

TECH NOTES

Microelectronics, Part I: Cutting, Mounting

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Introduction

For most microelectronic devices and packages, direct microscopic observation of a cross section is an important means of inspecting a particular defect. The creation of a cross section, as a destructive measure, is often used in the microelectronics lab as a decisive and final inspection tool after all other economical means of nondestructive inspection are employed.

In order to produce a cross section, many of the techniques used in the metals industry have been borrowed; to a large degree, with success. However, the philosophy and logic for choosing a particular method of cutting, mounting, and abrasive preparation has often been lost in the process. This is of extreme significance because the needs of the microelectronics industry vary greatly from those of the metals industry. Issues such as feature size, specific area cross sectioning, and the ability to prepare a variety of materials with different mechanical properties within a single plane of polish require an understanding of basic abrasive processes so that appropriate sectioning methods might be developed.

This issue of TECH-NOTES is the first half of a two part effort to summarize some of the basic concepts involved in proper preparation of microelectronic materials. We will discuss some simple guidelines which the microelectronic materials analyst might draw upon in the development of better preparation techniques. In particular, this issue will cover the variables involved in cutting and mounting of microelectronic materials, and summarize some of the technique and consumable choices that must be considered in order to achieve quality results. The next microelectronics issue of TECH-NOTES will continue with the abrasive processes of grinding and polishing these materials.

Specimen Preparation Philosophy

When considering preparation of a microelectronic device and/or package, the first step is to determine which materials are present in the cross section of interest. This is critical since these materials and their mechanical properties will determine, to a large degree, the course of action we take.

Consider, for example, a small epoxy package in which we desire to cross section a silicon die and a gold ball bond near the die's edge. If we were to encapsulate the package and grind to the edge of the die, (assuming the use of appropriate abrasives and technique), we might produce satisfactory results in a reasonable period of time.

This course of action would not be so easy, however, if the package were instead composed of ceramic. In this case, several choices present themselves. We can try to grind through the package, but we would, of course, require an aggressive grinding medium which may annihilate the brittle silicon upon contact. In addition to destroying the materials we plan to analyze, we would probably spend an inordinate amount of time (not to mention expense) getting to this point. A better option is to cut the package near to the plane of interest, using a precision diamond saw, and then to encapsulate the specimen for subsequent preparation.

Table 1. Choosing an Appropriate Metal-Bonded Diamond Blade for Cutting

Blade	Purpose
15 HC, LC	General purpose blades for sectioning metals, ceramics, composites, etc.
10 LC	Ideal for sectioning packaged semiconductors with mineral filled epoxy, glass organic, or ceramic packages.
5 LC	Ideal for sectioning bare die semiconductors, and some ceramic-based packages

The basic example above hints at a simple philosophy of preparation in which we carefully consider each stage of the process and its consequences towards the materials we choose to analyze. The following text summarizes basic cutting and encapsulation processes in order to promote a logical course of planning for microelectronic materials preparation.

Cutting

Cutting a specimen close to the target plane has one major benefit, if performed properly. It allows us to bypass much of the grinding that consumes both abrasives and operator time. This is especially true, as explained previously, when ceramic packaging materials are present.

The errors that are commonly associated with cutting microelectronic devices have caused many to fear this method of specimen reduction as an alternative to grinding. However, if one is armed with some basic knowledge of available blades, and some simple techniques to protect the specimen, much wasted time and frustration can be avoided.

Table 1 describes the three series of metal-bonded diamond blades typically used for cutting microelectronic devices. Decreasing number designations represent decreasing abrasive size, while HC

and LC represent high and low abrasive concentration. Typically, low abrasive concentration is desired for sectioning hard, brittle materials, such as ceramics and semiconductors, due to the high load per unit diamond required for reasonable cutting rates. Figure 1 illustrates relative abrasive sizes for the three blades listed in Table 1. Figure 2 illustrates the surface finish and induced damage produced by these blades.

Although the finest abrasive produces the best surface finish, there is a trade-off. Finer abrasives may, in some cases, significantly increase cutting times. This is especially true when polymeric packaging materials are involved. For package applications, the 10LC series blades tend to give satisfactory results in a reasonable period of time.

While blade choice is extremely important in minimizing cutting damage, it is only half the battle. Other important factors for producing good results include choosing an appropriate lubricant/coolant, dressing the blade, and orienting the specimen in order to preserve the features of interest.

Typically, the better a lubricant/coolant wets the specimen and the abrasive in the blade, the less blade 'loading' will occur. Loading is the process by which ductile materials, such as copper, aluminum, or polymers, adhere to the constituents of the blade and decrease their cutting effectiveness. This type of loading may occur in a variety of ways. For instance, when the contact point between specimen and blade is not well lubricated, friction creates high local temperatures. Such temperatures may result in localized welding or 'galling' between ductile metals and blade constituents. Many polymers, on the other hand, soften under high temperature conditions, and adhere tenaciously to the edge of the blade, again reducing blade effectiveness. Hard materials, such as ceramics, can also produce loading, but through a completely different mechanism. They may cause the ductile binder material in the blade, itself, to smear over the abrasive, thus reducing the cutting rate. For low-speed applications, the best results will be achieved by using a lubricant such as ISOCUT® Fluid. This product provides extremely good surface wetting at low speeds, but it has a drawback for microelectronics applications. It is an oil-based lubricant, which can be difficult to thoroughly clean from small recesses found in many microelectronic devices. An alternative is ISOCUT® PLUS Fluid. This water-based lubricant/coolant was designed for both low and high

speed cutting, and provides excellent wetting properties for nearly all applications. The fact that it is water-based makes it easier to rinse from the specimen after cutting.

Figure 3. ISOCUT® and ISOCUT® PLUS cutting fluids. ISOCUT® PLUS should be diluted with water prior to use.

Figure 4. Dressing of the blade should be performed before each cut. Using a dressing stick holder (as shown in the figure), instead of holding the stick by hand, prevents blade damage.

While an appropriate lubricant/coolant can reduce the effects of loading, it would not eliminate them entirely. Dressing the blade is also critically important and is often overlooked when cutting. Dressing involves cutting into a special abrasive stick (the appropriate dressing stick is supplied with each blade) to remove loaded material from the blade's cutting surface, see Figure 4. Typically, a single cut which extends halfway through the dressing stick is sufficient

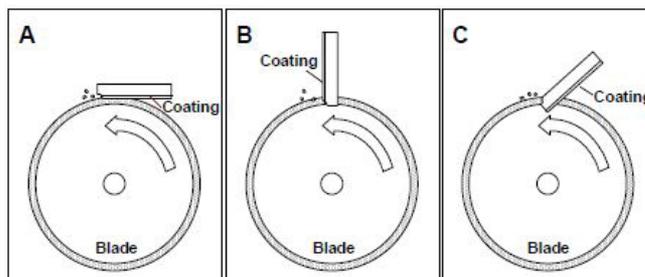


Figure 5. a) Orienting the specimen with longest dimension tangent to the blade produces long cutting times. In addition, thin film coatings and substrate may be damaged. b) Orienting the specimen with shortest dimension tangent to the blade decreases cutting times. Thin film layers on trailing edge of the specimen are in tension and can be damaged or separated. c) Proper orientation is illustrated. Tilting the specimen minimizes vibration, and placing thin film layers at the leading edge keeps them in compression against the substrate.

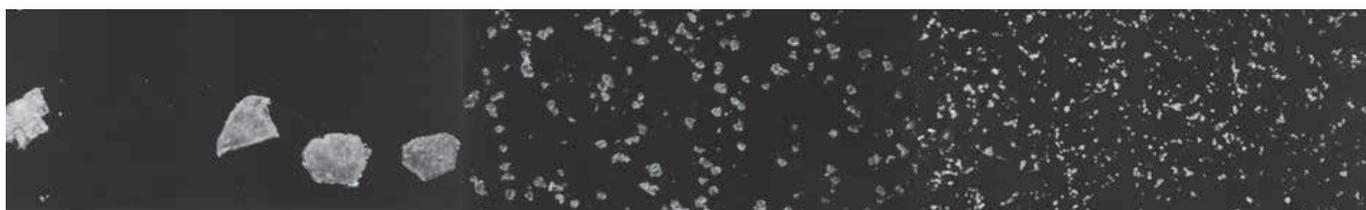


Figure 1. Darkfield images of relative diamond sizes from a) 15 series, standard diamond wafering blade; b) 10 series diamond wafering blade for packaged microelectronic devices; c) 5 series diamond wafering blade for small packages and bare devices.

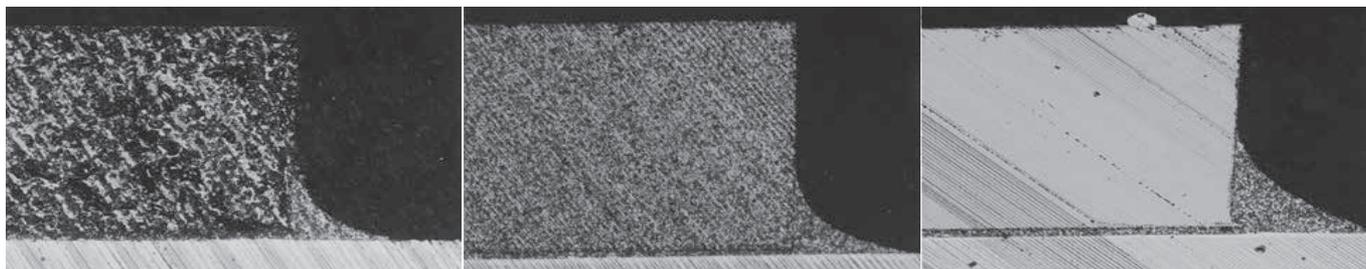


Figure 2. Brightfield images representing cut surface finish produced in a microelectronic device by a) 15 series diamond wafering blade; b) 10 series blade; c) 5 series blade.

to dress the blade before each specimen cut. If cutting through a specimen which has previously been mounted in resin, dressing should be performed continuously during the cutting process to clean the resin material from the abrasive surface of the blade.

Finally, and possibly most important of all, is the issue of specimen orientation during the cutting process. Brittle materials such as silicon and ceramics are much stronger in compression than in tension, it is important to orient the specimen so that the surface or interface of interest is put into compression by the approaching abrasive. Figure 3 illustrates the best orientation for a specimen in which the thin film circuitry must be preserved. It should be noted that the trailing edge of a brittle material, if unsupported by packaging, for instance, will be put in tension during cutting. Therefore, choices must sometimes be made about which edge of the specimen will be sacrificed in order to protect an interface of interest. If all features must be protected, but the specimen is not self supported, it may be necessary to 'butter coat' the specimen with epoxy resin. This is a process by which a thin layer of epoxy is applied to the surfaces of the specimen and allowed to cure prior to cutting. By butter coating, a supporting layer is created, which reduces the chipping due to tensile forces, but which is not so thick as to significantly slow the rate of cutting.

Mounting Media

The process of mounting involves encapsulating the specimen in a protective material. The specimen is often mounted in a two part polymer resin system, although other mounting systems are occasionally used. The reasons for mounting or 'potting' a specimen are threefold. First, mounting protects features at the leading and trailing edge of the specimen from polishing relief. Second, mounting compounds provide the leading edge of brittle specimens with protection from the damaging effects of impact loading caused by fast moving abrasive particles. Third, mounting produces a common geometry which facilitates both manual and

Table 2. Castable Resins (Cold Mount)

Materials	Properties
Acrylic	<ul style="list-style-type: none"> • Rapid rate of cure (5-10 min.) • Translucent • Moderate shrinkage • High exotherm • Moderate to low abrasion resistance
Epoxy	<ul style="list-style-type: none"> • Range of cure times (45min.- 20 hrs.) • Transparent • Very low shrinkage • Moderate low exotherm • Moderate abrasion resistance
Polyester	<ul style="list-style-type: none"> • Moderate rate of cure (2-8hrs.) • High transparency • Low shrinkage • Moderate exotherm • Very low abrasion resistance • Solvent sensitive

automated preparation.

Though there are significant benefits to proper mounting, there are instances where mounting may create a hindrance to achieving good results. This is especially true when cross sectioning unpackaged die. While the unmounted preparation of bare die is an important aspect of microelectronic specimen preparation, the subject requires an extensive review of abrasives and fixturing to do it justice. Therefore, we will restrict our discussion to those specimens which specifically benefit from mounting.

Table 2. Castable Resins (Cold Mount)

Name	Peak Temperature	Shore D Hardness*	Cure Time	Comments
EPO-THIN	80°F (27°C)	78 Excellent Edge Retention	18-20hrs. or fill small voids	Low, viscosity, low shrinkage, transparent use with Vacuum Impregnation
EPOXIDE	82°F	82 Excellent Edge Retention	6-8hrs.	Moderate hardness, transparent, low shrinkage; most general usage epoxy
EPO-KWICK	185°F (85°C)	82	30-45mins.	Faster cure epoxy, some shrinkage, transparent
EPO-COLOR	175°F (79°C)	82 Excellent Edge Retention	1-2hrs.	Dye-enhanced epoxy, displays red under darkfield and polarized light to highlight cracks and pores

* Hardness differences appear negligible but abrasion resistance has a significant effect on edge roundin

There are a number of methods and resins available for the encapsulation of microelectronic materials. Of these resins, the two part castable compounds provide the best protection without the need to input heat or pressure, which might damage the specimen. Table 2 lists the three most commonly used members of the castable resin family. Of these three, the resins least often used for microelectronic materials preparation are the polyesters. While they have extreme clarity and low shrinkage, their poor resistance to abrasion and solvents relegate them to uses where specimen edge retention and chemical etching are not critical. The acrylics deserve special mention for one reason: they cure in an extremely short period of time (8-10 minutes). This property makes the acrylic family indispensable when immediate results are required. Drawbacks of the acrylics are their high exothermic temperatures, and shrinkage which produces gaps between the specimen and resin, resulting in poor edge retention. The resins with the best combination of properties for microelectronic specimen encapsulation are the epoxies. Although they do not have the shortest cure times, the advantages of their clarity, their abrasion resistance, and their low shrinkage assure that accurately sectioned, well protected specimens will be produced.



Figure 6. Buehler's Vacuum Impregnation System for epoxy encapsulation.

An additional benefit of the epoxy family is their ability to be cast under vacuum. This is uniquely beneficial because, in this way, resin can flow into hollows in the specimen to protect solder connections and other unsupported materials. Figure 6 shows a typical vacuum system for epoxy encapsulation. This system allows vacuum to be pulled on the epoxy resin prior to casting the resin around the specimen. The specimen is under vacuum at the same time. By allowing entrapped air to be removed from small crevices in the specimen in this way, atmospheric pressure, returning to the vacuum chamber after pouring, causes any remaining air to compress to insignificant levels.

Table 3. Trouble Shooting Chart for Castable Resins

Problem	Possible Cause	Suggested Remedy
Non-Curing	Wrong component ratio; Cold environment; Expired shelf life	Measure ratio carefully; Force cure with heat; Use fresh resin & hardener
Slow Curing	Incomplete mixing; Wrong component ratio; Low ambient temperature	Mix thoroughly; Measure ratio carefully; Place in warm area
Rapid Curing	Wrong component ratio; Too much thermal mass; High ambient temperature	Measure ratio carefully; Mix smaller batch; Increase air circulation
Gas Tunnels	Wrong mixing ratio; Wrong molding cup	Measure ratio carefully; Increase air circulation; Chill components; Use heat conductive mold
Stuck in Mold	Failure to use mold release	Use mold release on all inside surface of mold
Solvent Softening	Poor mount resistance to solvents	Switch to epoxy
Shrinkage	Cured too rapidly; Too much hardener; Wrong choice of resin	Normal cure cycle; Correct component ratio; Switch to epoxy
Poor Edge Retention	Mounting resin too soft application	Add hard filler to resin; Choose harder resin
Delayed Shrinkage of Mount from Sample	Post curing; Cured too rapidly	Use slower curing resin system

Epoxies, for all their benefits, can be troublesome if proper procedures are not used. Table 3 lists some common problems encountered when encapsulating with epoxies, and gives suggestions for their solution.

Probably the most common problems relating to the use of epoxy mounting material are fast/slow curing, and non-curing specimen mounts. These problems are often the result of inadequate component mixing. Proper mixing technique is illustrated in Figure 7. Experience has shown that a lifting action, as opposed to a simple stirring action, tends to assure thorough dispersment of the hardener throughout the resin. Epoxies also tend to be more sensitive to mixing ratio than resins such as acrylics. While a recommended mixing ratio for acrylics is generally supplied with each mounting kit, this ratio can be varied significantly to produce a thinner or thicker resin mixture, depending on the situation. In either case, the mount will generally cure. Resin and hardener components of epoxies, on the other hand, must be mixed with care to ensure proper ratios for the specific epoxy being used. Even slight variations can cause a mount to remain soft, or to harden too quickly. Some slow or non-curing mounts may be encouraged to cure by heating to a temperature of 120°F (50°C) for several hours, but this method does not always work. Fast curing mounts produce excessive heat generation which may result in cracking and yellowing of the resin. Once such a mount has cured, there is no way to repair it. Therefore, measure and mix carefully.

Controlling environmental conditions can also aid in the proper curing of epoxy mounts. As they cure, epoxies undergo an exothermic reaction. For proper curing, epoxies must reach a temperature equilibrium capable of sustaining the reaction. If too much or too little heat is generated, the specimen will cure too fast or may not cure at all. For example, if the specimen has a large thermal mass, it may draw heat away from the epoxy, and the epoxy may never reach a temperature equilibrium at which the reaction can sustain itself. In this case, it is important to use a mounting mold which insulates the epoxy and retains as much heat as possible. BUEHLER's SAMPL-KUPS® are an example of an appropriate insulating polymer mold for use with epoxies. In the case of specimens with very low thermal mass, the heat generated may accelerate curing too much. In this situation, it is best to use a metal ring form for casting the mount so that some of the heat of reaction may be conducted away from the epoxy. By choosing either an insulating or a conducting flat surface on which to place the ring forms, more or less heat may be conducted away from the mount, allowing for greater control of the curing rate. Some experimentation may be necessary to determine the conditions and molds necessary to produce quality mounts in your laboratory environment. Keep in mind that room temperature and humidity

also play a roll. High humidity allows heat to be drawn away from the mount, which results in slow or non-curing samples. High room temperatures may cause mounts to cure too quickly. Localized high temperatures may also result if too many samples are cast in close proximity to each other. Be sure to allow enough room between curing samples for good air circulation.

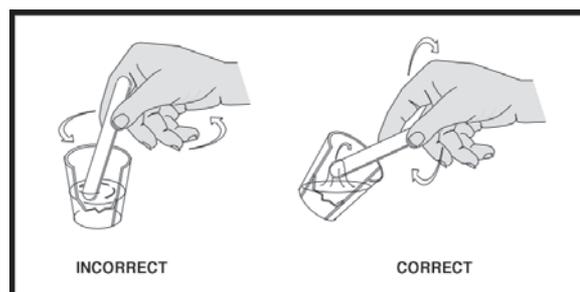


Figure 7. Proper stirring of epoxy involves a lifting action which ensures thorough mixing of resin and hardener.

Conclusion

Choices made in the initial stages of preparation can significantly influence the outcome of cross sectioning for many materials. This is particularly true of microelectronic materials. In this issue of TECH-NOTES, we have explained the advantages of cutting versus grinding in order to reduce the bulk of a microelectronic specimen. In addition, we have illustrated the effects of two specialty blades, the 5LC and the 10LC series, in reducing specimen deformation during cutting, as compared to a standard 15 series blade. For most packaged microelectronic applications, the 10LC series blades provide the best combination of cutting rate and damage minimization. In addition, proper dressing of the blade prior to each cut, as well as choosing an appropriate coolant/lubricant with good wetting characteristics will improve cutting efficiency and reduce specimen damage at the same time. It is important to note, however, that making the proper choices with regard to blade, coolant/lubricant, etc., is wasted effort if improper specimen orientation causes damage at the critical materials interface. Therefore, be sure to orient the specimen in order to keep hard, brittle materials in compression during the cutting operation. This is especially true of the interface between thin films and their substrates.

Choosing an appropriate mounting material is another issue of importance, and one which can greatly affect the outcome of any preparation. We have described the general properties of three castable resins which are widely used in cross sectioning. For microelectronic materials, the epoxy family provides the best

combination of properties for filling voids and providing edge retention for ductile materials such as solders.

When casting epoxies, keep in mind environmental conditions in your laboratory when deciding upon a particular type of mold. For warm conditions, consider using a metal ring form to draw away some of the heat of reaction. For cool conditions, or high humidity situations, consider a more insulating mold such as SAMPL-KUPS.

The next microelectronics issue of TECH-NOTES will continue with a discussion of appropriate abrasive choices for microelectronic materials, and their proper application in producing a deformation free cross section.

Tech-Tips

Question: What load (or pressure) should I apply to the specimen when cutting microelectronic materials?

Answer: There is no simple answer to this question. For packaged devices, greater loads are acceptable because the packaging material will often support much of the load. The thinner a blade is, however, the less load it can support. An overloaded blade can warp and produce a non-flat surface, or crack brittle specimen materials. On the other end of the spectrum, insufficient loading can also be a problem. If the specimen is not loaded enough to keep it in constant contact with the blade, it may bounce and cause impact cracking.

Question: What speed of rotation should I use for the blade during cutting?

Answer: As a general rule, speeds up to 1000 RPM are acceptable. Many microelectronic materials can be cut at speeds exceeding 1000 RPM, but care must be given to proper coolant application so that heat damage is not a problem. In fact, the faster the blade is rotating, the faster material is sheared in a direction tangential to the blade. If material is sheared away faster than the load between specimen and blade can be reapplied, less damage occurs in the specimen.

Question: Is it ever better to encapsulate the specimen prior to cutting?

Answer: The cutting process is always more efficient when the blade is in contact with less material. In addition, resin encapsulation materials tend to load up the blade quickly. Therefore, it is generally better to cut unmounted samples. But, when one must cut a mounted sample, it is critical that dressing of the blade be performed during the entire cutting process in order to continuously remove the loaded resin. Encapsulating the specimen prior to cutting is only advantageous when certain features must be supported. In some situations, a 'butter coat' may be a better option. A butter coat is a thin layer of mounting resin spread over the surface to be protected. When this layer cures, brittle materials which would otherwise be exposed, are protected from chipping. Once cut, the butter coated halves can be fully encapsulated for subsequent preparation.

Question: Acrylic encapsulating resins cure so much faster than epoxies. Should I use them to speed up my work?

Answer: While acrylics do cure faster (8-10 minutes vs. 45min.-24hrs. for epoxies), the faster cure times result in significant shrinkage. This means that the acrylic resin pulls away from the

specimen, leaving a gap. This gap can cause edge rounding problems because there is nothing adjacent to the specimen to give it support during polishing. Gaps can also trap abrasive particles during a grinding or polishing step, only to release them later, contaminating a finer polishing step. In addition, acrylics cannot be used to fill voids around such features as solder balls under a BGA package. Because they begin to cure so quickly, they entrap air in these spaces. Epoxy, on the other hand, can be put under vacuum to release entrapped air prior to curing.

Question: I use epoxy for mounting, and I think I am measuring and mixing properly, and the environment where I do the mounting is rather cool. Still, my samples cure far too quickly. What else could be wrong?

Answer: If you are using a metal ring form mold with a metal base and the mounts are still curing too fast, first check to be sure the epoxy's shelf life has not expired. If this is not the case, try mixing the epoxy in smaller batches. Since the curing reaction of epoxy begins as soon as the resin and hardener are mixed, heat is generated immediately. If too much epoxy is mixed in one batch, heat generated near the center of the mix cannot escape, and the curing reaction can accelerate too quickly. Once the reaction begins, spreading the epoxy out by pouring it into molds does not necessarily circumvent the problem.

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