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A PROCESS FOR THINNING AND POLISHING HIGHLY WARPED DIE TO HIGH SURFACE QUALITY AND CONSISTENT THICKNESS: PART I

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INTRODUCTION

The use of aplanatic solid immersion lens microscopes requires samples where the bulk silicon is typically thinned to 0.025 to 0.100 ± 0.005 mm (thinner samples are preferred).[1] This can be problematic when the die/substrate system is highly curved due to differential thermal expansion. The substrate, in this context, is the packaging component that the C4 bumps of a flip-chip are attached to or, in the case of a plastic-encapsulated device, the encapsulant. The curvature occurs due to the difference in thermal expansion between the substrate material and the die. Because the die is mounted on the substrate at elevated temperature, the only equilibrated temperature where the system is flat is the mount temperature. Once cooled to near ambient, a large die may have as much as 0.150 mm of curvature; that is, the die corners are 0.150 mm different in elevation than the die center. For example, with standard die-thinning processes, thinning from a starting thickness of 0.770 mm to 0.070 mm at the die center would result in corner thicknesses of 0.220 mm. New techniques and equipment are required to thin warped die to the requirements of the latest visualization technology.

THE PROCESS

The process described results in minimal surface imperfections and a very constant die thickness. The results are demonstrated and augmented with automated laser interferometry thickness measurements.

The die selected was 13.8 mm × 16.2 mm and 0.770 mm thick. It was mounted on a ball grid array substrate 27 mm × 27 mm and approximately 1.5 mm thick. Solder balls were in place on the mounting surface. The part was attached to a holding fixture specific to the thinning system using CrystalBond 509 (Aremco, Valley Cottage, NY). Enough wax was used to ensure filling of the entire area around the solder balls with no voids but with the die plane nearly parallel with the plane of the fixture surface.

"NEW TECHNIQUES AND EQUIPMENT ARE REQUIRED TO THIN WARPED DIE TO THE REQUIREMENTS OF THE LATEST VISUALIZATION TECHNOLOGY."

Equipment that will move the grinding or polishing tool in accordance to the stored surface profile is readily available. This process is generally referred to as contour machining. Tools available use either an external profile-measurement system or have an in situ measurement technique. A system was used that measured the surface profile in situ, eliminating any correlation errors. (An RKD Engineering UltraPrep II was used for processing and generating measured profiles.) The measured starting profile is shown in Fig. 1, which is a "wire frame" representation of the discrete surface measurements shown as deviation in height referenced to the die center height. The shown profiles are leveled; that is, planar rotation has been removed to show only the curvature.

The die was ground using a spherical, 3-mm-diameter grinding tool, removing a programmed 0.575 mm of silicon. The equipment was set to move the center of the grinding tool 0.5 mm beyond the die edges. The silicon is thinned 0.050 mm at a time, requiring multiple passes over the surface. The final pass removes only 0.025 mm of silicon, and the tool path makes smaller steps in the *X-Y* axis plane, resulting in a surface that theoretically has no more than ±0.001 mm deviation from the reference profile. After the die was grossly thinned by grinding, the die surface profile was measured again, with the results shown in Fig. 2. The surface after grinding is very rough, eliminating the use of any optical thickness measurements. The difference between the two profile matrix-point values has a range of –0.602 to –0.597 mm, with an average of –0.600 mm and a standard deviation of 0.0011 mm.

The next step in the thinning process is the removal of the damage done by the grinding tool. This was done by removing 0.050 mm of silicon using a 30 μm diamond lapping film disc attached to the end of a 3-mm-diameter lapping tool. This process is accomplished by moving the lapping tool in a zigzag pattern in the *X* and *Y* axes while adjusting the tool height according to the stored profile at the actual contact point between the tool and the curved die surface. This process was done using water as a lubricant. It is also possible to use a lubricant that

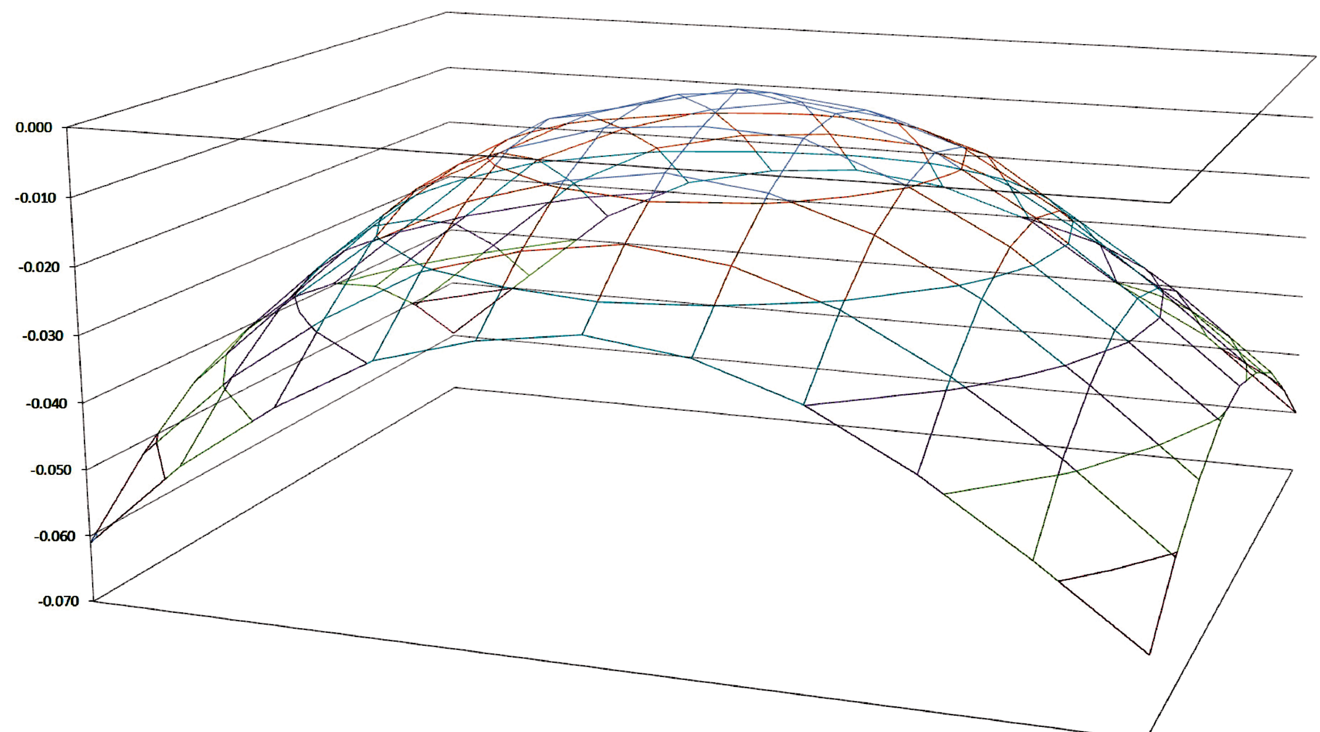

Fig. 1 **Wire frame representation of initial measured die surface profile**

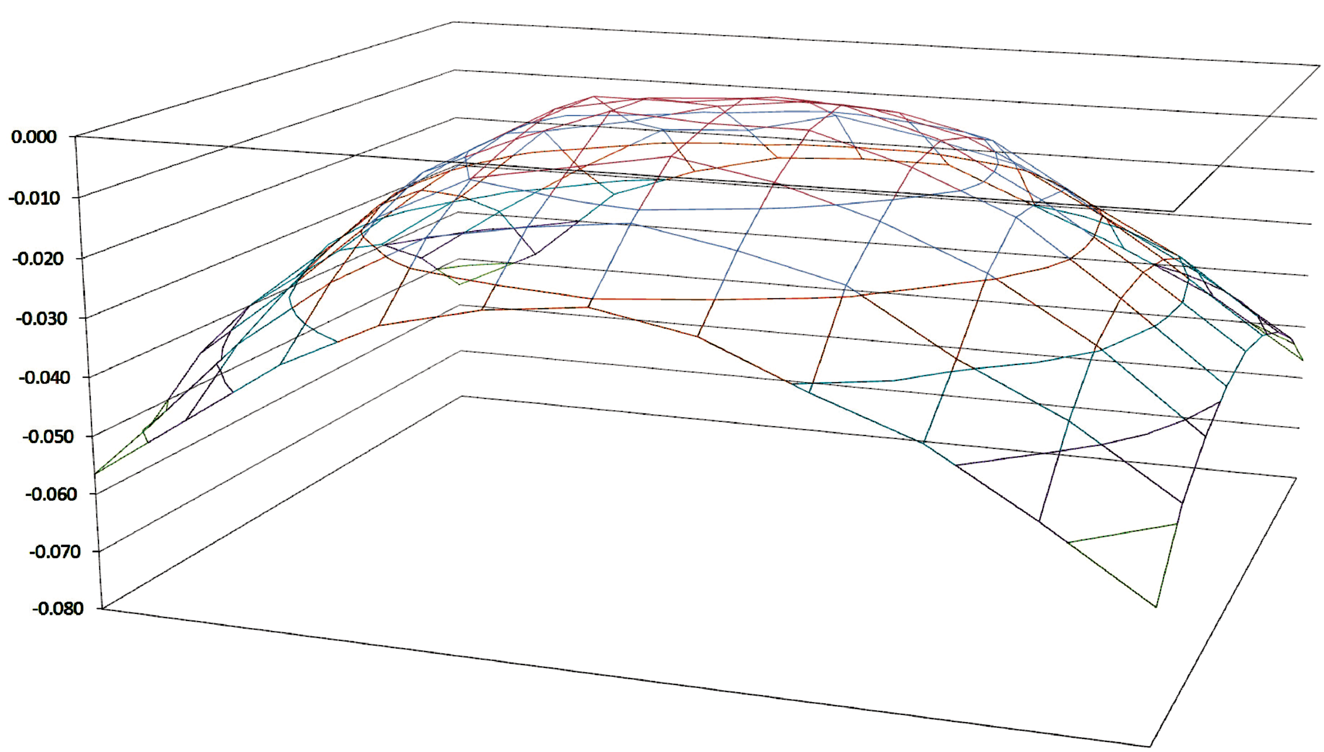

Fig. 2 **Wire frame representation of die surface profile after removing 0.575 mm of silicon with a 3-mm-diameter grinding tool**

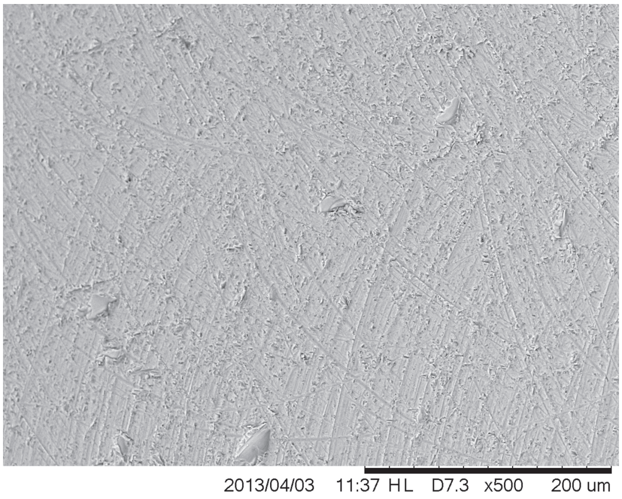

Fig. 3 **Die surface after lapping with 30 μm lapping film, showing amorphous hillocks formed by bonding of swarf to the die surface**

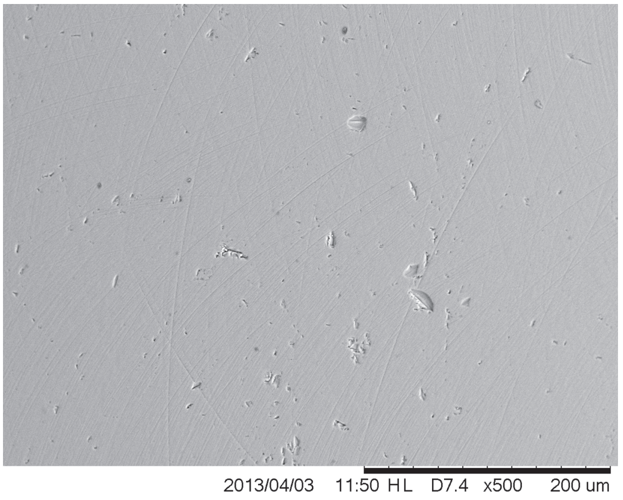

Fig. 5 **Die surface after lapping with 9 μm lapping film**

contains a mild oxidant (10% H_2O_2 [3%] + 0.5% nonionic surfactant in deionized water). This prevents the creation of amorphous hillocks, as shown in Fig. 3. This lubricant does not speed material removal, but the elimination of hillocks reduces the time required for subsequent processes. The tool center was programmed to move 0.75 mm beyond the die edges.

After the first lapping process, the surface is reasonably smooth, as shown in Fig. 3. It may be possible, although difficult, to obtain optical thickness measurements. Because these measurements are generally unreliable, only an ending profile was taken, which is shown in Fig. 4. The difference from the starting profile matrix-point data has a range of –0.631 to –0.641 mm, with an average of –0.636 mm and a standard deviation of 0.0017 mm.

The device was then lapped using a 9 μm diamond lapping film in the manner described previously to remove the surface damage from the coarser lapping process (Fig. 5). This required the removal of 0.015 mm of silicon. The results of this process are shown in Fig. 6. As shown in Fig. 5, this surface is good enough

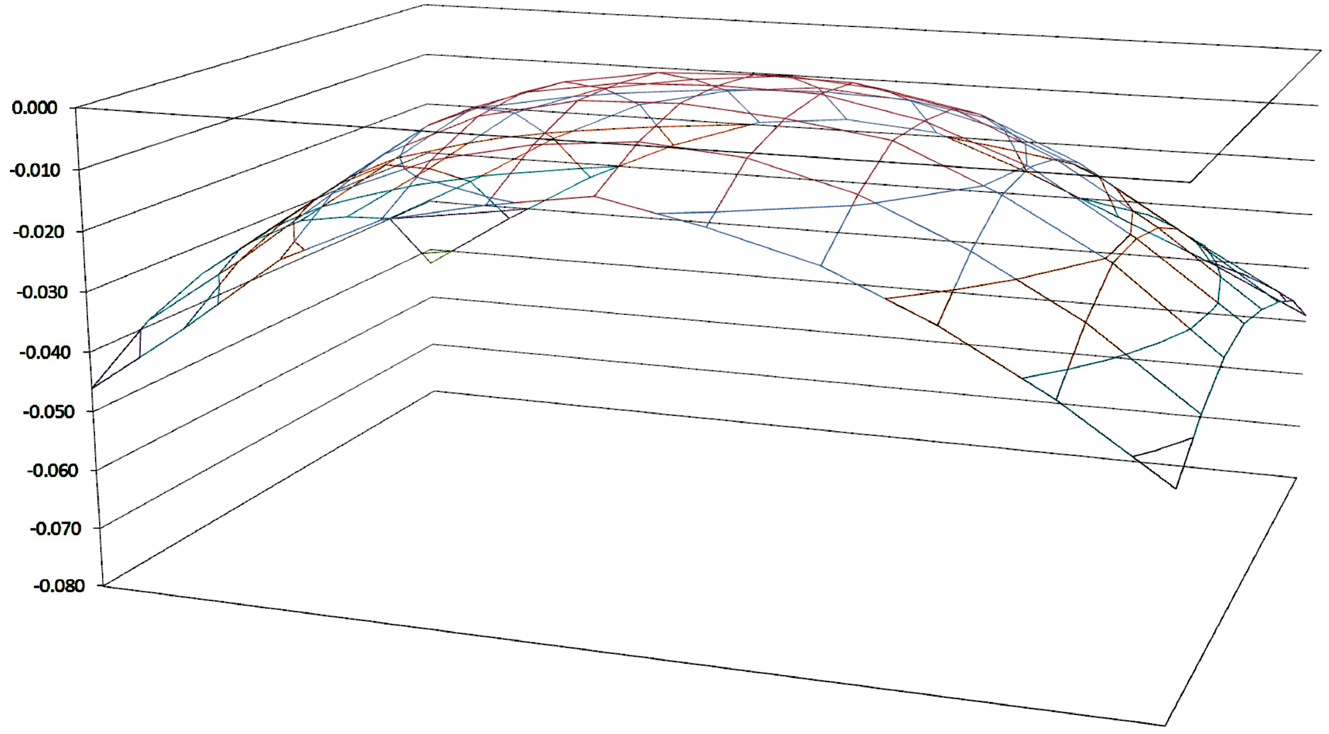

Fig. 4 **Wire frame representation of die surface profile after removing 0.575 mm of silicon with a 3-mm-diameter grinding tool and the removal of 0.050 μm of silicon with 30 μm lapping film**

to reliably measure the silicon thickness using optical techniques. Optical thickness measurements were made at 25 points (an RKD Engineering Measure was used in profiling mode) in a 5 × 5 matrix, starting 1.0 mm from each edge to eliminate any edge effects. The measured thickness values are shown in Table 1, the measured profile in Fig. 6, and the difference from the starting profile in Table 2. The range of profile difference is 0.646 to 0.656 mm, a profile reproduction fidelity of ±0.005 mm.

These thickness data were transferred to the processing tool and used to adjust the stored profile to compensate for measured thickness variation. The device was lapped again with 9 μm film to remove an additional 0.040 mm of silicon. The depth was selected on the basis of the target thickness and the amount of thickness variation that needed to be removed.

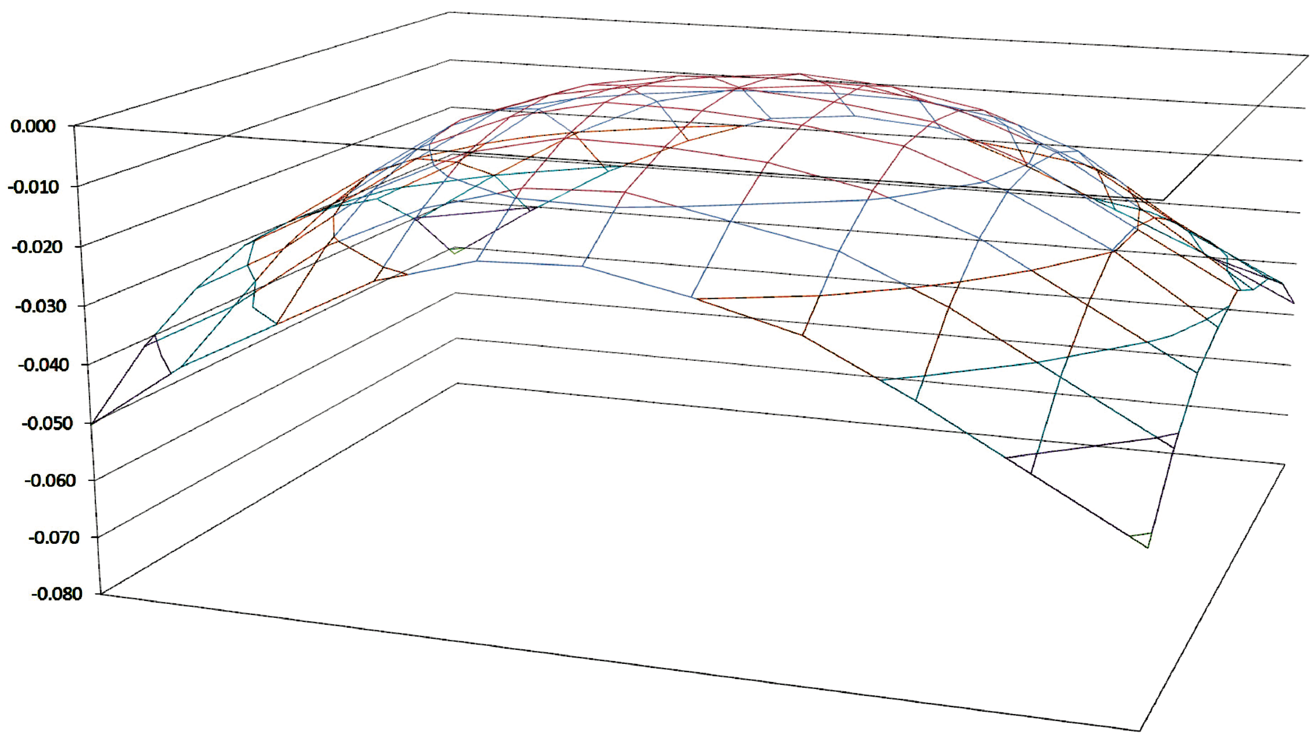

Fig. 6 Wire frame representation of die surface profile after removing 0.575 mm of silicon with a 3-mm-diameter grinding tool, the removal of 0.050 μm of silicon with 30 μm lapping film, and the removal of 0.015 mm of silicon using 9 μm lapping film

Table 1 Measured remaining silicon thickness after the first 9 μm lapping process and the variation from the central measurement

Y-axis distance from die center	*X-distance from die center*				
	−5.898	**−2.950**	**0.000**	**2.950**	**5.900**
Measured thickness					
−7.110	124.3	114.5	130.9	124.3	124.5
−3.556	104.0	109.9	111.3	113.7	107.8
0.000	117.0	108.6	110.5	121.4	126.6
3.556	103.0	106.6	110.6	116.5	114.6
7.110	107.6	126.0	115.1	119.8	116.7
Thickness variation					
−7.110	13.8	4.0	20.4	13.8	14.0
−3.556	–6.5	–0.6	0.8	3.2	–2.7
0.000	6.5	–1.9	0.0	10.9	16.1
3.556	–7.5	–3.9	0.1	6.0	4.1
7.110	–2.9	15.5	4.6	9.3	6.2

The processing was continued through the normal polishing steps, which are:

1. Coarse polish with 3 µm diamond suspension, removing 0.009 mm of silicon
2. Fine polish with 1 µm diamond suspension, removing 0.004 mm of silicon
3. Final polish with colloidal silica

Each of the polishing operations was done with a polishing pad disc attached to the end of a 3-mm-diameter tool. No profiles were taken between the polishing process steps.

Optical thickness measurements were made at 25 points. The measured thickness values are shown in Table 3.

DISCUSSION

As can be seen from the differences between the starting profile and the profiles after each of the initial steps, the profile integrity degrades with each process step. The tool position reproducibility of the equipment used is specified as ±0.002 mm. It is expected that reproducibility is nominally closer to ±0.001 mm. The total variation

Table 2 Leveled difference between the profile measured after the first 9 µm lapping process and the starting profile, indicating the removal consistency of the initial grinding and lapping processes

Y-axis distance from die center	*X-distance from die center*								
	−6.500	**5.174**	**−3.450**	**−1.726**	**0.000**	**1.724**	**3.448**	**5.174**	**6.498**
−7.710	−0.646	−0.646	−0.648	−0.649	−0.648	−0.648	−0.648	−0.649	−0.650
−6.488	−0.648	−0.648	−0.649	−0.649	−0.649	−0.648	−0.649	−0.650	−0.651
−4.866	−0.648	−0.648	−0.648	−0.650	−0.651	−0.651	−0.651	−0.651	−0.652
−3.244	−0.650	−0.649	−0.651	−0.652	−0.653	−0.652	−0.652	−0.651	−0.651
−1.622	−0.650	−0.651	−0.653	−0.654	−0.656	−0.656	−0.654	−0.653	−0.651
0.000	−0.650	−0.650	−0.653	−0.655	−0.657	−0.655	−0.654	−0.651	−0.650
1.622	−0.651	−0.650	−0.652	−0.654	−0.654	−0.653	−0.651	−0.649	−0.648
3.244	−0.652	−0.651	−0.651	−0.653	−0.654	−0.653	−0.651	−0.650	−0.649
4.866	−0.652	−0.651	−0.650	−0.651	−0.651	−0.652	−0.651	−0.649	−0.649
6.488	−0.650	−0.649	−0.650	−0.650	−0.651	−0.652	−0.652	−0.651	−0.649
7.710	−0.649	−0.647	−0.647	−0.648	−0.648	−0.648	−0.648	−0.647	−0.646

Table 3 Measured thickness and thickness variation from the center point after final polishing with colloidal silica

Y-axis distance from die center	*X-distance from die center*				
	−5.898	**−2.950**	**0.000**	**2.950**	**5.900**
Measured thickness					
−7.110	101.8	102.2	107.0	108.0	106.8
−3.556	103.5	101.9	108.1	108.7	108.7
0.000	105.3	101.7	106.3	102.0	109.9
3.556	103.2	102.7	107.9	109.2	101.8
7.110	103.0	100.8	105.6	107.9	107.8
Thickness variation					
−7.110	−4.5	−4.1	0.7	1.7	0.5
−3.556	−2.8	−4.4	1.8	2.4	2.4
0.000	−1.0	−4.6	0.0	−4.3	3.6
3.556	−3.1	−3.6	1.6	2.9	−4.5
7.110	−3.3	−5.5	−0.7	1.6	1.5

in the difference between the starting profile and the profile after the grinding process is shown as 0.005 mm or ±0.0025 mm. This is consistent with the specified positional reproducibility and the profile measurement uncertainty of ±0.002 mm. The total variation in profile difference after fine lapping is 0.011 or ±0.0055 mm. Each process step is subject to the same measurement uncertainties and positional reproducibility, resulting in an increase in profile deviation after each process step.

The variation in thickness measurements after fine lapping can be seen in Table 3. This does not correlate with the mechanically measured surface profile difference, as shown in Table 2. The contour milling system used will reproduce the initial profile to nearly the desired tolerance of ±0.005 mm per process step, but the measured thickness varies considerably more than the surface profile fidelity would indicate. The problem here is that the surface profile may not directly relate to the die thickness. The thinning results in changes in the stress equilibrium of the die-substrate system. The medium used to attach the sample to the fixture is critical. Mounting waxes cold flow; that is, they deform under stress. The thinning process alters the stress profile of the sample, putting stress on the mounting medium. If the mounting medium deforms under stress, the sample surface profile will be allowed to change. Because the thinning process reproduces the original measured profile, not the actual silicon thickness, the thickness will vary by the amount of profile change resulting from the mounting medium cold flow.

Dice are made very flat.[2] In packaging, two dissimilar materials, the die and substrate, are bonded together at a high temperature. As they cool from the process temperature, the differences in coefficients of thermal expansion generate stresses in the materials, causing the structure to curve. The curvature is present at any temperature other than the bonding temperature and will change linearly with temperature.

The curvature of two bonded dissimilar materials in infinite plane can be described as:[3]

$$K = T \cdot 6 \cdot (T_{C1} - T_{C2}) \cdot (H_1 + H_2) \cdot E_1 \cdot E_2 \cdot H_1 \cdot H_2 / (E_1^2 \cdot H_1^4 + 4 \cdot E_1 \cdot E_2 \cdot H_1^3 \cdot H_2 + 6 \cdot E_1 \cdot E_2 \cdot H_1^2 \cdot H_2^2 + 4 \cdot E_1 \cdot E_2 \cdot H_2^3 \cdot H_1 + E_2^2 \cdot H_2^4)$$

where K is the curvature of the surface as 1/radius, T is the difference between the reference temperature and ambient, T_{C1} is the coefficient of thermal expansion of the silicon, T_{C2} is the coefficient of thermal expansion of the substrate, H_1 is the thickness of the silicon, H_2 is the thickness of the substrate, E_1 is Young's modulus of the silicon, and E_2 is Young's modulus of the substrate.

The die and substrate are flat until cooling from reflow. The reference temperature, the temperature where the curvature = 0, is reached at the solidus temperature of the C4 balls. It can be seen from the equation that the curvature changes linearly with temperature and is a function of material thicknesses. This indicates that as the silicon is thinned, the curvature of the die-package will increase. The mounting of the sample is intended to immobilize the sample, keeping it from changing during processing, but the flow characteristics of the mounting medium allow the sample to change in curvature. The surface profile is reproduced, but the changes in sample curvature during processing result in thickness variations that are beyond those expected from processing uncertainty alone.

To compensate for the curvature variation during the thinning process and the combined processing uncertainty of the equipment, the thickness measurements must be used to correct the operational profile. This is done with the second fine-lapping process, where enough silicon is removed to reach the target thickness and remove the variations in thickness resulting from mounting medium cold flow. The time between the optical thickness measurements and the initiation of the "correction" lapping process is very small. The process steps that follow this correction remove little material and are largely not controllable in profile due to the resiliency of the polishing pad material. This profile correction may allow some of the previous processes to be done faster, because profile integrity requires very low forces and slow feed rates. Being able to correct the profile at the end of the gross removal steps could reduce process times significantly.

CONCLUSIONS

As dice become larger or multiple dice are mounted together on the same substrate, the profile variations of the resulting surfaces will increase; that is, the larger the die, the greater the height difference center to corner. Horizontal stacking on a single interposer results in a complex curved surface that may have more height variation than a single die of the same combined dimensions. Because using a solid immersion lens imaging system requires compensating for die thickness, the variation in thickness must be constrained. A variation limit of ±0.005 mm is currently acceptable, but no doubt this will change as structures reduce in size and higher resolution is demanded.

Even with the best equipment and processes, it is difficult to maintain ±0.005 mm variation in sample silicon thickness. With the push for faster process times and the

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demands on the technicians operating the equipment, a real-world maximum thickness variation is ±0.010 mm or more.

Multiple-point measurement of actual silicon thicknesses and the use of these measurements to correct the machined profile are necessary to move beyond the current ±0.010 to ±0.005 mm thickness variation. The thickness measurements must be made at known, well-controlled points on the die surface so that the values can be correlated to the surface profile used for lapping and polishing the surface. Without this positional control, the thickness measurements are useless, because they cannot be correlated to the stored profile. The standard procedures of taking five thickness measurements at somewhere near the die center and corners cannot easily be used for process profile adjustment.

The mechanically measured surface profile is generally taken with 1.5 to 2 mm grid spacing. This range will normally keep the linear (wire frame) approximation of the surface to within 0.001 mm of the actual curved profile. It is not necessary, or really desirable, to take thickness measurements at the same spatial resolution, because the measurement time is long in comparison to the mechanical measurements and the change in profile is distributed more or less evenly. A matrix with much less resolution can be used for the thickness measurements, and each individual mechanical matrix-point correction can be interpolated.

There is a trend to thinner samples, some being requested as thin as 0.001 mm. This is not possible with current equipment and processes, but 0.010 mm is possible if thickness measurements are used to adjust the profile and the amount of silicon removed.

The mechanical limitations of flattening a curved die in preparation for die thinning will be discussed in Part II of this article in the November issue of *EDFA*.

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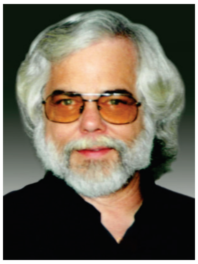
ABOUT THE AUTHOR



Kirk Martin has 40 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 2005, he became a founder of RKD Engineering, which designs and builds equipment for semiconductor failure analysis and sample preparation. Kirk has patents in the fields of sample preparation, chemical vapor generation, and electrostatic discharge detection and mitigation.

NOTEWORTHY NEWS

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