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Paper

HIGH PRECISION AND HIGH POWER ASJ SINGULATIONS FOR SEMICONDUCTOR MANUFACTURING

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ABSTRACT

The back end of the semiconductor manufacturing industry utilizes blades to singulate all various types of package arrays. The application is limited to straight lines only. In case of curvilinear cutting or multiple layers of material type (i.e. brittle, ductile) the blade cutting operation encounters limitations which require significant reduction in cutting speed, or it cannot be utilized at all.

This paper explores a high precision and high power abrasive suspension jet (ASJ) and presents ASJ singulations for semiconductor manufacturing. The key issues and solutions around the developing of the technology are discussed, which include high pressure ASJ system, long life nozzle and X-Y table.

The ASJ singulations can cut substrate with width 0.2mm and speed up to 200mm/s, provide a cost-effective cutting process for any material with both straight line and curvilinear edges, make the highest quality cut.

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1. INTRODUCTION

The Semiconductor Industry uses several types of material for microchip manufacturing. **Figure1** shows us an array of different types of substrates encountered in the singulation process. The substrates contain different package sizes, different layers of material, with different properties as far as hardness, thermal resistance properties, matrix array, layouts etc.

The basic operation of blade cutting is through the process of grinding. The abrasive used with the cutting blade (usually synthetic diamond) grinds away the different layers of material which make up semiconductor package. An alternative to standard singulation is emerging with the use of abrasive suspension jet cutting method.

1.1 Challenges and Limitations of Diamond blade Singulation [1]

- **Brittle device singulation:** LTCC (low temperature co fired ceramic) and Ceramic Alumina tend to be some of the harder materials singulated with a blade. The main obstacle is propagated microfractures into the active area, which are caused by the blade during cutting.
- **Ductile device singulation**: QFN, PQFN and other types of copper strip devices make up the category of ductile materials. During cutting, the copper tends to 'load' the abrasive layer on the blade and finish quality failures are apparent early in the blade life. The failures are categorized as: smearing, burring, shorting of copper leads, etc.
- **Curvilinear device singulation:** Memory card, Photonic devices require curvilinear boundaries. Diamond blade singulation can only cut straight line.
- **Small device singulation:** When device dimensions are less than 3mm x 3mm, the holding force of the vacuum fixture is less than the shear force of blade on the substrate. Due to the cutting angle of the blade, forces generated during cutting tend to shift the units from their original position, thusly creating package dimensions failures. Vacuum fixtures are unable to retain the small devices.

1.2 Requirement of Substrate and Wafer Cutting

- Cold cut: no heat affected zones
- Fine cut widths: range from 0.05 mm to 0.5 mm, most 0.3 mm
- High precision: the 25 micron tolerance
- High quality: no smearing, no burring, no chipping, no wave
- High ability: can cut straight devices and curvilinear devices.
- High cut speed
- Reasonable cost

1.3 Advantages of Water Jet Singulation

- Free of heat affected zones.
- Cut quality higher than diamond saw, without smearing, burring and chipping.

- With cut widths ranging from 0.05mm to 0.5mm, ASJ provides an ideal cutting process for fine geometry devices with both straight line and curvilinear edge.
- The water jet cutting process is material non-specific, laminates and coated devices with both ductile and brittle material can be cut in a single pass.
- Water Jet can cuts through substrate at more than 160 mm/s.
- ASJ cutting beam interacts with a substrate or wafer only along the vertical axis preventing the formation of shear forces. Devices are retained in their intended position and cut geometries remain consistent.

This paper explores a high precision and high power abrasive suspension jet (ASJ) and presents ASJ singulations for semiconductor manufacturing. The key issues and solutions around the developing of the technology are discussed, which include high pressure ASJ system, long life nozzle and X-Y table.

The ASJ singulations can cut substrate with width 0.2mm and speed up to 200mm/s, provide a cost-effective cutting process for any material with both straight line and curvilinear edges, make the highest quality cut.

2. METHODS OF GENERATING ABRASIVE WATER JET FOR SINGULATION

Abrasive waterjet cutting is an ideal candidate for semiconductor singulation. The main obstacle in cutting with a water jet is the ability to bring the cut width below 300 microns.

2.1 Kinds of Abrasive Water Jet for the Singulation

There are two kinds of abrasive water jet, known as **Abrasive water jet** and **Abrasive suspension jet.**

Abrasive water jet (AWJ): after passing through a nozzle, an ultra-high pressure (50,000psi) water jet entrains abrasive particles into a mixing tube, then mixes and accelerates the abrasive particles through the mixing tube to form an abrasive water jet.

AWJ has following features:

- The mixing tube diameter is required to be 3 times greater than the waterjet diameter, so that the abrasives can be injected in a water jet in the mixing tube. Consequently, the AWJ diameter is three times greater than the waterjet diameter, which increases the cut width and reduces the cut speed.
- As mixing tube diameters are decreased below 0.5 mm the abrasive injection process begins to break down and the transport of abrasive particles to the mixing tube becomes problematic[2]. The minimum diameter for conventional abrasive waterjets is about 0.5mm.
- A large amount of air is mixed in the cutting beam as dry abrasive is added to the water, and will expand after exiting the mixing tube causing the beam to widen and affect the cut precision.

- Abrasive injection is an inefficient method of mixing and accelerating abrasive since it utilizes much of the energy as jet pump action. Therefore, AWJ needs ultra-high pressure (50,000psi) intensifier.
- The abrasive concentration has to be a maximum of 10-15% by weight.

Abrasive suspension jet (ASJ): before passing through a nozzle, the abrasive particles are mixed into water to create abrasive suspension; then high pressure pushes out the premixed abrasive suspension through a nozzle to form an abrasive suspension jet.

ASJ has following features:

- ASJ diameter approximately equals to the nozzle diameter, therefore the cut width can be from 0.5 mm down to 0.05 mm,
- No air causes ASJ beam to expand, which affords maximum cut precision.
- ASJ is most efficient way to accelerate the abrasive particle along with the water through a nozzle, having an order of magnitude higher power density than AWJ. ASJ cuts five times faster than AWJ under identical hydraulic and abrasive conditions.
- Due to the suspension fluid, there is no need for 50k+ psi pressure pump. The ASJ can cut with a pump as low as 10 k psi. This reduced drastically the footprint of the machine, as well as the noise level generated by the pump.
- The abrasive concentration can be up to 70% by weight.

Table 1 is a comparison between AWJ and ASJ for singulation. We could know that the AWJ cannot produce the 0.25mm cut widths required in semiconductor singulation, whereas the ASJ operate down to 0.05 mm jets. ASJ is more precise and more powerful than AWJ.

So, we choose ASJ for the singulation not AWJ although AWJ system is simple and more easily realized continuously cutting.

2.2 Method of Generating ASJ for the Singulation

There are two methods that could be used to generate ASJ, known as **the additive method** and **the carrier method**.

Additive method [3] [4**]:** The system uses additive to suspend abrasive particles in water to make abrasive suspension before introduced in a vessel; then high pressure pushes out the premixed abrasive suspension through a nozzle to form an abrasive suspension jet.

Figure 2 shows the principle of additive abrasive suspension jet system. This system has two subsystem for water and for abrasive slurry. Because the water subsystem does not pump the water to the nozzle, it only pushes the abrasive slurry with isolator as a diaphragm pump, it can be looked as a high pressure diaphragm pump.

Carrier method [5] [6] [7] [8] [9] [10]: The system directs water flow to fluidize and to carry abrasive from a high pressure vessel into main water flow to create abrasive suspension; then high pressure pushes out the premixed abrasive suspension through the nozzle to form an abrasive suspension jet.

Figure 3 shows the principle of the carrier method.

Table 2 is comparison between additive method and carrier method for singulation. We could know that:

- Carrier method for the Singulation can have the similar cutting performances to additive method for the Singulation when operated at same pressure, same jet size and same abrasive conditions.
- For carrier method, the pressure vessel is simpler; the life of recharge valve and discharge valve is longer; almost whole vessel volume is for abrasive; change vessel is less frequently.

So we choose carrier method for the singulation not additive method.

2.3 Size of ASJ Cutting System for the Singulation

According the nozzle diameter, the ASJ cutting systems can be classified as following:

- Big Jet: nozzle diameter from 1 to 2.5mm
- Mid Jet: nozzle diameter from 0.5 to 1mm
- Small Jet: nozzle diameter from 0.1 to 0.5mm
- Micro Jet: nozzle diameter from 0.05 to 0.1mm

Normally Substrate and Wafer Cutting width is range from 0.05mm to 0.5mm.

3. DEVELOPMENT OF ASJ SINGULATION

The basic flow circuit for ASJ systems is shown in **Figure 3**. Filtered water is pressurized by a pump and fed to a control unit. The control unit either directs all the water to the nozzle, or it diverts a fluidizing water to an abrasive storage vessel to displace abrasive and carry out of the vessel to mix with the main water; then high pressure pushes out the premixed abrasive suspension through the nozzle to form an abrasive suspension jet.

A continuous cutting mode contains two high pressure discharging abrasive subsystems and two recharging abrasive subsystems. Two vessels will be in the status of discharging abrasive and recharging abrasive respectively, and will exchange functions automatically when the abrasive in the discharging vessel has been discharged out fully.

Figure 4 is the picture of ASJ singulation which includes ASJ unit and manipulator unit.

3.1 High Pressure Pump

The spec of high pressure pump is:
Power: 3.5Kw
Pressure: 700bar
Water flow rate: 2 L/min

3.2 High Pressure Vessel

The High pressure vessel is designed to accommodate abrasive, its spec is:
Capacity: 15L
Working pressure: 870bar.
One vessel of abrasive can be discharged about 1 hour.

3.3 ASJ Nozzles

ASJ nozzles are showed in **Figure 5**.

The ASJ nozzle life is depended on the nozzle shape and material.
The preferable nozzle shape is the conical convergent nozzle with three sections: 40° convergent section, 13 ° convergent section and 15 times longer than the diameter of focus section.

The practical nozzle material is diamond**.** The diameter of the diamond nozzle only increases about 0.001mm after used for 1 hour, the life is about 100 times longer than carbide nozzle. The range of diamond nozzle diameter in the ASJ singulation can be 0.15 mm to 0.35 mm.

3.4 Abrasives

The average abrasive size depends on the allowable kerf width and the nozzle hole diameter. In addition, the sieve from the Sieve Shaker needs to be selected accordingly. Since all the abrasive must be able to pass through the cutting nozzle, the ASJ Singulation can only utilize fully screened abrasive of the appropriate maximum particle size. It is not adequate to rely on abrasive manufacturer's screening. Most industrial abrasives are available as a range of particle sizes, rather than as a single sized material. The ASJ Singulation requires 220# (65um) or 240# (63um) abrasive.

The ASJ Singulation will operate with a range of industrial abrasive including: Garnet Abrasive, Aluminum Oxide Abrasive, Silicon Carbide Abrasive. Usually Garnet Abrasive and Aulminium Oxide Abrasive performs on soft material, for example, BGA, QFN; Silicon Carbide Abrasive performs on hard material, for example, Ceramic, LTCC.

An abrasive feed rate of 20% to 40% by mass of the water flow, is recommended for efficient operation. A higher abrasive feed rate will increase cutting performance, although not in proportion to the extra amount of abrasive used. It is not advisable to increase conceration above 70% of water flow, because of increasing risk of nozzle blockages.

3.5 X-Y Table

ASJ singulation have a working area under 300 X 300 mm and have a motion system made up of a combination of linear ball screw actuators that have a repeatability better than 10 µm. There is great flexibility in how actuators are configured to form an X-Y table. A 300 X 300 mm table, **Figure 6** is being used for singulating substrate.

Proprietary linear motion actuators with the required positional accuracy and repeatability are readily available for moving ASJ nozzle, or substrate fixture. This means there is considerable flexibility in deciding how X-Y motion systems are configured for a particular machining duty. During the development program the following configurations have been used successfully:

- Moving an ASJ nozzle in the X-Y direction over a fixed substrate fixture.
- Moving an ASJ nozzle in the X direction and a substrate fixture in the Y direction.
- Moving a substrate fixture in the X-Y directions under a fixed ASJ nozzle.

The accuracy and repeatability of the motion system has to be selected to achieve the objectives for specific machining operations. A 250μm diameter jet can reproduce micron size features but only if the motion system can position the cutting nozzle with the required accuracy and repeatability.

4. APPLICATIONS OF ASJ SINGULATION

4.1 Brittle device singulation (LTCC, AlTiC, Ceramic Alumina, etc.)

The standard method of cutting these types of material is by using a blade. However, due to the materials' properties, large fracturing of the package occurs during cutting. The only method to compensate for such quality failure is by drastically reducing the cutting speed to as low as 3 and 5 mm/sec. This drastically reduces the throughput, rendering the process not feasible for production. Softer types of blade bonding materials have been tested to reduce the stress factor during cutting. This particular method has cause very high blade wear, which consequently increases the blade change frequency and machine down time.

The solution brought by the ASJ singulation has managed to eliminate the issue of cut quality failures, while increasing the cutting speed up to 30 mm/sec. **Figure 7** is LTCC Cut with ASJ Singulation

4.2 Ductile device singulation (PQFN, QFN, MLF)

As mentioned above, cutting soft/ductile materials with a blade, generates heat which in turn causes the soft materials, mainly copper, to 'coat' the blade. This causes the blade to lose its ability to cut, and the singulation is done by 'pushing' the blade through the material layers. Blade loading has been the number one cause of failures such as lead-shorting, burring, smearing, etc. Softer bond blades which allow the 'coated' layer of abrasive to break off and expose fresh diamonds, have a high rate of wear, which drastically lower the yield of the product.

Based on the initial results the water jet singulation of PQFN is shown to be more cost effective than the blade singulation. Due to the fact that water is the main abrasive carrier, limited to low heat is generated therefore the materials which are being cut maintain their structural thermal integrity. Also, since there is no 'loading' effect, fresh abrasive is used for cutting along all lines of the package. This process is similar to continuously using a new blade for every cut. Some obvious advantages of blade cutting are:

- The nozzle cost is equivalent to blade costs

- The feed speed is at a minimum of 30 mm/sec
- Cutting is done in one pass only
- Quality is superior to blade dicing quality

Figure 8 is PQFN cut with ASJ Singulation.

4.3 Curvilinear device singulation (Memory card, Photonic devices)

The blade singulation process is limited to straight lines only. With the semiconductor industry moving towards exotic types of packages, such as Smart Cards, Flash Memory devices, Light Transmitting devices, the singulation of such types of products requires ability to perform curvilinear cutting, rounded corners, angled sides of packages.

The ASJ is able to deliver such cutting performance, with a combination of x/y table movement which generates non linear motions, and cutting patterns with the use of a water jet.

Figure 9 and 10 shows a memory substrate singulated by ASJ. There are 48 pieces of device in the substrate. The device size is 15x11mm. Each device involves 10 straight line, 7 radii and 3 corner. Cutting speeds varied from up to 200mm/s; Cutting acceleration varied up to 3000mm/s^2

5. CONCLUSIONS

- With cut widths range from 0.05mm to 0.5mm, ASJ provides an ideal cutting process for fine geometry devices with both straight line and curvilinear edge.
- The AWJ cannot produce the 0.3mm cut widths required in semiconductor singulation, whereas the ASJ operate down to 0.05 mm jets. ASJ is more precise and more powerful than AWJ.
- Comparing additive method, for carrier method, the pressure vessel is simpler; the life of recharge valve and discharge valve is longer; almost whole vessel volume is for abrasive; change vessel is less frequently.
- The ASJ system usually includes discharging, recharging, sieving and recycling.
- ASJ singulation cut brittle device without chipping.
- ASJ singulation cut ductile device without smearing and burring.
- ASJ singulation Enables curvilinear cutting for memory card, photonics and other devices.

6. ACKNOWLEDGEMENTS

Several engineers in Towa Intercon Technology, INC. have contributed in the design and development of ASJ singulation. The administration, sales and materials of Towa Intercon Technology, INC. is much appreciated. The authors also gratefully acknowledge AIT, Sandisk, ChipPac, ASE, FreeScale for invaluable support with this project.

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8. TABLES

Table 1. Comparison between AWJ and ASJ

	Abrasive Water Jet	**Abrasive Suspension Jet**
System	simple and reliable, continuously cut easy	complicated and unreliable, continuously cut difficulty
Cut width	3 times greater than the nozzle diameter, minimum cut width is 0.5mm	approximately equal to nozzle diameter, cut width is 0.05mm possible
Cut precision	Air causes precision to suffer	afford maximum precision
Accelerating abrasive	inefficient	most efficient
Abrasive concentration	less than 10-15% by weight	up to 70% by weight
Power density	low	An order of magnitude higher
Pressure	ultra-high pressure needed, 3000bar	lower pressure needed, 700bar
Cut speed	low	5 times faster than AWJ for same cut condition

Table 2. Comparison between Additive Method and Carrier Method

Additive Abrasive Suspension Jet	**Carrier Abrasive Suspension Jet**
Similar system	Similar system
Additive suspends abrasive	Carrier water suspends abrasive
Need solve suspension unstability	Need solve block and uneven
There is a piston or a bladder in the vessel, the isolator need seal	The pressure vessel is simple
less than 20% of vessel volume is for abrasive, change vessel is more frequently	Almost whole vessel volume is for abrasive
The life of inlet check valve and outlet check valve is short	The life of recharge valve and discharge valve is long
Same nozzle life	Same nozzle life
Similar cutting performances	Similar cutting performances

9. FIGURES

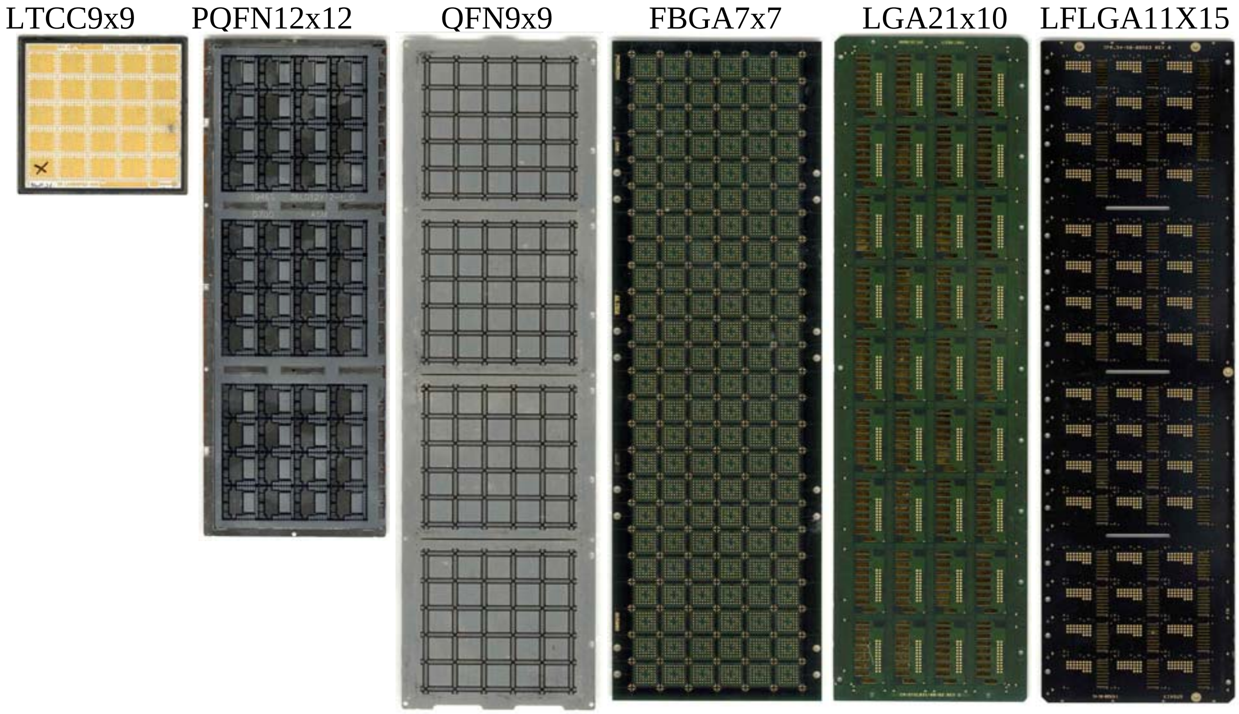


Figure 1. Different Kinds and Sizes of Substrates

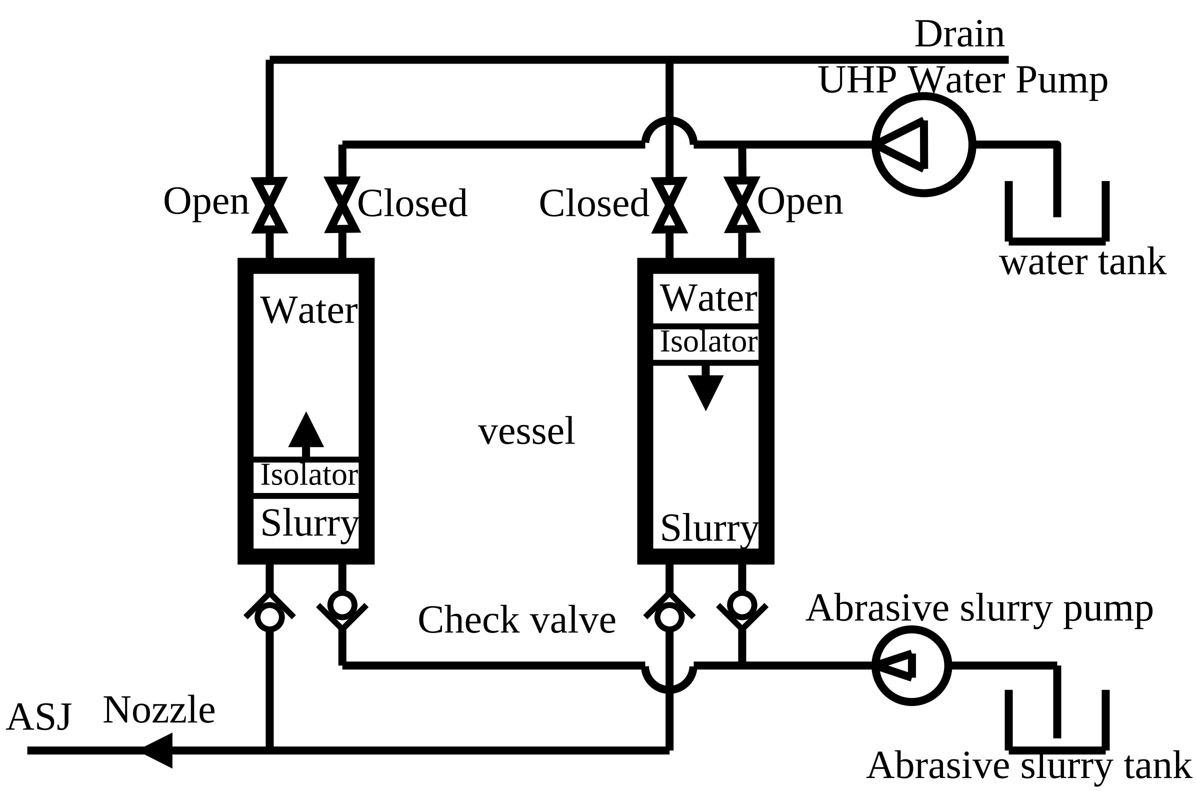


Figure 2. Additive Abrasive Suspension Jet System

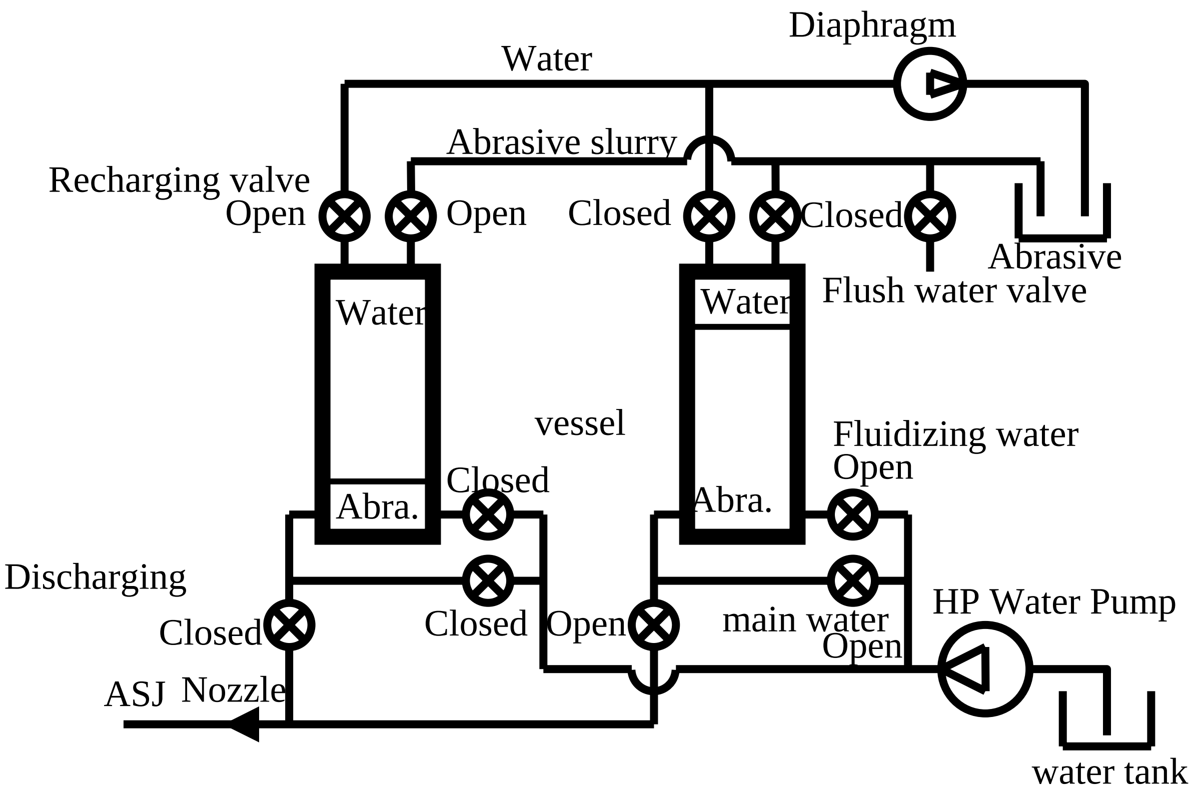


Figure 3. Carrier Abrasive Suspension Jet System

Figure 4. ASJ Singulation

Figure 5. ASJ Nozzle

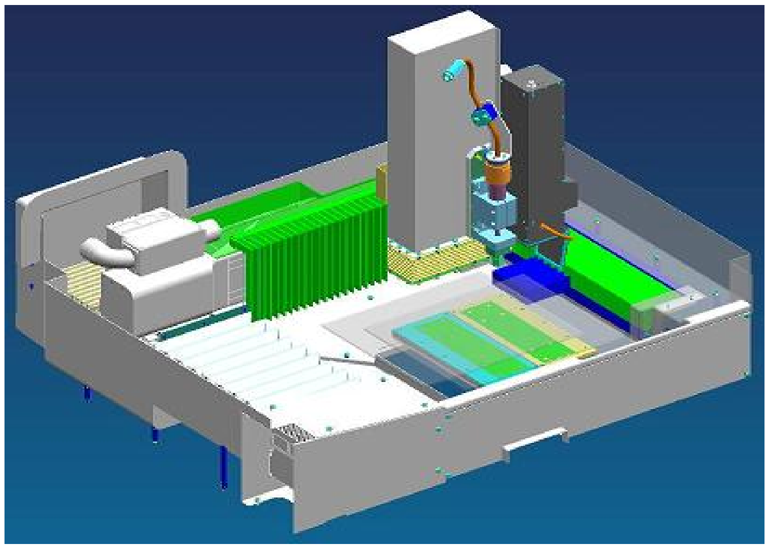
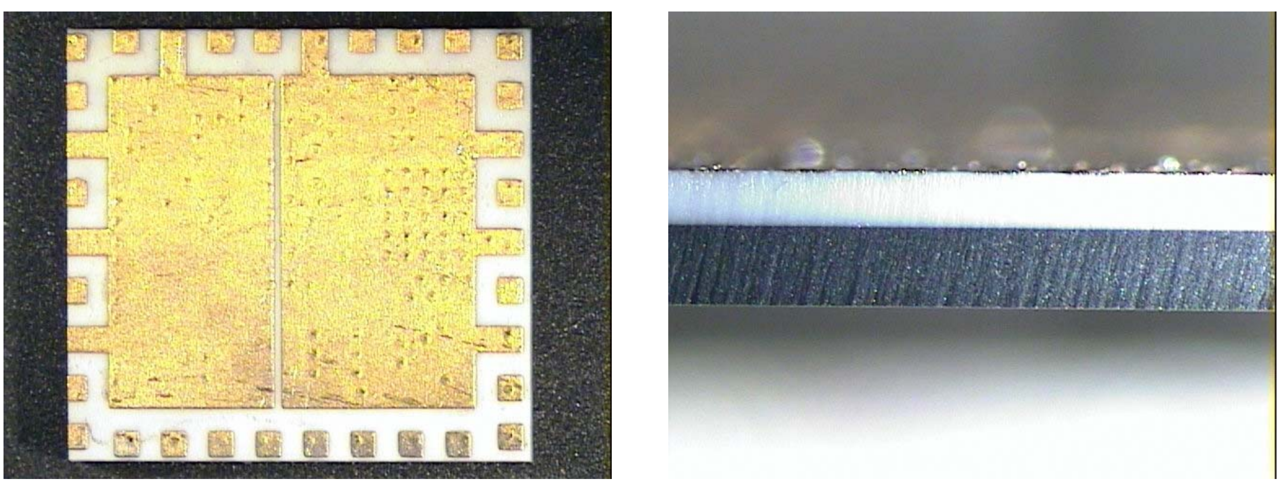


Figure 6. X-Y Table



Water Jet Parameters: P=10,000PSI, D=0.25mm.
Abrasive Parameters: AT=SiC, AS=220#, AC=20%.
Process Parameters: SOD=0.2mm, V=20mm/s.

Figure 7. LTCC Cut with ASJ Singulation

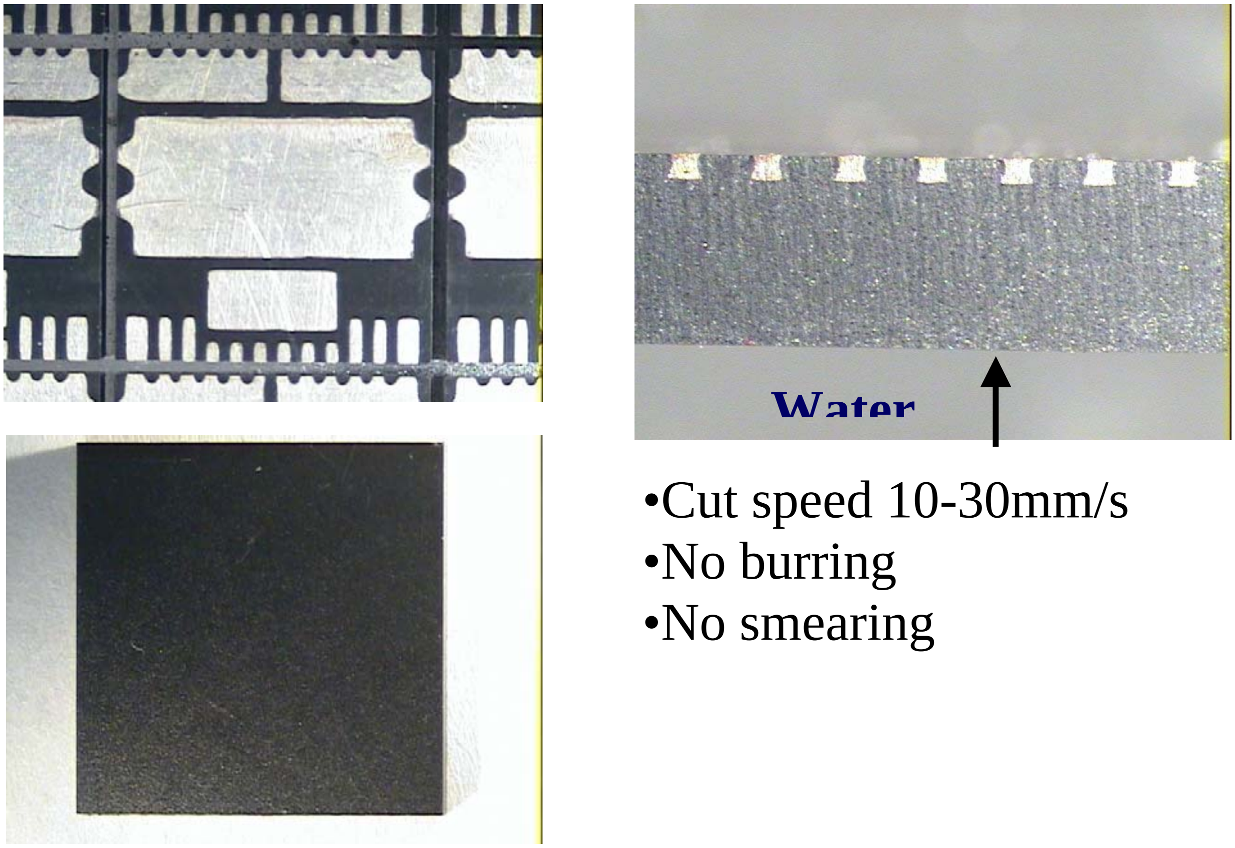
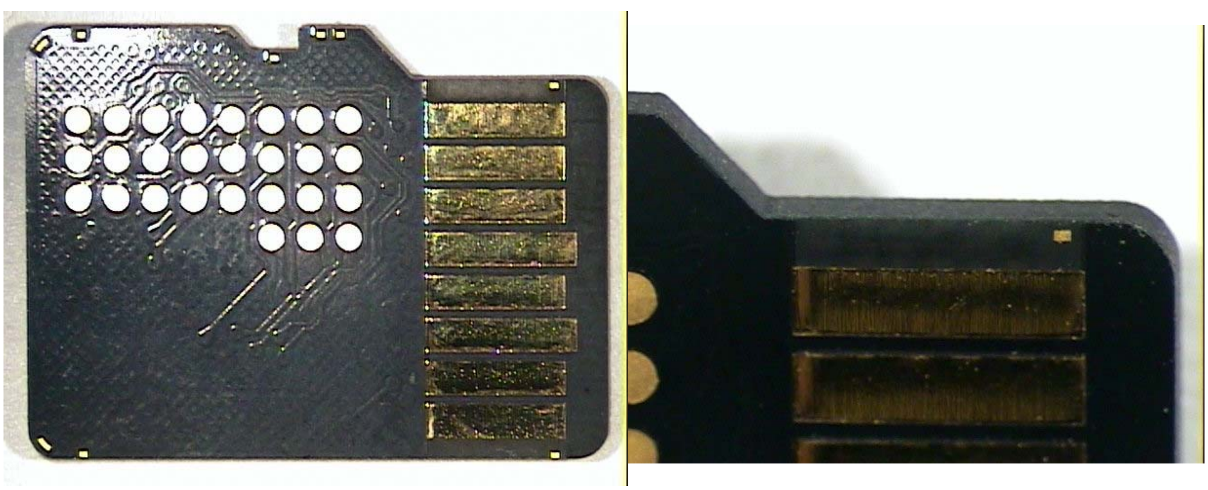


Figure 8. PQFN Cut with ASJ Singulation



Cut width 0.2mm, Cut speed 200mm/s
Figure 9. Memory Card Singulated with ASJ Singulation

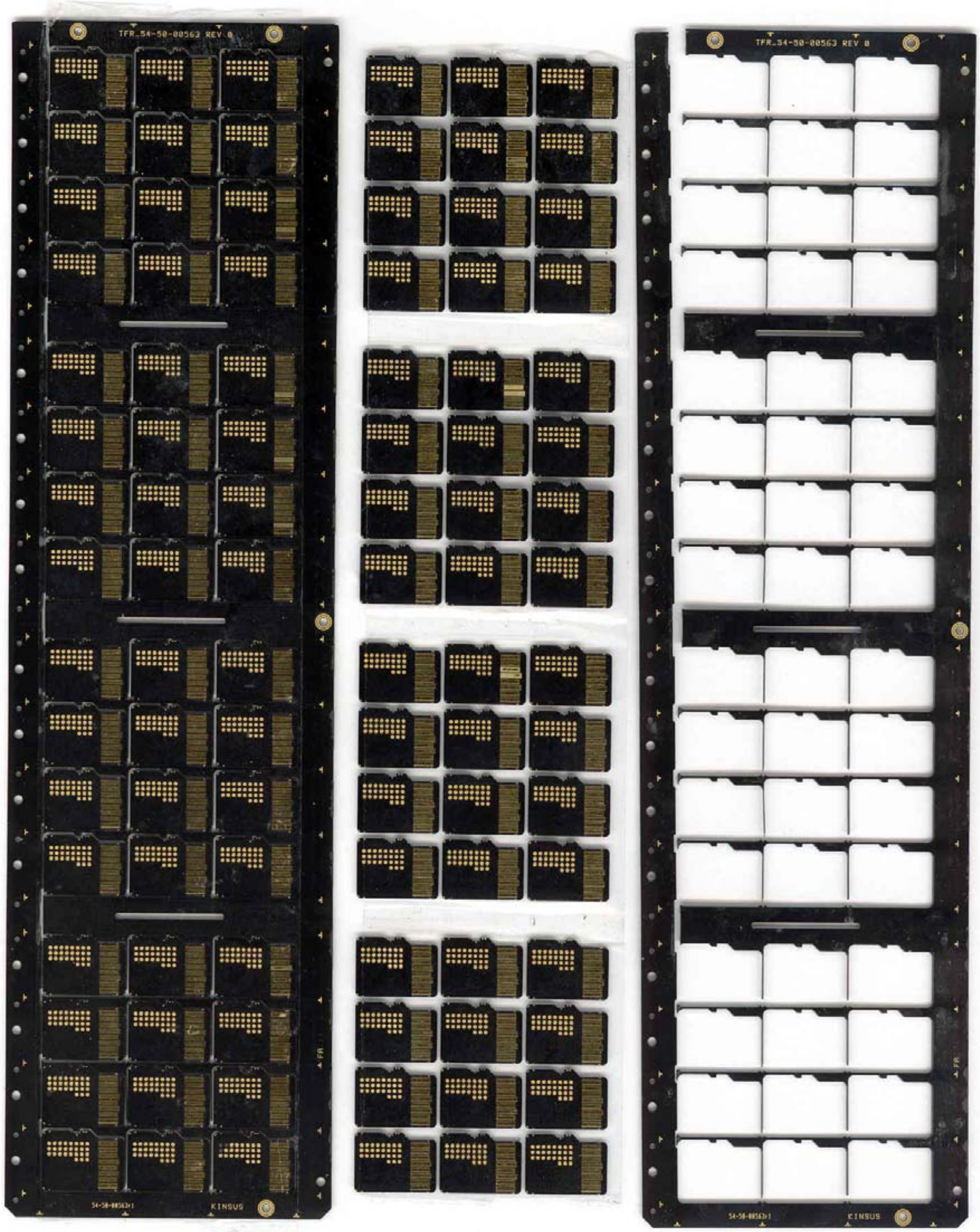


Figure 10. Curvilinear Device Singulated with ASJ Singulation