2005 WJTA American Waterjet Conference
August 21-23, 2005 ● Houston, Texas

Paper

ABRASIVE WATERJET CUTTING OF MICROELECTRONIC COMPONENTS

Mohamed Hashish
Flow International Corporation
Kent, WA

ABSTRACT

A new process for cutting and singulating chips has been commercially introduced. This process is based on cutting contoured lines with fine-beam (~0.38 mm) AWJ and then singulating with straight-lines diamond saw cutting to capitalize on the excising chip handling equipment on these saws.

The work in this paper is focused on cutting strips containing flash memory card components similar to those found in digital cameras, cell phones, and USB storage devices. Both process and machine performance was critical to meeting a process capability index (Cpk) greater than 1.33.

The relatively small AWJ (~ 0.38 mm) nozzle was equipped with new features to insure robust process operation without abrasive clogging. For example, enhanced vacuum assist and clean-in-place features were used. A machine with enhanced accuracy and equipped with machine vision for probing the strips to be cut was used along with special fixtures. The software was adapted to interface with the vision software for automated cutting and inspection. While the AWJ process was found capable of cutting at speeds of 200 mm/s, the speed was limited to about 30- 45 mm/s to insure parts accuracy. At this rate, a unit-per-hour (UPH) yield was about 400 (for 11x 15 mm components) which is acceptable at this time. Further improvements with automation, machine accuracy, and in-process inspection are likely to increase the UPH to over 2000.

1. INTRODUCTION

There are continuous and emerging needs in the microelectronics industry for improved yields. One of the critical processes in fabricating microelectronic components is dicing and singulation of wafers and such products as IC cards, LTCC, MEMs devices, multi-chip modules (MCM), RFID tags, flash memory cards, and system-in-package (SIP) for cellular phones, and other mobile products. With new trends using new materials, reduced size components, reduced thickness, and ever increasing volumes, new fast and reliable cutting methods are always sought.

This paper is on using abrasive waterjets for cutting microelectronics components in general with particular focus on cutting flash memory card strips similar to those used in cellular phones and digital cameras. First, some background information on cutting methods will be presented. This will be followed by listing some typical cutting requirements for flash memory cards. Description of process parameter, sequence, machine features and results of AWJ will then be presented followed by discussing some selected applications. Conclusions and recommendations are given at the end of the paper.

2. DICING METHODS

Dicing is a term typically used to describe cutting wafers into small dies. Singulation is also used to describe dicing but extends to other than wafers in the IC and electronic package (QFN and BGA for example) market.

2.1 Diamond Saw

The most common method is using a diamond-bonded wheel to cut through the full depth of the wafer and into the mounting tape so as not to completely singulate the dies for handling purposes. Diamond saws with less than 100-micron width are typically used. Scribe-and-break (snap) also uses diamond saws to scribe lines 3- to 5-micron lines between the dies.

2.2 Laser

Laser dicing is used when wafers (with low-κ) are subjected to damage at the inner level dielectrics that may be caused by saws. Laser is more suitable for thinner wafers where cutting speeds could be increased while saws may slow down (Levine 2004). UV laser is used to drill small diameter holes (vias) which can not be achieved with other methods at this time.

2.3 Waterjet-Guided Laser

In this process, a low pressure (laminar) DI and filtered waterjet (50 to 500 bars) is used to guide the frequency-doubled ND:YAG laser beam. This process has been found advantageous for thin (50 to 75 microns) wafers due to reduction of micro-cracking. It was also found useful for dicing materials such as gallium arsenide compared to saws but concerns exist about the possible release of arsine gas. Multiple layer material with different properties is problematic to lasers.

2.4 Abrasive Waterjet (AWJ)

Abrasive waterjets are versatile tools for cutting a wide range of electronic components without introducing heat or mechanical distortion. The process uses entrained abrasives in a high velocity waterjet pumped at pressures of 400 MPa. New trends are towards using higher pressures of 600 MPa (to reduce water and abrasives). The mixing of the waterjet (75 micron) and the abrasives (mesh 220 and finer) occurs in a mixing tube of about 0.38 mm. This represents a limitation of the current AWJ process.

2.5 Abrasive Suspension Jet (ASJ)

In this process, premixed water and abrasives are directly pumped through the nozzle. Accordingly, smaller diameter jets can be obtained. Because of the severe wear conditions caused by the slurry flow, the pressure of the jet is typically limited to about 69 MPa. ASJs of about 250 microns and smaller could be produced; however, the current state-of-the-art jet size is 250 microns to obtain reasonable cutting speeds at the relatively low pressure of 69 MPa (Iscoff 2003, and Dean et. al. 2002).

3. TYPICAL REQUIREMENTS

The typical requirements for singulating flash memory card strips are as listed below:

- Typical strip size: 300 x100 mm
- Typical component size: 11 mm x 15 mm
- Minimum inside corner radius: 0.2 mm
- Maximum part thickness: 2 mm
- Typical space between components 1 mm
- Minimum space between components: 0.1 mm
- Surface finish of cut edges: ≤ 4 microns
- Process capability index Cpk: 1.67
- Equivalent Yield to Cpk: 99.999%
- Maximum allowable dimensional tolerance: ± 0.1 mm
- Productivity (based on 10mmx10mm component size): ≥2000 per hour
- Machine uptime ≥96%
- Mean Time Between Failures (MTBF) ≥ 200 hrs
- Mean Time to Repair (MTTR) ≤ 10 minutes

In addition to the above, the cut edges should be free from cracks, chip striations, or delamination

To meet the above requirements, the following needs to be considered:

- A machine with ± 0.025 mm accuracy is needed. Because the strip size is relatively small, the machine working area will also be small. This helps obtaining the required accuracy. For relatively high speed shape cutting, the motion system must be capable of the proper acceleration and deceleration values while keeping smooth motion. For accurately locating the jet relative to the cut paths, probing (vision or other methods) may be needed. In case of vision, fiducials on the strip will be used. Also, the strip must be held accurately and rigidly to prevent any motion during cutting.

- The cutting process should meet the required dimensional features, surface finish, edge integrity, and the productivity requirements. For the AWJ, this implies using a mixing tube of no more than 0.4-mm in diameter, carefully selecting the other process parameters, and possibly using process sensors to monitor the health of the process.
- The cutting process and the motion system should be stable and robust to meet the reliability and performance requirements. For the AWJ process, this implies using robust pumping and high pressure components, robust abrasive flow condition for no plugging, and relatively long lifetime components.
- To meet the 0.1-mm spacing-between-components requirement, either a new micro AWJ or ASJ must be used. The state-of-the art of AWJ and ASJ is limited to 0.38 mm and 0.25 mm respectively.

3.1 WaterJet Singulation Process Description

To singulate a strip, several processes can be used:

3.1.1 Hybrid Waterjet-Saw Process

In this method, the AWJ is used to cut the shaped patterns around the components in the strip without completely singulating it. Diamond saws are then used to singulate the strip by cutting a number of straight lines across the AWJ-made cuts. Figure 1 shows a sample strip to be singulated. This process is currently in commercial use. It was selected to capitalize on the exiting handling equipment associated with diamond saw engines.

To maintain the integrity of the strip while moving it from a waterjet cutting table to a saw engine, the perimeter of the strip (picture frame) was not cut. Accordingly, the AWJ cutting process consisted of piercing starting holes and then cutting the required shaped geometry. Figure 2 shows the areas to be removed by the waterjet while figure 3 shows a picture of an actual cut-out.

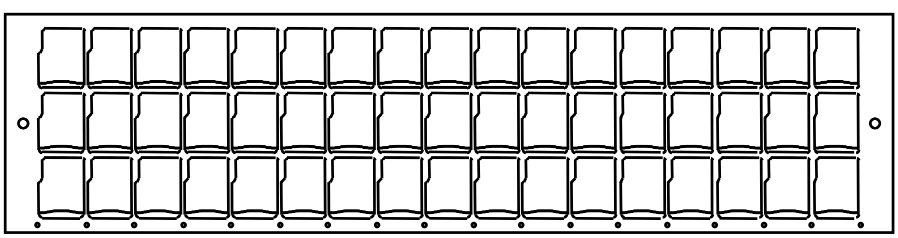

Figure 1: Typical Strip Configuration

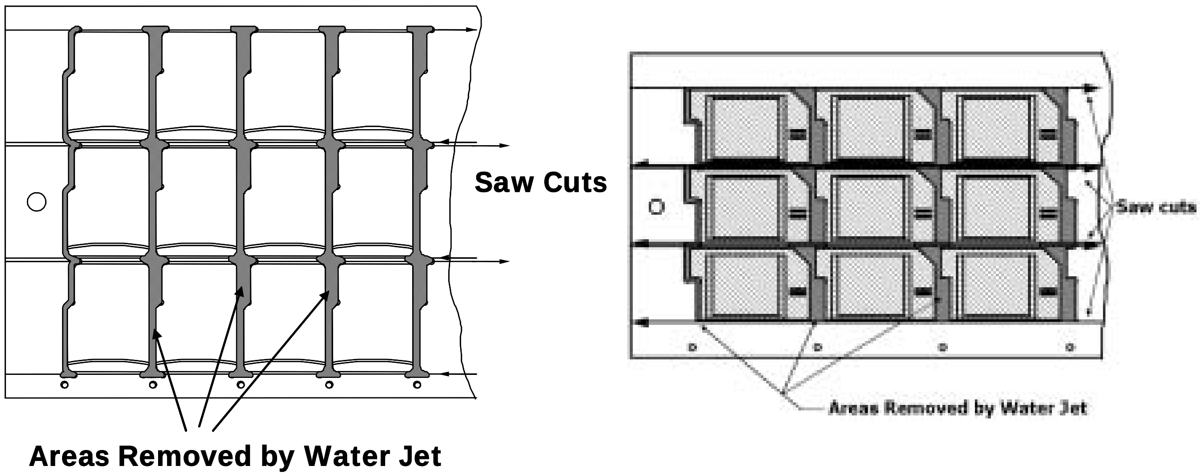

Figure 2: Areas to be cut by AWJ and Saw

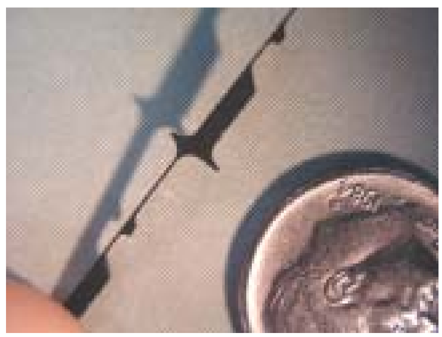

Figure 3: Cut-Out Produced after AWJ cutting

3.1.2 Waterjet Singulation Process

To eliminate the diamond saw process, the AWJ singulation system must perform all cutting operations and be equipped with a handling system such that singulated components are loaded on JEDEC trays at the output side of the machine. This complete AWJ singulation process can be accomplished in two ways depending on part chucking (fixturing) methods.

3.1.2.1 Dual-Area Chucking

In this case, the strip is chucked (fixtured) twice in two separate areas. The first chuck is used for cutting selected patterns, but leaving tabs or certain lines or contours uncut. The other chuck (fixture) is used for singulating the strip by cutting the tabs, or the uncut contours or lines. Accurate transition and handling between chucks is needed.

3.1.2.2 Single-Area Chucking

In this case, the strip is loaded in a single area for complete singulation. This can be accomplished in two ways:

Single Path Cutting
In this case, the part is completely singulated without moving it from the fixture (chuck). The fixture must be designed such that its integrity is not affected by the closed path cuts made around the components. Because vacuum chucking is typically used for holding the components, each component must be supported and held. Also, the jet should not cut the vacuum passages in the chuck. A bed-of-nails type chuck concept is used in this case.

Dual Path Cutting
In this case, the strip is held stationary using its perimeter frame and two chucks are shuttled underneath the strip. Two jet passes will be used to singulate a strip similar to the dual area approach mentioned above.

With two-stage chucking, either a single or dual jet could be used, one for each stage. Using two jets will increase the throughput but will make the strip handling system more complex.

3.2 AWJ Parameters Nozzle for Singulation

The AWJ process was selected over ASJ for singulating the above part because the part geometry is within the capability of AWJ which is at the current state-of-the-art and more reliable for around-the-clock use than ASJ.

To meet the above geometrical requirements, an AWJ with a mixing tube diameter of 0.38-mm was selected (smallest commercially available) with a length of about 63-mm (longest commercially available). The need for relatively long mixing tubes with l/d ratios approaching 200 is driven by producing as much collimated jet as possible and also for extended mixing tube lifetime. This places additional demand, however, on nozzle design to insure jet-mixing tube alignment. The waterjet orifice diameters tested were 0.076, 0.012, and 0.127 mm. While larger orifice sizes may result in faster cutting rates, jet alignment and abrasive entrainment becomes more problematic. The selection of the mixing tube diameter, to meet kerf width, limited the abrasive size selection to 220 mesh and finer.

To obtain the highest cutting rates, the pressure was kept at its highest value of 375- 400 MPa range. The abrasive flow rate was then optimized.

To insure reliable process performance, an AWJ nozzle was modified to handle the above unique set of parameters. These modifications include:

Vacuum Assist: The abrasive transport from a hopper to the nozzle is accomplished by using waterjet-entrained air as a carrier. Because of the relatively small sizes of the waterjet orifice and the mixing tube, the waterjet jet-pump effect for air entrainment is insufficient for reliable abrasive feed process. To enhance the air flow rate into the nozzle, another air-to-air jet pump was connected to a side port in the AWJ nozzle. The amount of additional (assist) air to be entrained was regulated by adjusting the flow rate of the primary air in the air-to-air jet pump. A vacuum gauge connected in place of the abrasive feed line was used to set the required vacuum level and thus the required air flow rate.

Clean-In-Place: Another port was added to the AWJ nozzle (per Hashish 1990) to allow cyclic injection of flushing water after cuts or pierces are made. This insures no abrasive accumulation and build-up in the nozzle body.

Diamond orifice holder: A standard diamond orifice was used. However, the orifice mount was improved to resist fatigue of the sintering material. Orifice holder downstream wear due to abrasive upward impact was reduced by adding vent holes to the mount. While this was proven to be effective in the laboratory, consistent venting levels were found important for process repeatability and implementation in the field at this point.

Jet-Mixing tube alignment: A precision collet is used to hold the mixing tube in the nozzle body. Also, a specially designed water body with above- and below-threads pilot diameters was used as not to cause orifice mount tipping during assembly.

Figure 4: Special AWJ Nozzles for Singulation Applications

4. PROCESS IMPLEMENTATION

4.1 Parameters

A study was performed to determine a set of robust AWJ parameters for cutting the strips. The following is a list of these parameters.

Cutting parameters:

- Waterjet orifice diameter: 0.075 mm
- Mixing tube diameter: 0.038 mm
- Nozzle length: 50 mm and 75-mm
- Pressure: 379 MPa
- Abrasive: 220 Mesh Garnet
- Abrasive flow rate: 0.75 g/s
- Traverse rate: 45 mm/s

Drilling parameters:

- Waterjet orifice diameter: 0.075 mm
- Mixing tube diameter: 0.038 mm
- Nozzle length: 50 mm and 75-mm
- Pressure: 82 MPa
- Abrasive: 220 Mesh Garnet
- Abrasive flow rate: 1.13 g/s

4.2 Process Description

A hybrid waterjet-saw process was selected for quick implementation and utilization of existing components handling unit on the saw machine. The AWJ process consisted of the following main steps:

Strips loading on tray: 5 strips (300 mm x 100 mm) are loaded on a tarry using pins and reference holes on the strips.
Tray loading on vacuum chuck: The loaded tray is placed on a vacuum chuck where vacuum is applied to secure the strips in place.
Vision probing: A dry run is used where a vision camera locates the center of selected (programmed) fiducial. The cut patterns are referenced to these fiducial.
Piercing: Starting holes are then drilled in all the selected locations on the 5 trays using the above selected set of parameters.
Cutting: The cutting process follows the piercing process using the parameters shown above. The software used has a feature of slowing down automatically around tight corners to obtain the required geometry.
Vision Inspection: After cutting is completed, a vision camera is used to inspect kerf width and some selected dimensions. Kerf width data were used for cutter diameter compensation.
Tray removal: The tray is then removed manually from the vacuum chuck after releasing the vacuum. The strips are removed, washed, dried and loaded into cassettes for loading on a diamond saw.
Selected inspection: Some selected components on selected strips are inspected to determine process capability index C_{PK}. A comparator may be used to measure the required features and to double check the in-process vision measurement data.

The above steps will be altered based on the selected machine and on whether the singulation process is completely performed by the AWJ (or ASJ) and whether an automated or manual machine is used. For example, for an automated machine using two stage singulation, the steps for singulation may be as follows:

- Unload a strip out of a standard magazine
- Load the strip on a cutting table fixture (fixture A)
- Use vision to locate and verify part location
- Cut programmed paths and wash top surface
- Use vision to inspect (at selected intervals)
- Unload (lift) strip and wash bottom
- Load partially cut strip on cross cutting fixture (Fixture B)
- Use vision to locate and verify part location
- Cut programmed singulation paths and wash top surface
- Use vision to inspect (at selected intervals).
- Unload (lift), and wash bottom surface of components
- Remove strip residuals from cutting area
- Load components in JEDEC tray except those failed inspection
- Load JEDEC tray in receiving magazine or stack

4.3 Singulation System

The AWJ cutting system consisted of the following main components:

- UHP pumps: 60-Ksi pumps were used to power the cutting head. One pump was used to power more than one cutting head as pump capacity exceeded the cutting head needs for pressurized water flow. However, at another installation, every cutting machine was equipped with its own dedicated pump.
- Two station cutting table: The cutting table consisted of two cutting stations. A base plate mounted inside of a catcher was used to mount the vacuum chucks.
- Motion arm: A cantilever arm was used to move the cutting head over the cutting area in two dimensions with automated vertical motion for stand off distance adjustment.
- Vacuum chucks: Two vacuum chucks are mounted on the base plate and connect to a vacuum system via vacuum ports.
- Vision camera: A vision camera mounted in housing with a shutter door is mounted near the cutting head.
- The cutting head: An AWJ nozzle is described above including vacuum assist and flushing capability.
- Abrasive collection system: A single system consisting of a screen, pump, and a collecting tank was used to extract the garnet and cut out from the catcher tank to concentrate them in the collecting tank for disposal.
- Software: PC-based software was used to develop tool paths program out of strips CAD information. The software is integrated with the vision system so that coordinate locations of fiducials are transmitted to the cutting program. Not shown in this illustration is the pumping unit which is located behind the cutting station or at a remote location.

Figure 5 shows the cutting area of a WJ machine using cutting flash memory cards. Figure 6 shows a picture of the cutting head on a loaded tray on the cutting table while cutting.

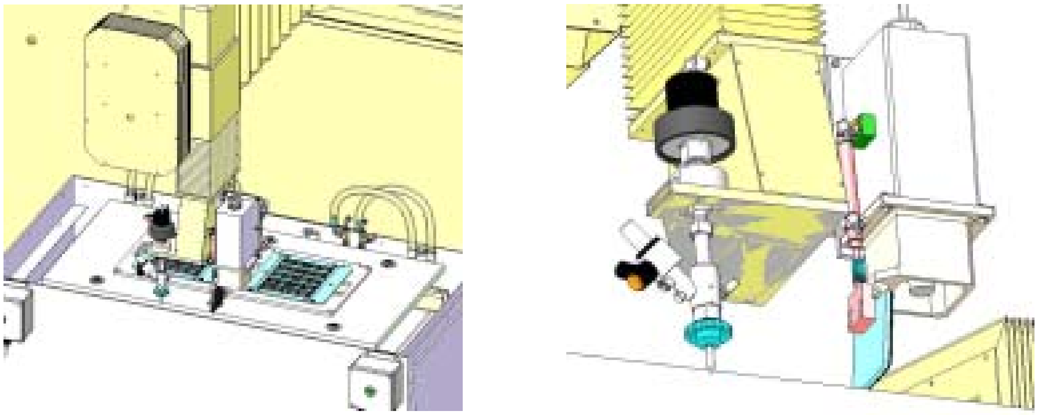

Figure 5: AWJ Machine Features

Figure 6: AWJ Nozzle and Strips on a Tray

Figure 7 shows post-cutting inspection of cut strips using an optical comparator. Critical dimensions on randomly selected components were measured to calculate the process capability index Cpk.

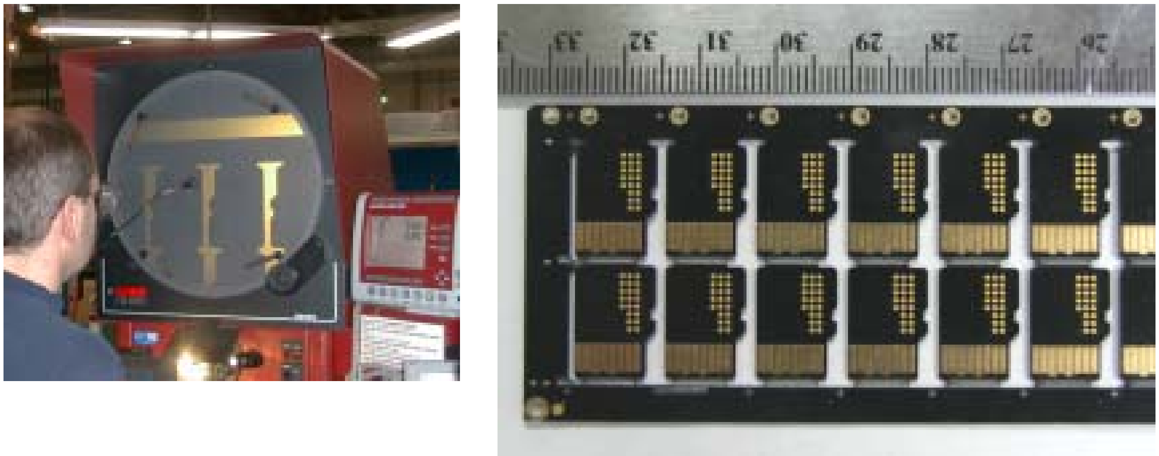

Figure 7: Cut Inspection and AWJ-Cut Strip

4.4 System Performance

The current semi-automatic system has the following performance characteristics based on cutting strips containing 28 components in two rows of about 11 mm x 15 mm each. The strip thickness is about 1-mm:

• Minimum inside corner radius on component (mm)	0.2-0.25
• Space between components (mm)	0.7
• Cut edge quality and integrity	Free from cracks, chips striations, or delamination
• Surface finish of cut edges	≤ 4 microns
• Process capability index Cpk	1.6
• Equivalent Yield to Cpk	99.990%
• Cutting accuracy to meet CPK (mm)	± 0.05 mm
• Singulation	Partial
• Productivity (based on 11mmx15mm TFR design)	~400-500
• Operating cost per component	~$0.04
• Up time	~85%
• MTBF	≥ 100 hrs
• MTTR	5-10 minutes

5. OTHER APPLICATIONS

Figure 8 shows a picture of multi-layered carbon fiber composite material cut for mini-hard drive arm. A cutting data matrix was performed for cutting relatively thin (0.71-mm) composite materials using plain waterjets and droplet (fuzzy) jet. This fuzzy jet was formed by mixing air with a waterjet is a special mixing tube similar to AWJ nozzles. A 0.1-mm diamond orifice and a 50-mm long 0.5-mm-diameter mixing tube were used. It should be noted that the best edge quality is achieved when cutting along the grain of material. It was also observed that hole piercing of the composite material require a vacuum assist and using 220 mesh abrasive at a reduced waterjet pressures to 5 –15 Ksi to avoid any delamination.

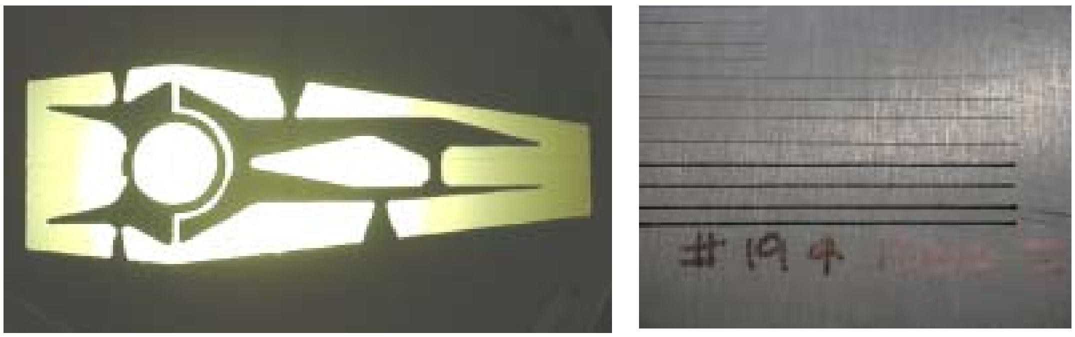

Figure 8: WJ-Cut in 20-mm long Micro Hard Disk Composite Arm

Cutting multi module components (MMCs) has also been demonstrated using AWJ. These components are raised and cutting at the roots of the leads is required. Two AWJs mounted at a slight taper angle have been used to cut the MMSs at the correct location resulting in burr-free cutting surfaces.

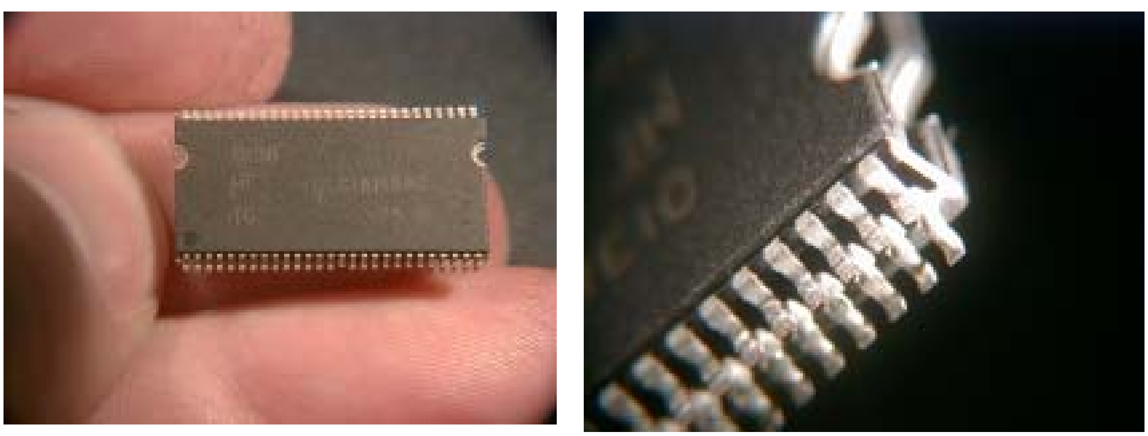

Figure 9: AWJ-Singulated Multi Module Components

An additional application is shown in Figure 10 where small diameter holes need to be drilled in ALN (Aluminum Oxynitride) material. The drilling of 0.5-mm diameter holes in relatively thick ALN with an AWJ was found to be highly feasible. No adverse effects were observed. Also drilling times are acceptable and with 2 seconds hole-t-hole. Pressure ramping was needed to enable drilling of ALN to control the integrity of the hole and its shape. Vacuum assist is also critical at the early stages of AWJ contact with the material for preventing chipping. For this application, dwell time was used and accurately controlled by using a microphone for breakthrough detection. Hole location with +/- 0.075-mm could be accomplished using an accurate machine.

Figure 10: AWJ-Drilled Holes in ALN Material Substrate

6. CONCLUSIONS

- The AWJ process has been successfully implemented for cutting microelectronic components requiring shaped edges. The AWJ machining systems and process capability index is over 1.33 for critical dimensions.
- The AWJ process has been demonstrated for cutting a wide range of electronic components including hard cutting materials such as Alumina (Al2O3), Aluminum Nitride (AlN), and laminating base materials.
- An advanced AWJ cutting head with both vacuum assist and flushing capabilities proved to be critical for robust AWJ cutting process with minimal downtime.
- Further improvements are underway to further improve the lifetimes of components and to add sensors, diagnostics, and data logging capabilities for ease of operation, maintenance, and quality assurance.

7. REFERENCES

Bernard Levine, (2004), “Wafer Dicing”, Semiconductor Manufacturing, December 2004, pp17-22.

Hashish, et. al., (1990) “Abrasive jet nozzle assembly for small hole drilling and thin kerf cutting,” US patent Number 4,951,429

Iscoff, Ron, 2003, “On the Cutting Edge: Laser, Water Singulation Bid for Acceptance in a Saw-Diamond Market,” Chip Scale Review, August, pp 45.

Dean, V, Tan, K., and Gadd, M., (2002) "New Fine Beam, Abrasive Water Jet Technology Enables Photonic and Small Device Singulation," Chip Scale Review, August-September, pp. 43.