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

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INTRODUCTION

Part I of this series, published in *EDFA,* November 2022, 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 I, it was suggested that instead of attempting to thin an entire die to a thickness of less than 10 microns, the entire die can instead be thinned to 50 microns for initial evaluation. The initial evaluation would result in defining general, rather small areas of interest. The small area of interest would be thinned to the desired, less than 10 microns, remaining silicon thickness.

The reasons for thinning large die to 50 microns instead of the desired 1 to 5 microns remaining silicon thickness (RST) were discussed. A large die sample can be processed to 50 microns RST quickly. It will be robust enough to survive de-mounting and can be powered in a test socket. Analysis can be performed that identifies the area of the die that is of interest.[1]

The area of interest is then thinned to the desired thickness, leaving the rest of the die thick enough to allow powering the sample. Thinning only a small area significantly reduces processing time and results in a much more robust sample.

In this article, the processes and considerations for locally thinning an area of interest to the desired RST are discussed.

THE NEED FOR A ROBUST SAMPLE

The forces that cause the die surface to curve are built in when the die is mounted on the substrate. As the die is thinned, the force is redistributed, causing the die surface to flatten when the sample is removed from the holder.[3] This causes increasing compressive strain in the remaining silicon. The force involved does not change but is applied to thinner silicon. At some thickness, the remaining silicon will no longer be able to support the force and the die will fracture. During the thinning process, the forces generated by the process add to the packaging forces. This can cause the die to fracture at greater thickness than the desired RST.

Some of the packaging force is distributed to the wax that attaches the substrate to the sample holder. When the sample is de-mounted, most of the packaging force will be applied to the silicon. Thinning the entire die could easily cause the die to fracture during de-mounting and make any handling of the sample problematic.

An RST of 50 microns should survive de-mounting, insertion in a test socket, or any other post-processing handling required. Locally thinning an area of interest will have little effect on the mechanical strength of the sample as long as the area thinned is limited to a small fraction of the die surface.

LIMITS ON THE THINNING PROCESSES

Each processing step causes some level of damage to the remaining silicon. The depth of the damage is a function of the abrasive size and the down force of the tool. The general rule of thumb is that the bulk material damage extends 1 to 1.5 times the grit size of the abrasive. This indicates that a grinding tool with 75-micron diamond should not be used to thin to less than 120 microns RST. The bulk of the silicon can be removed using large grit size if possible, but as the desired endpoint is approached, finer grits should be used. The endpoint for each process step should be at a thickness equal to the final RST plus the grit size plus the RST tolerance. If the final thickness is to be 1.0 +/- 0.5 microns, then a process using 3-micron slurry should be stopped at a minimum thickness of 4.5 microns. This requires all but the last two process steps to remove material equal the difference between the last step's grit size and the previous step's grit size. This is generally more removal than is used processing the 50-micron sample, but at 50 microns RST, damage that extends a micron or two has no effect on the integrity of the sample. Removing this much material increases the process time but is required to produce a usable result.

Increasing pressure may speed up the process but may also increase sample breakage. The strength of the silicon is a function of the cube of the thickness. A 50-micron sample should be able to take 125 times more force than a 10-micron thick sample. The thinner the desired process endpoint, the lower the allowable process force and the finer the permissible abrasive. A typical series of thinning steps, along with starting and ending thicknesses are shown in Tables 1 and 2. It can be seen that the time required to get 1 micron RST is largely the same as 5 micron RST.

SELECTING THE SIZE OF THE AREA OF INTEREST

The size of the area to be analyzed is determined from the evaluation of the 50-micron thick sample. The size of the thinned area must be larger by at least two times the diameter of the tools to be used in the thinning process. If a 2 mm square area is needed, and 2 mm diameter tools are to be used, the minimum size of the thinned area should be 6 mm square. Larger is better for several reasons.

The outside edge of the total area has the least amount of material removed as it has less time in contact with the tool face. This produces a fillet, or radius, at the intersection of the cavity edge and floor as shown in Fig. 1. This fillet will raise the tool slightly when the tool is at the edge causing it to extend further toward the center of the cavity. By then the tool has moved its diameter from the cavity wall; there is no longer any edge effect.

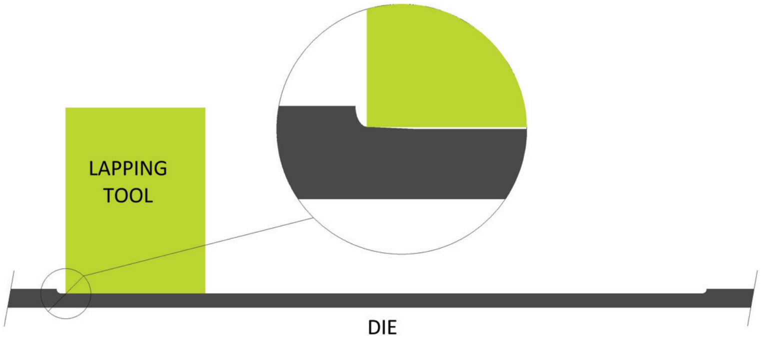

Fig. 1 **The edge fillet is not a radius, but gradually slopes to join the cavity floor. This will lift the tool slightly when it is near the cavity wall, thereby extending the edge distortion toward the center of the work area.**

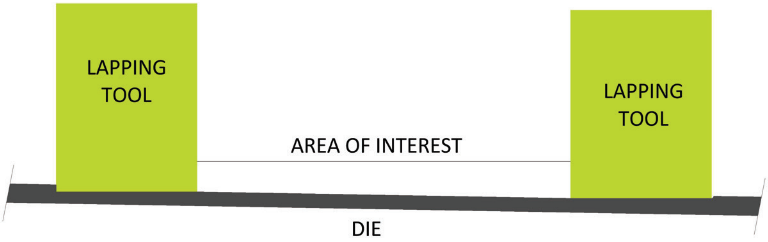

Fig. 2 **As can be seen, the slope of the area of interest can be faithfully reproduced in the lower end of the cavity. At the upper end, the fillet at the cavity wall will raise the tool creating surface distortion into the area of interest.**

Table 1 1 micron final RST

Process step	Abrasive, microns	Starting RST, microns	Ending RST, microns	Removed, microns
Final polish	0.04	1.5	1	0.5
Fine polish	1	4.5	1.5	2.5
Coarse polish	3	10.5	4.5	6
Fine lap	9	21.5	10.5	11
Coarse lap	20	50	21.5	28.5

Table 2 5 micron final RST

Process step	Abrasive, microns	Starting RST, microns	Ending RST, microns	Removed, microns
Final polish	0.04	5.5	5	0.5
Fine polish	1	9	5.5	3.5
Coarse polish	3	15	9	6
Fine lap	9	26	15	11
Coarse lap	20	50	26	24

Although the area of interest may appear planar, it will usually have a slope in relation to the axis of the spindle on the polisher. The flat face of the tool is normal to the spindle axis and, therefore, the tool face plane is not parallel to the plane of the cavity surface. This requires the tool position relative to the cavity surface to be determined by the actual area of contact between the two planes. Figure 2 shows the effect of this and the cavity edge fillet. If the cavity size is limited to the area of interest plus two times the tool diameter, there can be edge distortion at the lowest part of the cavity floor that extends into the area of interest. If the slope is minimal, or the cavity extends off the die edge, this may not be a concern. Otherwise, the cavity edge may need to be more than one tool diameter from the area of interest to prevent edge distortion from extending into the desired area.

As the sample needs to be removed from the polisher for cleaning at the end of each step and replaced on the polisher, there is the possibility of some misalignment. Even if the die corners are realigned, there will still be some difference in position after a sample has been removed, cleaned, and replaced. The alignment difference needs to be added to the cavity size to prevent the tool from contacting the cavity wall. This implies that the total cavity size needs to be decreased with each process step, making the cavity similar to an upside-down wedding cake. If the sample can be repositioned to within 20 microns, then the first step of a five-step process would have to be 200 microns larger than the final. The cavity size would then be reduced by 40 microns for each of the following steps.

This approach works well for preventing the tool from banging against the cavity wall and reduces the buildup of fillet height as a series of smaller fillets are formed.

THICKNESS AND PROFILE MEASUREMENT

At the beginning of the area of interest thinning process, a mechanical profile needs to be taken as well as thickness measurements. The mechanical profile can be used as the physical reference for the entire process if it is corrected for the thickness measurements taken before each processing step. The thickness measurements should be in a 9-point pattern with all but the center point at the edge of the area of interest.

An area of interest larger than 4 mm square should be avoided as surface curvature can introduce variations in the resulting thickness, depending on the actual curvature and mean slope. A 5 mm square area may require 25 thickness measurements in a repeatable pattern. With an RST target of 5 microns, this may not be necessary due to the larger tolerance of the target thickness. The thickness measurements need to be taken before each process step to ensure that the material removed comes from the right place. Since little material is removed in final polish, the measurements are not required before the final polish.

THICKNESS CONTROL

At 5-micron RST absolute thickness control is not so critical. As most polishing systems have 1 micron position repeatability, a final average thickness variation of less than +/- 1.5 microns can be expected. This is generally in the acceptable range for a 5-micron target. Getting to a 1-micron target is problematic. It can be done, but not every time with every sample. When one is working with field failures, many of which are one of a kind, a “hit or miss” process is not acceptable. No data should ever be lost due to sample preparation. The +/- 1 micron tool face position accuracy is the problem. In normal polishing, the tool face is in contact with the die surface. This makes a 1-micron RST essentially not possible, or, at best, iffy.

There are only three mechanisms for abrasive material removal, scratching, rolling-scratching, and rolling-indenting.[2] Fixed abrasives, such as a grinding tool or lapping film, operate in the scratching mode. A lapping tool and abrasive slurry will operate in the “rolling-scratching” mode with some abrasive particles held by the tool face scratching the work surface while other particles are rolling across the surface. The use of a polishing cloth is close to the “rolling-indenting” mode but still holds some abrasive particles to allow scratching. If a hard-faced tool is operated at some position above the work surface, the mode of removal can be exclusively rolling-indenting. This mode removes the least material per unit time but ends up being the most controllable. The rolling of the abrasive particles is due to the velocity gradient of the slurry. The tool is rotating at high speed and the die surface is stationary. This produces a relatively linear gradient in fluid velocity between the die surface and the tool face. If the gradient is small in relationship to the average diameter of the abrasive, the particles will not be very effective. As the gradient increases, by the gap between the tool face and die surface decreasing, the abrasive particles do more. If one assumes that in normal operation, the tool face is separated from the work surface by only the abrasive average diameter, and that the mode of material is the same, doubling the separation should reduce the removal rate by 50%. Increasing the separation by a factor of 10 will reduce the material removal rate by a factor of 10. With a 1-micron slurry, operating the tool 10 microns from the die surface will reduce removal rates by a factor of 10, but will also reduce the effects of positional uncertainty. A 1-micron variation in tool position only results in a 10% change in material rate. Operating with a defined separation between the tool face and the die surface, therefore, makes material removal rate less dependent on absolute tool position. Although this is a gross simplification of the physics of material removal, the concept is valid. Operating with a significant gap between the tool face and die surface will reduce the material removal rate and its dependence on absolute tool position.

Using this method may require stopping the thinning process to measure average thickness and continuing the process to the desired endpoint, but it is much better than having 0.0 microns RST.

CONCLUSIONS

With careful processing, cleaning, RST measurements, and a sample processing machine that moves the grinding, lapping, and polishing tools to a thickness corrected surface profile, samples can be reliably processed to a 50 micron thickness with an RST variation of +/- 2.5 microns across the majority of the die. There are variations in RST near the edges of the die that are created by the lapping and polishing tools not moving off the die surface and distortions relating to the slope of the surface near the die edge. All thickness measurements need to be made inside of the die edge distortions.

Within these limits, +/- 2.5 micron, or better, RST variation is achievable without operator intervention. All the operator needs to do is clean everything, measure the RST at 9 points on the die surface, install tools, and apply the correct slurries. Adjustment of nominal material removal in each step may be required to get the final desired thickness, but no operator involvement should be required during processing. Push the run button and go to lunch.

The resulting sample is robust enough to go into a test socket and powered up. It is thin enough for evaluation and identification of areas of interest that can be thinned further for detailed analysis. Local thinning to less than 10 microns can be done quickly and does not compromise the robust nature of the sample. This two-step process gets samples completed in hours instead of days required for whole sample thinning to less than 10 microns.

Thinning to 1 micron RST is a bit more difficult and may require material removal with a significant gap between the tool face and die surface. This mode of operation reduces absolute tool position effects on material removal rates but may require interrupting the process to measure average thickness.

The described processes allow rapid processing of a sample while keeping it robust enough to be handled and powered up and allowing analysis of specific areas at the thinnest possible location.

REFERENCES

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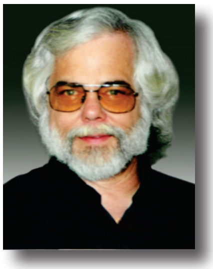
ABOUT THE AUTHOR



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.