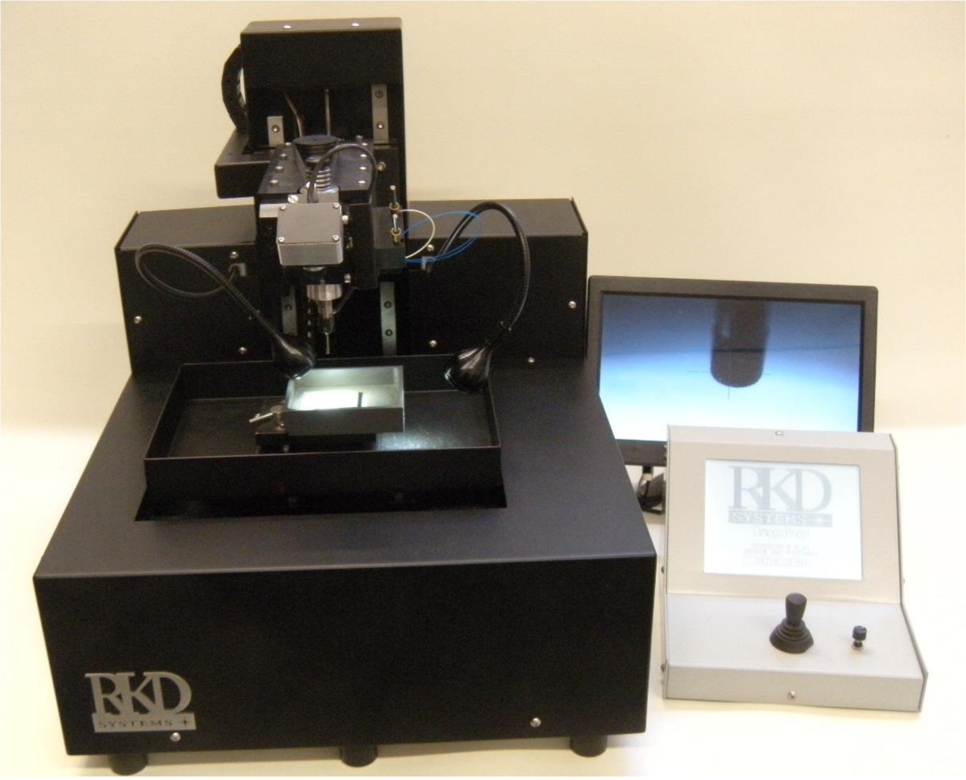
The OmegaPrep II And UltraPrep IV

Easy to use, automatic, machining systems for all mechanical sample preparation needs

What you need to know when selecting a die thinning system



RKD SYSTEMS

What you need to know when selecting a die thinning system

Preface

This presentation is intended to help anyone who is selecting a die thinning or delayering system choose the correct system for the job. It contains some pointers on how to interpret specifications on a data sheet as well as what is actually required to get the desired results. Most of what is included was published before in an article in EDFA May, 2016 issue [1]. Much has changed since then and this paper reflects those changes.

Introduction

Many semiconductor failure analysis sample-preparation procedures require mechanical machining processes. These processes include removing encapsulant; removing heat spreaders; cutting of the sample for cross sectioning; package substrate printed circuit board delayering; die thinning by grinding and polishing; die delayering and many others. The machines used for mechanical sample preparation have ultimate limitations based on the machine's accuracy, resolution, reproducibility, and environmental effects. These limitations will affect the results of the sample preparation process. Limitations include the intrinsic machine resolution, accuracy, and repeatability of the tool-positioning system, including the characteristics of tool bits, pads and fixtures used in various processes. Note that a *tool*, as used here, is an end mill, grinding tool; saw blade or other simple functional device. A *machine*, or machine tool, is that which utilizes a tool to perform a specific task. A milling machine is a machine. The end mill it uses is a tool.

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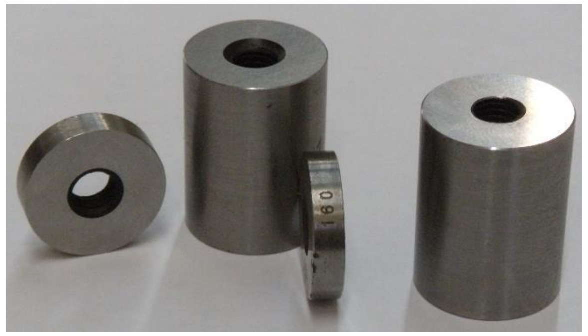
A discussion of terms

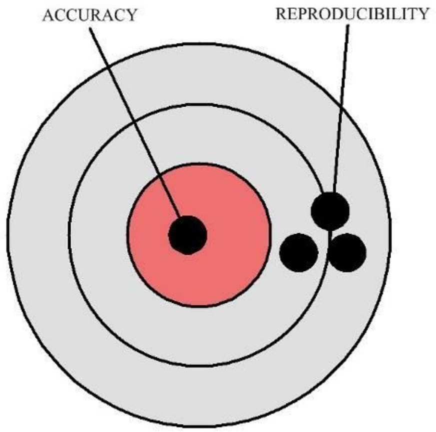
The dictionary definition of *accuracy* is “the extent to which a given measurement agrees with the standard value for that measurement.”[2] The standard used as the “standard value” generally is a National Institute of Standards and Technology (NIST) traceable length standard with an absolute tolerance defined by the reference standard and class. A length reference is normally a gauge block. A gauge block is a piece of metal having flat and parallel opposing gauge surfaces. A grade 2 NIST 100 mm gauge block matches the NIST reference standard to +0.0003/-0.00015 mm; but only at the standard conditions:[3]



- Temperature = 20 ° C (68 ° F)
- Barometric pressure = 101,325 Pa (1 atm)
- Water vapor pressure = 1333 Pa (10 mm of mercury)
- CO_2 content of air = 0.03%

The steel of the gauge block expands with increasing temperature at a rate of 11.5 ppm/° C.[2] A 1° increase in temperature of the 100 mm gauge block will result in a dimensional change of 0.00115 mm, or nearly three times its specified accuracy at standard conditions.

The dictionary definition for *resolution* is “the fineness of detail that can be distinguished.”[4] When taking any measurements, there is a limiting fineness of the measurement, as determined by the measurement reference. When using a ruler marked with only 1 mm increments, a length can only be determined to the nearest 1 mm. If the ruler’s overall length is off by 10%, the measurement can still be taken to a 1 mm resolution. Resolution is not a function of accuracy.



The definition of *repeatability* is “the variability in measurements taken by a single person or instrument on the same item and under the same conditions.”[5]

The easiest way to illustrate the difference between accuracy and reproducibility is to refer to the rifle target. A tight grouping is repeatability.

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What is required?

The geometric properties of parallelism and orthogonality determine the performance of a mechanical system.
Simple mechanical devices used for sample preparation, such as diamond saws, dimplers, and many others, have easy-to-understand mechanical systems, and as long as they are properly maintained and calibrated, they will perform their designated tasks. With simpler machines, if the quality of the results is lacking, then service and adjustment are required.

A more complex machine is the flat lapper. There are two basic types of lappers: open face, where the sample being lapped is mounted to a fixture that is placed inside or attached to a rotating ring, and lappers with a mast that supports a sample holder and provides sample rotation and movement across the lap surface. Either type can use abrasive lapping films or a slurry feed system. Critical parameters of a lapper include axial runout, lap flatness, and the parallelism of the rotational, scan and lap spindle axes. The axial runout is the variation in height of the lap surface at the edge as the lap rotates. For controllable results with any lapper, the lap should be flat and not have axial runout. The parallelism of the rotational, scan, and lap spindle axes determines the surface shape of the sample. Axial runout will produce scalloping at the sample edges. Lack of parallelism of the rotational axis will produce a conical surface. Lack of parallelism of the scan axis will produce a spherical surface. Aligning all three axes is difficult to impossible, depending on the machine, but it is necessary if die delayering is to be done. A 1 mm or 2 mm axial runout on the lap; or the rotational axis not being parallel to the spindle; or the scan axis not being aligned will produce a nonplanar result. The geometries of the inaccuracies are easy to calculate. A 0.2 mrad. misalignment of the sample holder rotational axis will produce a 10 X 10 mm sample with the corners more than 100 nm. lower than the center. When delayering, this conical shape can result in unacceptable results. Accuracy depends on set-up adjustments for the machine. Ongoing successful sample preparation depends on maintaining these adjustments. On most lappers, this is beyond the skill level of the operators; a very skilled technician or engineer must periodically check and adjust the machines.

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Three axis movement machines

There are machines available for die thinning or delayering that have movement in three axes as well as a rotating spindle that holds the tool. It is with these machines that the concepts of accuracy, resolution, and repeatability are most relevant. These machines move a tool over the die surface by moving the sample in the *X* and *Y*-axes and moving the tool in the *Z*-axis.

In linear positioning systems, such as used on these machines, the linear motion is commonly produced with a lead screw, and the position is measured by a linear encoder and scale. A computer controls the motor driving the lead screw so that the encoder gives the desired position value. The encoder has specifications for linearity and resolution and, occasionally, zero reference reproducibility. In a numerically controlled machine, there is always a reference, or zero point, that is periodically checked to establish a positional reference. This is usually at the extreme travel of the machine in *X* or *Y*, while most work is done near the center of the travel. The temperature effects on the linear encoder scale then alter all positional values by a function of the total travel from the zero point. This means that the longer the travel, the greater the zero shift produced by temperature changes. A machine with 200 mm of travel will have twice the thermal zero shift as a machine with 100 mm of travel.

In addition to the temperature effects, there is a tolerance on the zero position. This is a result of the switches used to detect when an axis is at the zero position. These switches may be mechanical, optical, or magnetic. No matter which type of switch is used, it will have some level of uncertainty that results in uncertainty in the zero position.

The resolution of the machine is a function of how well the linear encoder reads the scale. A good encoder can provide positional resolution of 50 nm., but the accuracy is a function of the scale.[6] A typical optical scale will have a nonlinearity of 0.005 mm per meter of travel and a thermal expansion coefficient (T_c) of the material that it is mounted to.[6] Steel has a T_c of 11.5 ppm/° C, and the T_c for aluminum is 23 ppm/° C. A 100-mm-long scale will change 0.0023 mm/° C if mounted to an aluminum frame. All of this is additive. The uncertainty due to scale resolution adds to the nonlinearity, zero position uncertainty, and the thermal variations of the scale. With a typical ±2° variation in temperature and a 100-mm-long scale, zero uncertainty of ±0.5 mm, and the scale nonlinearity, the positional uncertainty is ±5.6 mm. This is 110 times greater than the encoder resolution.

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The concept of uncertainty

Uncertainty is the ultimate tolerance on any positional move. The factors that affect uncertainty are reproducibility and environmental effects. The reproducibility, as shown by the rifle target, will drift in pattern position resulting from temperature effects. As the temperature changes, the center of the pattern will change.

The geometry of machine performance

All machines involve linear and rotational movement. Most machines involve multiple axis movements. All of these movements can affect the accuracy of the other axes.

With multi-axis machines, such as those used for backside thinning or front side delayering, the relationship of the axes to each other directly affects the position in the other axes. For example, if the *X* and *Y*-axes are at 89° instead of 90°, a move in either axis will produce a positional shift of 1.745% of the move in the other axis. Resolution, accuracy, and repeatability in one axis are meaningless if the axes are not truly orthogonal. If the *Z*-axis is not normal to the *X*-*Y* plane, changes in *Z* position produce changes in the tool tip's position referenced to the *X*-*Y* plane.

Determining axis repeatability requires knowing the geometric relationships of all three axes and the rotational axis of the tool. This requires the manufacturer to specify the orthogonality of the axes to each other and the normality of the *Z*-axis and spindle to the *X*-*Y* plane. Lack of the Z-axis normality to the X-Y plane will allow the tool edge to gouge the surface creating ‘furrows’ that cannot be removed.

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Processes for back side thinning

Backside thinning of a sample often requires the removal of encapsulant, die-attach pad, and die-attach adhesive. These processes are defined by the position of the extreme edge of the cutting tool. Because the tool is rotating, the eccentricity of the tool and spindle and the actual tool diameter all determine the location of the extreme cutting edge. A typical end mill will have a diameter tolerance of ±13 mm[7] or more. A very good spindle and collet for securing the end mill to the spindle may have a runout of ±5 mm. The runout is a function of the concentricity of the spindle to the collet axes. The end mill may also have runout that results from the cutting edges not being coaxial with the shank. All of this makes the uncertainty of the edges of the machined area ±30 to 35 mm from tool and spindle tolerances alone. A desire to define the machined area to ±1 mm requires taking the running tool and spindle inaccuracies into account. This can only be done in situ. That is, an operator must adjust the machined area during machining. Once this is done, the repeatability of the *X*-*Y* movement only needs to be within the desired positional tolerances to produce an acceptable result.

Adjusting tool position and travel during operation is problematic. Attempts to have video viewing during operation are obscured by slurry and swarf. Because the video camera cannot view directly down the tool axis, there must be some parallax. The parallax makes any *Z* positional movement also appear to be a movement in the *X*-*Y* plane. Moving the sample to a viewing position creates measurement and correlation problems.
When thinning a die to a measured surface contour, *X* and *Y* positional uncertainties have an effect on the *Z* position due to the surface profile. The maximum slope of the profile, multiplied by the *X*-*Y* positional uncertainty, adds to the *Z*-axis positional uncertainty when determining the overall profile reproduction. A slope of 20 mm/mm will add to the *Z*-axis uncertainty as the *X*-*Y*-positional uncertainty (in mm) times the 20 mm/mm slope. Therefore, a ±5 mm *X*-*Y* uncertainty will introduce an additional *Z*-axis uncertainty of 0.1 mm.

What is required?

The system reproducibility must be equal to or slightly less than the desired positional accuracy. If a machined pattern must be maintained at ±1 mm, then the reproducibility of *X*-*Y* positioning must be 1 mm or less. A resolution of less than one-half of the positional uncertainty is unnecessary and only increases the cost of the system. The *Z*-axis uncertainty must be equal to or better than the required profile integrity. If it is desired to reproduce a surface profile to ±1 mm, the *Z*-axis reproducibility need not be less than 0.5 mm. If *X*-*Y* positional reproducibility is not constrained directly, it can be defined as the maximum profile slope divided by the *Z*-axis maximum uncertainty. Therefore, if a 1 mm *Z*-axis limit is required, and the maximum profile slope is 20 mm/mm, the *X*-*Y* uncertainty needs only to be less than 50 mm. Nowhere is there a requirement for 50 nm resolution in any axis or “submicron” accuracy.

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What is required? - continued

If a machine is required to thin plastic-packaged devices and produce a thinned die with less than ±1 mm in thickness variation, the following specifications are all that are required. Tighter specifications only result in increased purchase and maintenance costs:

- *X* and *Y* axis resolution: 1.0 mm
- *Z* axis resolution: < 0.5 mm
- *X*, *Y* axis reproducibility: 2.0 mm
- *Z* axis reproducibility: 0.5 mm
- Spindle runout: 5 mm
- Axis orthogonality: 0.5 mrad, maximum
- Variation from straight line travel: 0.002 mm per 25 mm of travel, maximum
- Axis pitch and yaw: 0.5 mrad, maximum
- Stage deflection: 50 Newtons / mm, maximum

The axis resolution defines the minimum required scale resolution. It should be 50% or less of the reproducibility. The spindle runout limits the effective increase in tool diameter caused by “wobble.” The axis orthogonality and axis pitch and yaw each limit axis-to-axis interaction to 0.05 mm/mm of travel. Because all materials and machines are elastic, the stage deflection specification is required to limit the *Z* axis positional change as a result of the tool forces. This results in 1 mm direct reproducibility, 1.25 mm per 25 mm travel axis interaction, and approximately 1 mm *Z*-axis variability resulting from tool forces. In total, this is 2.25 mm *X*-*Y* position reproducibility over a 25 X 25 mm area and a *Z* position reproducibility of less than 1 mm. Any more than this is unnecessary and costly, and any less does not guarantee performance.
Note; that no manufacturer provides all of this on its data sheets.

At your request, we will provide all production limits and specifications that insure RKD Systems machines will do the job.

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The next step

The above specifications are what is required to create a sample that is 50 microns thick and has a thickness variation of +/- 2 microns. The next step is local area thinning to 5 microns or less.

Why only thin ‘areas of interest’?
A sample thinned to 5 microns cannot be powered. Regulators and drivers consume much power that must be dissipated. Without truly heroic efforts, powering a 5 micron thick sample will destroy itself with the heat generated. Most samples will survive powered operation at 50 microns remaining silicon, but we have seen samples that could not be powered at any thickness without its heat spreader attached. The areas of interest needed to be exposed through a 2.5 mm thick heat spreader and then thinned to an observable thickness.

The above specifications can generate samples with locally thinned areas at 5 +/- 1 microns. Getting to 1 micron RST is problematic, particularly over the entire die. There are ways to do this, first time, every time, locally, but the processes are not available, except from RKD Systems. It takes a lot of time but the results are consistent and do not require an engineer to operate the equipment or the operator to ‘baby sit’ the machine. Set up the process, push the ‘run’ button, and go to lunch. This capability cannot be put into ‘data sheet’ specifications, but it works.

Good results take time. Do you want it right, or do you want it fast? Selecting fast means, damaged, unacceptable or destroyed samples, a loss of data, and a lot more analysis time.

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Front side delayering requirements

Delayering requirements are much more complex. Delayering on a flat lap requires that the device rotational axis and the scan axis be parallel to the platen rotational axis to a degree of precision that is not usually encountered. Maintaining 10 nm planarity of a 10 X 10 mm sample requires that all axes be within 0.002 mrad. In addition, the vertical runout of the platen must be less than 0.2 mm. Measuring the runout is difficult, as are the alignment measurements, but all are possible with the right measurement equipment and personnel, neither being available in the average FA lab.

Delayering on a backside-thinning machine is even more problematic because axis alignment is either not available or difficult to adjust to the accuracy required. Delayering requires that the spindle be orthogonal to the *X-Y* plane within 0.0067 mrad. for a 3-mm-diameter tool. A larger tool diameter tightens the requirements. Normally, the spindle orthogonality of a backside system is more than 10 times that required to do die delayering. Additionally, 10 nm *Z-axis* positional reproducibility is not truly available. Remember that some people try to deceive. This indicates that using a flat lap is difficult and using a backside thinning system is problematic. If one is delayering a 5 mm design-rules die, almost anything can be used. Currently for the latest design rules, only a very carefully set up flat lap or a backside system with special processes can be used. There are ways to reduce the effect the inaccuracies of a backside system has on the sample by more than a factor of 10. These special processes are only currently available from RKD Systems. The details are available upon request.

Whatever mechanical system is used, end point detection can only be done by the operator. No system can control tool position to the required accuracy. The tool has a physical length. That length changes with temperature and applied force. The operator breathing on a sample can change the tool length by more than the thickness of any given layer.

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CONCLUSIONS

Claiming or stating resolution as accuracy is disingenuous because accuracy is a function of many different parameters. Accuracy, reproducibility, and resolution must be matched to the process requirements. Normally, increased resolution, reproducibility, and accuracy will not increase sample quality. The desired process results determine the required equipment specifications. There are some critical parameters that currently are not specified by some equipment suppliers, such as the geometric relationship of the axes. To ensure that the desired results are obtained, these parameters must be defined. For some processes, there are no readily available, simple, and easy equipment solutions, but most requirements can be met by selecting the correct machine.

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