CONSIDERATIONS FOR MLP/QFN SUBSTRATE SINGULATION

Gideon Levinson
Haifa, Israel

Biography:

Gideon Levinson is ADT's Application Laboratory Manager. In the past, Gideon headed the development of the different dicing blade matrices in K&S. He was for many years the product manager for dicing blades, and during those years he worked with key customers on developing new dicing processes. This activity resulted in high volume production lines involving numerous dicing saws. Gideon is a Practical Mechanical Engineer and has vast experience in precision grinding processes. He spent four years as the Senior Product Specialist for North America and was the Application Center and Singulation Development Manager in the K&S dicing business unit. Gideon has been granted several patents related to dicing blade-manufacturing processes and has published several technical articles on dicing, which were published in leading microelectronics magazines. Prior to dealing with dicing at K&S, Gideon was a QC Manager at K&S and led a unique grinding development program for manufacturing precision linear slides.

Abstract:
Dicing MLP / QFN substrates behaves very differently from most known materials in the microelectronics industry. This paper will cover the materials structure and behavior, the quality spec that our industry is aspiring toward, the substrate design requirements for optimizing the dicing process and the parameters involved in the dicing process. It will cover in particular the blade options now available and identify opportunities for improvement and optimization.

Introduction:
The microelectronics industry has long sought a robust singulation process for MLP / QFN type substrates. The substrates are made of composite materials with different hardness and brittleness characteristics, which in a high volume production mode is a real challenge. The final die sizes vary from 1x1mm up to 12x12mm. The market is pushing also for dies smaller than 1x1mm. Die smaller than 4x4mm create mounting challenges, which will be discussed later. The industry is investigating stand-alone dicing saws and full-integrated systems that include pick and place, dicing and inspection station all in one integrated set-up. This paper will focus on challenges posed By the dicing process only and the different available options for meeting them.

MLP/ QFN Substrate and Material Characteristics:
The substrate geometry consists of 2 major materials: (1) copper leadframe coated with nickel or other soft metals; (2) Polymer molding with silica particles as a filler [Si_2O_3]. Figure 1 is a general sketch showing the geometry of a common **MLP/ QFN** type substrate.

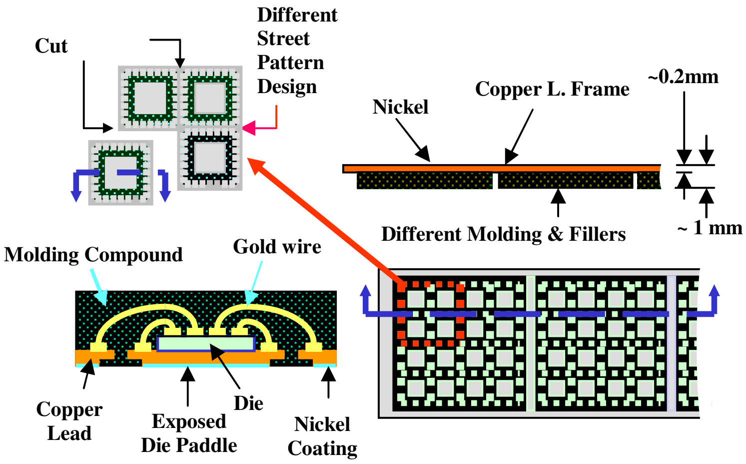

*Figure 1: Common **MLP/ QFN** type substrate.*

The leadframe in most cases is a copper alloy C-194 / with a hardness of ~ 135-145 HV [½ hard]. The copper material is relatively soft and mainly ductile, which during dicing causes burrs and smearing. See Figure 2 - SEM micrograph. The polymer-molding compound is reinforced by silica particles [Si_2O_3] in the range of 30-70mic. in size. The molding compound is relatively brittle compared to the copper leadframe, and chipping on the molding part is the main problem during the dicing process. In general, the combination of a ductile material with a brittle material in the same dicing process creates some real challenges. Figure 3 is a generic plastic deformation graph showing the difference between a brittle material and a ductile soft material, in this case copper:

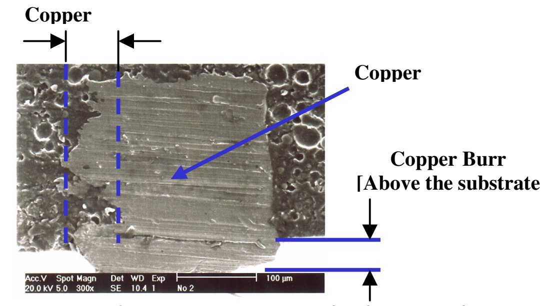

Figure 2 – SEM Macrograph of Copper burrs

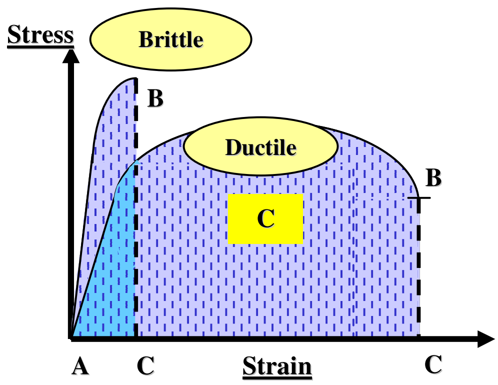

Figure 3 – Plastic deformation.

The silica particles in the polymer-molding compound are used as a stabilizer to minimize stresses and to control the flatness of the substrate. The size of the silica particles affects the size of the chipping, larger silica particles will cause larger chipping on the molding. The silica grit pullout mainly causes this phenomenon from the molding during dicing. See Figure 4 - SEM micrograph:

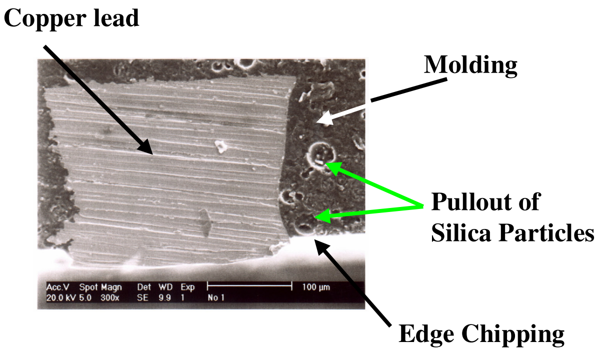

Figure 4 – SEM Micrograph of cross section of lead area

The Effect of Substrate Geometry on Cut Quality:
The geometry of the copper leadframe has a major impact on the blade loading which affects the cut quality. Figure 5 is a general **sketch / glossary** to outline all the elements involved in a QFN type substrate, which should help to better understand the following discussion:

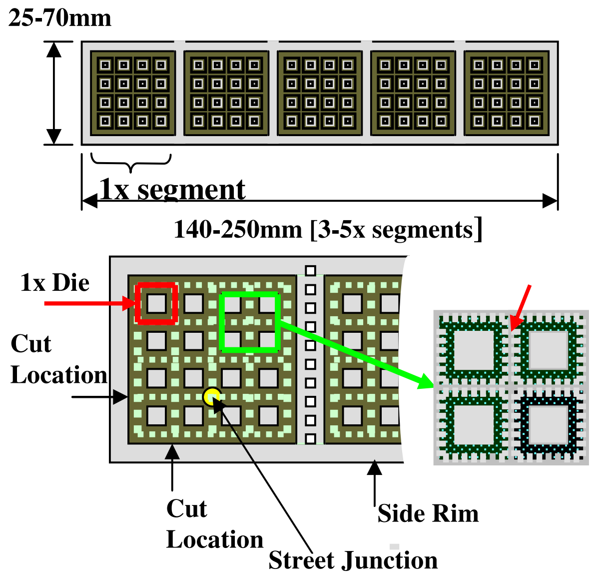

Figure 5 – MLP / QFN Glossary

Following are some important elements affecting the dicing process that should be considered when designing a new MLP/QFN substrate:

General

Minimizing the amount of copper that the dicing blade will face is a key element that should drive the substrate design. This will minimize the loads on the dicing blade and will result in higher throughputs, higher yields and better cut-quality.

Lead Geometry Design – Cross-section

The lead cross-section at the dicing area needs to be as small as possible. From experiments, a small square lead cross section is a better design than any other irregular shape, see the sketch below. Both indicated parameters will help to minimize the smearing between the leads and to maintain a load-free dicing action.

Large smearing can cause electrical shortcuts between the leads. See Figure 6

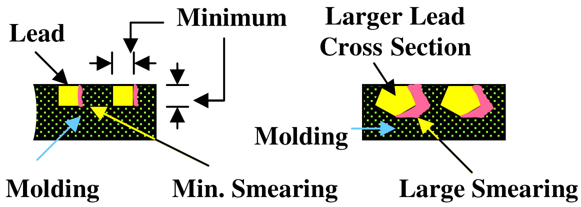

Figure 6 - Lead cross section design.

Lead Geometry Design – Top View

The geometry of the leads at the intersection with the copper line in the street affects the blade loading and the cut quality. Special **releases / relief's** at the intersection can dramatically decrease the Burrs and the smearing – See Figure 7. Needless to say, minimizing the copper in the street is very important as well.

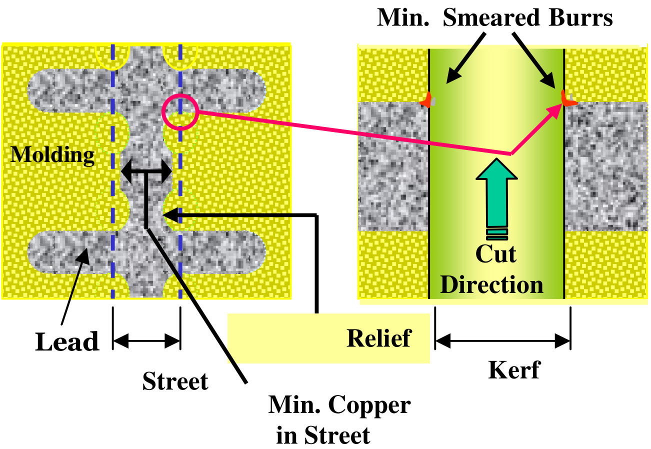

Figure 7 – Lead / Street relief.

Eliminating Copper at the Street Junction:

Eliminating the copper at the street junctions will also minimize the load on the blade and will result in better-cut quality and blade life. See Figure 8.

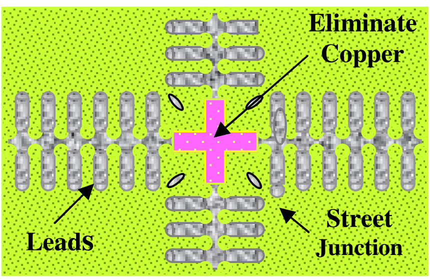

Figure 8 – Eliminate copper in the street junction.

Minimize Unsupported Copper around the MLP /QFN Substrate:

Today's QFN /MLP substrate designs have large amounts of unsupported copper leadframe area. The unsupported areas are mainly at the outer rim of the substrate and between the segments. See Figure 9.

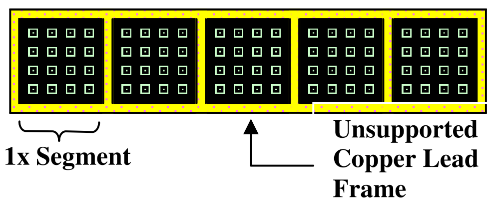

Figure 9 – Un-supported lead frame edges.

Unsupported copper can easily break the blades and cause down time.

The best solution is to design the mold to be as close as possible to the copper leadframe edge. This will support the copper leadframe and minimize any blade vibration and breakage during the dicing process. See Figure 10.

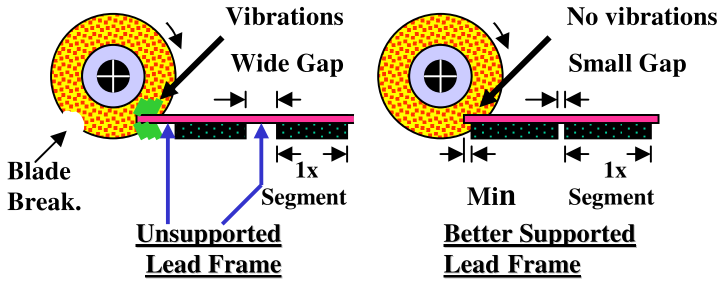

Figure 10 – Minimize the leadframe un-supported area.

Release Openings on Leadframe / between Segments:

The purpose of the release opening is to minimize the stresses during the molding process and to maintain the substrate flatness. It is very important to align those openings to the dicing streets and to design them to be as wide and as close as possible to the molding. This will minimize the amount of copper that needs to be removed. See Figure 11

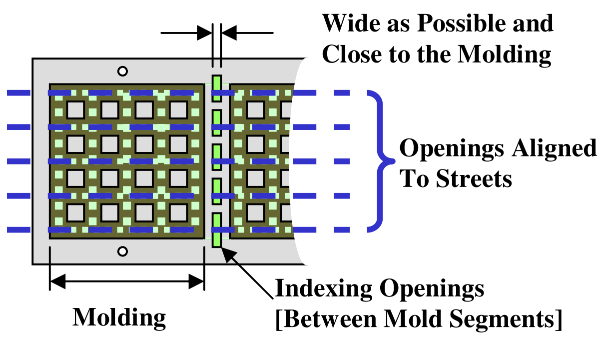

Figure 11 – Stress release opening.

Half-Etched Leadframe Design:

A half-etched leadframe design can greatly improve and ease the dicing process. The idea is to minimize the amount of copper that the blade needs to remove from the substrate. In general, the larger the etched area the easier it is for the blade during the dicing process. See Figure 12. Half-etched substrates are easier to dice and therefore can be diced with harder blades [metal sintered or nickel]. Those harder blades can be used at higher feed rates and will last longer. Half etched substrates can also be diced with resin blades that normally perform with better-cut quality but with higher wear. These types of dicing blades will be discussed later.

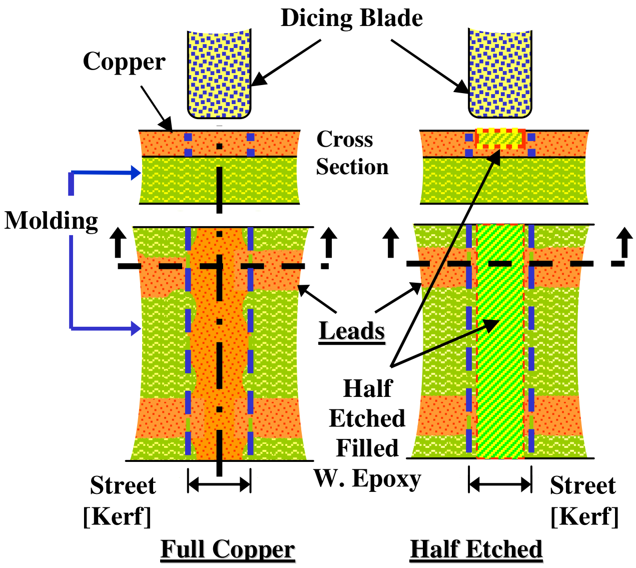

Figure 12 – Half etched and full copper

Other substrate parameters that affects the cut quality:

Lead Coating:

The lead coating needs to be as hard as possible. Soft lead coating will create a smearing effect and will overload the dicing process.

Molding Type and Silica Filler:

A stress-free molding is very important mainly for the cut quality. The molding needs to be flat and the silica particles in the molding need to be optimized for both the molding flatness and the kerf edge roughness. Smaller silica particles will perform with small pullouts and smaller edge chipping.

Quality Issues and Spec:

Following are the main quality issues that are directly related to the dicing process. See figures 13, 14, 15 &16.

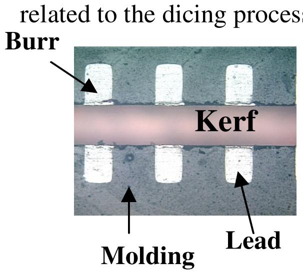

Figure 13 – Burr width

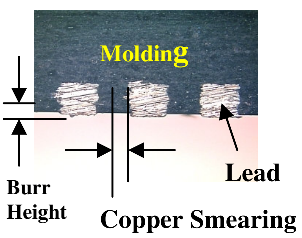

Figure 14 – Burr height & Copper smearing

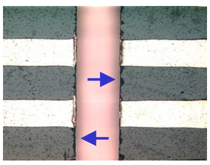

Figure 15 – Chipping.

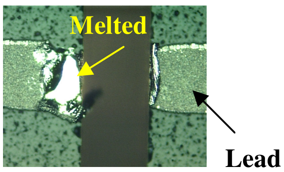

Figure 16 – Melted lead

The actual quality and the quality spec. may change at each customer site due to substrate design, the type of blade being used and the dicing process / parameters. The substrate quality will be discussed in more detail later.

The quality specifications for each of the above issues vary from customer to customer and also due to different product requirements. Following is an average quality spec. For each of the issues, based on the current market demand. This spec may change during time and for each customer. See figures 17-21.

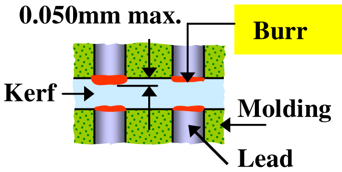

Figure 17 – Burr width.

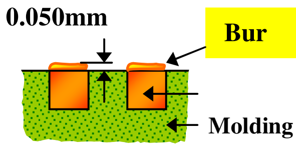

Figure 18 – Burr height.

The marketplace is now characterized by new demands for smaller burrs in the range of 0.020-0.025mm. This will affect mainly the dicing process throughput and the need to fine-tune the blade matrix.

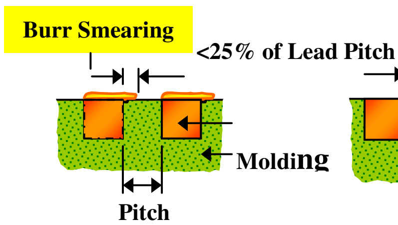

Figure 19 – Burr smearing.

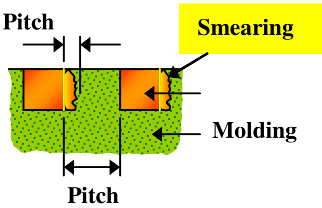

Figure 20 – Lead smearing.

Smearing between the leads can cause electrical shorts between the leads.

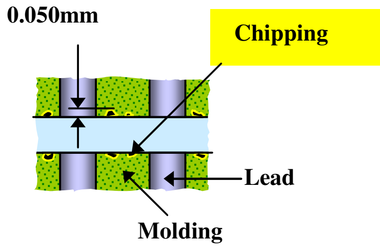

Figure 21 – Chipping on the molding.

Lead Melting or Lead Delaminating:

No lead melting or lead delaminating is allowed.

The Dicing [Singulation] Process:

The dicing process consist the following elements:

- Mounting
- Dicing blade type and matrix
- Coolant
- Dicing saw and process parameters

Mounting:

There are 2 mounting options for dicing **MLP / QFN** type substrates.

1. Tape mounting
2. Tape-less mounting

Tape Mounting:

The fact that the MLP / QFN panels are not 100% flat requires good adhesion. In addition, the standard tapes do not have good adhesion characteristics to these packages' plastic molding surfaces. **UV** Tape has much better adhesion characteristics needed to handle molding panels, which are not 100% flat and have small die size geometry (3x3mm and even smaller). UV tape is relatively easy to handle, and the mounting is similar to other standard applications, using metal frames on automated or semi-automated wafer mounting systems. The UV tape being used is about 0.170mm thick, the thickness and the adhesion characteristics may vary depending on the customer requirements.

On some ADT saws, two to four MLP /QFN panels can be mounted on one metal frame. The number of panels is a function of the panel geometry. See Figure 22.

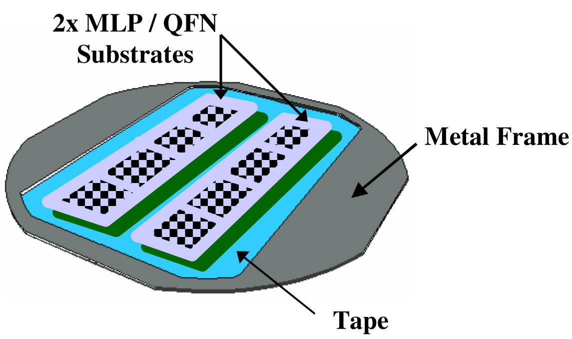

Figure 22 – Two MLP / QFN panels mounted on one frame.

Advantages of Tape Mounting:

- Proven dicing and handling processes
- Any die size can be diced
- Enables dicing of multiple panels
- Easy change to other applications

Disadvantages:

- Requires a wafer mounter
- UV tape cost
- Requires a UV station
- Tape not friendly to the blade

Tape-less Mounting:

Tape-less mounting is mainly used on pick and place singulation systems. A special vacuum plate collects the die after the dicing process.

Tape-less mounting can also be used on standard saws with some mechanical modifications. The tape-less process is less expensive but flexibility is an issue. For each die size, a specially designed chuck is needed. See Figure 23.

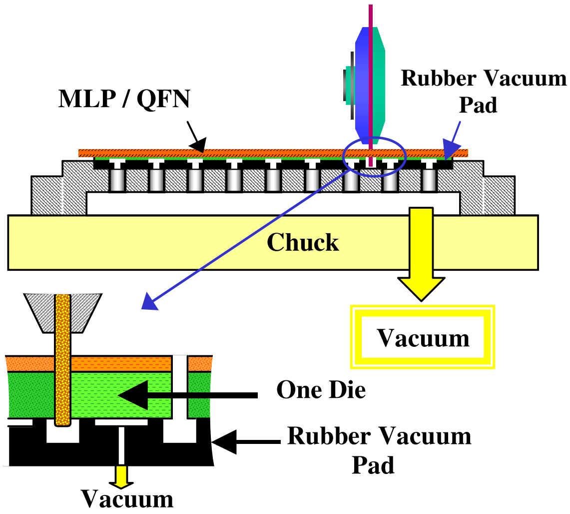

Figure 23 – Tape-less Chuck Concept.

Advantages of Tape-less Mounting:

- Tape and tape mounter are not needed
- UV station is not needed
- Shorter handling time
- Cut depth is not as critical – multiple blade/flange set can be used
- A support for the side copper edges can be designed.

Disadvantages:

- A specific tape-less chuck design is needed for each geometry – **expensive**
- Any "accidents" during dicing may reject the top tape-less chuck
- If used on pick and place system will require offloading
- Loosing die during dicing may affect the clamping of the rest of the substrate

Diamond Blade Matrixes:

Using Diamond type blades is the most common method for singulating substrates in the microelectronics industry. Most materials in our industry are hard and brittle, which normally requires a straightforward dicing process. As discussed before, dealing with a combination of ductile and brittle materials at the same time makes the process very complicated.

The common blade matrixes are:

- Nickel electroformed blades
- Metal sintered blades
- Phenolic resin blades

Nickel Electroformed Blades:

Characteristics:

- Hard binder
- Low wearing matrix / overloading
- Uneven wear on blade edge

See Figure 24

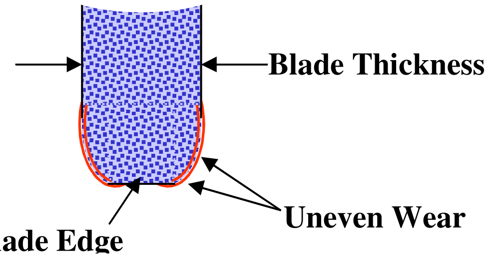

Figure 24 – Nickel blade edge.

Constraints:

Theoretically the nickel matrix looks very attractive for the MLP / QFN singulation process. In reality this matrix has some disadvantages that eliminate the use of this blade type in a high-volume production mode.

1. **Blade Overloading:**
   A relatively long dressing is required prior to the singulation process.
   The fact that the nickel binder is very hard eliminates dull diamonds wearing out and exposing new sharp diamonds. In addition, the soft ductile copper residue from the dicing is laminated on the blade edge in a way that, after a short dicing time, leaves no exposed diamonds to perform the dicing. This phenomenon creates high temperatures during dicing, which cause the copper leads to melt and to delaminate from the molding matrix. See Figure 25.

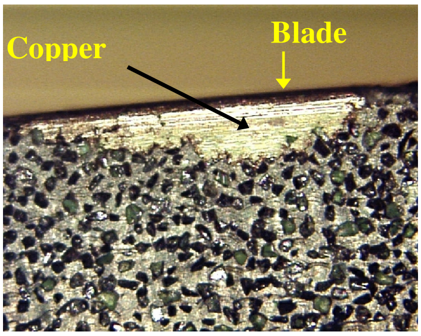

Figure 25 – Copper lamination to blade. Edge.

2. **Uneven Wear:**
   The hardness of the nickel binder results in minimum wear on the blade edge, causing a higher wear at the blade side corners. The side wear will affect the die size after a relatively short time. See Figure 26.

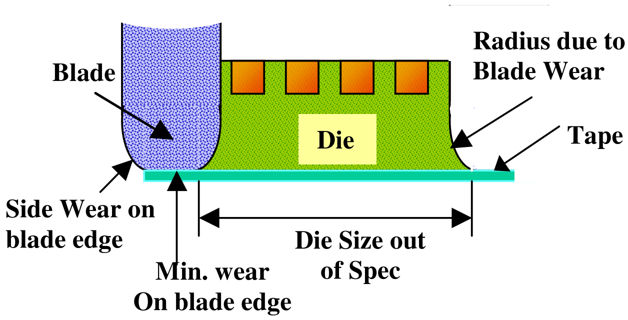

Figure 26 – Nickel blade edge wear.

The above phenomenon was proven during high-volume BGA and P.C. board singulation.

Metal Sintered Blades:

Characteristics:

- Medium hard binder
- Medium wearing matrix
- Relatively easy matrix to modify

The metal sintered matrix is softer than the nickel-electroformed matrix and therefore has more wearing characteristics. However it is still considered as a hard matrix, and similar copper lamination to the blade edge on full copper QFN substrates is seen.

Advantages of Metal Sintered Blades:

1- Easy modifications of matrix to minimize loading
2- Less wear compared to resinoid blades
3- More homogenous edge wear, see figure 27.

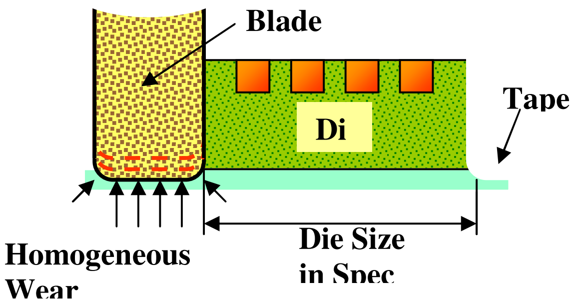

Figure 27 – Sintered blade edge wear.

4 - Half-etched QFN substrates can be diced with Metal Sintered blades.
The fact that the blade faces less copper at the dicing area enables metal sintered blades to dice half-etched QFN type substrates in a production mode. The applications on which this can be

achieved depend on the substrate geometry. See Figure 28.

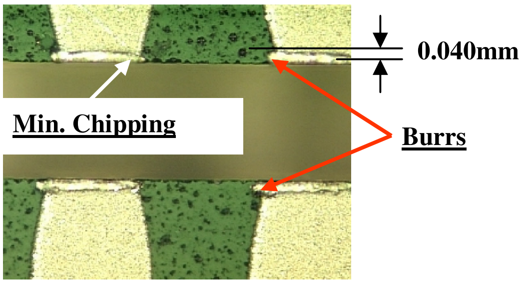

Figure 28 – MLP /QFN half-etched diced with metal sintered.

Constraints / Disadvantages:

1- Copper lamination to the blade edge:
Metal sintered blades are softer than nickel electroformed blades but still do not wear enough when dicing full copper MLP / QFN type substrates. Metal sintered blades will get copper laminated on the blade edge on most full copper QFN type Substrate. This will cause high copper burrs, copper smearing between the leads and copper leads melting and delaminating from the molding. See Figure 29.

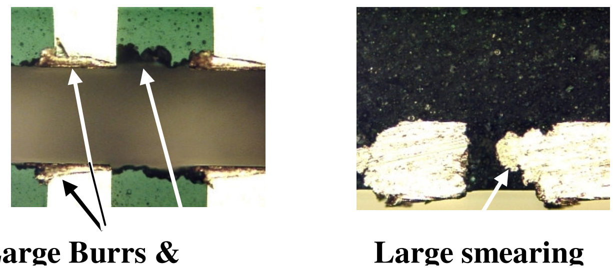

Figure 29 – Full copper QFN diced with M. Sintered Blade.

Metal sintered blades require initial dressing and dressing on-line to clean off the copper laminated to the blade edge. Efforts are being made to modify the metal sintered matrix to improve wear characteristics to minimize or eliminate the copper lamination to the blade edge. Creating a more wearing type sintered matrix makes it more brittle and more sensitive to breakage. The goal is to increase wear during the dicing process to meet the cut quality requirements while surviving the high feed rates that the market requires.

Phenolic Resin Blades:

Characteristics:

- Soft binder
- High wearing matrix
- Load free dicing action
- Easy matrix to modify

Resinoid blades are made in a phenolic molding process. They behave very differently from the metal type blade matrixes; they have some major advantages and some disadvantages.

Advantages of Resinoid Blades:

1 – Higher wear / freer cutting. See Figure 30.

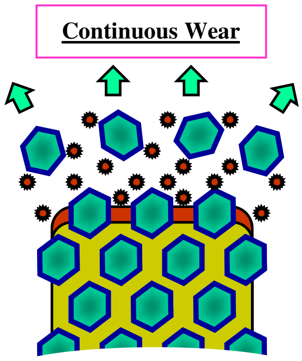

Figure 30 – Self re-sharpening blade.

2 - Easy modifications of matrix to control cut quality & wear rate.
3 – Minimum dressing is needed
4 - The best cut quality from all diamond type blades. See Figure 31.

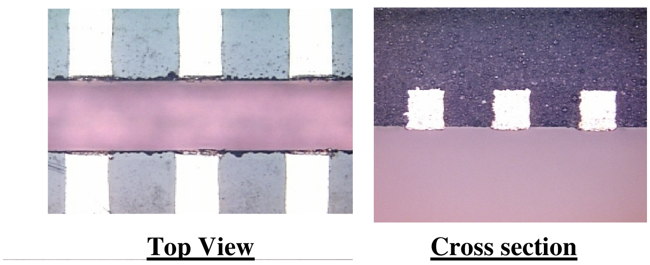

Figure 31 – Typical QFN cut. Quality using resinoid blades at 30mm / sec feed rate.

Constraints / Disadvantages:

1- Relatively short blade life
2- More height calibration is needed during the dicing process
3- Limitation in high feed rates

At the moment, resinoid blades are the most common blades used for singulating MLP /QFN type substrates. There is a continuous effort to modify and optimize the resinoid matrix. The efforts are mainly in the following areas:

- Optimizing the diamond type and size
- Modifying the resin binder by toughening the matrix in order to minimize wear and to be able to

dice with faster feed rates while maintaining the cut quality needed.

Tungsten Carbide Saw Blades

Principle of Product:

A non-diamond tungsten carbide (T.C.) saw blade that is designed similar to saw blades for cutting wood. The geometry of the saw blade is similar to a diamond blade: O.D. x I.D. x blade thickness. The only difference is the use of teeth instead of the diamonds. There are many teeth on the O.D., and each tooth acts like a single cutting tool. The raw material of the saw blade is made with a tungsten carbide powder sintering process.
See Figure 32.

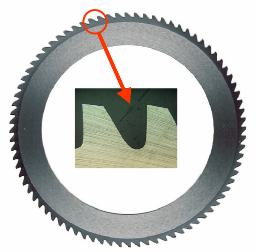

Figure 32 – Tungsten carbide blade.

Principle of Dicing with a T.C. Saw Blade:

Tungsten Carbide saw blades are normally used in slow speed milling type machines, which rotate at low RPM (normally below 1,000 rpm, depending on the outer diameter of the saw blade). Applications that are known in the microelectronics industry are green ceramics, P. C. Board materials and the like. MLP / QFN type materials can also be diced with T. C. Saw blades. The standard spindles the industry is using on dicing saws are air-bearing types at relatively very high RPM in the range of 20-60Krpm on 2" saws and 8-16Krpm on 4" saws. Using such high Krpm on T. C. saw blades will damage immediately the fine teeth and will obsolete the saw blade after a few cuts. Even the lowest spindle speed of ~ 4Krpm will damage the T.C. saw blades. In addition, most of the air bearing spindles at very low RPM are running at very low torque which cannot be used in the MLP /QFN loading type process. The above leads to the need of a high torque ceramic type ball bearing spindle [mechanical spindle]. The low RPM is also needed for dicing the copper portion in the MLP / QFN substrates. High spindle speed will result in over heating the copper leads resulting in lead melting and lead delaminating. It was proven in many hours of testing that T.C. saw blades running at 500 - 800rpm at a feed rate of 100mm/sec result in excellent cut quality on the copper leads. The burr size, width and height are smaller than burrs achieved with any diamond type blade. The problem is the chipping; T.C. saw blades cause much larger chipping in the molding area. See Figure 33. The T.C. saw blade process needs a special lubricant to better cool the QFN type substrates and to minimize the copper lamination to T.C. saw blades. This will be discussed later.

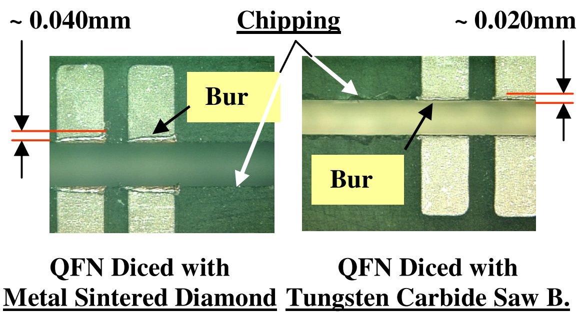

Figure 33 – Quality comparison between T. C. and metal sintered on full copper QFN.

Following are the advantages and constraints / disadvantages of the T.C. saw singulation process:

T. C. Process Advantages:

- Superior cut quality of the copper leads, mainly small burrs and minimum smearing.
- Can run the process at 100mm/sec.

T. C. Process Constraints / Disadvantages:

- Short blade life of about 200meters. The main reason is dulling of the T.C. teeth, resulting in poor cut quality. See Figure 34.

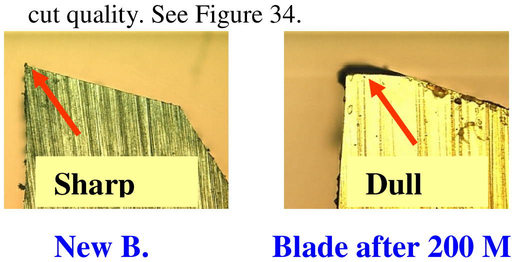

Figure 34 – T. C., new and used teeth.

- Can be used only with tape. T.C. saw blades produce much greater pushing power forces on the substrate, therefore die may move on tape-less chucks.
- Higher cost of blades and longer lead times for new geometries.
- Much larger chipping on the molding.

T.C. Saw Blade Development / Optimization:

T.C. saw blades need to be fine-tuned, and efforts are being made in the following areas:

- Fine-tuning of the raw material to increase density and hardness. The goal is to improve the blade life to meet marketplace requirements.

- Improving the surface finish of the teeth for a sharper teeth edge.
- Optimizing the number of teeth and the tooth geometry to improve cut quality and blade life. See Figure 35

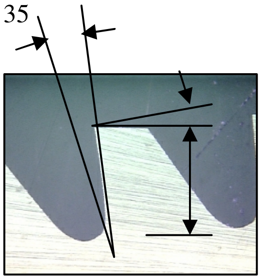

Figure 35 – Optimization requirements on T. C. blade. Geometry.

T.C. Saw Blade Main Process Goals:

- To achieve 500-750 meters of dicing. T.C. blades may be re-sharpened 2-4 times, which can improve blade life dramatically.
- To optimize the tooth geometry to improve the cut quality mainly by minimizing the chipping size on the molding.

Coolant in the Singulation Process:

When dicing soft and ductile materials like copper, the coolant becomes very critical. It is important to properly cool both the substrate and the blade edge at the same time. It is also important to make sure that there is minimum copper residue laminated to the blade edge for all blade matrixes. Following are the main factors that should be optimized:

- **Coolant additives and temperature –** This was found to have a major direct impact on both the cut quality and the blade life. The additive has a few chemical properties that act as a lubricant during the dicing process. The idea in general is to lower the surface tension of the coolant in order to better penetrate to the kerf. The temperature, which is lowered to bellow 10 C, also has a major effect on the cut quality and on the blade life. Figure 36 is a graph summarizing an experiment using the same blade and cutting parameters with different coolant types. The chilled coolant + additive performed dramatically better.
- **Cooling nozzles –** As in any application, the coolant pressure and cooling nozzle alignments are important. With the QFN process when using chilled additive type coolant, it was found that a continuous coolant flow contact on the blade faces helps to improve the cut quality and the blade life. See Figure 37.

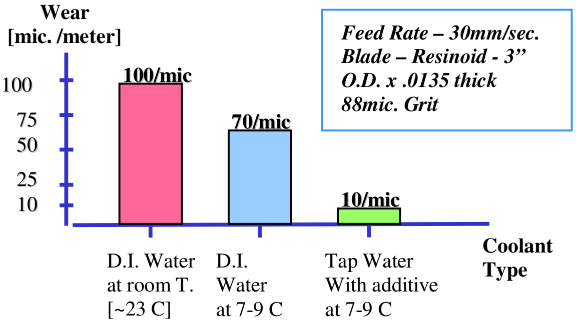

Figure 36 – Coolant type experiment.

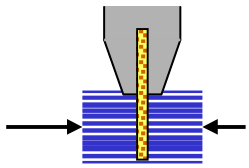

Figure 37 – Water flow on blade.

Dicing Saw and Dicing Parameters:

As previously discussed, there are 2 dicing options to consider. The first is the diamond blade option, which at the moment is preferred in the marketplace. The second option is the Tungsten Carbide saw blade option, which has advantages but is not mature mainly due to short blade life. For the diamond type blades, air-bearing spindles with close to 30Krpm [using 3” blade O.D.] are being used as well as mechanical spindles. Mechanical spindles have the limitation of a lower RPM, which is not ideal for diamond type blades. Mechanical spindles have a power advantage, allowing use of using multi-blades.

The feed rate goal in the marketplace is to dice MLP / QFN substrates at 100mm/sec. This will probably be practical only with metal type blades. The feed rate used today with resinoid blades is in the range of 20 – 60mm/sec, depending on the substrate geometry (mainly the amount of copper in the active dicing area).

Conclusions:

A successful MLP /QFN singulation process starts from designing the substrates and only then continues with the best dicing process. The name of the game is to minimize as much as possible the amount of copper in the active dicing area. Minimizing the amount of copper is a key parameter for optimizing cut quality, throughput and blade life. It is obvious that the above requires efforts from both the substrate designers and from the dicing equipment and blade manufacturers. Following is a summary of all main aspects that need special attention:

Substrate Design:

- **Minimize the lead cross section size.**
- **Minimize the street width, mainly the copper.**
- **Eliminate if possible the copper in the street junction.**
- **Add the round releases at the leads and street junction – to minimize burr smearing.**
- **Eliminate or minimize any unsupported copper on the substrate sides and between the segments.**
- **Align the stress releases on the copper between the segments to the dicing streets.**
- **Use the half-etched street design if possible**
- **Optimize lead coating to minimize smearing.**
- **Optimize molding for optimum mounting and to minimize mold chipping.**

Blade Development:

- **Modify resinoid blade matrixes to improve toughness in order to maintain higher feed rates and better blade life.**
- **Modify metal sintered blade matrixes to create a more wearing type binder in order to minimize loads and copper lamination. Metal blade brittleness needs also to be optimized in order to eliminate blade breakage.**
- **Nickel blades are second priority after metal sintered blades, but similar modifications are required.**

Process Optimization:

The following parameters must be optimized:

- **Mounting tape and process.**
- **If mounting by tape-less – best vacuum possible.**
- **Cooling type and temperature.**
- **Cooling nozzle geometry, alignment and pressure.**
- **Spindle speed and feed rate.**