International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Characterization of Mold Surface Morphology to Achieve Optimum Scan Yield in a Complex Mark Format

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Abstract— *Laser technology is the widely used technology in marking semiconductor devices. However, the demand for more data content on marking like 2D code impose a big challenge in marking quality. On top of this some mold compound types are also aggravating the legibility of the marking as pigments of laser are not so legible.*

While conventional way of improving legibility of marking is via optimization of laser or mark scan parameters, this technical paper however will focus on the study on the correlation effects of mold surface morphology by identifying what surface roughness range that will yield optimum marking quality on an automatic scan environment. In this paper we will also discuss how surface roughness on different molding technology like compression and transfer mold can be controlled.

Keywords— *Flipchip Package Voids.*

I. INTRODUCTION

Laser marking is a process to mark materials using a fine spot diameter laser beam and is widely used for putting marks such as brand name or logos, best-before-date, serial numbers, on a variety of materials. Many exposed silicon packages are used in memory applications, and direct laser marking has been widely accepted in this part of the industry as the best solution for these devices. Because memory devices are low-value products, manufacturers are very focused on cost, so the lower cost of ownership (COO) of laser marking compared to traditional ink marking is appealing. The speed, lack of consumables and compatibility with silicon package handling contribute to the lower COO for laser marking. In addition, the non-contact nature of direct laser marking is attractive to manufacturers because there are no static issues.

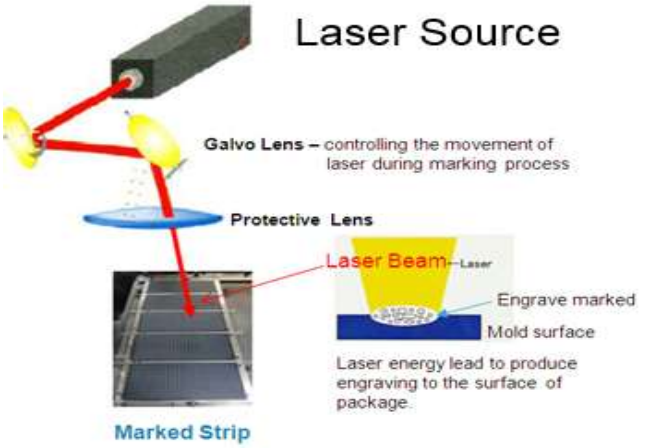


Figure 1. Laser Marking Process

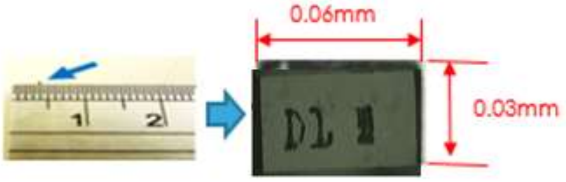
Basically, the laser creates an engrave by burning away the mold compound in order to make a visible marking. The engrave or depth can vary depending upon the speed, power, and pulse rate of the laser marker.

1.1 Understanding the Challenges of Laser Marking

As semiconductor manufacturing trend goes smaller, more functionality and with highly reliability, this also impose difficulties in doing marking quality and readability both at marking and scanning.

1.1.1 Marking size

Marking size is reduced significantly as package size goes as small below 1.0mm x1.0mm which is true for packages in small QFN's and scalable packages.



(a) (b)

Figure 2. (a) Scalable package (b) Package/Mark Size

1.1.2 Marking format

The traditional alphanumeric identification format on the surface of the package has also evolved due to broader data content which is only possible on 2 dimensional coded mark or 2D. However, 2D code is more sensitive on mark scan and marking readability is very important. Shown below is the comparison of the marking formats alphanumeric and 2D code.

(a) (b)

Figure 3. Laser marking on molded IC (a) Alphanumeric (b) 2D coded

1.1.3 Marking depth

As the package becomes thinner and wirebonding becomes complex, smaller process margins is allowed for marking depth to prevent expose wire or die.

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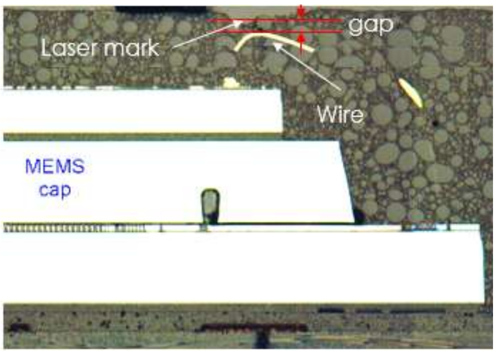

Figure 4. Cross section for gap between laser depth and wire

1.1.4 Compatibility to molding compound

There are qualified mold compound that reacts differently using the same laser mark parameters.

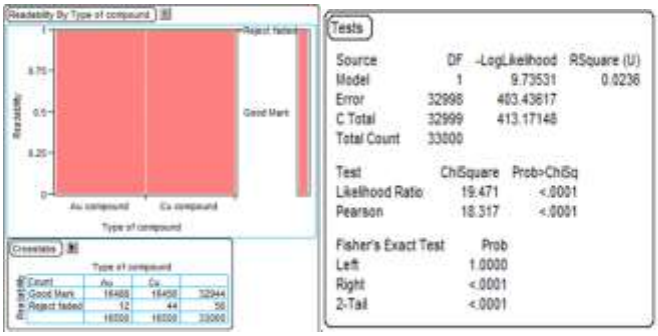

Figure 5. 2-Proportional test of mark quality between mold compound for gold wire against copper wire products

1.1.5 Mark scan limitation

Finish scan also is encountering high fall-outs mainly due to mark defects but further adjustment cannot be made as it will compromise other scan defects from escaping.

The major problem associated with laser marking is the relatively poor contrast between the exposed area and the background, the coding having only a slightly lighter and less reflective appearance than the body of the part. Below shows Finish mark scan with 5.76% fall-outs.

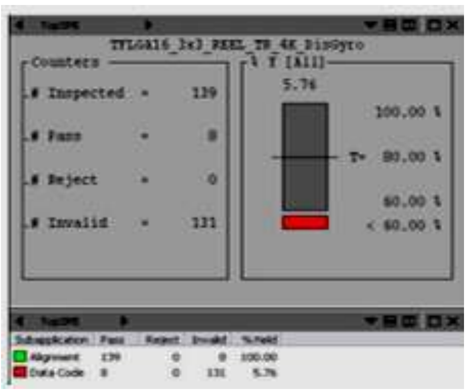

Figure 6. Mark scan failures

II. Review of Related Literature

2.1 Understanding Effect of Polishing for Surface Roughness Determination on Mold Tool

[1]Polishing technology is very critical to determine quality and performance of the final products and occupies up to 30~50% of the whole die manufacturing time. Polishing purpose is to reduce the surface roughness to a desired amount and keep form accuracy. However, polishing is a kind of complex material removal operation, and the surface roughness after polishing is related to many factors such as machining parameters: polishing pressure, feed rate, tool speed, polishing times, grit of abrasive tool etc.

The mould polishing is a complex material removal process under various polishing conditions. The process parameters (polishing pressure, tool speed, feed rate, polishing times, pose angle, etc.) and material parameters (workpiece material, abrasive tool material) have effects on surface roughness. In this paper, a new surface roughness model based on artificial neural network (ANN) is presented, which consider workpiece material hardness and grit of abrasive tool. ANN model consists of three layers: input layer, hidden layer and output layer. Input layer has 7 neurons: hardness, grit, pressure, tool speed, feed rate, polishing times, surface roughness prior to polishing. Hidden layer has 12 neurons. Output layer has 1 neuron: surface roughness after polishing. The training samples are 64 and testing samples are 16. The training function is the powerful Levenberg-Marquardt (LM) algorithm. The training epoch is 29 when mean square error (MSE) is less than the goal value (3.6×10^{-4}). Average relative error is less than 0.05 when testing. The testing results show that surface roughness model based on ANN presents a good agreement with experimental results.

2.2 Mold Release Film Surface Roughness on Package

[2]Film Assisted Molding (FAM) is based on standard transfer molding (TM) technology and presents a new, advanced industrial manufacturing technology. The major modification compared to TM includes the application of a foil of Ethylen-Tetrafluoroethylene (ETFE) with a thickness between 50 μm and 100 μm.

Figure 7. Mold release film in compression mold

The advantage of using such a film is the protection of the tool from the EMC, leading to a virtually unlimited tool-life and therefore a first part identical to last part principle. Additionally, tool complexity and abrasion is reduced as mechanical ejector pins are not required. Furthermore, sealing

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

of the tool is improved by the compression seal of the foil, leading to a simplified tool making in regard to precision and tolerances. Mold release film also dictates the surface roughness of package as the mold compound follows the contour of the release film surface.

[3]The Film Assisted Molding technology (FAM) for transfer molding has been introduced for encapsulating microelectronic devices. FAM enables a bleed and flash free window for MEMS/sensors and LEDs. The EMC bleed and resin flash can be prevented with relatively low clamping force of the compressed film, not steel-steel direct contact. The mold life can be extended and mold cleaning is not needed with FAM because the EMC will only fill the mold cavities between the films, not touching the mold. The sucked film by vacuum makes enough space to prevent the film from touching the wires during the mold close process and molding compound filling the mold cavities. The film keeps the mold free from the encapsulation material. This also avoids contamination even if the EMC is a very sticky encapsulant. The films also act as “gaskets”, providing a good seal and stopping encapsulant material flowing out of the molding area. This allows the opportunity to mold MEMS/sensors with exposed windows. Film assisted technology can meet the MEMS/Sensors with exposed window encapsulation challenge with low cost and good quality.

2.3 Character Recognition on Mark Scan with Different Background

[4]In the process of packaging Integrated Circuits (ICs), special markings are drawn to indicate the defective chips detected by test inspection equipment’s. During the automated optical inspection process, these markings are detected and identified by the inspection equipment for a special treatment of detective IC packages. The marking is sometimes difficult to segment by the imaging device due to the complex background features among which the marking is drawn, such as circuit features and other graphic features. We develop several marking segmentation algorithms based on grayscale hit-or-miss morphological transformation operations. The markings are assumed of known width different from other background features and of detectable contrast from background. Performance of the newly developed algorithms are extensively tested and compared with simple well-known morphological algorithms and the result shows equal or better segmentation accuracy.

Morphological hit-or-miss transform is extended from binary to gray-level and applied to the character segmentation. Algorithms are proposed for various character extractions along the functions using Hval and Mval. Simulations are devised with the almost realistic image, and the detection ratios are shown statistically. The characters, which have constant difference from background, are segmented precisely in spite of their shapes. Even from the images that have illumination irregularity, the characters are segmented successfully. However, if the difference between the background and character is small, the segmentation is not effective. In the future work, automatic algorithm for optimal parameters selection will be developed for character segmentation

III. Experimental Section

3.1 Materials

For compression molding, mold release film with different surface roughness on the mold side will be used. Surface roughness that will be evaluated are Ra of 0.19, 0.9 and 2.0, For transfer molding, mold tool with different surface roughness of Ra 1.0 and 1.4 will be evaluated.

Same molding compound and package vehicle will be used. For compression mold, granular compound from supplier A using LGA package will be used. For transfer mold, mold compound to be used will be coming from supplier B using QFN as the package vehicle.

For equipment to be used, same mold compression mold and transfer mold, laser mark and vision system machine and parameters will be used during the experiment.

To ensure Vision system results are correct an attribute MSA will first be performed.

3.2 Procedure

Surface roughness evaluation for compression molding is done by setting up mold release film using the required surface roughness then run the evaluation.

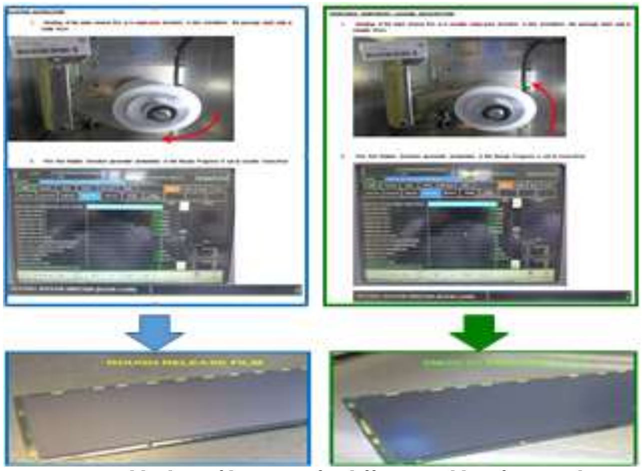

Figure 8. Mold release film set-up for different mold surface roughness

For transfer mold, set-up mold tool with required surface roughness then run the evaluation.

At marking, run all surface roughness legs using the same laser machine and parameters.

For all evaluation legs on both compression and transfer mold data gathering will be performed at Finishing wherein Finishing Yield will be compared on different surface roughness levels. Prior to the Finish activity, attribute MSA will be first conducted to gauge accuracy and repeatability of scanning.

IV. Results and Discussion

4.1 Attribute Measurement System Analysis, MSA

Based from the attribute MSA results, high percentage under each appraiser vs. std of 92.86-100% indicates good

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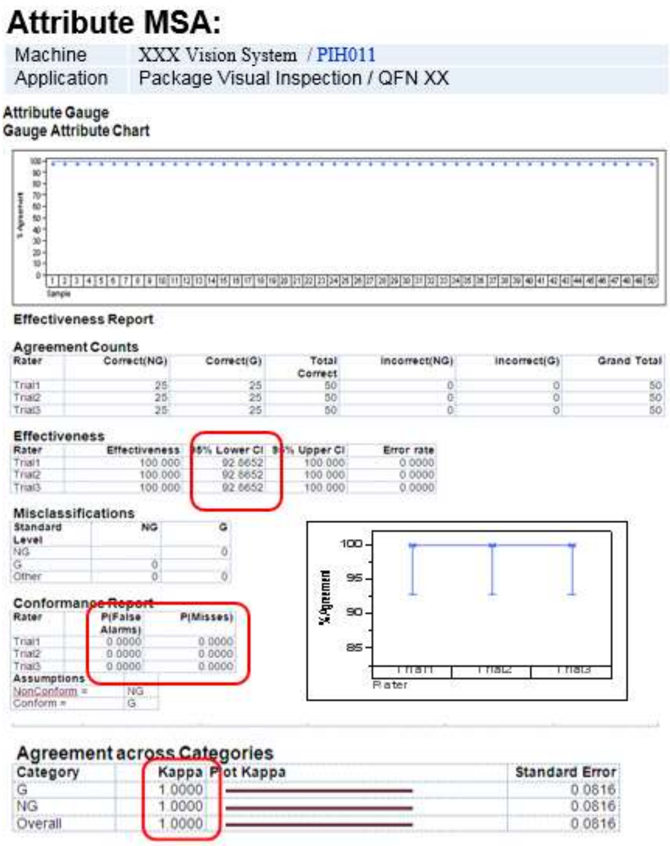
repeatability. High percentage under all appraisers of 92.86% indicates good reproducibility. Kappa of 1.0 is an indication of excellent agreement.



Parameter	E (95% LCI)	P (FA)	P (Miss)	Kappa
Acceptable for the appraiser	≥ 90%	≤ 5%	≤ 2%	≥0.75
PIH011	92.86%	0%	0%	1.0
PIH008	92.86%	0%	0%	1.0
PIH010	92.86%	0%	0%	1.0
PIH007	92.86%	0%	0%	1.0
PIH006	92.86%	0%	0%	1.0

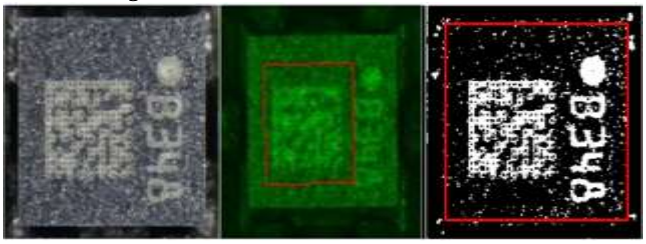
Figure 9. Attribute MSA results

4.2. Mark Scan Performance

4.2.1 Actual visual comparison per surface rouhghness for compression mold

Actual mark scan images of different mold surface roughness for compression molding as shown below shows clear distinction of surface roughness on captured image at camera. For Ra 1.4, vision binarized image shows many with white pixels across the package that affects pixel count recognition of actual marking. For Ra 0.19, vision binarized image shows no white pixels across the package however it is susceptible to scratches as shown by lines affecting actual mark recognition. For Ra 0.9, very few white pixels are seen across the package and is more robust to scratches.

Surface roughness at Ra 1.4



Surface roughness at Ra 0.9

Surface roughness at Ra 0.19

Figure 10. Mark scan image per surface roughness

4.2.2 Actual visual comparison per surface roughness for transfer mold

Actual mark scan images of different mold surface roughness for transfer molding as shown below shows clear distinction of surface roughness on captured image at camera.

Surface roughness at Ra 1.0

Surface roughness at Ra 1.4

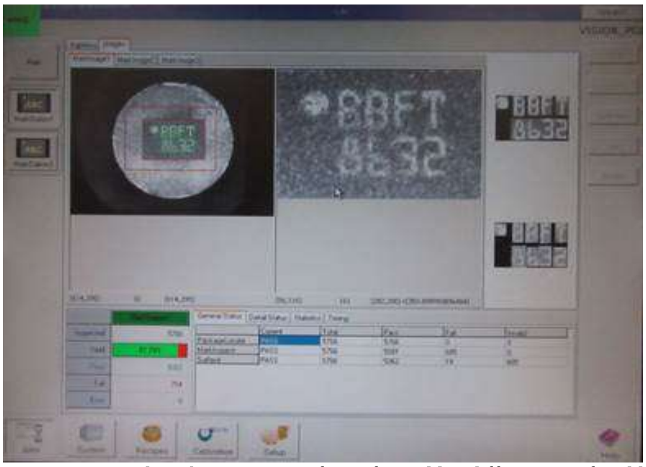


Figure 11. Actual mark scan image of transfer mold at different Ra of mold tool

4.2.3. Finishing yield performance

Based from the Finish scanning yield results on compression molding, for first pass yield, FPY, Ra 0.19 yielded the lowest with 99.33% mainly due to scratch followed by Ra 1.4 at 99.5% while Ra 0.9 has a very high yield of 99.94%. For final yield after rescreen, Ra 1.4 improved to 99.95%, Ra 0.19 improved to 99.97% while Ra 0.9 yielded the highest at 99.98%.

The first pass yield of Ra 0.9, is already high and is comparable to the final yield of Ra 1.4 and 0.19 as such rescreen is now longer required which will save valuable allocation for rescreen and cycle time.

Table 1. Finishing Yield comparison per surface roughness at compression mold

	(In-mark rejects)/In	(In-All rejects/In)
	FPY (top)	Final Yield (top mark only)
Ra @ 1.4	99.50%	99.95%
Ra @ 0.19	99.33%	99.97%
Ra @ 0.9	99.94%	99.98%

Based from Finish scanning yield performance of the two surface roughness for transfer mold, both first pass yield, FPY and Final Yield, FY for surface roughness of Ra 1.0 has higher Yield at 98% and 99.04% respectively as compared to surface roughness of Ra 1.4 with 88% and 94.22% respectively.

Table 2. Finishing Yield comparison per surface roughness at transfer mold

	First Pass Yield,FPY	Final Yield, FY
Ra @ 1.4	88.00%	94.22%
Ra @ 1.0	98.00%	99.04%

V. Conclusion

Based from the results, we can conclude that surface roughness has a significant influence on marking quality during Finish scan as contrast between mold surface to marking is more pronounce.

Targeting surface roughness at a range of Ra 0.9-1.0 will result to optimum Finish Yield. Lower surface roughness will result to very smooth package surface which is susceptible to scratches and reflection of lighting at Vision scan resulting to low Finishing Yield while higher surface roughness will cause less pronounce contrast of package surface to marking due to light pigments of mold compound similar to marking pigments resulting to low Finishing Yield.

Compression mold surface roughness is easier to control as it is dictated by the mold release film and is not subject to wear and tear as compared to transfer molding whose surface roughness becomes lower as the mold shot count increases.

VI. Recommendations

It is recommended to implement a surface roughness range of Ra 0.9-1.0 during selection of mold release film for compression molding or other film assisted molding and qualification of mold tool for transfer molding. It is equally important as well to have incoming controls for mold release film to ensure surface roughness requirement is sustained. For transfer mold tool, roughness monitoring on different mold compound should be pursued to validate if current defined tool life will not cause degradation on mark scan quality as surface roughness smoothen through continuous use that can lead to more package scratch rejects.

Acknowledgment

We bring back all the glory and honor first and foremost to GOD who gave as the strength and knowledge to make this possible.

Our family who serve as my inspiration to persevere in work.

We also would like to acknowledge Jun Bernabe our Assy MT for his commitment to support us in the resolution of the problem. Joseph Tuazon, who served as my adviser.

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