Screen and Stencil Printing Processes for Wafer Backside Coating

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Abstract

Stencil printing equipment has traditionally been used in the surface mount assembly industry for solder paste printing. In recent years the flexibility of the tool has been exploited for a wide range of materials and processes to aid semiconductor packaging and assembly. One such application has been the depsoition of adhesive coatings onto the backside of silicon wafers.

This paper looks at the application of two totally different epoxy materials to the non active side of silicon wafers – one providing a B-stageble die attach layer and one providing a protective laser-markable cover layer aimed at protecting individual die from damage during dicing.

Printing trials, with the two commercially standard, non-conductive epoxy based materials were conducted. For each material, 24 200mm wafers were printed. Both screen and stencil printing processes were compared for each material. Effects of printing process parameters were also considered.

Coating thickness planarity across a wafer is the key metric for a successful coating process. For each wafer processed a minimum of 16 thickness measurements were made. Results showing thickness control capability are presented. The study demonstrates that coating co-planarity accomplishing ±12.5µm @ 6 sigma control with cured thickness's down to 30µm is possible.

Keywords: Coating, screen print, stencil print, wafers, die attach, B-stage, printing.

1. Introduction

Much of today's development in electronics packaging is focused towards adding value at the wafer level, motivated by opportunities to reduce manufacturing cost while continuing to improve performance. This has resulted in convergence of semiconductor manufacturing and final assembly in design and deployment. Productivity can be further optimized through the manufacturing efficiencies gained by the use of traditional final assembly equipment in wafer level processes.

With the advent of the wafer level packaging concept in the mid nineties one of the first production processes considered was the printing of a protective layer onto the backside of a wafer to provide a surface which could be easily marked with a laser for ultimate product identification, and also to help minimize die chipping and die fly during dicing processes.

Subsequently the same technique has been adopted for the blanket coating of wafers with a new breed of B-stageable die attach adhesives.

Traditionally, die attach is achieved by dispensing adhesive pastes onto lead-frames and substrates. By applying die attach material directly to silicon while still in the wafer form a manufacturing step is effectively removed, with the individual finished packages supplied to final assembly, with this feature now pre-applied. Furthermore, any yield loss attributed to former dedicated die attach deposition processes is also eliminated due to only known good die (KGD) being used. This methodology also helps control/minimize fillet formation and bond line thickness in final assembly.

Irrespective of the final application, performance criteria associated with large area printed coatings include thickness (or thinness), uniformity, surface texture, and ability to replicate results. Some work has already been done to characterize coating thickness as a function of mesh material selection for screen printing wafer backside coatings.[1] In this study, two wafer backside coating materials, which exhibit quite dissimilar rheological properties, are compared between mesh screen and stencil print processes to help establish a foundation for defining coating method capability.

2. Experimental

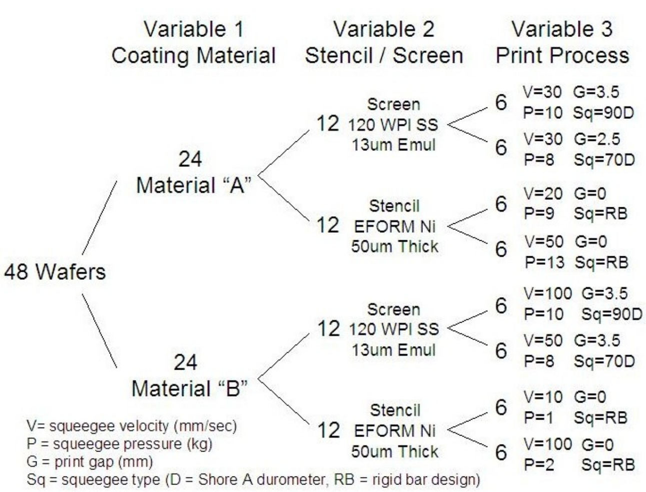
To simplify the study, only two screen printable wafer coating materials were selected for process investigation. These materials exhibited substantial differences in rheology, shown in Table 1, which was deliberate by experimental design to expose any unique process window effects. Material "A" can be compared to the consistency between molasses and honey, while Material "B" resembled more the feel of a kitchen cooking oil. Material "A" is a non-conductive, snap curable (after B-stage) wafer applied die attach adhesive. Material “B” is a low CTE, low warpage, wafer backside applied protective coating.

A batch of 48 bare silicon wafers (200mm dia. / 725µm thick) were allocated for print coating and cure testing as per the schedule in Table 2. Half the wafers were designated for printing with Material A and the other half for Material B. Groups of 12 wafers for each material were printed by both mesh screen and metal stencil processes. The same mesh screen and metal stencil was used for both materials. The mesh screen was designed at 120 wires per inch using 65µm diameter stainless steel wire (140µm mesh openings / 140µm mesh thickness) with 13µm thickness emulsion defining a 198mm diameter circular aperture. The metal stencil was manufactured by electroforming a nickel foil at 50µm thick and also using a 198mm diameter circular aperture size.

Table 1. Print material properties

Material	A	B
Function	WL Die Attach	Protection
Viscosity	42,000 cps	4,000 cps
Specific Gravity	1.5 g/cc	1.8 g/cc
Color	Yellow	Black
Conductive	No	No
B-Stage Capable	Yes	No
Snap Cure Capable	Yes	No

Table 2. Test variables



A DEK Galaxy fully programmable, automatic stencil printer was used to apply material on the wafers together with a special vacuum chuck fixture to secure wafers in the machine during the print coating process. Standard 60 degree polyurethane type squeegees of both 70 and 90 durometer hardnesses were installed for coating mesh screen printed wafers, while a specialized rigid squeegee type was utilized when operating in stencil print mode shown in Figure 1. This rigid squeegee was developed specifically for large aperture stencil print coating processes, to deliver the following improvements over conventional thin/flat/flexible metal squeegee blade designs.

High flatness and rigidity – to prevent aperture scavenging resulting in more planar coatings.

Constant angle of attack design - to reduce sensitivity to print pressure variations.

Strategic profiled backside – to encourage cleaner material separation during squeegee travel.

Removal of sharp edges – to offer safer handling and lowers stencil wear.

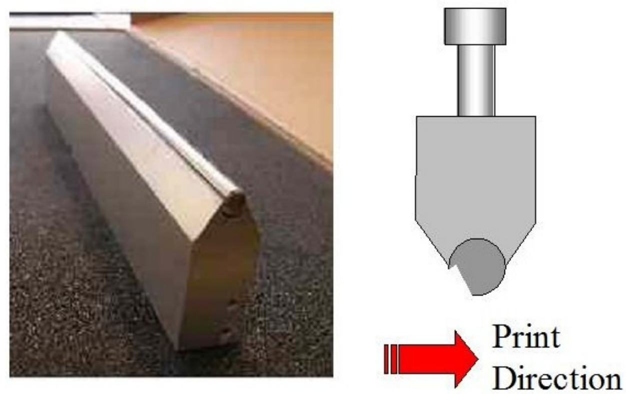


Figure 1. Rigid squeegee for stencil print coating (patent pending)

3. Test Process

Several bare silicon wafers were printed and weighed with an electronic scale for both print adhesive materials applied at various print process parameter settings. Using mass measurements, along with known print area and material specific gravity values, it was possible to calculate theoretical wet print thickness values. This data was useful to judge print process stability and helped to establish printing machine parameters used in the formal print experiment. The wet print thickness target for process parameter selection (i.e. Table 2, Variable 3) was loosely set at 50µm, based solely on matching the thickness of the metal stencil used. It was learned later, different materials have different shrinkage effects in cure and it was impossible to replicate the same cured coating thicknesses across all the process designs used.

During the formal print test as per Table 2, wafers were cycled into the printer at timed intervals approximately 3 minutes apart to closely simulate a manufacturing line process condition. Alignment fiducials designed into the vacuum chuck tooling were used to register the large aperture consistently on the wafer.

The mesh screen print process was performed in a *Flood/Print* mode. The rear mounted flood blade first distributes a layer of material across the large open mesh aperture to provide preliminary mesh wire lubrication. This is followed by a second stroke in the opposite direction by the forward mounted polyurethane squeegee where material is pushed down into the open area forming the pattern and the surplus is removed by the edge of the squeegee (Figure 2). A print gap is quite common in mesh screen printing to encourage the mesh to peel away from the surface immediately behind the squeegee, leaving all the material that was in the mesh deposited on the wafer surface.

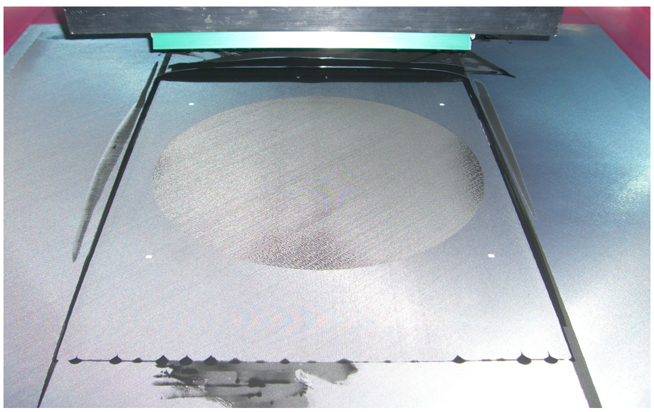


Figure 2. Mesh screen print process (Material B)

The stencil print process was operated with a different squeegee set and process parameters. The *Print/Print* mode was set to perform one on-contact print stroke per wafer. A set of specially designed straight and rigid squeegees (Figure 1) were installed on both rear and forward squeegee holders. Since these squeegees do not have a sharp printing tip, a thin film of material is expected to trail behind the moving squeegee and remain on the stencil as shown in Figure 3.

All 24 printed wafers were cured in an industrial convection batch oven at settings listed in Table 3. Material A was initially B-stage cured, followed immediately by a second stage to fully harden the coating. Material B did not require a secondary stage to achieve full cure.

Table 3. Cure parameters

Material	A	B
Stage 1	30 min at 125°C	30 min at 150°C
Stage 2	60 min at 180°C	---------

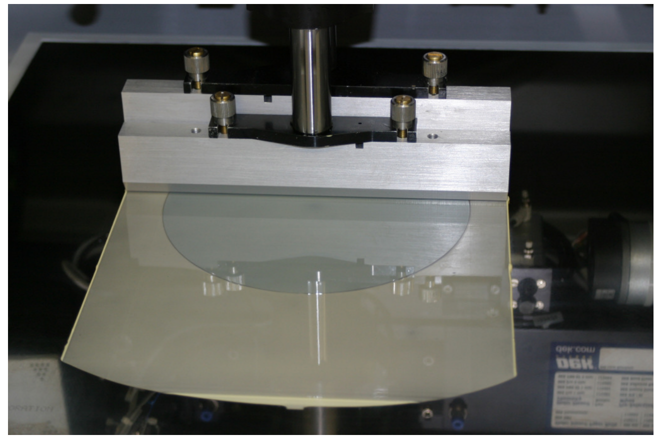


Figure 3. Stencil print process (Material A)

4. Inspection Procedures

Data acquired from all 48 cured wafers consisted of coating thickness values at several positions across the wafer. In addition, surface roughness was also characterized for cured wafers printed with Material A, since this is an important performance criteria for die attach applications. The locations measured for thickness and roughness on wafers printed with Material A are identified in Figure 4, while Figure 5 shows the thickness measurement points on wafers printed with Material B.

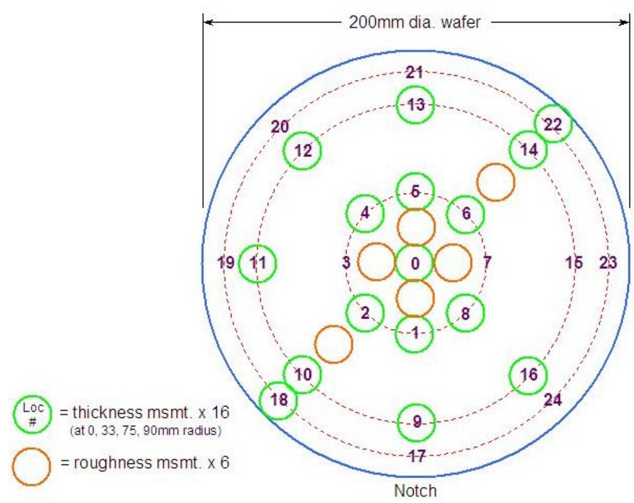


Figure 4. Measurement locations, Material A wafers

Different tools were used to measure the wafers, depending on the coating material printed. Wafers printed with Material A were measured for coating thickness and surface texture with a Surfcom contact stylus profilometer instrument. Print thickness measurements were taken at locations on the wafer labeled in Figure 4 where the stylus traversed regions of scratched away coating material, producing a ticker tape readout as shown in Figure 6.

Thickness measurements were manually interpreted on the printed tickets to the nearest estimated 0.25µm. A sample measurement is shown in Figure 6, which clearly reveals the silicon base which has been exposed from scratched away material. Major thickness axis divisions are separated by 10µm, finest division increments are 1µm.

The stylus profilometer was also programmed to record surface roughness measurements on Material A printed wafers. Output data included R_a (average roughness), R_z (average maximum height), and R_t (maximum peak to valley) values. In this report though, R_z values are reported exclusively.

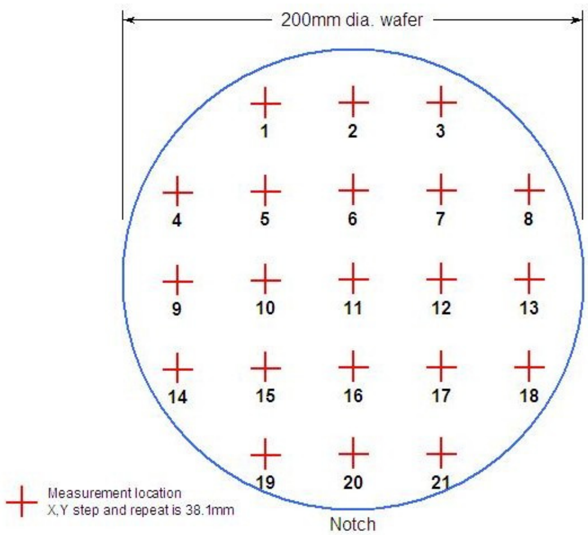


Figure 5. Measurement locations, Material B wafers

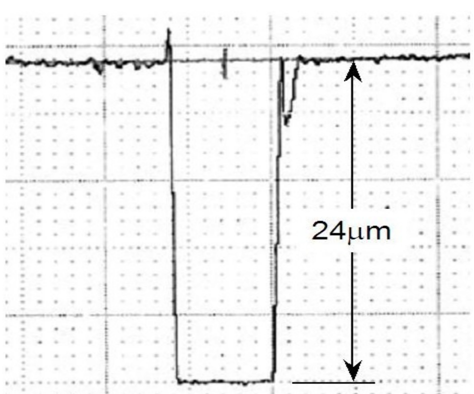


Figure 6. Example stylus profilometer measurement

Cured coating thickness measurements for wafers printed with Material B were performed by a much more labor intensive method. Scribed wafer die were removed from measurement positions indicated on the template in Figure 5. The 21 extracted die per wafer were sandwiched together and arranged in an epoxy potted stack for metallurgical cross-sectioning. A high powered optical microscope was used to measure thickness at three positions within each measurement location on the wafer. An example measurement view is shown in Figure 7. A total of 21 x 3 = 63 thickness measurements per wafer were logged.

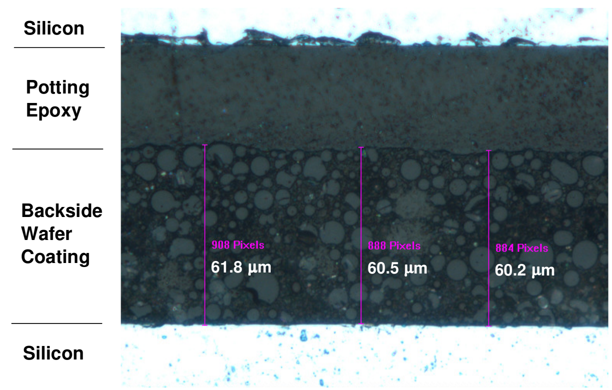


Figure 7. Cross section coating thickness, Material B

5. Results

Process Control

Cured coating thickness measurements results for Material A are shown in Figure 8. The data has been color coded to help distinguish process sensitivity to thickness and it also has been grouped to identify individual wafer thickness measurement outcomes. The distribution of thickesses appears tighter for both screen print conditions compared to the stencil print processes. The screen print data also does not show a significant effect of squeegee hardness on coating thickness.

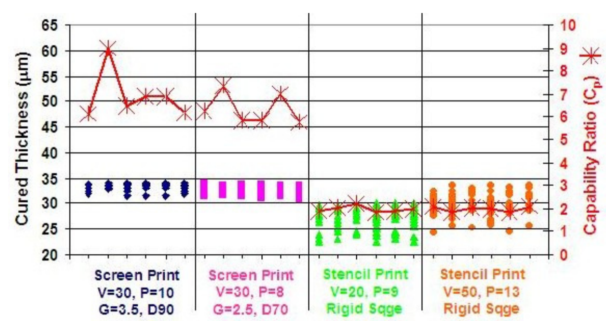


Figure 8. Material A wafer to wafer thickness comparison

Another statistical method of comparing thickness control is by presenting the data in the form of a capability ratio, or C_p. Mathematically this is the process tolerance divided by six sigma, and for this testing the following equation was used.

$$C_p = \frac{25\mu m}{6 \times \text{Std.Dev.}}$$

The process tolerance, or specification limit, which has customarily been accepted for this process is ±12.5µm, which explains the derivation behind the numerator value. There is some debate and confusion on the use of C_{pk} (process capability index) to characterize the process performance instead of C_p. To clarify, the use of C_p in this analysis is based on characterization of print uniformity without concern to the actual thickness values measured. In other words, this testing is not designed to measure how accurate the print thickness can be relative to a specified target value, which is fundamental to a C_{pk} analysis.

The C_p trends for Material A on Figure 8 concur with the spans in thickness distributions plotted. Lower standard deviations translate to greater thickness uniformity, and perhaps this also generates better repeatability across wafers. Higher values of C_p are favorable, typically with the aim to achieve a goal of 2.0 in order to accomplish 6-sigma level process capability. Although the stencil print process generally reports C_p values at an acceptable 2.0 level, the mesh screen print results track quite remarkably better at an impressive 6.0 and above level. There is no question that Material A is more uniformly printed with the mesh screen process, however, this factor alone doesn't necessarily define the process choice.

The stencil print process could very well be acceptable for most applications at the C_p of 2.0. It was observed in the closing minutes of the experiment during clean down that Material A was extremely stubborn in its tendency to remain firmly lodged in the mesh screen openings, requiring extraordinary effort to unblock. It may, in fact, be the nature of this material to require replacement of the mesh screen each time a manufacturing run is performed. A decision scenario such as this could make the stencil print option look far more attractive, as this was indeed much easier to clean in comparison.

The same print thickness analysis for Material B is shown in Figure 9. The coating thicknesses in general are higher for this material compared to Material A. If thinner results were required for some reason, further process testing could be explored using mass analysis to predict thickness from trends all ready observed. Mesh screens with reduced wire diameter or thinner foil stencils could also be methods to achieve thinner coatings.

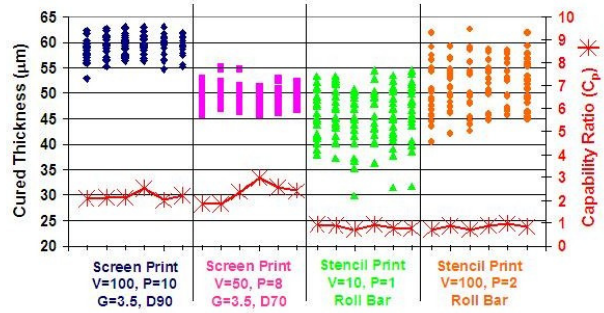


Figure 9. Material B wafer to wafer thickness comparison

From Figure 9, screen print C_p performance for Material B again is shown here to be better than stencil print performance, but not by the margin displayed for Material A. The thickness differences shown between processes is logical in that faster print speeds tend to increase print thickness. Print process changes within screen print and stencil print categories seem to have little influence on significantly changing C_p. The alarming data here is the poor C_p values reported in the stencil print process, at the 1.0 level. Material B may have to be screen printed if a C_p level of 2.0 is required. Fortunately, from a clean down standpoint, there were no problems in cleaning the mesh screen for Material B.

Thickness Trends

The next several plots present thickness data grouped by location on the wafer and arranged in specific sequences to highlight potential issues associated with scooping, wedging, and material aging.

Scooping

A concern with printing through large diameter apertures, particularly with metal stencils, is that the printed coating will be thinner at the center of the pattern compared to the circumference. While screen printing provides a fixed mesh layer between squeegee and wafer to prevent scooping, the stencil print process depends on a firm and straight squeegee blade to maintain its form across a large unsupported print area. Figure 10 displays screen print coating thickness data that has been grouped by process and material type, and ordered to show how thickness behaves as a function of radial location on the wafer. The expectation is either to detect shallower deposits in the center of the wafer or no print thickness difference between center and edge. It would be unusual to find thickness measurements higher at the center. Typically the screen print results show uniformity in thickness from center to perimeter, as expected.

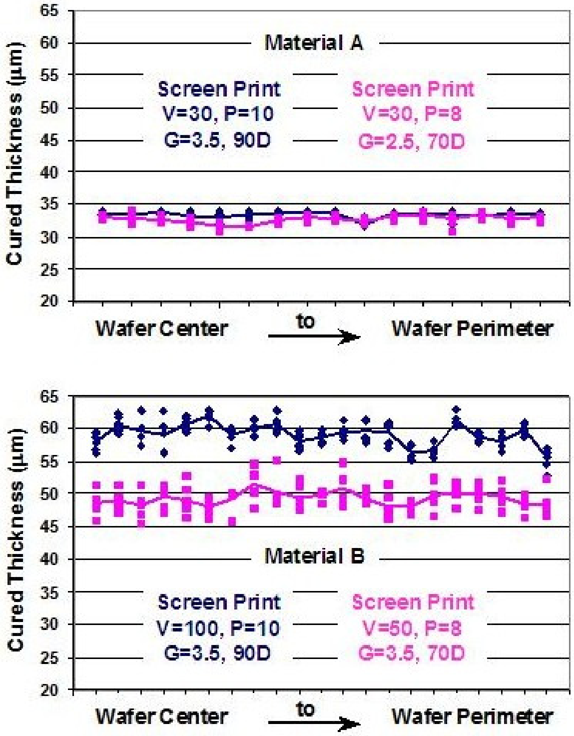


Figure 10. Mesh screen print scoop analysis (2 plots)

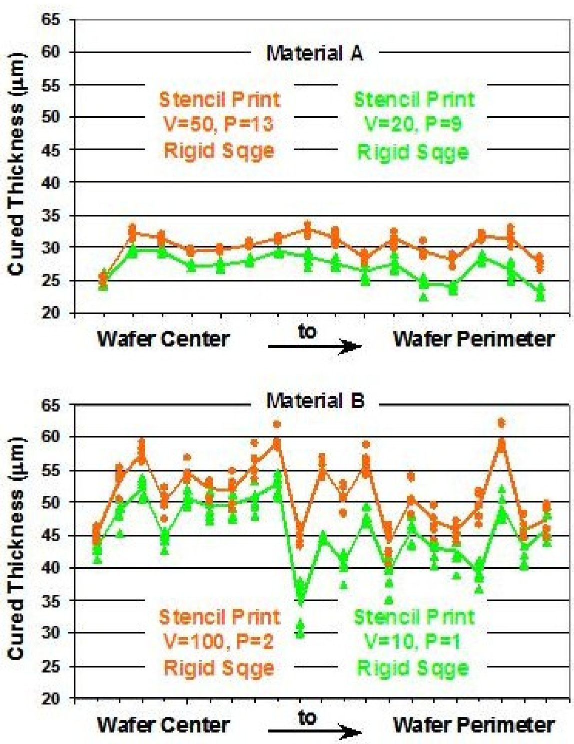


Figure 11. Stencil print scoop analysis (2 plots)

The variation in thickness occurring on the stencil printed wafers is much more amplified in comparison in Figure 11. Although the stencil print center data point tends to be low, the best fit straight line through all data points does not reveal any significant slope to suggest scooping is present. The good news here is the data confirming that the special purpose rigid squeegee blade resists deflection into the aperture, even under high print pressures used for Material A. It is interesting to point out, however, that there are prominent thickness features occurring with Material B results. The peaks and valleys align themselves consistently with one another across the two process conditions. It is speculated these ups and downs may actually coincide with topography occurring on the wafer vacuum support chuck surface. The wafer itself could in fact be conforming such support surface variations, and this could be showing up in the print. The screen print process may conceal this effect due to the mesh's ability to conform against such surface irregularities. Compared to Material A, Material B may have the ability to highlight small wafer tooling support surface deviations due to it's much lower viscosity.

Wedging

Another potential vulnerability on large print area applications is for coating thickness to systematically grow or shrink along the print travel axis, crudely expressed as "wedging". The same data presented previously can be ordered differently to investigate this effect as well. Screen print results are shown in Figure 12.

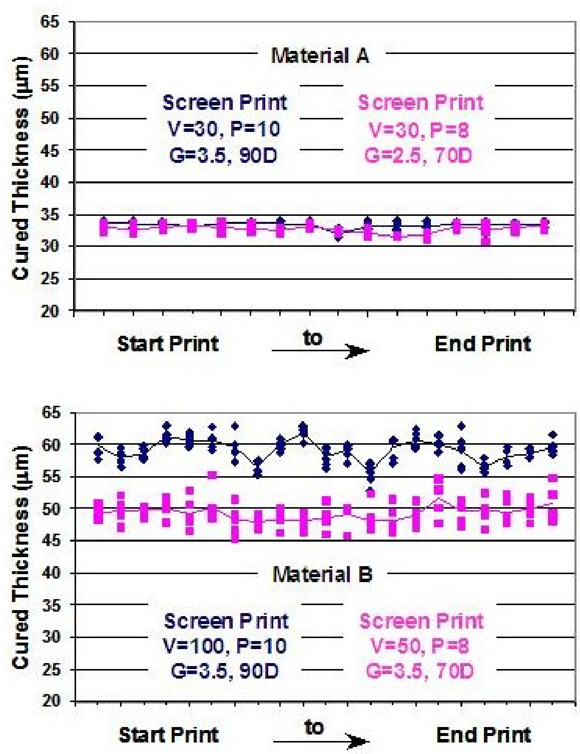


Figure 12. Mesh screen print wedge analysis (2 plots)

If wedging were present, a best fit straight line through the data would exhibit a positive or negative slope. The screen print results do not reveal any significant slope trends to suggest the presence of wedging.

The stencil print wedging trends are shown in Figure 13. The data is formatted somewhat differently here as reverse and forward print directions have been plotted independently. This print direction filtering is actually quite important and serves to reveal a noise variable that is causing significantly unfavorable thickness control performance. Note the solid lines tend to gain thickness from start to finish, while the dashed lines are losing thickness from start to finish. This does identify a significant process fault, however, this is also an issue that can be repaired.

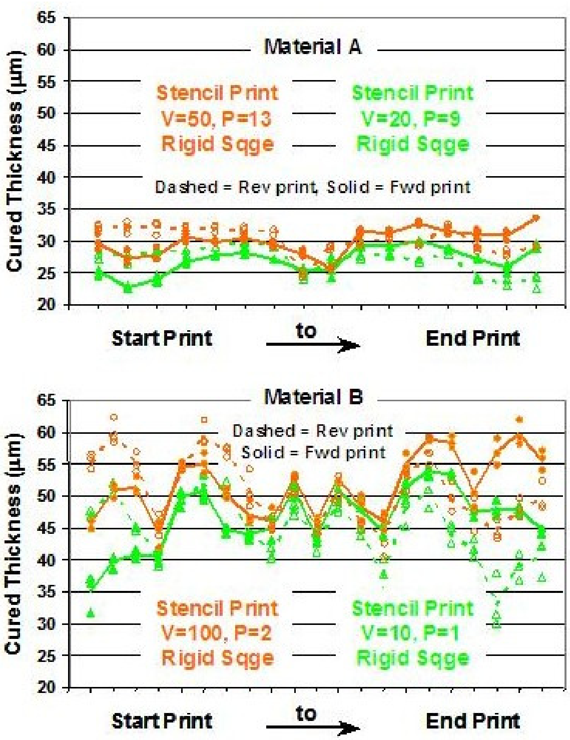


Figure 13. Stencil print wedge analysis (2 plots)

Figure 14 provides further interpretation of the trends plotted in Figure 13. What appears to be happening is that coating thickness is consistently thinner on one side of the wafer compared to the other, which by definition is wedging. The interesting part about the data is that print direction is not found to have any effect on changing coating thickness distribution. This data is useful in that it suggests that the stencil and wafer may not have been truly parallel to one another during the print process. If the wafer is not presented level to the stencil surface, this may result in either side to side, or in this case, front to rear print pressure discrepancy. In this case, the wafer is probably more loosely contacting the stencil at it's bottom side compared to the top. Mechanical adjustments to re-level the conveyer rail support system should resolve this, enabling improved stencil print coating uniformity performance.

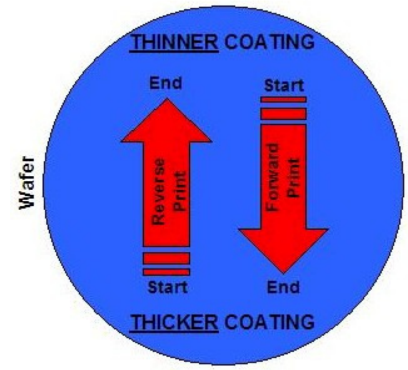


Figure 14. Stencil print wedging trends

Material Aging

The purpose of this test is to detect changes in print thickness that could be linked with material aging. Wafer coating adhesive materials will thicken as a function of ambient exposure time. The sensitivity to open time can vary from material to material. This experiment was not intended to include material aging as a significant variable, but nonetheless it is useful to verify that this assumption is correct. A simple analysis is presented in Figure 15. Time is not explicitly defined on the chart, but the data points are grouped into common process settings. Within process setting groups the data is ordered in chronological print sequence. Although thickness data points reveal some scatter, patterns of significant coating thickness increase within process groups is not obvious, which would be expected to occur with material thickening over time. Adhesive coating materials were probably not used for a long enough period in this study to produce a distinguishable aging effect.

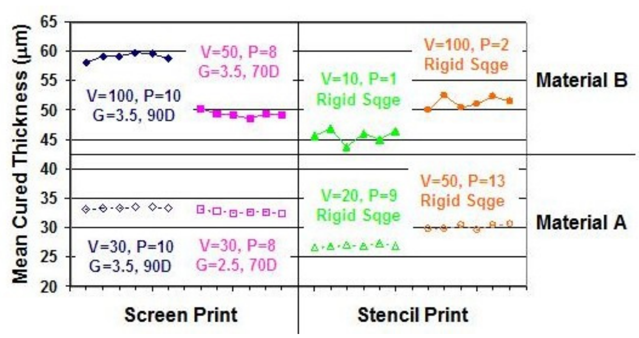


Figure 15. Coating thickness response to time

Surface Roughness

Smooth print surfaces promotes better wafer level die attach adhesion to dicing tape, helping to improve yield in that process. Material A was measured on a stylus profilometer at 6 positions per wafer to evaluate cured surface texture achieved by four printing processes. The distribution of data is shown in Figure 16. Target surface roughness performance is based on achieving below 10µm R_z. All process conditions tested were observed to comply comfortably inside this specification. The screen print results tend to produce a slightly more textured surfaces than stencil print coated wafers. The "orange peel" surface characteristic for mesh screen printed wafers may appear visibly more obvious than what is actually reported by measurement.

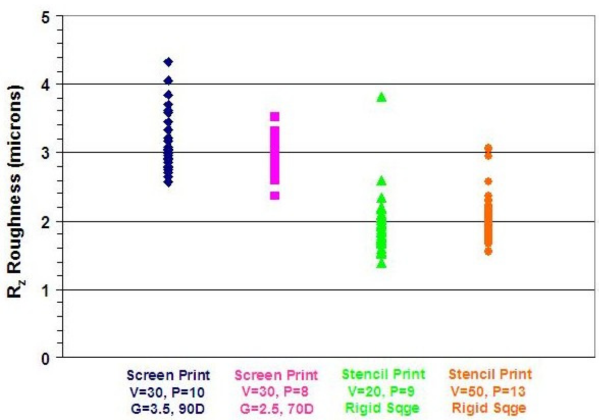


Figure 16. Material A surface roughness measurements

6. Conclusions

Large area thin film wafer backside coatings can be rapidly and uniformly applied by screen and stencil print processes. This study has demonstrated coating coplanarity success for two widely different material rheologies that achieve ±12.5µm @ 6 sigma control down to 30µm cured thickness. Of the materials and conditions tested, the process capability ratio (C_p) tends to favor mesh screen printing. Establishing mesh screen resistance to blockage over extended runs as well as clean down compliance are main concerns that warrant review for any printing material. Demonstrated stencil print process coating uniformity may be somewhat conservative based on discovery of noise variables related to equipment setup and support tooling finish. Based purely on viscosity differences between materials tested, results here indicate thinner materials may be more sensitive to printer machine component parallelism and wafer chuck flatness, suggesting such materials are more ideally suited for mesh screen printing. Smooth coating surface texture measurements obtained for both print techniques using one of the latest generation non-conductive die attach materials available shows promising performance consistently below 4µm R_z.

7. Future Work

This study has produced some evidence that stencil print coating thickness distribution may be influenced by mechanical planarity attributes during material deposition. This not only includes the printer tool itself, but also the quality of the wafer support tooling and squeegee blade. Further progress to optimize the performance of the printing system for this process will continue and improvements will be reported.

Conductive materials containing coarse and randomly shaped filler particle ingredients to provide electrical and/or thermal conductive properties are also available in B-stageable adhesive formats. It is speculated such materials could be more difficult to mesh screen print and may produce more textured surface finish results. With the application of these as wafer applied die attach coatings by printing already taking place, this material category will be included in a subsequent process study.

Finally, to test more realistic substrate conditions the strategy of incorporating thinner wafers into formal experiments are planned. Dummy 200mm diameter silicon wafers of at least to 300µm thick and if practical sourcing is available, to 150µm thick, will be incorporated into forthcoming process development.

8. Acknowledgements

Stephen Ruatta and Kevin Lindsey from the Ablestik division of Henkel Corp. are gratefully acknowledged for providing assistance in measuring wafer samples and valuable technical guidance.

9. References

[1] T. Winster, Henkel-Ablestik, A. Hamstra, H. van Rijckevorsel, Philips NXP, "Wafer Backside Coating (WBC) of Die Attach Adhesives", Proceedings of IMAPS 2005, Brugge, Belgium, June 2005.