Camera-assist automation for bond testing of MEMS interconnect

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The term MEMS (microelectromechanical systems) appeared and started gaining popularity in the mid-80s. MEMS refers to a complete system on a single platform that consists of both mechanical and electrical/electronic components. This permits the system to incorporate both the sensors (e.g., pressure meters or accelerometers) and the control/reporting electronics on a single chip within the Si wafer. MEMS have enjoyed a tremendous growth in recent years because of the continuing trends for miniaturization and increased complexity that govern the manufacturing output in all fields including consumer products, industrial, medical, military, automotive, and so on. Currently, one can find these tiny devices within any contemporary cell phone or automobile diligently performing their tasks as high-quality microphones, micro accelerometers and gyroscopes, pressure sensors, RF modulators and microfluidic controllers.

Naturally, the increased complexity and miniaturization poses new challenges for testing equipment and testing methodology in general, and bond testing technology in particular. The need for automation is critical to streamline the testing process and also reduce the influence of human errors. While simple "step and repeat" automation has been sufficient in the near past, currently microelectronic interconnect in general is experiencing a number of changes. Geometries are continuing to shrink and operator manual alignment of the test head to the bonds is becoming more and more difficult. Thus, focus is returning to camera-assisted automation that originates from the Dage BT25/2500 projects in the early 1990s.

In this paper, we present the technology behind the modern fully automated bond testing of MEMS devices using camera assist. The image capture camera that is integrated into the bond tester main frame is used as the main teaching device, providing the accuracy and ease of programming needed. Various software features come in handy in streamlining the programming and keeping the process within the necessary precision parameters. We find this automation technology to be useful for a wide range of applications, including wafer-level bond and die shear, Cu pillar/flip-chip micro-bumps, ultra-fine pitch interconnect, lead frame wire pull and shear/pull applications of hybrid devices.

In recent years, we have seen a constant increase in the requests and need for automating the bond testing process. The reasons behind this can be grouped in several general categories. First, there is a widespread push in the industry for increased productivity. Replacing the manually performed operations by an expensive operator with an intelligent fully automatic machine performing the same tasks is faster and cheaper. For another group of users, speed and price are secondary to precision. For these end users, performing the test with the highest possible accuracy is of crucial importance. This involves precise alignment and positioning of the test tool before the test, which needs to be exactly reproduced over and over again. Manual tool alignment and test execution is always prone to inaccuracies due to inconsistencies in individual operator performance, as well as the variation introduced by multiple operators using the equipment.

The first principle for automating the bond testing process is to make sure that all the parts that need to be tested are mechanically placed and secured at the same physical location at all times. This is accomplished using precise work holders that ensure placement accuracy. For MEMS devices as shown in **Figure 1**, the sample holder is of comparably simple design as the individual parts have fixed locations within the large printed circuit board (PCB) assembly. This is also valid for MEMS devices that need testing at the wafer level before being cut and packaged individually.

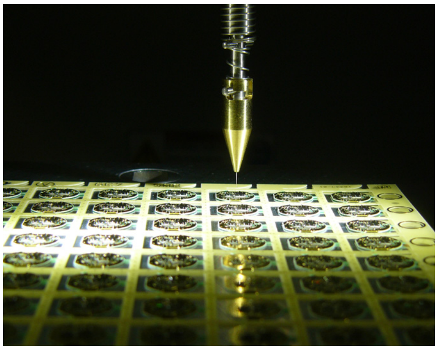

Figure 1: MEMS devices set up for an automatic non-destructive wire pull test.

In the case of individual packages that have the MEMS device already installed within the plastic packaging, however, the requirements for the sample holder are significantly more demanding (**Figure 2**). The sample holder needs to be designed and built allowing for many different parameters, some of which are working against each other. The sample holder needs to accommodate as many devices as possible that need to be loaded as fast as possible and at the same time as accurately as possible.

In cases similar to the one in **Figure 2**, multiple sample holders are suggested so the parts can be loaded at the same time as the testing is executed. Appropriate fiducials for the camera-assist system need

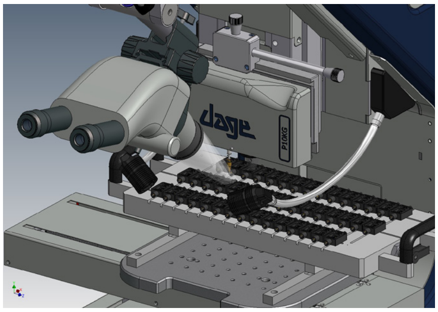

Figure 2: Sample holder designed for automatic bond testing of individual MEMS devices loaded into the system.

to be identified within the sample itself or machined within the sample holder. In addition to the sample holder accuracy, there are also very stringent requirements for speed and mechanical positioning to the X-Y stage. The stage needs to be as fast and accurate as possible and at the same time not prohibitively expensive in order to accommodate tight budgets typical for current economic conditions.

Once the best possible mechanical alignment and securing of the devices is assured, the rest of the auto programming and execution steps need to be done in an appropriate manner. While auto programming has been accomplished in the past by simply using the test tool as a teaching device, much better accuracy and ease of programming can be achieved by using integrated camera assist systems that are an essential part of every modern bond tester. As an added benefit, these camera systems can also be programmed to automatically take high-resolution images of the failure modes while the automatic test is carried out. There are routines within the software that account for the offset between the camera and the test tool, so all the teaching and fiducial recognition can be carried out by just using the camera system. In addition, in the case of wire pull applications, the software provides routines that handle possible hook eccentricity variations.

As shown in **Figure 3**, the camera system has looked at a feature of a ball grid array (BGA) type device that will be used as a fiducial. Usually a set of three fiducials is utilized that encloses the area of the testing. Advanced image recognition algorithms are employed by the bond tester software to compensate automatically for transitional and rotational misalignment. To achieve a repeatable system operation, the fiducial mark needs to be easily recognizable

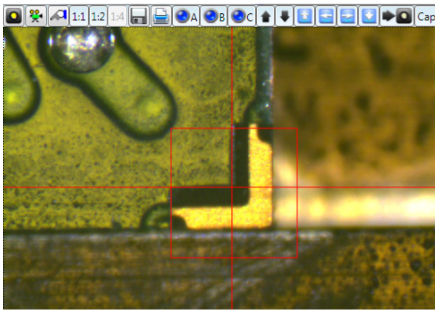

Figure 3: Fiducial recognition routine within the auto-teaching procedure. The fiducial is locked within the red square.

by the optical system and be of unique nature within the camera's field of view. The capability of multiple fiducial levels assures that complex samples that exhibit die placement variations can also be programmed. Fiducials can also be machined within the sample holder for the cases of multiple discrete devices or if appropriate fiducials are not available in the case of PCB/wafer samples. It is very important to emphasize that, based on our experiments, the introduction of optical fiducials and image recognition algorithms brings the accuracy and the repeatability of automatic bond testing to a new, much higher level that cannot be achieved using only mechanical means.

After the fiducial alignment is programmed successfully, the next step is teaching the locations for the test. As mentioned before, these could be bond wires, BGA solder balls, Cu pillars, micro-bumps, or individual dies within a wafer. The main types of tests being automated include wire pull and various types of shear. For bond wire auto testing, there is the option to select the two ends of the wire and a testing point, or to select the two ends of the wire and specify the test position along the wire as a fraction or percentage of the wire length.

As shown in **Figure 4**, the operator

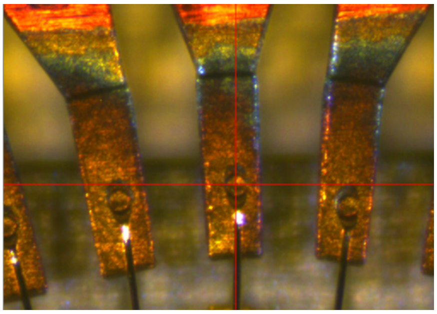

Figure 4: Teaching bond wires within the automation routine using camera-assist functionality.

is using the crosshair displayed in the camera window to teach the essential location for the wire pull test. Using the camera streamlines the programming process and results in very high accuracy that is not achievable by simply using the test tool as a teaching device.

In addition, as shown in **Figure 5**, the graphical user interface (GUI) incorporates areas that graphically display the test surface, giving the opportunity to the operator to fine tune the program by using CAD tools and slightly

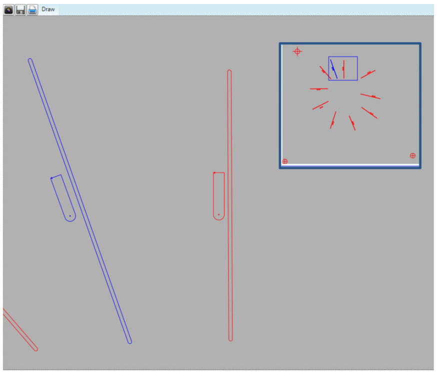

Figure 5: A CAD drawing that was automatically generated through the programming process. Interactive tools permit slight modifications of tool position. Copy/paste functionality is very useful for repeating patterns.

modifying or even drawing test locations manually.

For the particular example in **Figure 5**, the inset shows a computer-aided design (CAD) drawing of the test area within the fiducials. The operator has just slightly modified the test position of the hook as marked in blue. The bond wire dimensions and hook size are input in the software, thus permitting worry-free programming. For the case of shear tests of bumps and BGA balls, the operator inputs the ball diameter and the offset corresponding to the desired shear tool placement.

Copy/paste functionality is also available to the programmer. This programming capability is very useful for BGA balls/bumps/multiple die shear applications as well as wire pull applications of multiple discrete devices.

Figure 6 shows an example of CAD output automatically generated by the software. The inset shows the whole test area within the three fiducial marks. The

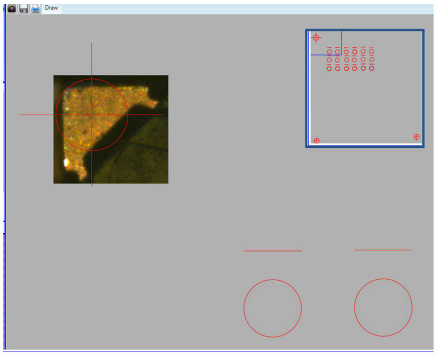

Figure 6: CAD drawing of the testing surface within a BGA device. The inset shows the whole area within the fiducials. The large image is an enlarged view of the blue square within the inset showing BGA ball positions, tool positions and an optical image of one of the fiducials.

operator has programmed the first row and used the copy/paste functionality to populate the test positions for the next two rows. Ball diameter and tool offset have been input by the operator. The software automatically displays the CAD drawing, including fiducial image, and test locations for BGA balls and tool positioning. The area in the blue square within the inset corresponds to the enlarged view that includes the optical image of one of the fiducials. The operator can move the little blue square and display different areas of the testing surface.

Summary

The addition of high-resolution camera systems has resulted in a streamlining of the modern bond tester automation capabilities for a wide variety of applications exhibiting much improved testing repeatability. This includes high-accuracy/high-speed automatic testing of MEMS devices as discussed in the above paper. The camera-assist automation capability is also vital in many other bond testing applications including wafer-level bond and die shear, Cu pillar/flip-chip micro-bumps, ultra-fine pitch interconnect, wire pull, and shear/pull of hybrid devices.

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