Bumping of Silicon Wafers using Enclosed Printhead

By James H. Adriance
Universal Instruments Corp. – SMT Laboratory

By Mark A. Whitmore
DEK Screen Printers – Advanced Technologies

Introduction

The technology of attaching Silicon die to substrates by the use of solder bumps is expected to grow substantially in the coming years. One major process step within this technology is bumping of the Silicon wafers. A variety of different techniques are currently used to bump wafers including electro-plating, evaporation, pre-form ball placement and solder paste printing to form bumps.

Deposition of solder paste by metal mask stenciling is one of the most promising cost effective processes that has been researched by a number of companies during the past few years. This process is based on a technique of "over printing" solder paste onto wafers with the use of a metal mask stencil. The term "over printing" is used because the solder paste deposits that are printed onto the wafer are always larger than the attachment pads.

The primary advantage of this wafer bumping process is that it does not require a sacrificial masking process for each wafer. Eliminating the masking process reduces the number of steps in the process as well as the cost of the process. The only consumable material cost in the process is a stencil for each wafer design, solder paste and deionized water for flux residue removal.

The major steps in this wafer bumping process consist of stenciling the solder paste directly onto the wafer, inspection of the solder paste, mass reflow of the solder paste, and post soldering flux residue removal with deionized water. Some lower cost wet chemistry based under bump metallization processes are currently being used with this bumping technique.

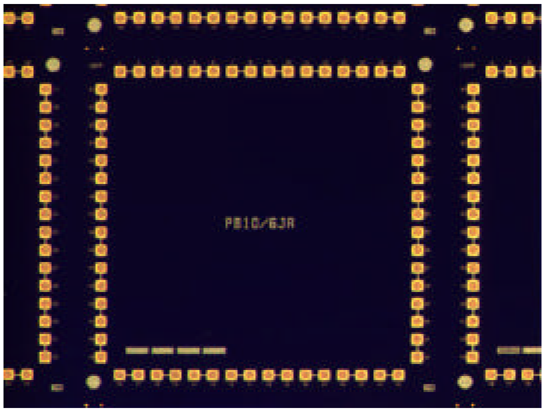
Discussion

Most metal mask stencil printing research for bumping of Silicon wafers has been based on the use of traditional squeegees where as the thrust of this research is to investigate the use of a “new” printing technique based on pressurization of the print head. The process called DirEKt Imaging uses the print head called ProFlow from DEK. A direct comparison was made using traditional squeegees and the ProFlow unit. Wafers were bumped using both techniques where stencil apertures were not wetted with solder paste. A second run was made where stencil apertures were wetted with solder paste. The measured responses from the experiment were bump height and yield. We compared bump height to the targeted bump height, and bump height repeatability within the die as well as across the entire wafer.

Test Wafer & Bump Height Target

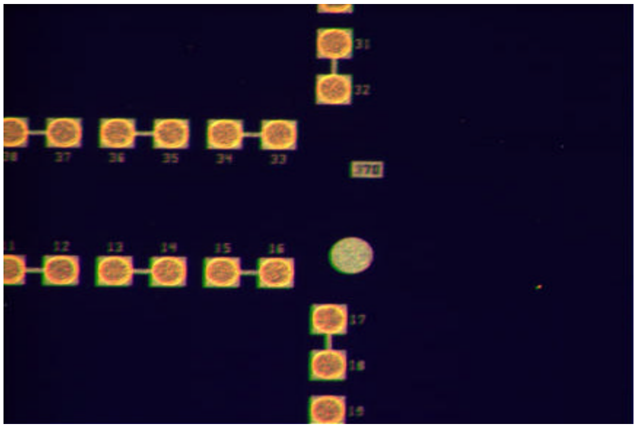
The wafers used for this research were supplied by Delphi Delco Electronics Systems with a wafer diameter of 125mm and a thickness of 0.65mm. The passivation layer on the test wafers was Silicon Nitride. Each wafer contained 344 die with a single perimeter pattern of 68 bumps on a 10 mil (254 micron) pitch. Each wafer contained 22,016 bumps. Photo #1 shows the die used for the experimentation.

Photo #1



The under bump metalization is Nickel\Copper on an attachment pad 6.0 mils (152.4 micron) in diameter. The target for bump height was 5.0 mils (127 micron). A solder bump 5.0 mils (127 micron) tall on a 6.0 mil (152.4 micron) diameter attachment pad produces a bump diameter of approximately 6.8 mils (172.7 micron). The solder volume needed to produce this bump is 136.14 cubic mils. The distance between the bumps is 3.2 mils (81 micron) when a 5.0 mil (127 micron) tall bump is achieved. Photo #2 shows the round fiducial and rectangle box used for wafer to stencil alignment features.

Photo #2



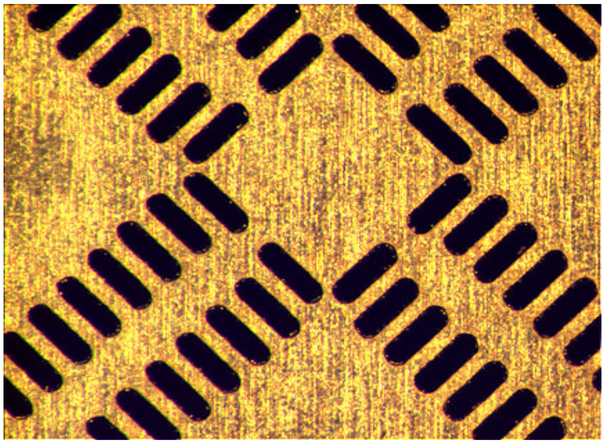
Solder Paste

The solder paste used for the research was a water soluble based product. The paste contained 90% solids with a type V powder size. The alloy was a standard Sn63 Pb37. The Viscosity range for the product was approximately 800KCPS to 900KCPS.

Stencil

The stencil used for the research was laser cut from stainless steel. The mask thickness was 3.0 mils (75 micron). An oval stencil aperture of 6.0 mils (150 micron) wide by 19.0 mils (475 micron) long was used for all testing. This produced an aperture to aperture spacing of 4.0 mils (100 micron). All but the eight corner apertures were centered over the attachment pads. The eight corner apertures were moved out by approximately 2.0 mils (50.8 micron) to provide adequate spacing between the ends of the inside corner apertures. The wafer was rotated 45 degrees to provide an equal angle of attack for the squeegee relative to the stencil apertures. Photo #3 shows the stencil apertures used for the wafer bumping.

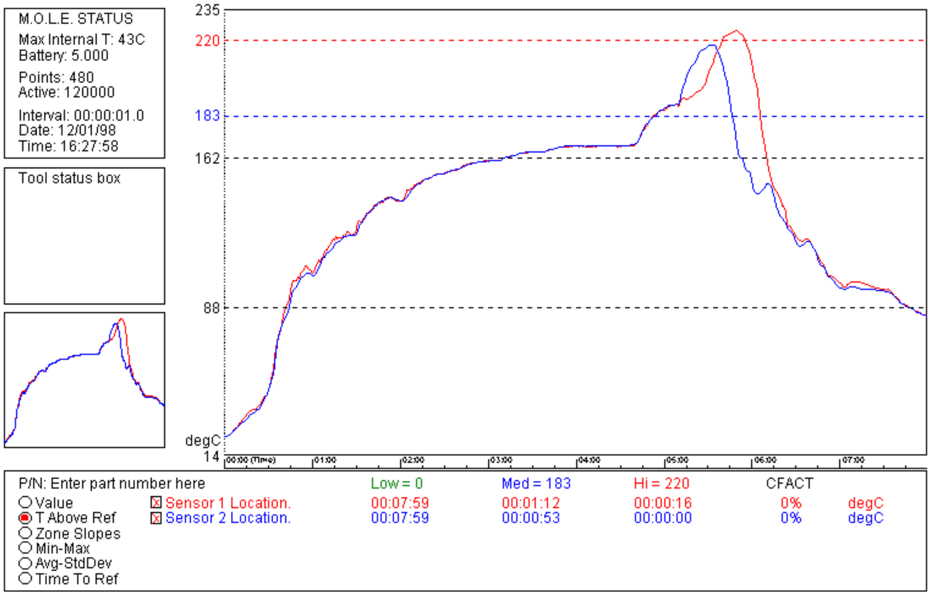
Photo #3



Solder Paste Reflow

All wafers were reflowed in a full forced convection oven. The reflow atmosphere was Nitrogen with an oxygen content of less than 75 ppm. Figure #1 shows the thermal profile used to reflow all wafers.

Figure #1



M.O.L.E. STATUS
Max Internal T: 43C
Battery: 5.000
Points: 480
Active: 120000
Interval: 00:00:01.0
Date: 12/01/98
Time: 16:27:58

Tool status box

P/N: Enter part number here

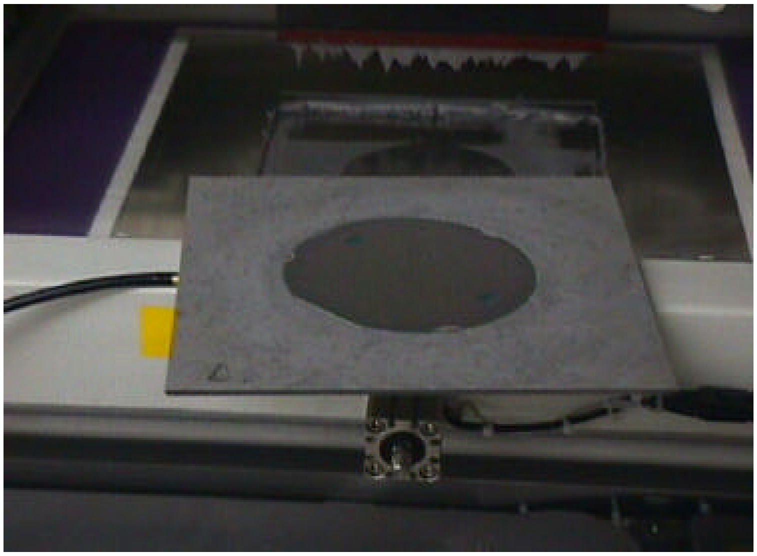
○ Value
● T Above Ref
○ Zone Slopes
○ Min-Max
○ Avg-StdDev
○ Time To Ref

	Low = 0	Med = 183	Hi = 220	CFACT	
☒ Sensor 1 Location.	00:07:59	00:01:12	00:00:16	0%	degC
☒ Sensor 2 Location.	00:07:59	00:00:53	00:00:00	0%	degC

Wafer Handling

All wafers were solder paste printed using a pallet designed with a recessed pocket that held the wafer flush with the top of the pallet. The pallet was manufactured from a machinable composite material. Vacuum was also applied to the recessed pocket to keep the wafer from sticking to the bottom of the stencil after completion of the print cycle. A flat was also machined into the pocket to provide rough alignment of the wafer relative to the pallet. Photo #4 shows a photo of the pallet used for the experimentation.

Photo #4



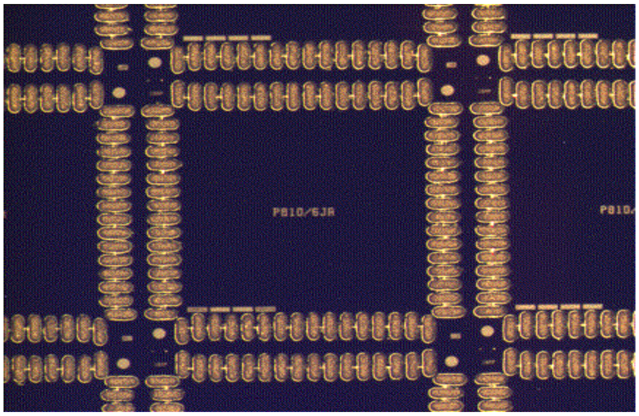
Post Solder Wafer Cleaning

All of the wafers bumped during the experimentation were post solder cleaned with deionized water to remove flux residue. The cleaning process consisted of placing the wafers in hot (50C) deionized water with agitation for 10 minutes, followed by a room temperature rinse in DI water. The wafers were then dried by applying pressurized Nitrogen onto each wafer after which the wafers were baked at 100C for one hour.

Results

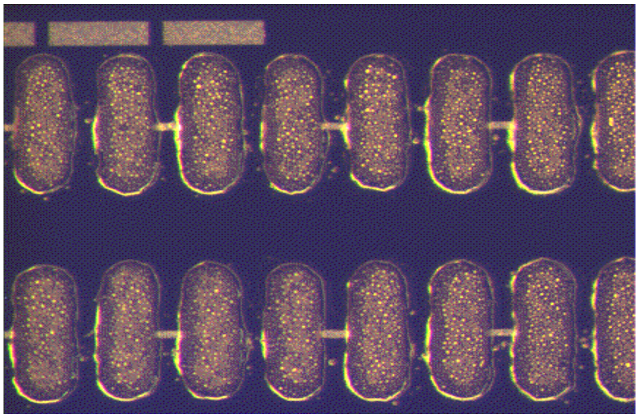
The main responses monitored in the experiment was bumping yield, bump height deviation (across the wafer and within a die) and bump height relative to the target bump height of 5.0 mils (127 micron). The objective of the experiment was to bump five wafers using stencil apertures that were clean (not previously wetted with solder paste) and stencil apertures that were wetted with solder paste. Both the traditional squeegee process and ProFlow process were conducted. Each five wafer process produced over 110,000 bumps for the sample size. Earlier research was done to optimize solder paste formulation, stencil design, wafer pallet design, solder paste reflow and post solder wafer cleaning. Print speed, squeegee pressure and print gap were the main variables investigated for the squeegee process. Solder paste pressure, print speed and print gap were the main variables investigated for the ProFlow process. Visual inspection was used to determine if the print deposit quality was acceptable from a bumping yield stand point. Photo #5 shows high quality printed solder paste deposits that produced high bumping yields.

Photo #5



All solder paste deposits must be correctly positioned over the attachment pads with no wet solder paste bridging to obtain high bumping yields. Photo #6 shows at higher magnification the type of solder paste print quality needed to obtain high bumping yields.

Photo #6



A full factorial experiment using three screen printer variables were tested at three levels to determine the optimum settings for each bumping process. Solder volume quantity and repeatability was verified after solder paste reflow. All test wafers were fully measured using a Wyko bump measurement system. Bump height and bumping yield were the two main responses measured by the system. No bump height data or bumping yield data was collected from the squeegee process on the wetted stencil aperture experiment. Acceptable solder paste print deposits could not be achieved from this process. Photo #7 shows the heavy solder paste bridging that was produced after a few prints were made without cleaning the stencil apertures.

Photo #7

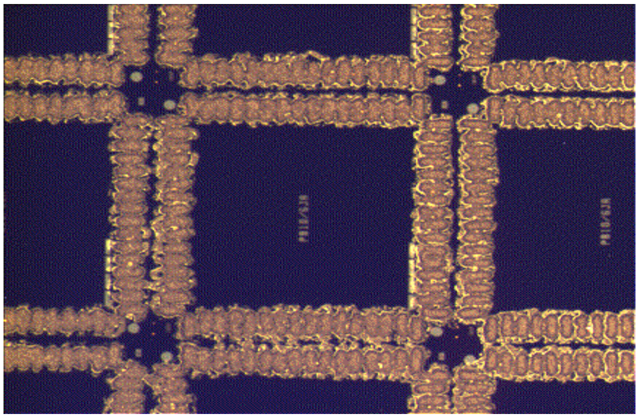


Table #1 shows the bumping yield that was achieved for all wafers bumped in the experiment. The table contains two main bumping defects, missing bumps and bridged bumps.

Table #1

	Missing	Missing ppm	Bridged Pairs	Bridged ppm	Missing & Bridged	Missing & Bridged ppm
SQCS#1	1	45	1	45	2	91
SQCS#2	0	0	0	0	0	0
SQCS#3	0	0	2	91	2	91
SQCS#4	0	0	1	45	1	45
SQCS#5	0	0	1	45	1	45
Total	1	Avg. ppm 9	5	Avg. ppm 45	6	**Average ppm 55**
PFWS#1	0	0	0	0	0	0
PFWS#2	0	0	0	0	0	0
PFWS#3	0	0	0	0	0	0
PFWS#4	1	0	0	0	1	45
PFWS#5	0	0	0	0	0	0
Total	1	Avg. ppm 9	0	Avg. ppm 0	1	**Average ppm 9**
PFCS#1	1	45	0	0	1	45
PFCS#2	0	0	1	45	1	45
PFCS#3	0	0	0	0	0	0
PFCS#4	0	0	1	45	1	45
PFCS#5	2	91	0	0	2	91
Total	3	Avg. ppm 27	2	Avg. ppm 18	5	**Average ppm 45**

SQCS# = Squeegee process bumped from clean stencil apertures.
PFWS# = ProFlow process bumped from wetted stencil apertures.
PFCS# = ProFlow process bumped from clean stencil apertures.

Table #1 shows that all three bumping processes produced acceptable bumping results. Bridged bumps produced slightly more defects than missing bumps based upon the entire data set. Missing bumps are generally produced by clogged or semi-clogged stencil apertures that produce low or no solder paste deposit. Mis-aligned solder paste deposits may not wet the attachment pad producing a missing bump. Solder paste wetting or solderability of the attachment pad can also produce missing bumps.

Bridged bumps are generally caused by poor solder paste print definition. Any solder paste deposits that touch prior to solder paste reflow will have a high probability for bridging. Gross mis-alignment of solder paste deposits relative to the attachment pads can also contribute to bridging of the bumps.

Bump height distribution across the wafer and more importantly within each individual die is critical to successful die attachment. Large bump height deviations will increase the chance of open solder joints or solder bridges during the die attachment process. Table #2 shows the bump height average and standard deviation for each wafer. All bumps from each wafer are included in the data set. The table also shows the average bump height and average standard deviation for the five wafers bumped by each process.

Table #2

	Average Bump Height	**Standard Deviation**
SQCS#1	131um	2.7um
SQCS#2	130um	2.4um
SQCS#3	130um	2.4um
SQCS#4	130um	2.4um
SQCS#5	131um	2.7um
Average	**130.um**	**2.5um**
PFWS#1	122um	4.0um
PFWS#2	120um	3.8um
PFWS#3	120um	3.9um
PFWS#4	119um	4.2um
PFWS#5	118um	4.3um
Average	**120um**	**4.0um**
PFCS#1	120um	3.5um
PFCS#2	120um	3.5um
PFCS#3	121um	3.4um
PFCS#4	122um	4.0um
PFCS#5	121um	3.5um
Average	**121um**	**3.6um**

Table #2 shows that the squeegee process produced bumps that averaged 3.0um over the target height of 127um. The process produced an average standard deviation of 2.5um. The average solder volume produced based on the average height of 130um is 142.5 cubic mils of solder. The target height of 127um should produce a solder bump volume of 136.1 cubic mils. The squeegee process produced a solder volume that averaged 4.5% larger than the target. The ProFlow process using clean stencil apertures produced bumps that averaged 6.0um under the target height of 127um. The average standard deviation was higher than the squeegee process at 3.6um. An average bump height of 121um produced a solder volume of 123.9 cubic mils. This solder volume is 8.9% less than the targeted solder volume of 136.1 cubic mils. The ProFlow process that used wetted stencil apertures averaged 1.0um less than the ProFlow clean stencil aperture process. The five wafer average of 120um is 7.0um below the target bump height of 127um. As expected the standard deviation from the wetted stencil aperture process increased to 4.0um relative to the clean stencil aperture process. The ProFlow wetted stencil aperture process produced an average solder volume of 122.0 cubic mils which is 10.4% below the targeted solder volume of 136.1 cubic mils.

Figures #2 to figure #6 show the bump height range by die for each of the five wafers that were bumped using the squeegee process.

Figure #2

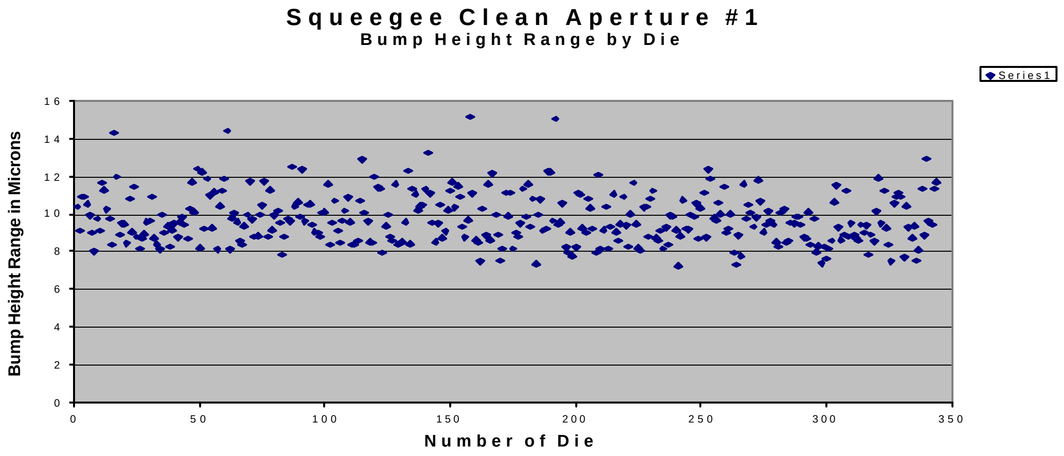


Figure #3

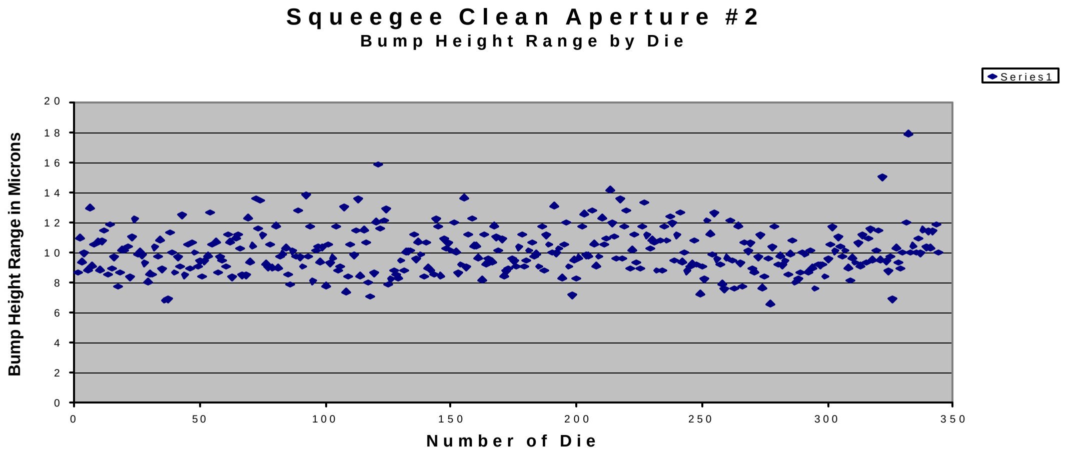


Figure #4

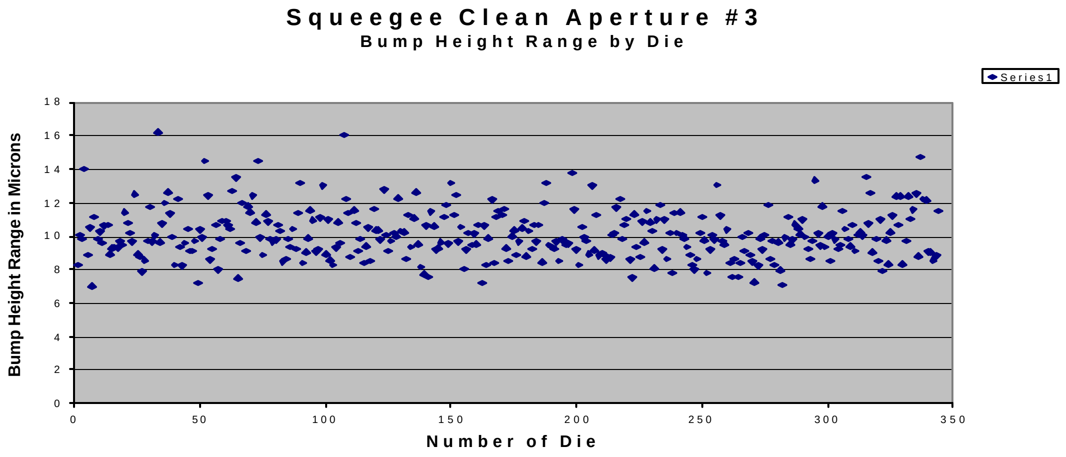


Figure #5

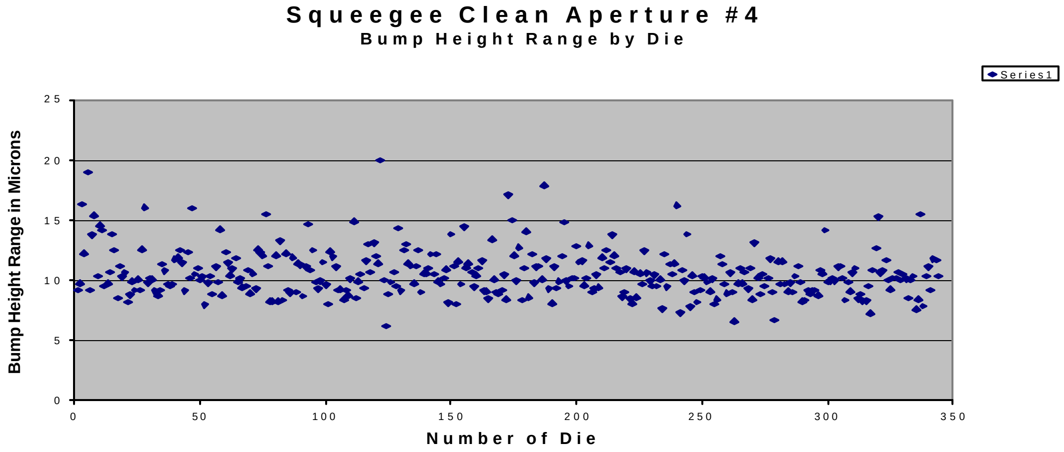
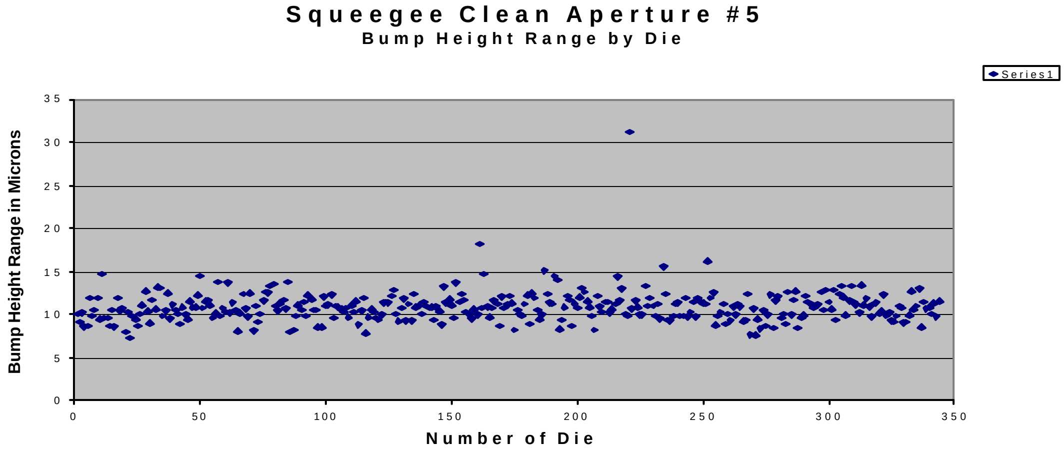


Figure #6



Figures #2 to figure #6 show that the bump height range within a die for all five wafers averaged 10.3um. All die from the five wafers (1720 die) with the exception of one die had a bump height range less than 20um.

Figures #7 to figure #11 show the bump height range by die for each of the five wafers that were bumped using the ProFlow wetted stencil aperture process.

Figure #7

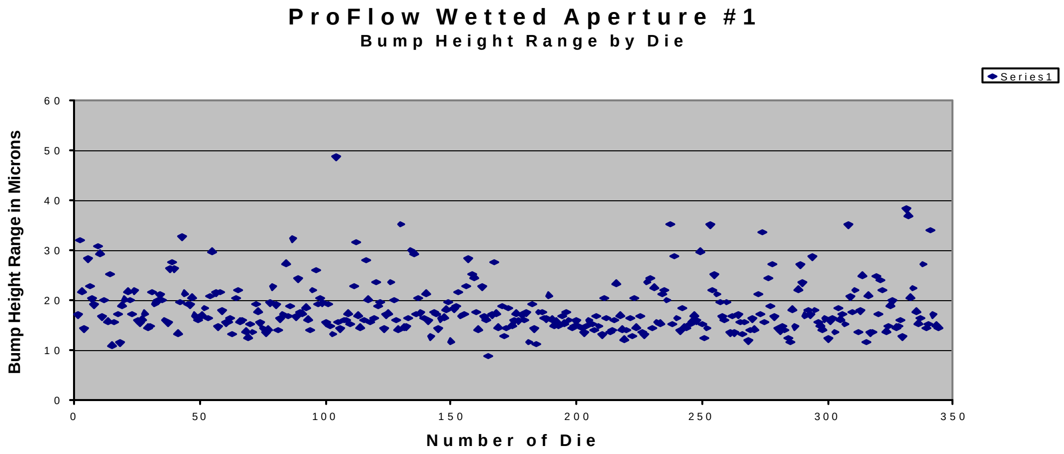


Figure #8

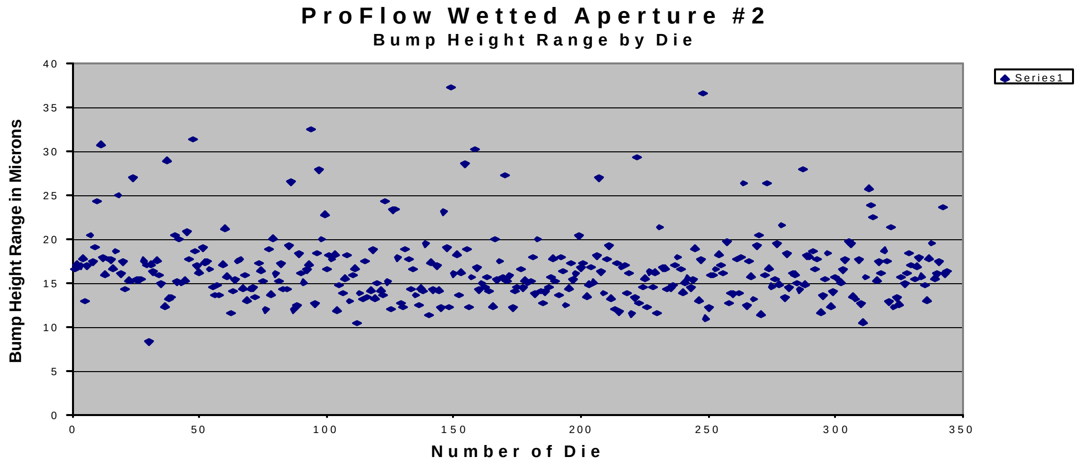


Figure #9

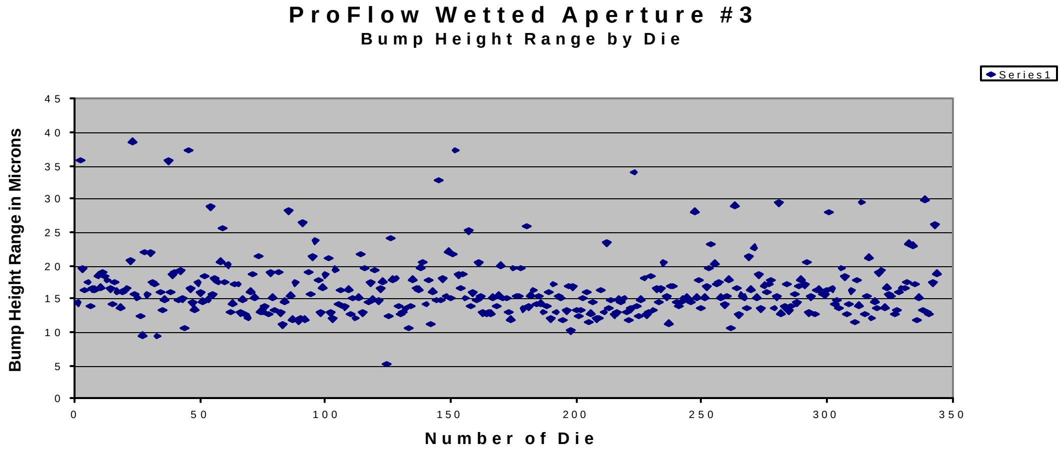


Figure #10

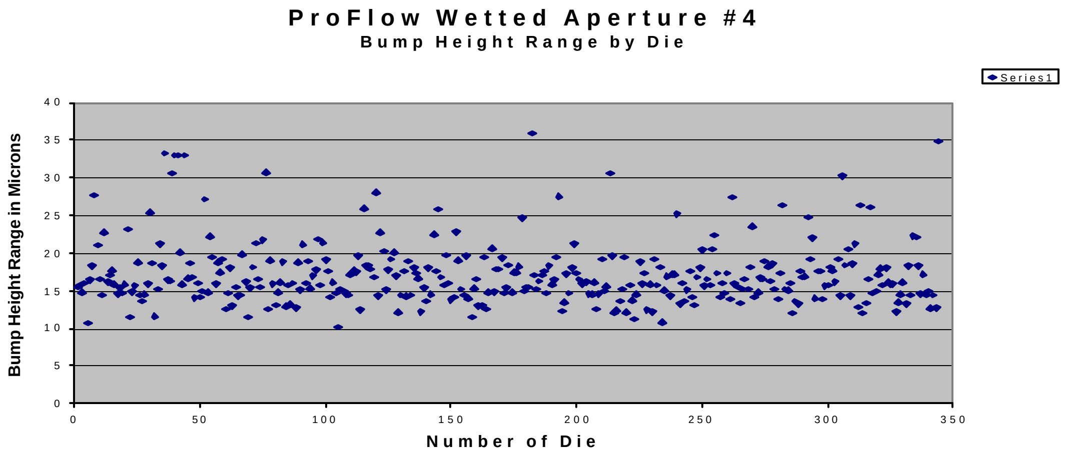
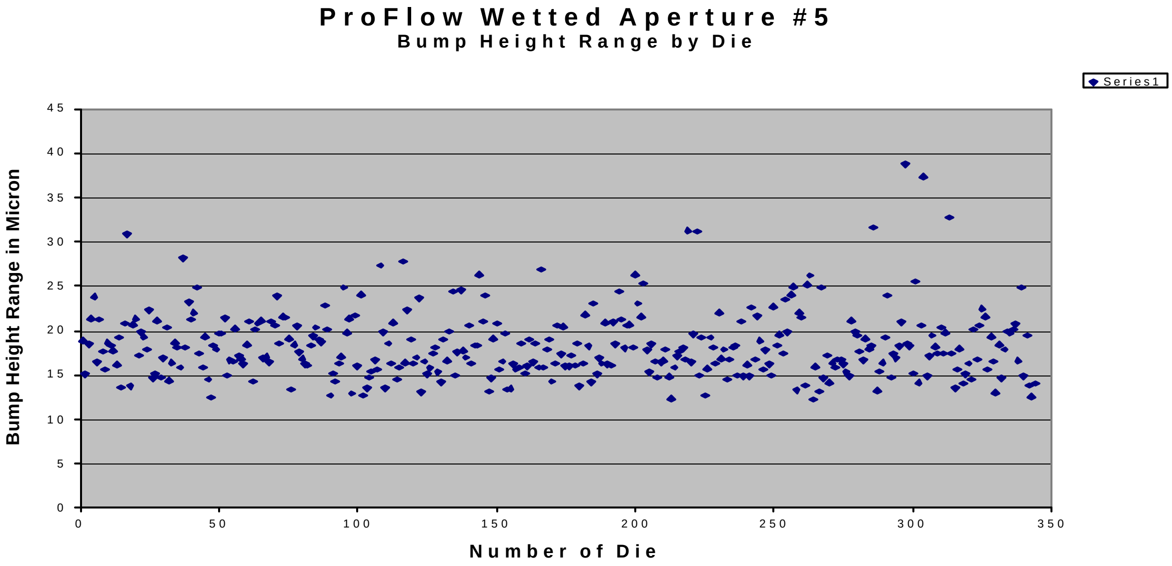


Figure #11



Figures #7 to figure #11 show that the bump height range within a die for all five wafers averaged 17.4um. A number of die contained bump height ranges over 25um.

Figures #12 to figure #16 show the bump height range by die for each of the five wafers that were bumped using ProFlow with the clean stencil aperture process.

Figure #12

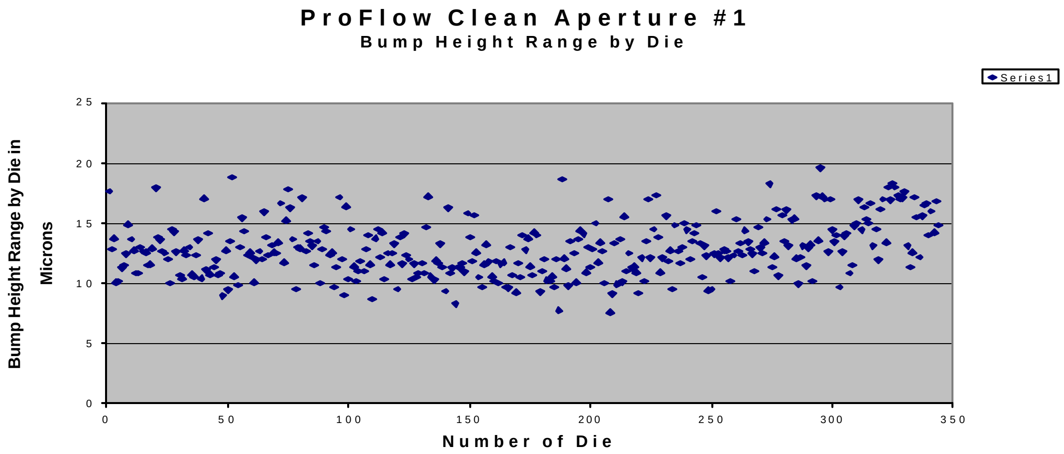


Figure #13

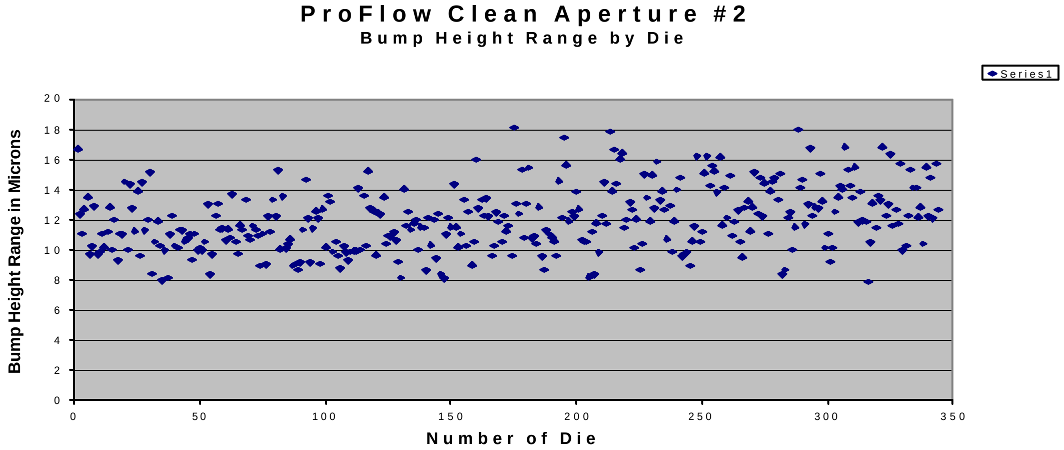


Figure #14

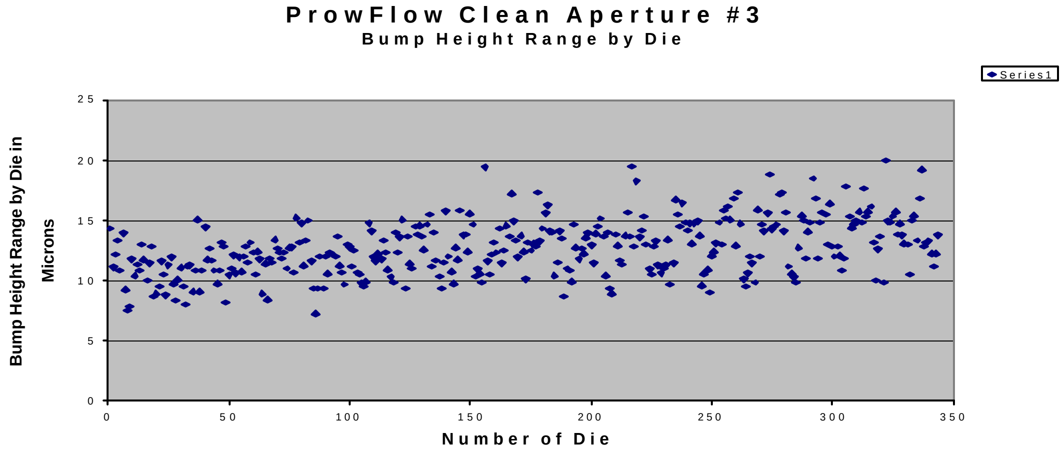


Figure #15

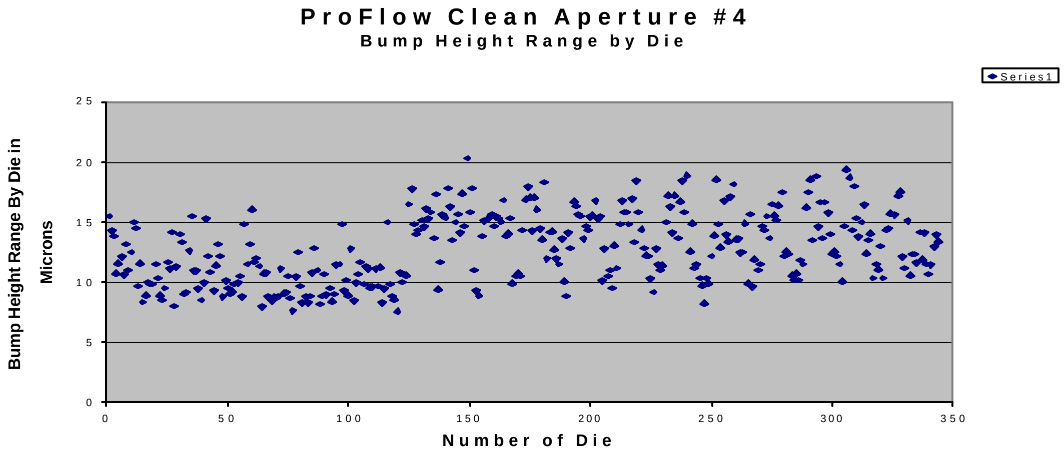
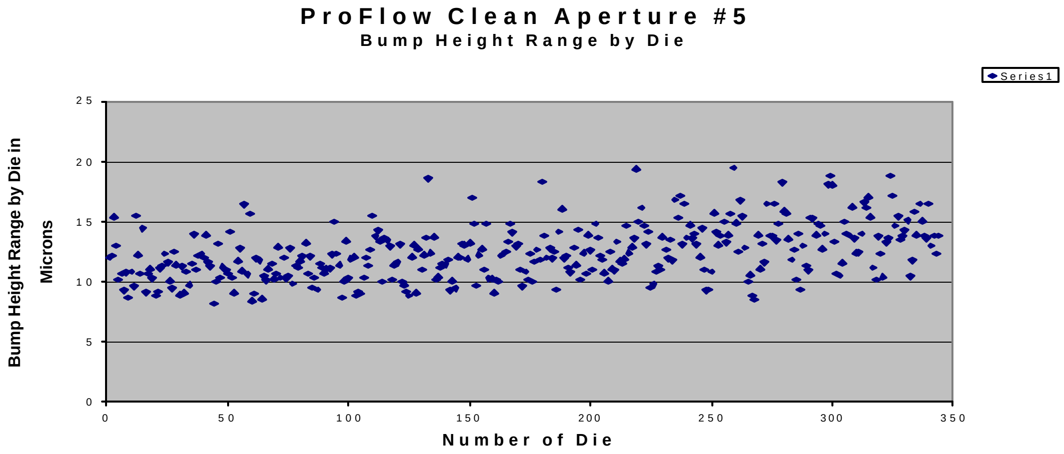


Figure #16



Figures #12 to figure #16 show that the bump height range within a die for all five wafers averaged 12.5um. All die fell within a maximum deviation of 25um. All die (1720) but one contained a bump height range of 20um or less.

Conclusions

Stencil printing of wafers with ProFlow and traditional squeegees is a low cost and effective method of bumping wafers. The main advantages of the ProFlow process is the ability to bump wafers without cleaning of the stencil between prints. This type of process is much more conducive to high volume wafer bumping. The only short coming to this process is the higher bump height deviation that is produced from the wetted stencil aperture process. ProFlow also provides a cleaner and less hands on type of process. Clean stencil aperture processing by both ProFlow and squeegees produces less bump height deviation. All three processes produce acceptable bumping yields. It should be noted that the use of ProFlow for wafer bumping is new and improved results can be expected with further research.