Low Force Placement Solution For Delicate and Low IO Flip Chip Assemblies

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Abstract

Traditionally most flip chips were designed with large bumps on a coarse pitch. However, as the trend towards smaller, more compact assemblies continues the sizes of semiconductor packages are forced to stay in line. New designs are incorporating smaller bump diameters on increasingly aggressive pitches, and in many cases decreasing the total IO count. With fewer and smaller bumps to distribute the load of the placement force it is becoming increasingly vital for equipment manufacturers to meet the challenge in offering low force placement solutions. One such solution will be presented in the following discussion. Also presented will be ways to minimize the initial impact spike that flip chips experience upon placement.

Introduction

Most microelectronic manufacturing sectors are experiencing a renaissance of sorts as traditional surface mount components, in particular large leaded devices make the transition to more compact chip scale packages and flip chip technology. With the continual advancement of flip chip technologies, an ever increasing number of functions are able to be transferred to a single chip, which plays in the favor of chip designers who have demands to minimize package dimensions. With smaller package dimensions comes the need for fewer bump counts and/or more dense bump arrays.

The medical electronics industry segment is one sector that is leading the way with smaller, more aggressive packages. Implantable devices such as pacemakers and defibrillators are continually refined to be smaller and lighter with ever increasing functionality. The flip chips used have a low bump count and many must be placed with low force. For the purposes of this paper any pick, dip or placement force < 150g is considered low force. If standard forces are applied during the pick, flux dipping or placement process the solder bumps will coin. This coining or reduction in bump height becomes a very critical process parameter when dipping low bump count flip chips into a thin flux film.

Equipment manufacturers have addressed the issue of placements below the standard force range in various ways from software control to mechanical assemblies or a combination of both. For many electronics manufacturers the primary concern is the total applied force exerted during placement. However, a commonly overlooked aspect of equal or perhaps more concern is the initial impact spike flip chips experience during pick or flux dip. This impact spike contributes to bump coining and if severe enough, can lead to excess flux on the bumps and die surface, thus resulting in electrical bump shorts.

The governing laws of physics apply regardless of approach. Because energy is conserved, the kinetic energy of the placement tool and flip chip before impact is equal to the resistance force of the substrate[1]. Therefore, if we wish to reduce the initial impact force we must reduce the overall mass of the placement tool and/or reduce the velocity at which the tool is moving when impact occurs.

Reduced impact force becomes even more significant when we consider the overall process. Take for example flip chips packaged in waffle packs. Each component will be subject to 3 impacts, each of which will contribute to the overall coining of the bumps. The first is at pick, the second during the dipping operation, and the third when the component is attached to the substrate. If the impact forces of the placement tool are significant then there exists the risk of over-collapsing the solder balls, resulting in permanent bump deformation and electrical shorts.

Low Force Methods

Low force placement methods vary depending on the equipment manufacturer. An example of one such method is described below, and accompanied by the updated design approach.

The traditional low force approach utilizes a combination of hardware and software control. The nozzle is equipped with an internal spring assembly and Teflon sleeve that allow the nozzle shaft to retract into the body. The placement force is a function of the spring rate. Software control drives the spindle and nozzle assembly in the Z-direction to the position where the component is contacting the substrate with zero placement force [board height – component thickness]. With the spring rate known the spindle can then overdrive the distance necessary to achieve the programmed placement force. Placement forces ranging from 30g – 100g are possible using this method.

Low Force Method using LMR (low mass redesign) Spindle Assemblies

The traditional low force method was widely used across many different applications. However, there were some inherent limitations that became increasingly prevalent as bump IO count and overall package size became progressively smaller. For this reason it was necessary to take a different and more robust approach to low force placements.

As previously discussed, the initial impact force is a function of the mass of the placement tool and the velocity it is moving at when impact occurs. The traditional method addressed the normalized load on the component during placement, but it could not effectively account for the initial impact spike. The largest factor in the spike was the combined mass of the spindle and nozzle assemblies. It was therefore necessary to investigate ways to reduce the overall moving mass.

Individual spindle assemblies are fairly heavy. It was necessary to find ways to reduce the mass without impacting performance. The new design was aptly named LMR (Low Mass Redesign). These spindles replace existing spindles on the placement head. In addition to having a lower mass there were other advantages to the new design.

1. Force range is 30g – 2500g, as compared to 20g – 90g and 150g – 2500g.
2. Bulky low force nozzles are no longer necessary. This translates to a cost savings.
3. The impact sensors can be used and are adjusted to trigger at approximately 30g. Small substrate height variations no longer have an influence on the actual placement force.
4. Extremely concentric - very little spindle run out during rotation, giving better accuracy at pickup and placement.
5. Initial impact spike reduced by approximately 70% (when incorporated with reduced velocity).

Figure 1 shows a comparison of the LMR vs. traditional low force approaches. Clearly they are vastly different. The LMR nozzle is significantly lighter and does not use a nozzle adapter. It is aligned by a collar that is held in place on the spindle shaft via a setscrew.

The nozzle simply slips onto the shaft and a groove on one side aligns to a pin on the collar.

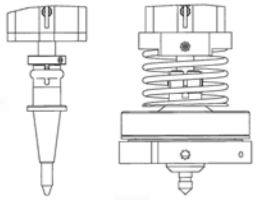
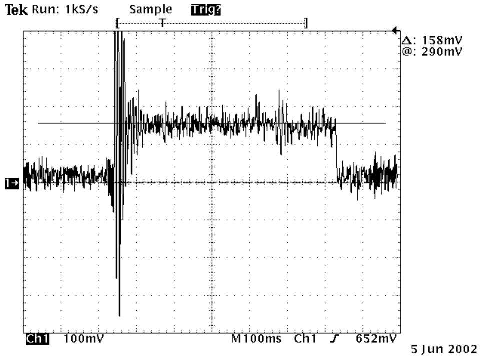


Figure 1

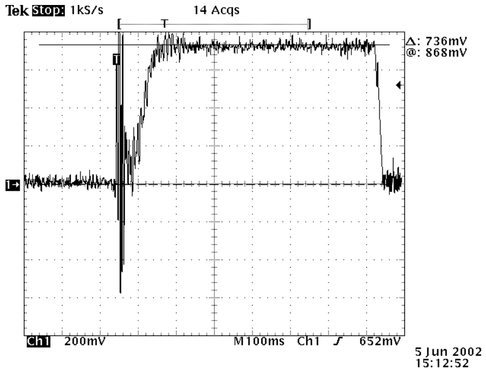
As mentioned above, the LMR spindle uses the impact sensor to detect touch down and therefore does not need a spring assembly like the Low Force nozzle. This translates to lower cost per nozzle.

LMR Performance

Figure 2 shows the force plots for placement forces of 30g and 150g using an LMR spindle. The initial impact spike is larger than the programmed force. Above 150g the spike is irrelevant as the placement force exceeds the magnitude of the spike. Standard spindles exhibit this same spike, but due to their higher mass and velocity the initial spike is in the range of 500-600g. Please note that the force conversion to voltage measured is 200 grams force per volt.



Place force = 30g



Place force = 150g

Figure 2

Slew Rates

LMR spindles address the moving mass issue, but by reducing the velocity of the placement tool the impact spike could be further reduced. In the past one option employed to reduce the impact spike was to reduce the slew parameters of the spindle. However, slowing the slew rate comes at a price. We gain a reduced impact spike, but the cycle time suffers.

Slew rate is the velocity and acceleration of the spindle over a given distance above the board. Basically, when placing components the spindles typically drive at maximum velocity and acceleration for much the Z-travel. At set distance above board height the machine control software transitions the spindle into a slew mode with a controlled deceleration and reduced velocity. The impact force is thereby reduced.

From a manufacturing perspective even small changes to machine throughput can have a considerable impact on overall line performance. It is therefore necessary to adjust the slew rate to achieve maximum spike reduction while maintaining a minimal impact to overall machine throughput. To do this slew parameters should be optimized to enable the spindles to drive at maximum speeds through much of the Z move before decelerating. This, coupled with active impact sensing will translate to a controlled, repeatable low force placement with minimal bump damage and improved product yield.

Test Strategy

To determine the magnitude of the initial impact spike exerted by the placement tool on the component a Schaevitz MP series LVDT was used to collect impact data. It was determined that the sampling rate of the microprocessor/controller was not sufficient to capture the impact spike. Therefore an oscilloscope was connected to the output of the controller, which provided real time complete viewing of the applied force seen by the LVDT.

- Force Accuracy and Repeatability
    1. The Pick and Dip forces on the LMR spindle are ~ 30 grams regardless of the programmed placement force. Using the LVDT and Oscilloscope validate the LMR pick and dip forces at the following programmed placement force settings: 30, 50, 150, 350, and 500 grams.
        a. Minimum of 10 readings per each setting.
    2. Using the LVDT and Oscilloscope measure the LMR placement forces at the following programmed force settings: 30, 40, 50, 75, 100, 150, 300 and 500 grams.
        a. Minimum of 59 readings per setting.
- Force/Bump Height Correlation
    1. Measure and document the 'Baseline' bump height on 150 flip chip die. Perform the following tests as defined below and then re-measure the bump height. Compare post force application bump heights to 'Baseline' values. Quantity of 10 die/8 bumps each for a total of 80 measurements for each test.
        A. LMR Spindle Force Evaluation.
            1. Pick only (Test 1) – Pick die from waffle pack. Remove die from nozzle. Measure bump height.
            2. Pick and Dip (Test 2) – Pick die from waffle pack and allow to dip on flux plate (no flux on plate). Remove die from nozzle. Measure bump height.
            3. Pick, Dip and Place (Test 3 through 10) – Pick die from waffle pack, allow to dip on flux plate (no flux on plate), and place on PWB. Remove die from PWB and measure bump height.
        ▪ Please note that LMR pick and dip forces are not programmable, but are a function of the mechanical/electrical design = 30g

        B. Standard Spindle Force Evaluation.
            1. Pick only (Test 1) – Pick die from waffle pack. Remove die from nozzle. Measure bump height.
            2. Pick and Dip (Test 2) – Pick die from waffle pack and allow to dip on flux plate (no flux on plate). Remove die from nozzle. Measure bump height.
            3. Pick, Dip and Place (Test 3 through 5) – Pick die from waffle pack, allow to dip on flux plate (no flux on plate), and place on PWB. Remove die from PWB and measure bump height.
        ▪ Please note that standard pick and dip forces are not programmable but are a function of the mechanical/electrical design = 150 grams.

- Real Time data
    1. Using flip chip die, assemble (pick, dip, place and reflow) a quantity of 100 hybrids for each setting below. Flux thickness to be as close to upper thickness limit (0.002") as possible. Remove the die and inspect for bump shorts.

Test Results

- Force Accuracy and Repeatability Results
    1. LMR pick/dip forces at programmed placement force settings: 30, 50, 150, 350, and 500 grams.
    2. LMR placement forces at programmed force settings: 30, 40, 50, 75, 100, 150, 300 and 500 grams.
- Force / Bump Height Correlation Results
    1. Please refer to figure 15 & 16 for 'Baseline' bump height measurements on the test flip chip die. Please note that each data point is the average bump height for all eight bumps on each die.

During the 'Baseline' inspection of the flip chip bumps it was noted that one bump had excessive probe damage. It appeared that the tester probe, which contacts the top 1/4 of the bump from a slight angle, pushed or smeared the solder to form a small peak. Since all bump height measurements were taken at the highest formation on each bump the peak on this one bump typically measured higher than the other seven bumps. Figure 15 shows the average bump height for each die – including the bump with the higher smeared peak. Figure 16 is the average bump height for each die – excluding the bump with the higher smeared peak.

- Force/Bump Height Correlation Results
  A. LMR Spindle Force Evaluation Results – See figure 3
  B. Standard Spindle Force Evaluation Results – See figure 3

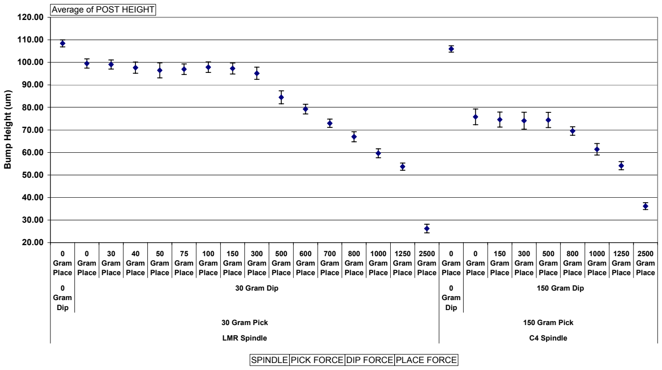


Figure 3

Looking at figure 3 we can see that when the dip force (30g for LMR and 150g for standard spindle) was applied there was evidence of bump deformation (~10µm for the LMR and ~30µm for the standard spindle). It was concluded that there is an applied load/force present during the dip process which causes bump deformation.

Finally, a pre-programmed placement force was applied to each die after the pick and dip process. If you look closely at figure 3 you will see that minimal to no change in bump deformation occurred between the place forces of 0 to 150 grams for the LMR spindle and 0 to 500 grams for the standard spindle. Knowing from basic physics, material characteristics of Sn/Pb, and the deformation seen after a force was applied at the dip process that as a higher force is applied you would expect an increase in the deformation of the solder bump.

It was first believed that an error had occurred during the processing of the die at the pick and place operation – possibly the entered programmed placement force did not register into active memory therefore only applying the initial dip force to each die. A thorough review of the equipment (mechanical and software) indicated that all functions were operating according the manufacturer's specifications and the force was in fact activating and being applied at the spindle. As a cursory check a sample of the pick, dip and placement forces were measured again using the LVDT/Oscilloscope. Referring back to figure 2, we can see examples of typical waveforms captured during the measurements. Please note that the force conversion to voltage measured is 200 grams force per volt.

When reviewing each of the waveforms in figure 2 we see what appears to be oscillation or ringing of the signal. At first this ringing or oscillation was dismissed as being inherent to the design or characteristics of the LVDT due to the oscillation briefly falling below the zero value and the dampening of the oscillation over time. It is now believed that part of the oscillation or ringing, especially the first initial positive (+) spike, is a true real time capture of the impact force applied by the head/nozzle assembly. As seen in the waveforms the first spike often is greater than the pre-programmed placement force. For the LMR spindle an initial impact force was seen at approximately 170g and for the standard spindle the force was approximately 600g.

If we take into consideration the impact force and the fact that bump deformation is dependent upon the load applied then we could clearly see from figure 3 that in the range of 0 to ~150g for the LMR and 0 to ~500g for the standard spindle that the bump deformation remains constant until the pre-programmed force exceeds the impact force. The original thought of the impact force being ~30g for the LMR spindle and ~150g for the standard spindle was incorrect. These values were target regions set by the equipment manufacturer and are force approximations required to open the contact switch for each spindle.

The characterization plan initially called out performing the LMR & standard spindle force vs. bump deformation study between the programmed force range of 0g to 500g. After seeing minimal changes to bump deformation in these ranges and to validate the theory of the initial impact spike the plan was modified to test die in the higher force range. The additional forces tested for the LMR spindle included 600, 700, 800, 1000, and 1250 grams. The additional forces tested for the standard spindle included 800, 1000, 1250 grams. In both cases one die only was tested at 2500 grams.

A slight bump deformation difference was seen between the LMR spindle and the standard spindle for the same programmed placement force. This is believed to be accounted for by two factors: one which is manual bump measurement error and the other which is that the two spindles do not travel at the same speeds during impact. The LMR spindle travels at 1 count/mSec whereas the standard spindle travels at 2 counts/mSec. Because the solder properties are highly strain rate dependant, bump deformation amounts will be a function of the spindle speed.

To add to the validity of the results obtained in this characterization, it was necessary to model the affects of a force/load on Sn/Pb flip chip bumps. The object of the model(s) created is to predict the height of a Sn/Pb flip chip bump after a force is applied. The models could be considered a first level iteration where the variables: machine '-Z' Axis speed; basic bump geometries; and yield strength of solder based on given strain rate were considered. In regards to bump geometry the shapes considered or modeled are a sphere and an ellipse. It is hypothesized that the true shape of the bump would fall somewhere between these two shapes modeled because the bump starts out somewhat spherical and after large forces are applied the bump smashes to a shape similar to an ellipse. Exact shape of the post-smashed bump was not matched identically therefore this could impose a slight error in the predicted values within this model. Please refer to figure 4 for modeling results.

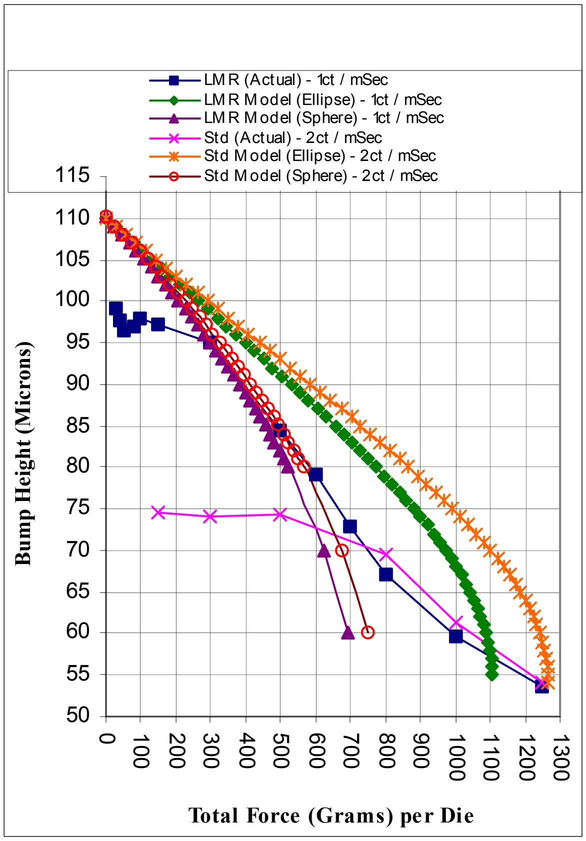


Figure 4

In figure 4 we will find the 'actual', ellipse model and spherical model data for both the LMR and standard spindle. In this graphical representation all information was overlaid for visual comparison. As can be seen in figure 4 the 'actual' bump heights did indeed fall between the modeled heights as theorized.

As a reminder the initial step function (decrease in bump height) in figure 4 for both the LMR and standard spindles are the result of the initial impact force present for these spindles. Once the programmed force exceeds the initial impact force then the output (measured bump height) tracks a similar path / slope to the modeled values. One additional limitation of the model is its ability to predict bump smash/height as the bump approaches equilibrium (smashed to half of total start height). This limitation is reflected by the sharp curve seen at the tails of each model. Based on much engineering discussion regarding the model information it is comfortable to say that the data obtained in the characterization is valid.

- Real Time data Results

A quantity of 400 hybrids were assembled using the small flip chip die. 200 hybrids were built with the LMR spindle (100 at placement force of 30 grams & 100 at placement force of 150 grams) and 200 hybrids were built with the standard spindle (100 at placement force of 150 grams & 100 at placement force of 300 grams). In both cases the spindle impact force was present at dip. A flux thickness of ~0.00190" to 0.0020" was maintained for this characterization. It should also be noted that the hybrids were divided amongst 3 different PWB lots – this was not mentioned in the original plan.

When looking at figure 5 we can see that in all combinations when using the standard spindle that there was one or more bump shorts and when using the LMR spindle there were zero bump shorts. These results in combination with the data in figure 3 help to substantiate the theory that due to the impact force at pick and dip the bumps are being deformed to a height that allows excessive flux.

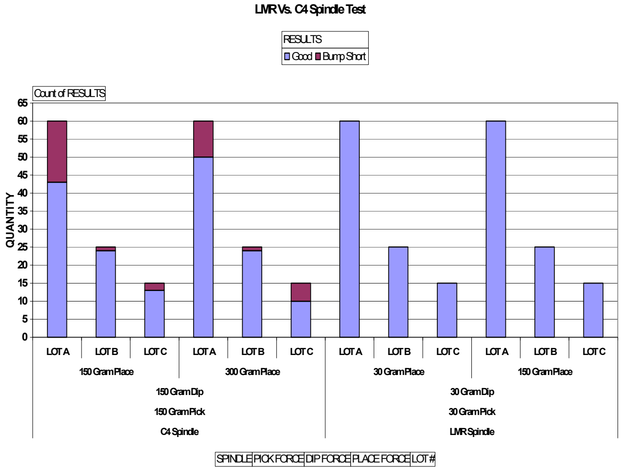


Figure 5

This would be more prominent on a few bumps if the die is tilted (i.e. bent nozzle, etc.). Any tilting of the die could allow transfer of the equalized load / force across all the bumps to a more segregated group of bumps. This shift of total force to fewer bumps would have an affect on total bump deformation. Overall final results in this situation are typically smashed or shorted bumps.

Confirmation Run

When running the 'Real Time Data' segment of the characterization the PWB's were stacked on top of each other after they came out of the reflow furnace. The PWB's were then placed into ESD bags, stacked on top of each other, and carried to an inspection area. At the inspection area the die were removed and the PWB's were inspected for solder shorts. The PWB's built with the standard spindle exhibited bump shorts as well as some slightly smashed bumps. On the PWB's built with the LMR spindle there were no shorts but there were some slightly smashed bumps. It was believed that the slight smashing of the bumps came from the stacking and improper handling. To confirm this theory thirty (30) hybrids were assembled, using the LMR spindle with ~.0020" flux thickness and reflowed. Ten (10) were placed with 30g, ten (10) with 150g and ten (10) with 1500g of force. After reflow they were carefully removed and placed into a plastic carrier (same carrier as used for production). The parts were then carried to an inspection area where the die was removed and the PWB's were inspected. Zero shorts or bump deformation/smash was found.

Summary

The overall objective in DCA (Direct Chip Attach) is to apply ample force to coin the bumps to approximately the same height while at the same time ensuring that maximum bump height is obtained thus keeping the die surface away from the flux. Looking at the data in figure 3 it would appear that at 300 total grams or 37.5g per bump (8 bump die) the bump height would be approximately 95µm. It also appears that as we approach the 1250g total force or 156g of force per bump (8 bump die) we are encroaching the 'Danger Zone' where the bump height could be lower than the max flux thickness. At 156g the bump height decreases to approximately 55µm, which is roughly half the starting bump height or just above the 50.4µm (.0020") maximum flux thickness.

The LMR spindle has ~1/3 the impact force than the original standard spindle (170g vs. 600g). The LMR is also capable of providing a minimum of 30g programmable placement force vs. the 150g for the standard spindle. Thus the LMR spindle is preferred over the standard spindle when placing small, low bump count flip chip die.

Bump damage is of great concern not only from a product yield perspective, but also from a cost per defect perspective. Referring to figure 6, many of the identified defects were the result of electrical shorts and shorted package runners primarily due to over-collapsed solder bumps in the flip chip packages. After implementing a low force solution the electrical shorts due to bump damage were completely eliminated. This improved the overall product yield by 2.5% and immediately resulted in cost savings.

Projected Savings

Figures 7a and 7b show a breakdown of the monthly and total savings for the period July 2002 – May 2003. This is a projected cost savings based on LMR testing results and observed product yield after implementation of the low force solution across all products.

Clearly the savings can be significant depending on the severity of defect rate and the resulting yield improvement after low force implementation.

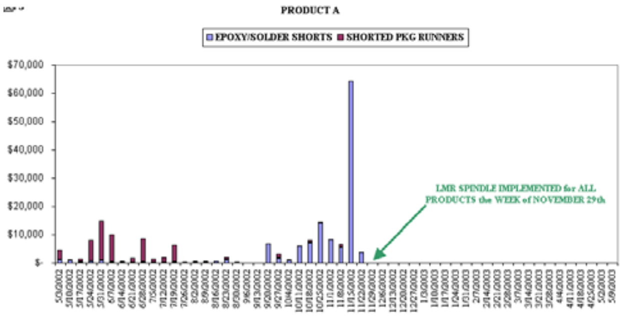
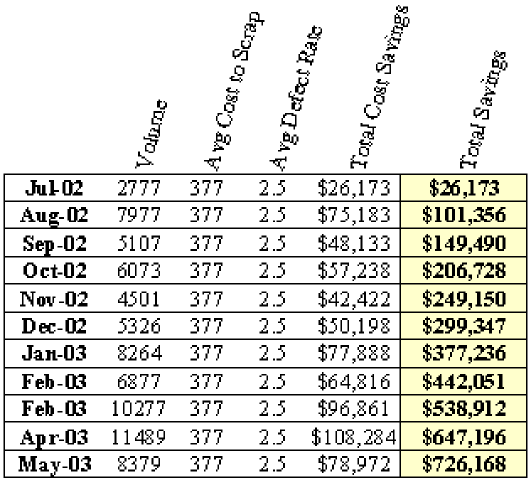
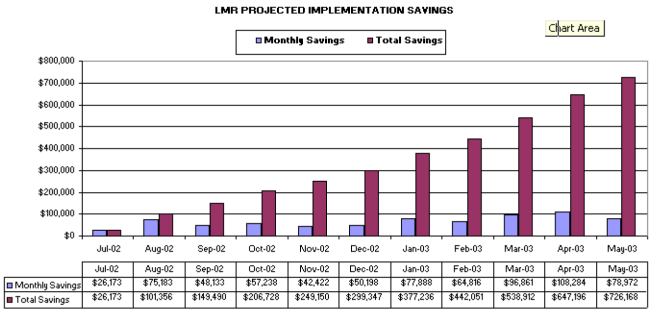


Figure 6



	Volume	Avg Cost to Scrap	Avg Defect Rate	Total Cost Savings	Total Savings
Jul-02	2777	377	2.5	$26,173	**$26,173**
Aug-02	7977	377	2.5	$75,183	**$101,356**
Sep-02	5107	377	2.5	$48,133	**$149,490**
Oct-02	6073	377	2.5	$57,238	**$206,728**
Nov-02	4501	377	2.5	$42,422	**$249,150**
Dec-02	5326	377	2.5	$50,198	**$299,347**
Jan-03	8264	377	2.5	$77,888	**$377,236**
Feb-03	6877	377	2.5	$64,816	**$442,051**
Feb-03	10277	377	2.5	$96,861	**$538,912**
Apr-03	11489	377	2.5	$108,284	**$647,196**
May-03	8379	377	2.5	$78,972	**$726,168**

Figure 7a



	Jul-02	Aug-02	Sep-02	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03
Monthly Savings	$26,173	$75,183	$48,133	$57,238	$42,422	$50,198	$77,888	$64,816	$96,861	$108,284	$78,972
Total Savings	$26,173	$101,356	$149,490	$206,728	$249,150	$299,347	$377,236	$442,051	$538,912	$647,196	$726,168

Figure 7b

Conclusion

Unfortunately there is no universally accepted rule for determining proper placement force for a given bump count. Many factors influence the magnitude of the resulting bump deformation including bump count, impact spikes, metallurgy of the bumps, total applied force, and duration of the applied force to name a few.

The results discussed in this paper are based on the LMR low force method. Depending on the equipment manufacturer the approach may vary. However, given the current trends and ITRS projections for bump size/pitch low force placement capability may very well become increasingly important. Understanding and characterizing the performance of the placement tool with respect to the impact spike is critical when considering low IO flip chips. For this case a 2.5% improvement in yield represented a tremendous cost savings.

Appendix:

1. LMR pick/dip forces

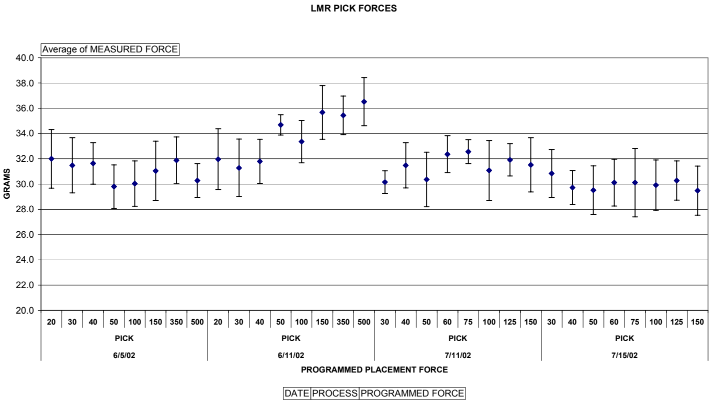


Figure 8: LMR force at pick

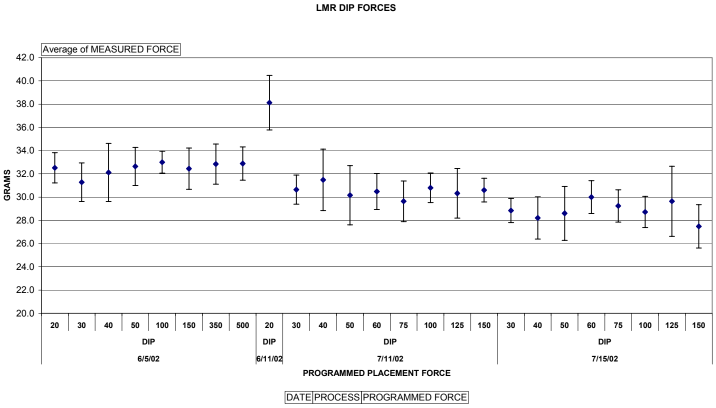


Figure 9: LMR force at dip

2. LMR placement forces at programmed force settings: 30, 50, 100, and 500 grams.

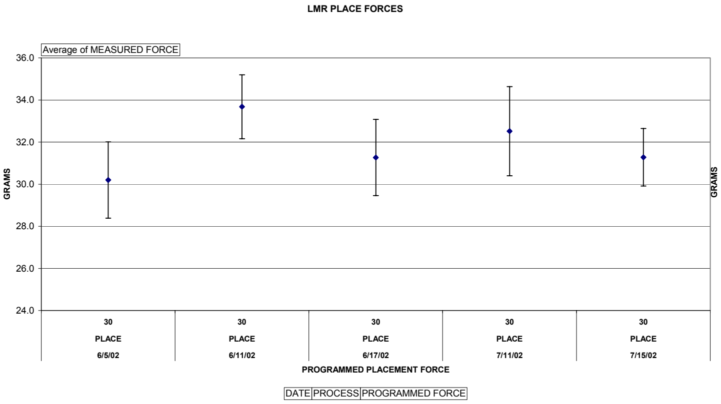


Figure 10: LMR Placement Force = 30g

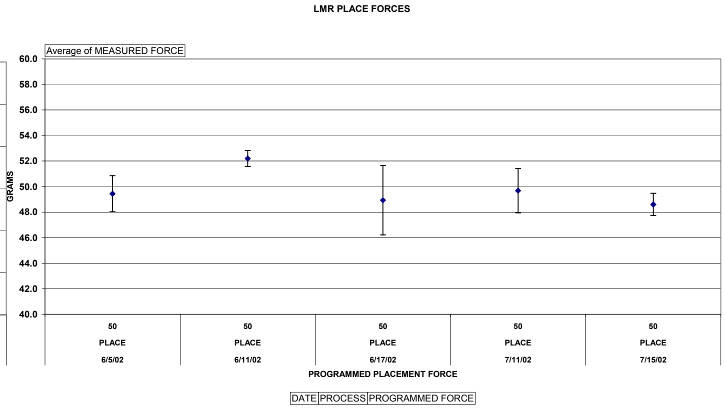


Figure 11: LMR Placement Force = 50g

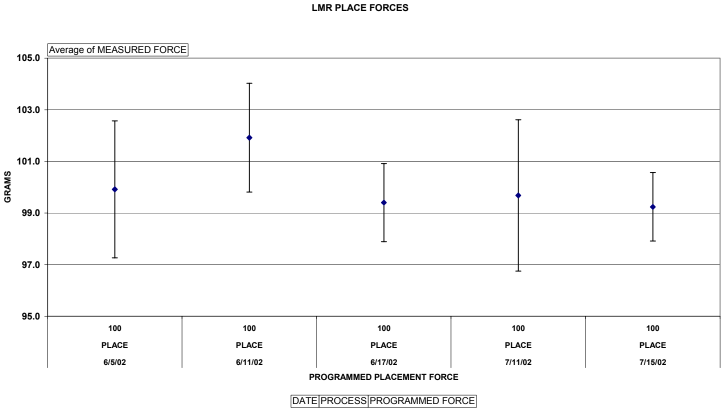


Figure 12: LMR Placement Force = 100g

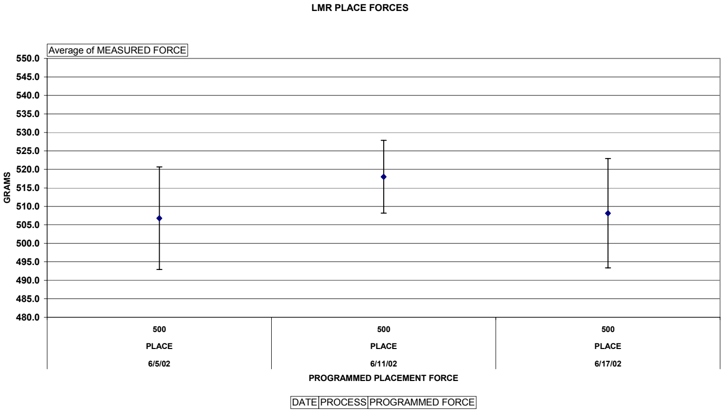


Figure 13: LMR Placement Force = 500g

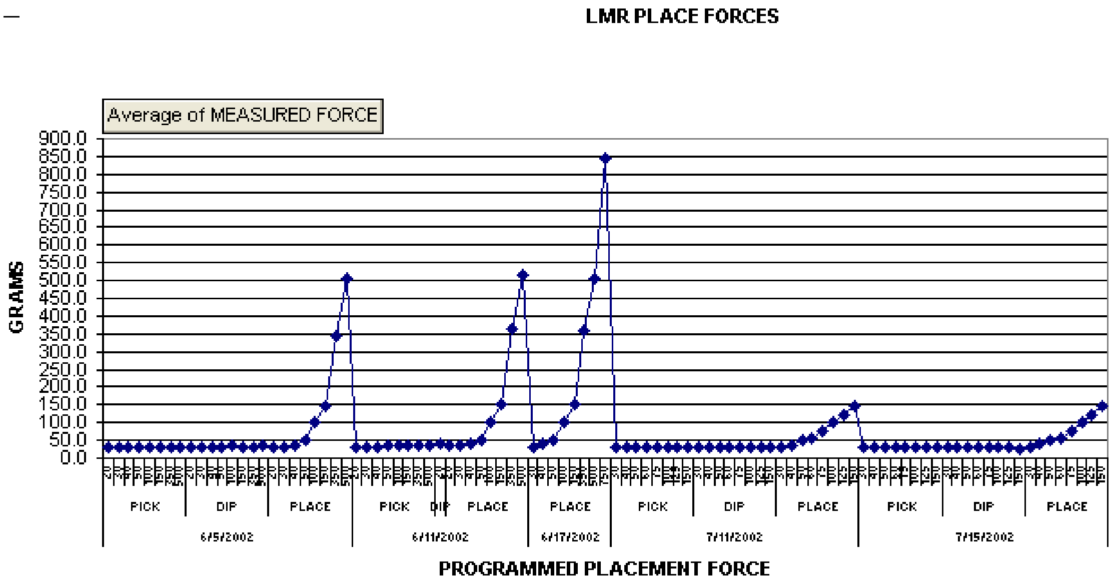


Figure 14

Force / Bump Height Correlation Results

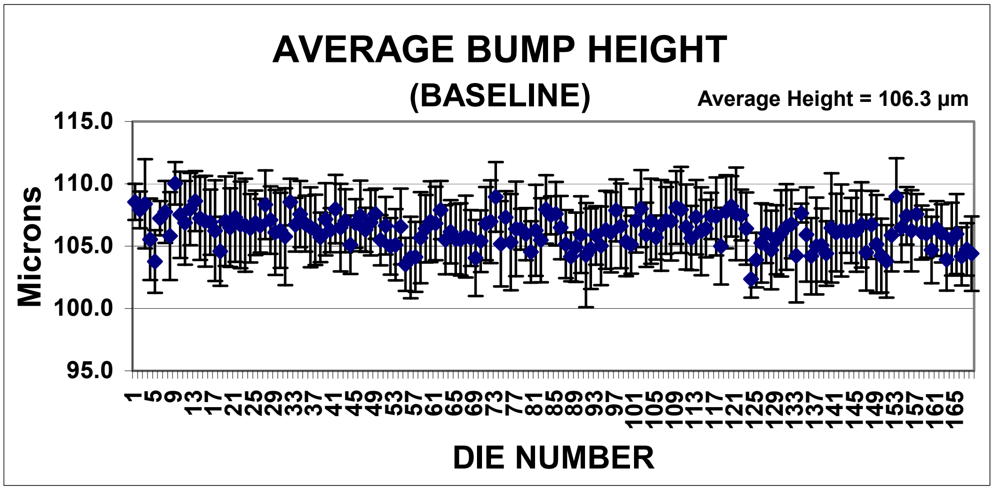


Figure 15

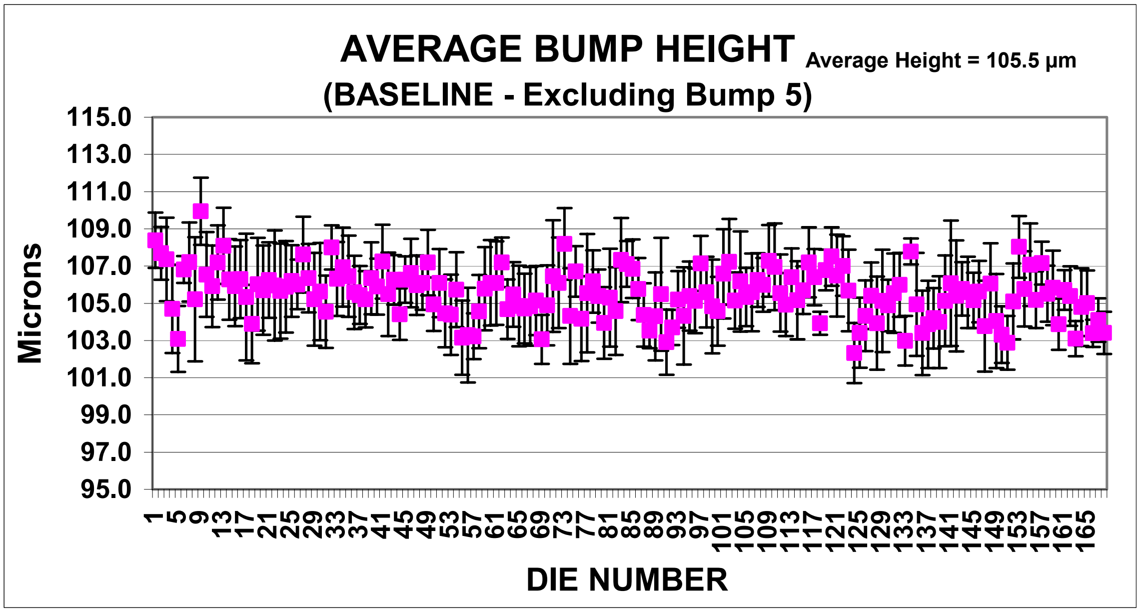


Figure 16

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[1] Lindeburg, Michael R., "Solved Engineering Fundamental Problems".Professional Publications, 1988, pp. 11-29.