and placed on the other scanning platform and the scanning of #3 & 4 wafers starts as per the recipe.

When wafer #1 is removed from the spin drier it is aligned for placement back into the carrier dry. Wafer #2 is taken from the staging area and placed into the spin drier. While wafer #2 is drying, wafers #5 & 6 are processed and placed into the pre-stage area. Upon completion of spin drying wafer #2 is aligned and placed back into the carrier dry. This parallel process continues on until all of the wafers in the carrier(s) are scanned and analyzed per the recipe chosen.

By the time the wafer is placed back into the carrier it has been analyzed by one of Sonoscan's digital imaging programs and either accepted or rejected based on your criteria. Some of the more popular analysis programs are simple % bond or disbond of a whole wafer; Die Mapping for determining if individual die meet the criteria and; Cavity Seal Analysis (CSA)™ for determining the minimum width of the seal for each device on a wafer or if the seal has a direct opening.

With the SECS/GEM platform on the AW system, it is possible to communicate the ID of the wafer level product(s), have the HOST choose the recipe/analysis function to be run and report the results back to the HOST. The system also has the ability to keep log files of its actions for reference if issues due occur.

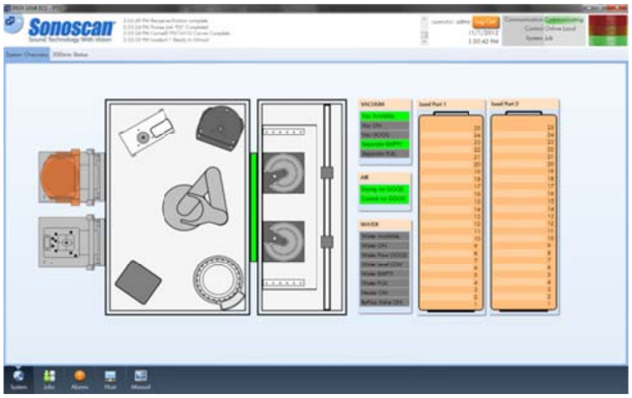

Figure 4. Typical layout of the status window on an AW Series™ system.

BACK END PROCESS CONTROL

Several generations of FACTS Systems have evolved into the latest model, DF2400™. We have learned from past versions, customer requests and from the challenging new electronics devices seen over the years in our SonoLab™. A fully controlled DF2400 system includes the abilities to manage water conductivity, temperature and flow rate; the vacuum pressure used to hold devices in place during scanning and/or drying; the air knifes' air flow rate, temperature and time; C-Mode or THRU-Scan™ imaging with or without vacuum hold down; Device out-of-pocket sensing; Dual X-Y scanners; System long term stability monitoring; and SECS/GEM capabilities. Everything you need on a C-SAM based process control tool.

As customers purchased multiple lab systems, there was a request to tighten the system to system consistency. Their main perspective was the images obtained, which could vary for many reasons, including simple differences such as the brightness of the display monitor. The requests have led to more and tighter controls within our systems and the transducers used in those systems.

The reality is that everything has a tolerance or can be affected by some outside forces. One simple example is the temperature of the water for acoustic imaging. Since the speed of sound and the amount of attenuation in water changes with temperature the depth of focus and the energy level will also change.[3] Without compensation or tighter controls the acoustic images can vary significantly, even in the same system.

We had to take a holistic approach and control the factors that affect the absolute outcome, quantifiable data. The ultimate goal was to have a sound, statistical basis for the acceptance of the data based on upper and lower control limits. Sonoscan already had quantifiable digital image analysis techniques in place, so we concentrated on input variables, which included, but were not limited to; 1) Water temperature; 2) Maintaining device location during scanning and drying; 3) Matching imaging electronics; and 4) Manufacturing transducers to a tighter tolerance. All of these things, and some additional items, had to be factored in and become part of the recipe recalled for the process control of a device.

Water Temperature Control

Relatively simple in concept is the need to control the water temperature in each scanner of a system and from system to system. It is common knowledge that the temperature of the water will affect higher frequency transducers more than lower frequency transducers. For a tighter process control it is necessary to monitor and maintain the water temperature within a range for all transducers and include it as part of the recipe parameters. To accomplish this both water heating and cooling functions are added to the DF2400 system. Since the system utilizes WaterFall Transducers the water temperature at the transducer can easily be monitored relative to hot and cool zones within a bath of water.

Maintaining Device Location

While the ultimate goal is to retain all the devices in a carrier tray throughout the whole process, it is more readily accomplished in a metal carrier that incorporates clip type holders. Devices in plastic JEDEC type trays have a tendency to move in their pocket or pop out of the pocket, making the retention of the devices more difficult. In addition, the design of a JEDEC tray can vary dramatically from user to user, even for devices with the same X-Y dimensions. Sonoscan expanded its vacuum hold down technologies in the scanning and drying sections of the DF2400 to better control the sticking force over the whole carrier tray area and more variable control of the force by recipe based on the tray design.

Matching Imaging Electronics

While Sonoscan has always had the technologies to get the best performance from the transducers, pulser, etc., that make up the imaging electronics it manufactures in-house, it was necessary to tighten the tolerances even further for tool matching. In addition, a long term stability monitoring capability called LTSM™ was added. With LTSM each scanner and system imaging electronics can be monitored with a special set of reference samples, see Figure 5, and automatically compensates for tolerances within an acceptable range. Outside that range the operator is notified that maintenance must be performed on that system. This is to ensure that the quantifiable data is statically sound for both scanners within a system and from system to system.

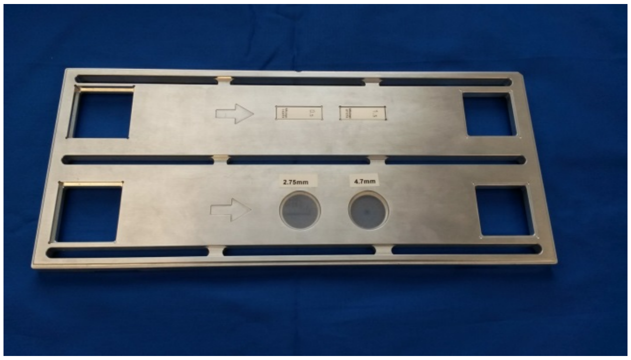

Figure 5: Sonoscan reference samples mounted in a JEDEC size tray for long term stability monitoring of the DF2400™ used for process control.

Transducers Manufacturing

Sonoscan has manufactured its own transducers for many years. Developing new versions as required for new electronic device types as they came to market. Several factors go into the new design of a transducer, starting with its center frequency and focal length. These two basic factors are commonly related to the spot size and the depth of focus of a transducer, respectively. Other factors that affect how a transducer performs include its trigger level, dB level, polarity of the piezoelectric, assembled structure, etc. All of these factors have variances, just as electronic devices do from device to device. Many of these variances can be adjusted for if they are not too far out of range. To ensure that the quantifiable data stayed within its control limits it was a two pronged approach for transducers, tighter manufacturing tolerances and additional compensation items in the transducer libraries stored for each S/N transducer.

SUMMARY

To meet the challenges of competition it is a fact that companies need to have better control of their manufacturing processes to increase output and still maintain quality standards expected by their customers. Sonoscan's C-SAM systems have evolved from laboratory tools to fully automatable process control tools to support these efforts as microelectronic devices have evolved over the years. C-SAM systems have moved from the capable hands of a Failure Analyst to an operator on the production floor providing statistical analysis data on your devices.

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