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

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INTRODUCTION

Previous articles by the author and others partially addressed the need for thinned and polished die that have a remaining silicon thickness (RST) of 50 to 100 microns and variations of +/- 5 microns or less. Tighter thickness tolerance and thinner samples are always desired. Thinner RST is required as doping density increases due to absorption and dispersion in highly doped silicon and better tolerances require less refocusing and less uncertainty in imaging. Finer line widths, new probing, and visualization techniques may require RST of 1 to 5 microns with variations of 0.50 microns or less.

Thinning the entire die to 1 to 10 microns can eliminate the possibility of powering the die after thinning due to heat dissipation considerations, and the thinning can take a rather long time. Thinning to 50 microns RST is fast and most samples can be powered at this thickness. Analysis is then performed, which identifies the area of the die that is of interest. The area of interest is then thinned to the desired thickness, leaving the rest of the die thick enough to allow for powering the sample. Thinning only a small area significantly reduces processing time and results in a much more robust sample. The processes for local area thinning will be discussed in a future article.

The present article describes processes for finer control of RST through the correction of measured mechanical surface profiles with multipoint thickness measurements. Also described are the dynamic changes in sample surface profile that make multipoint thickness measurements necessary. These surface profile changes are shown to be a function of the sample mounting process, process time, and the removal of bulk silicon. In addition, the realities of silicon thickness measurements are discussed.

REVIEW OF PREVIOUS ARTICLES

In previous articles, the authors have described a technique for controlling RST variation by taking low spatial resolution thickness measurements and using these measurements to alter the measured surface profile used to thin the sample.[1] They have also described the dynamic characteristics of the surface profile of a mounted device.[2] The surface profile of a mounted device varies with time as the mounting media cold flows in response to the forces generated during the mounting process. As wax mounting is done at a temperature higher than the wax melting point, the sample reduces in curvature at the higher temperatures. As the sample cools, without the mounting wax, it would return to the higher curvature it

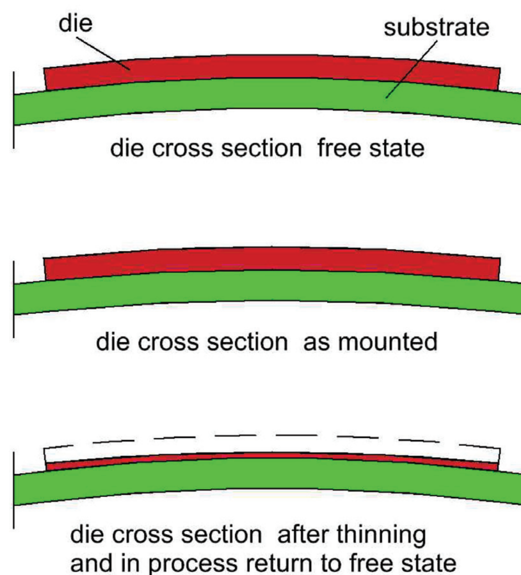

Fig. 1 **The thickness variation resulting from mounting wax cold flow during material removal.**

had at ambient. The wax interferes with the return to a free-state profile, flattening the profile and building forces into the mounted sample system.

It has been shown that the profile variation is not uniform across the die surface resulting in time variant profile changes greater than +/- 4 microns for some observed profile measurement points.[2] These time variant profile changes occur in times that are comparable to the gross thinning processes. With a thinning system that reproduces the initial measured die surface profile on the thinned die, the dynamic changes in surface profile will have the original profile machined onto them. Figure 1 graphically demonstrates the RST variation resulting from the thinning process and the substrate-die interface profile changes created by force redistribution resulting from the thinning.

DYNAMICS OF A MOUNTED SAMPLE

The short-term changes in sample surface profile have been characterized for flip chip devices.[2] The same variables also apply to plastic encapsulated devices although the magnitude of the changes will vary from those observed with flip chip samples. The basic rule is that the larger the die, the larger the deviation of the die surface from a plane and the greater the short-term changes from mounting forces and force redistribution resulting from thinning the die.

SAMPLE MOUNTING PROCEDURES AND REQUIREMENTS

Samples are usually mounted to some support structure with mounting wax such as Crystal Bond 509. All efforts need to be made to reduce the stresses in the package/die system as described previously.[2]. The sample should be covered with an insulating material to reduce thermal gradients and the stresses they create. Enough time needs to be allowed for full thermal equilibration both in heating, mounting, and cooling to ambient. If enough time is allowed, the only additional stresses added to the die/substrate system are related to the difference between the solidus temperature of the wax and ambient. These stresses have been described before[3] and can be significant, but the reduction or elimination of thermal gradient stresses will greatly reduce profile changes encountered during thinning.

It should be noted than neither the die nor the substrate are truly flat except at a single, elevated temperature. The metallization density across the die surface is not constant and multiple metal layers are often coupled vertically to reduce the impedance of power connections. The metallization and silicon have different coefficients of thermal expansion and the metallization may be applied and alloyed at elevated temperatures. This will produce both local small scale as well as total die profile variations.

The same effects from metal density and the vertical distribution of density variations will result in substrate warpage with temperature change. As the die and substrate are attached at elevated temperature, cooling to ambient can create very complex curvatures in the C4 ball "plane." The die and substrate may each come close to planar, but at very different temperatures and the union of the two at a completely different temperature. This ensures that there will never be a "relaxed" state where the die surface is flat and stable.

MEASURING THE INITIAL PROFILE

It is assumed that the starting silicon thickness variation is zero. Therefore, the measured die surface profile is the same as the die active surface profile. This is generally a good assumption as even thinned die processed in wafer form results in nearly uniform thickness.

The initial profile is the best reference to the first steps in die thinning and therefore need to be used to establish the tool path. If the part moves during the thinning processes, it will result in thickness variations that may be compensated for later in the process.

PROCESS VARIATIONS AND SAMPLE PROFILE DRIFT

At the beginning of the thinning process, the sample should be as close as possible to its unmounted or "free state" curvature. In the free state, all forces are in equilibrium and the profile of the die surface is static at any given temperature. If the sample could be mounted in free state, there would be no forces on the mounting medium resulting in the least changes to the die profile during processing. This is not possible, as there needs to be something that secures the sample to the holding fixture. Mechanical clamping will not adequately support the sample and may introduce additional distortions. Other adhesives, other than mounting wax, may get closer to a free-state mounting but generate problems with reusability of fixtures and demounting the sample for further processing.

Only a percentage of the change in the die surface profile will occur during the grinding process as it only takes about 60 minutes to thin a 16 by 20 mm die from 770 microns to 155 microns. During this time, the die center may rise as much as 15 microns resulting in the center being thinner by that amount. The sample movement will continue for many hours. Letting the sample

rest overnight will produce additional profile changes that can be quantified by re-measuring the surface profile and comparing to the starting profile. Reheating, or annealing, the sample may hasten the force redistribution by softening the mounting wax and allow the sample to come closer to its free state.

If a significant time elapses between process steps, or the sample is annealed, a new surface profile should be taken that does not compensate for sample movement in terms of RST variation, but does allow ignoring the changes that have already taken place. This would suggest that a surface profile should be taken before each step in the thinning process. This may be best, but the time to take a full profile increases overall process time and it only reduces thickness variation without eliminating it. Measuring the profile before each step will not eliminate the need for thickness measurements to control RST variation but it will reduce the amount of RST variation measured and the difficulty of compensating for it. A mechanical profile measurement will need to be done whenever thickness correction is done.

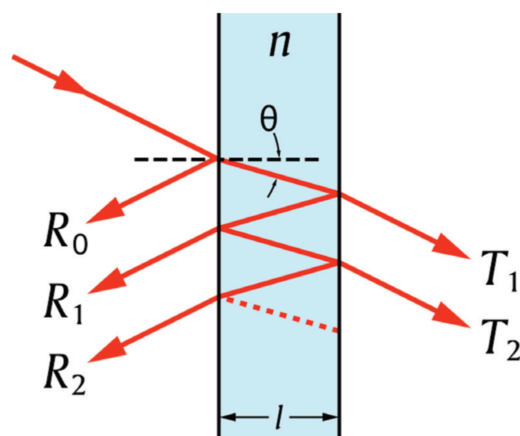

Fig. 2 **The basis of optical thickness measurements. The reflected rays R_0, R_1, R_2, and so on, interfere based on the wavelength of the incident light, the index of refraction of the material, and the thickness, *l*.**

HOW SILICON THICKNESS IS MEASURED

All silicon thickness measurement systems work on the same principle. The measurement model is the Fabry-Perot interferometer. It is necessary to understand how this model works to understand the various factors that can affect the validity of the thickness values generated.

Figure 2 shows the basic operation of the Fabry-Perot interferometer. Whenever light passes through a change in refractive index, both a reflected and transmitted beam is created. The amount of the light reflected from the change is a function of the indices of refraction of both mediums as described by Fresnel's equations.

The incident light is reflected from the illuminated surface, but some amount of the incident light is transmitted through the silicon only to have some amount again reflected off the back surface. The light reflected from the back surface is again reflected off the front surface with some passing through. The light passing through will interfere with the incident light reflecting off the front surface. When the effective light path through the silicon is equal to an integer number times the wavelength of the incident light, the two light beams will add, enhancing the reflected intensity. When the path through the silicon is equal to an integer + 0.5 times the wavelength of the incident light, the reflected intensity will be reduced by the back surface reflection.

The difference between the maximum and minimum reflected light is a function of the reflectivity of the front and back surfaces. If the front surface is not highly polished, the light entering the silicon will be greatly reduced. The reflectivity of the backside, the active surface of the die, is a function of what contacts the silicon. Areas covered with silica or nitride will be more reflective as there is a large difference in the refractive indices. Areas covered by polysilicon and areas with a high doping density gradient will reflect little light back to the incident surface. In active

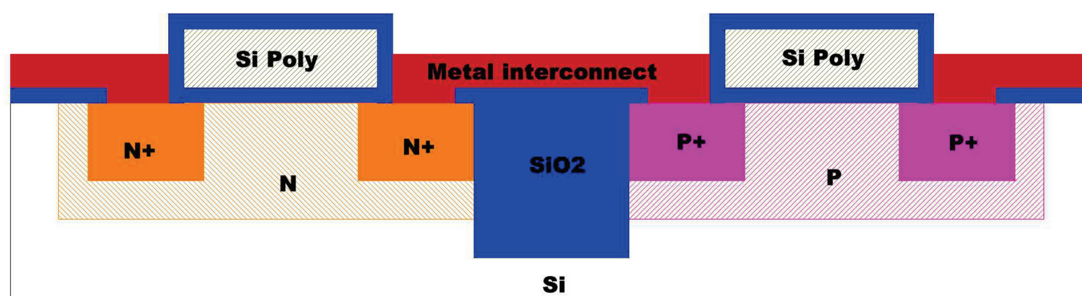

Fig. 3 **This hypothetical active structure demonstrates the problem with reflectivity. Each color change produces a reflection toward the back surface of the die. The amount of reflected light is a function of the refractive indices of the materials at the interface. The highest reflection is from a metal-silicon interface, followed by a silicon-dielectric interface.**

areas, each structure has different distance to the incident surface and different reflectance as shown in Fig. 3. This all has an effect on the reflected intensity to the point where some areas will have no measurable reflectivity.

The black areas in Fig. 4 will be very difficult to measure as there is little to no reflectance. This may require moving the point where the thickness is measured to get a valid measurement.

MEASURING THE REMAINING SILICON THICKNESS

The RST can be measured using either independent measurement systems or a measurement system that is integrated into the sample preparation system. There are advantages and disadvantages to both.

A typical independent measurement system requires the operator to select the measurement point, adjust the optical focus and point position to get the best, most reliable reading. An experienced operator can get reliable measurements, but the measurement position will be loosely controlled, and a lot of operator time will be consumed.

An automated measurement system, either external to, or incorporated into the polishing machine, can precisely control the measurement position, and will run without operator involvement. The problem is the reliability of the measurements in difficult circumstances. Measuring the thickness after grinding and coarse polishing steps can result in invalid or missing thickness measurements. Multiple measurements at slightly different positions and complex analysis software helps but is not foolproof.

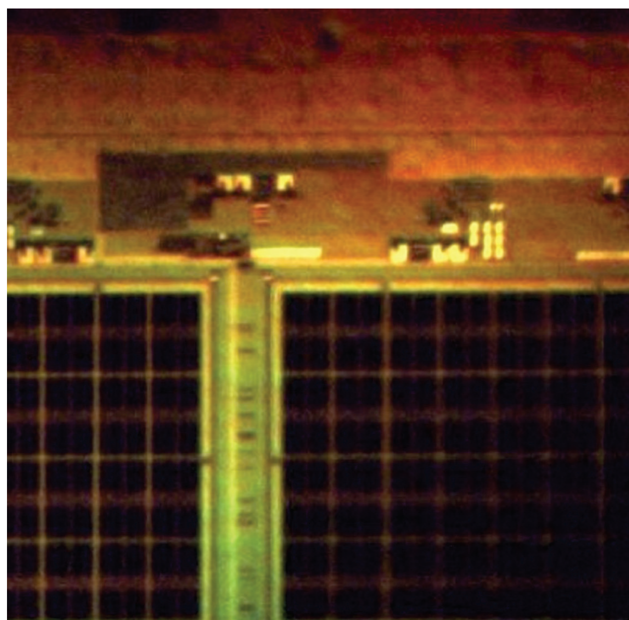

Fig. 4 **The very dark areas contain the highest density of active structures. The brightest areas are metallization. The picture is taken with visible light.**

In any case, the thickness measurements are used to correct the mechanically measured profile for the generation of the tool path.

EDGE EFFECTS FROM SURFACE SLOPE AND TOOL TRAVEL

A lapping or polishing tool has a flat face and the tool can seldom travel completely off the die surface. There are usually surface mount components, capacitors, and filters which limit the travel of the tool beyond the die edge. Unless the tool inside edge reaches the die outside edge, the profile near the die edges will not be controlled. In addition to this, the higher the surface slope, the less tool surface is in contact with the die surface. This results in lower material removal from areas with higher slope. Unless there is a compensating algorithm in the tool path calculation, the highest slope areas of the die surface will end up the thickest after processing. This can easily result in edge areas much thicker than the die center.

No tool path algorithm can compensate for a tool that does not travel beyond the die edge. If there is less than the tool diameter clearance from the die edge to obstructions that restrict tool movement, the die edges will be thicker than the rest of the die. This edge distortion area will be equal to, or greater than the distance the tool center travels beyond the die edge less the tool radius from the die edge. That is, if the tool center only moves to the die edge, the edge distortion will extend, at least, the tool radius from the die edges.

The best case would be enough clearance and a tool pattern that moves the inside of the tool edge to the die edges. If this is not possible, which it never is, there will be edge thickness distortions where the edges of the die are thicker than desired.

MULTIPLE THICKNESS CONTROL STEPS

It may not be possible to reliably measure RST after the bulk removal of silicon by grinding. A grinding tool is very coarse and creates a rough surface with structural damage extending 50 to 100 microns below the surface. A quick very coarse lapping step can be added to the process, smoothing the surface and eliminating some of the damage. After this, some level of reliable RST measurements can be made.

At this point in the process, the die has changed its curvature and the grind and coarse lap processes have usually removed more material from the highest portion of the die. Measuring the surface profile needs to be done and thickness must also be measured. The mechanical profile establishes the surface to be corrected by the thickness measurements. The combination of thickness and mechanical profiles allows a tool path that will result in little RST variation.

In the beginning process steps, there are many possible errors. The thickness measurements are less reliable and the possibility of mechanical measurement errors is much higher. Surface contamination is problematic, requiring that the die surface be carefully cleaned for both thickness and mechanical profile measurements.

If the thickness measurements are made with an accuracy of 1%, mechanical surface measurements are made to 1.0 microns and tool path accuracy is 0.5 microns, one can expect the result RST, at 50 microns, to be consistent to +/-2.5 microns. This assumes that thickness measurements are taken inward of the edge thickness variations. It is obvious that thickness measurements taken too close to the edges will not result in good thickness control.

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.

A good operator can get from mounting through final polish in 5 to 6 hours for an 18-mm square flip chip with a final thickness of 50 +/- 2.5 microns over all but die edges, and do a lot more stuff while the polishing machine is running.

The resulting sample is robust enough to go into a test socket and power up. It is thin enough for evaluation and identification of areas of interest that can be thinned to less than 10 microns 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.

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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.