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PROCESSES FOR THINNING AND POLISHING HIGHLY WARPED DIE TO A NEARLY CONSISTENT THICKNESS: PART III

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INTRODUCTION

In Part I of this article series,[1] it was suggested that instead of attempting to thin an entire die to a thickness of less than 10 microns, the entire die be thinned to 50 microns for initial evaluation. The initial evaluation would result in defining specific, small areas of interest. The area of interest would be thinned to the desired, less than 10 microns, remaining silicon thickness (RST). Part I deals with the problems and considerations for thinning a large, warped, die to a uniform thickness of 50 ± 2 microns and suggests processes and procedures for obtaining this result.

In part II,[2] the process and problems of area of interest thinning was discussed. The reasons for thinning only areas of interest were given and basic guidelines and processing limitations described.

In this article, the processes and considerations for both global and area of interest are discussed and reference process recipes are given.

THE SAMPLE

Every failure analysis sample is of extreme value as it is usually one-of-a-kind and the customer who returned it wants to know what happened. No one wants to tell a customer that a returned field failure was lost in processing. Even if it was not a field return, but instead a device that failed final test, everyone wants to know why, and process loss is not an option. When “failure is not an option,” how do you prevent it?

The basic rules for this are very simple.

1. Do the same thing to every sample in exactly the same way.
2. Record what was done in all of the processes and how it was done.
3. Process practice samples first to develop and define the process.
4. When a process is developed on the practice samples, do exactly the same thing for the live sample.

This is only simple if the equipment and the processes used are consistent from sample to sample, and the process parameters themselves are not vague variables. Tool rotational speeds and linear travel rates must be defined and optimized. Cutting tool bits need to be sharp and replaced often. Lapping and polishing tools need to be checked for damage and reconditioned, or dressed, or replaced. The abrasives need to be very reproducible in use with the tools. A process step that requires the use of a lubricant must have the lubricant dispensed in the same way on every sample as the lubricant cleanliness directly effects material removal rates and uniformity. During the process, the slurry needs to be refreshed in the same way and time in the process.

Additionally, environmental parameters need to be controlled; not necessarily controlled for absolute values, but for changes. All labs have HVAC vents. When the heater is running, the vents will blow warm air or cold air when the air conditioner is active. If the processing is done in proximity to a vent, there will be significant thermal changes and the creation of thermal gradients. This will affect the processing results. An example to demonstrate this effect is the change in length of the tools used in the process. Tools typically have shafts made of stainless steel having a T_c of 17 ppm/K. with 20 mm of shaft exposed to a 5-degree wind from a heater vent, the tool will grow by

1.7 microns. This could be very problematic if the target RST is 1.0 microns.

All of this is obvious. Just do the same thing, the same way, on every sample. There are variables, though, that must be considered.

1. How well can the sample surface profile be measured and how well does the tool travel reproduce it?
2. How consistent is the material removal process, both in average and across the die surface?
3. How can the irregularities in the material removal process be corrected and to what accuracy?

It is not possible to process every sample exactly the same way as there are too many factors that affect the process and the measurement of results. First, the sample must be removed from the processing equipment for cleaning between process steps. Removal and replacement of the sample will change the alignment in all three axes. A single dead human skin cell can be 7 microns thick and about a million of these cells are sloughed off every day by every person. A single cell can interfere with contact profile measurements and, if lodged on the fixture mounting surfaces, will change axial alignments.

Add to this, the changes in surface profile and thickness variation resulting from the redistribution of the stresses built into the sample when it was assembled.

The diameter of the tool being used and the distance the tool center moves beyond the die surface have effects on the material removal rate and consistency across the die surface. The curvature of the die surface and the average plane deviation from the basic travel plane of the system used for processing will also affect removal consistency.

The variation in some supplies can also affect results. Slurries and the adhesive used on lapping films and polishing pads as well as colloidals change with age. This requires using fresh supplies for processing to get as much consistency as possible. Do not buy supplies in bulk. Limit supplies so that they will be consumed in a month or two.

PROCESS FLOW

The process flow is the same for any sample. The die surface needs to be exposed to allow access for thinning. The die is aligned and profiled. The die is thinned in a way that quickly will remove the bulk of the silicon. Lapping and polishing steps remove the damage to the silicon from the previous step and refine the surface profile to create a sample with a consistent thickness with usable surface quality.

EXPOSE THE DIE SURFACE

Before a die can be thinned, the backside needs to be exposed. This may require removing a heatsink or spreader, or the removal of encapsulant and a die attach pad. Both processes are easily done by any CNC milling machine. Each process requires the alignment of the sample package to the machine and proper selection of tools used to remove whatever overburden is present. Enough of the die surface needs to be exposed to allow significant travel of the tool center beyond the die edges.

DIE ALIGNMENT, LEVELING, AND PROFILING

Die alignment is a process that establishes the die size and location in relationship to the processing system's reference points and defines the area over which the tool must move. This is usually done by moving a die corner to cross hairs or a video monitor. Motion control for this is generally a joystick and either all die corners or two diagonal corners are aligned to the display markings, giving the machine the precise die size and position referenced to the machine coordinates, and, if all corners are aligned, the die edge rotation from the machines X and Y travel axes.

The orientation of the mean die surface to the X-Y movement plane of the machine can be critical. Some machines only move the tool in a planar fashion. The Z-axis position of the tool cannot be changed dynamically as the tool is moved over the surface. Other machines are capable of following a programmed or measured profile, continuously adjusting the tool's vertical position as it travels over the surface to reproduce the reference profile. In any case, either the sample needs to be leveled or the profile measured, or both.

GROSS SILICON REMOVAL

Depending on the starting die thickness and the desired remaining thickness, it may be necessary to grind off a lot of silicon. For a larger die with a starting thickness of 770 microns and a final thickness of 50 microns, about 640 microns needs to be removed through grinding. This leaves about 130 microns of remaining silicon. The damage done to the silicon by a grinding tool can easily extend as much as 1.5 times the diamond grit diameter. The normal grit diameter for a grinding tool is 66 to 115 microns. Attempting to grind to less than 2 times the grit size invites damage to the active surface and the disintegration of the sample. Controlling in-feed rates and tool linear-travel rate can allow grinding to 125 RST with a 115-micron grit diamond-grinding tool.

Some samples, those that have very high stress from packaging as in Fig. 1, or those with some types of low-K dielectric, may not be able to survive the high lateral force from a diamond-grinding tool. These samples can be thinned with 74 or 45-micron lapping film, as these will produce very little lateral force. The lapping film takes more time but the resulting sample has a chance at being functional. The constant push for reducing processing time is somewhat misguided as faster always means more force and a greater chance of destroying the sample. Faster is often not better.

SMOOTHING THE GROUND SURFACE

The use of diamond lapping film to remove the grinding damage works very well. The lapping film, at relatively low pressures, only damages the silicon to about half the grit diameter in depth. Using a 45-micron film to remove about 50 microns of silicon works well and is reasonably fast. This removes a large portion of the damaged silicon and leaves a surface that may allow thickness measurement. If thickness measurement is difficult, a 30-micron film can be used with minor increase in processing time.

The next lapping step, using 20 or 15-micron diamond film, should bring the RST down to about 63 microns. At this point, almost all of the damage done by grinding is removed. The remaining steps: fine lap, coarse polish, and fine polish, continue to remove damage done by previous steps and get the remaining thickness down to about 50 microns.

Each step has built in uncertainty, and it is usually biased toward a thicker result. All touchdown problems, from contamination or other things, will place the tool face higher than is desired. Sometimes, the errors produce a sample that is, realistically, too thick for the next process step. This may require running a process step a second time to get the remaining silicon thin enough for the next step. It is not wise to ask any process step to remove more than its grit diameter. In the finer grit steps, less is definitely better. Any step should not leave any more than the sum of the following step's grits to remove. If 50 microns is the target, there should be no more than 63 microns RST at the beginning of fine lap. That leaves 9 microns removed by fine lap, 3 microns by coarse polish, and 1 micron removed by fine polish to get to the target. These values are the same as the grit used for the step.

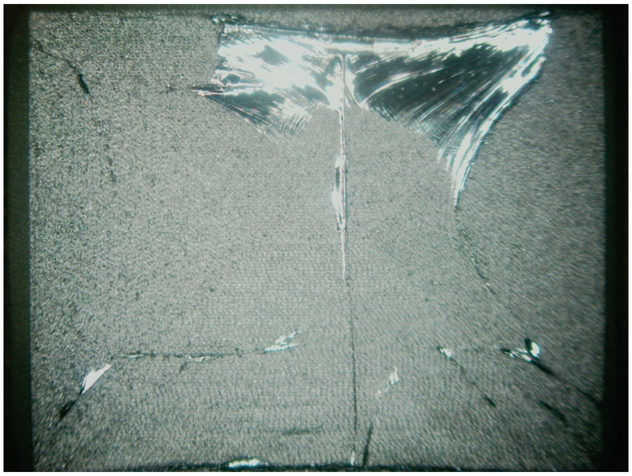

Fig. 1 **The result of grinding a die with large internal forces.**

The next step, which removes little silicon, is a final polish with colloidal silica. This produces an excellent, specular, surface that is suitable for any optical evaluation to isolate defects in the die.

In all of this is the uncertainty of material removal. The truth is in the thickness measurements. If enough material has not been removed, the step must be rerun to get to the required starting point of the next step. It needs to be remembered that all errors tend toward removing less material and each following step is limited in the material it can remove. The earlier in the process that the deficiency in removal is identified the better. Rerunning second coarse lap to remove 10 or 15 microns takes only 10 minutes or so. Trying to remove a 10-micron excess thickness in coarse polish could take more than an additional hour. Spend your time wisely by correcting removal at the coarsest step possible.

THE PROCESS TO 50 MICRONS

For a sample with a starting thickness of 770 microns, the process is as follows:

1. Grind to remove 640 microns of silicon.
2. First coarse lap using 45 micron film to remove 50 microns.
3. Measure and input thickness for profile correction.
4. Second coarse lap with 20 micron film to a thickness of 60 microns.
5. Measure thickness. If more than 60 microns average, then rerun second coarse lap entering the measured thicknesses.
6. Measure and input thicknesses for fine lap with a target of 53 microns.
7. Measure and input thicknesses for a coarse polish target of 51 microns.
8. Measure and input thicknesses for a fine polish target of 50 microns.
9. Run final polish with a programmed depth of 1 micron removing about 0.25 microns.

This should result in a 50 ± 2 micron thick sample with a perfect surface and minimal thickness variation. Evaluations can be easily made on these samples to identify areas of interest.

AREA-OF-INTEREST PROCESSING

The area of interest can easily be thinned to the desired thickness. Assuming the target is 5 microns and the area is 4 microns square; the process would be as follows:

1. Coarse lap with a 1.5 mm diameter tool and 30 micron film to a thickness of 18 microns.
2. Fine lap with a 1.5 mm diameter tool, a coarse pad, and 9-micron slurry to a thickness of 9 microns.
3. Coarse polish with a coarse pad and 3-micron slurry to a thickness of 6 microns.
4. Fine polish with a fine pad and 1-micron slurry to a thickness of 5 microns.
5. Final polish with a final polish pad and colloidal silica.

The first step must thin an area greater than 7 mm square, as the tool inside edge must be moved beyond the edge of the area of interest. The tool travel of each step needs to be somewhat less than that of the previous step to insure uniformity in thickness. A reduction of 100 to 200 microns in over travel for each step will give acceptable results. This requires that the first step have an over travel equal to the tool diameter plus 300 to 600 microns. Using the high value to be safe, the over travel for coarse lap needs to be 2.1 mm making an 8.2 mm square hole. This value reduced by 0.20 mm (0.4 mm total) for fine lap, coarse polish, and fine polish. Final polish can use the same over travel as fine polish.

There are some considerations for the selection and size of the area of interest. As some type of profiling must be done prior to each process step, the area of interest must not be so large or positioned as to prevent measuring the mean plane of the die. This is necessary to adjust the tool path for any plane rotation resulting from removing, cleaning, and reinstalling the sample and holder. As there can be no contact measurements of the surface made after the coarse lap step, measuring the 50-micron RST surface can indicate and surface plane rotation.

DEALING WITH THE VARIABLES

As stated above, there are variables to be addressed.

How well can the sample surface profile be measured and how well does the tool travel reproduce the profile?

Most machine manufacturers confuse the terms ‘accuracy,’ ‘resolution,’ and ‘reproducibility.’ Accuracy is an absolute and is related to NIST standards. That is, any movement of the tool will result in a tool position that is at an absolute position that can be traced to measurement standards. Most misuse “resolution” as accuracy. The two are very different. A voltmeter with a 1% accuracy may measure a 1-volt source as anywhere from 0.99 to 1.01 volts. The meter could have microvolt resolution resulting in measurements of 0.990000 to 1.010000, but the additional digits are meaningless as the readings are only good to two digits. The difference between accuracy and reproducibility is best indicated in Fig. 2. A profile is relative, not absolute. The capability of reproducing a profile depends on reproducibility, not accuracy or resolution.

> "ANY MOVEMENT OF THE TOOL WILL RESULT IN A TOOL POSITION THAT IS AT AN ABSOLUTE POSITION THAT CAN BE TRACED TO MEASUREMENT STANDARDS."

How consistent is the material removal process, both in average and across the die surface?

Material removal rates are dependent on contact area, down force, and the material characteristics. As the die has a curved profile, the contact area changes according to the local slope of the die surface. Although the lapping film or a polishing pad has some compliance, the greater the slope, the lower the contact area. On a flat surface that is parallel to the tool face, the entire face is active in material removal. On a curved surface, only some portion

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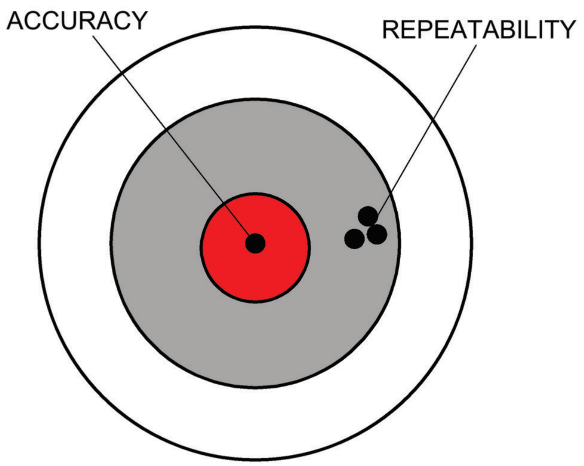

Fig. 2 **The difference between accuracy and repeatability. Accuracy is absolute; repeatability is relative but can be moved to the center.**

PROCESSES FOR THINNING AND POLISHING HIGHLY WARPED DIE

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of the edge of the tool face contacts the die. This makes the material removal rate a function of tool/pad compliance and the local slope of the die surface. This should be taken into account in the tool path and linear feed rate to reduce the effects of surface curvature on removal rate. Without this consideration, material will always be removed faster from low slope areas. This also means that the sample should be mounted so that the average plane of the die is as close as possible to the reference plane of the machine.

How can the irregularities in the material removal process be corrected and to what accuracy?

The addition of either in-situ or external thickness measurements can compensate for variations in material removal rates, but only to the characteristics of the correction algorithm. In the machines referenced in this article, a RKD Systems UltraPrep IV and OmegaPrep II, a nine-point thickness measurement is made either by the machine or externally. This data is used to linearly correct thickness with the reference points being the die center point and the edge measurements. The evaluation of the efficacy of this technique is very involved, but it should ensure a ± 2 micron result. At the area-of-interest level, thickness measurements may be made point by point with the surface profile on larger areas of interest. This ensures surface or thickness variations that are limited to the difference between actual curvature and the linear approximation.

THE CONCEPT OF COMPLIANCE

Everything solid is elastic. A steel I beam bends when force is applied to it. The forces on the cutter deflect the spindle of a 3000-pound milling machine. In this sense, compliance is the change in dimensions with applied force. In all cases, things deflect, move or compress, with applied force. In the case of lapping pads, the pad itself and the adhesive that attaches to the tool, is somewhat compressible. This makes the pad contact surface variable based on its compliance and the local die surface slope. Additionally, there is the compliance of the machine itself. The machine's frame and other components have some compliance. Even a 3000 lb. Series II Bridgeport mill bends with the force on the tool. The force verses deflection may be small, as little as 0.003 in. per 100 lb of cutter force, but this works out to 1.68 microns per kg on a big machine. Smaller, bench top machines may have over 10 times this. The machine referenced here has a spindle compliance of 25 microns per kg. As typical downward forces are limited to 30 to 60 g, the spindle and frame will deflect less than 1.5 microns. This level still has an effect on the process results.

Generally, without a compensating algorithm, the higher the slope of a surface, the lower the material removal rate and the less the die surface will meet the measured or desired profile. The relationship is based on the compliance of the lapping film or pad. The compliance of lapping film is in the range of 1 to 2 microns for a 50 g down force. A polishing pad could be over 20 times this. No algorithm can correct for wear at the edge of a lapping film disc or pad. A highly sloped surface will wear out the edges resulting in little material removal on the highly sloped areas and normal removal on the less sloped areas. The only way around this is frequent replacement of the par or film.

A FLAT TOOL AND A CURVED SURFACE

The problem with a flat tool on a curved surface is geometric. As the surface slope changes so does the contact area between the pad and the die surface. Figure 3 shows the problem. A flat tool has limited contact with a curved surface. The problem here is determining where the center of the contact area is in relation to the tool center position. Some machines have algorithms that relate the center of the contact area to the center of the tool, but this all depends on the compliance of the pad attached to the lapping tool and the surface slope. These parameters may be characterized over some range of pads and tools, allowing for a reasonable compensation for the variables, but only if the pads and tools used are those that have been characterized. Deviating from the specified tools and pads will produce deviant results.

The removal characteristics are also related to both tool rotational speed and tool face linear travel. Being allowed to alter these critical parameters can result in altered or inconsistent results.

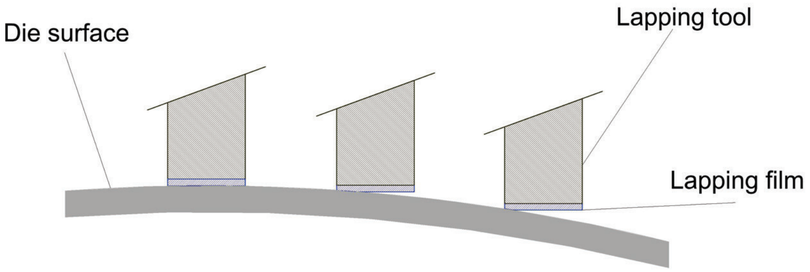

Fig. 3 **The center of the area contacted between the film and die changes with surface slope. At die center, nearly the entire film is in contact with the surface. As the tool moves away from the die center, the contact area reduces and the difference between the tool center and the center of the contact area increases.**

CONCLUSIONS

Thinning a die isn't, and cannot be, easy or simple. There are too many uncontrolled variables to have a turnkey process. With reasonable attention to detail and a moderate level of skill, every live sample can be thinned to the desired thickness and tolerance. It may take a few practice samples to finetune a recipe but, once this is done, reproducing the results should not be a problem. Some of the details that require reasonable attention are: solid and level mounting of the sample, the use of fresh films, pads, and slurries, not requiring a process step to remove more than a recommended amount of silicon, changing films and refreshing slurries when required, and reviewing the results of each process step. The last item is critical. If the results are significantly different from what is desired, it must be determined why. Some frequent problems include faulty pad or film attachment on the lapping and polishing tools, cross contamination of slurries, and particulate contamination from the environment or inadequate cleaning of the sample between process steps.

REFERENCES

1. K. Martin: "Processes for Thinning and Polishing Highly Warped Die to a Nearly Consistent Thickness: Part I," *Electronic Device Failure Analysis,* 2022, *24*(4), p. 34-38.
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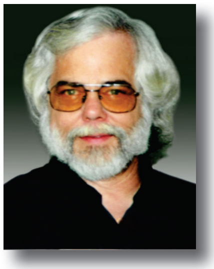
ABOUT THE AUTHOR



Kirk Martin has almost 50 years of experience in designing and building specialized equipment for all aspects of the semiconductor industry, from crystal growth through final test and failure analysis. In 2017, he became a founder of RKD Systems, which designs and builds equipment for semiconductor failure analysis sample preparation. Martin has patents in the fields of sample preparation, chemical vapor generation, fluid handling, and electrostatic discharge detection and mitigation. His previous positions include vice president at Nisene Technology Group, director of Advanced Products at Texas Materials Labs, a manufacturer of specialty semiconductor materials, and vice president at Automated Technology Inc., a manufacturer of front-end test and measurement systems. ■

NOTEWORTHY NEWS

ANADEF 2024

The 19th ANADEF Workshop will be held **June 3-7, 2024,** at Belambra Business Club, Seignosse-Hossegor (Landes), France. The conference addresses new issues related to the latest technological developments in electronic component failure analysis, presented through tutorials, plenary sessions, micro-workshops, as well as participation by equipment manufacturers and suppliers.

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