Designation: F 2358 – 04

Standard Guide for Measuring Characteristics of Sapphire Substrates[1]

This standard is issued under the fixed designation F 2358; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers a nondestructive procedure to determine the form of clean, dry sapphire substrates.

1.2 This guide is applicable to substrates 25 mm or larger in diameter, with a minimum thickness of 100 µm. This guide is independent of surface finish.

1.3 The measurements described in this guide may be applied to the entire global surface of the substrate, or to smaller localized areas.

1.4 The value of the measurements described in this guide will be affected by the amount of edge exclusion (that is, the area around the perimeter of the part which is ignored). The amount excluded should be agreed upon by the producer and consumer using this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *SEMI Standard:*[2]

M3 Specifications for Polished Monocrystalline Sapphire Substrates

3. Terminology

3.1 *General Definitions:*

3.1.1 *back surface*—the surface opposite the front surface. If there is no difference between the front and back surfaces, then the surfaces may be determined arbitrarily, and are therefore interchangeable.

3.1.2 *best-fit plane*—the theoretical plane established by using the least squares fit method, based on data obtained from the quality area only.

3.1.3 *best-fit sphere*—the theoretical sphere established by using the least squares fit method, based on data obtained from the quality area only.

3.1.4 *front surface*—the preferred surface, as defined by the user.

3.1.5 *quality area*—the central area of a wafer surface, defined by a nominal edge exclusion, over which the specified values of a parameter apply. If the quality area is not circular, the "circle defining the quality area" shall be defined as the minimum diameter circle which contains all of the data within the quality area.

3.1.6 *reference plane*—the plane from which deviations are measured.

3.1.7 *restrained condition*—this refers to the state of the substrate under test, when one side of the substrate is clamped to an ideally flat surface; for example, when pulled down by a vacuum onto an ideally clean flat chuck.

3.1.8 *sapphire substrate*—generic term for any flat wafer, window, wafer carrier, or substrate made of sapphire material. These terms may be used interchangeably in this standard.

3.1.9 *thickness*—the distance through the substrate between corresponding points on the front and back surfaces.

3.1.10 *unrestrained condition*—this refers to the state of the substrate under test, when the substrate is in a stress-free condition with minimal deformation due to gravity.

3.2 *Definitions of Unrestrained Parameters:*

3.2.1 *sag*—the distance from the apex of the best-fit sphere to a plane intersecting the sphere in a circle with a diameter equal to the diameter of the circle defining the quality area, measured in an unclamped condition. This value will be positive (+) if the measured surface is convex, and negative (−) if the surface is concave. See Fig. 1.

3.2.2 *sori*—the maximum distance above, plus the maximum distance below the front surface best-fit plane of a free, unclamped substrate. See Fig. 2.

3.3 *Definitions of Restrained Parameters* (see Note 1):

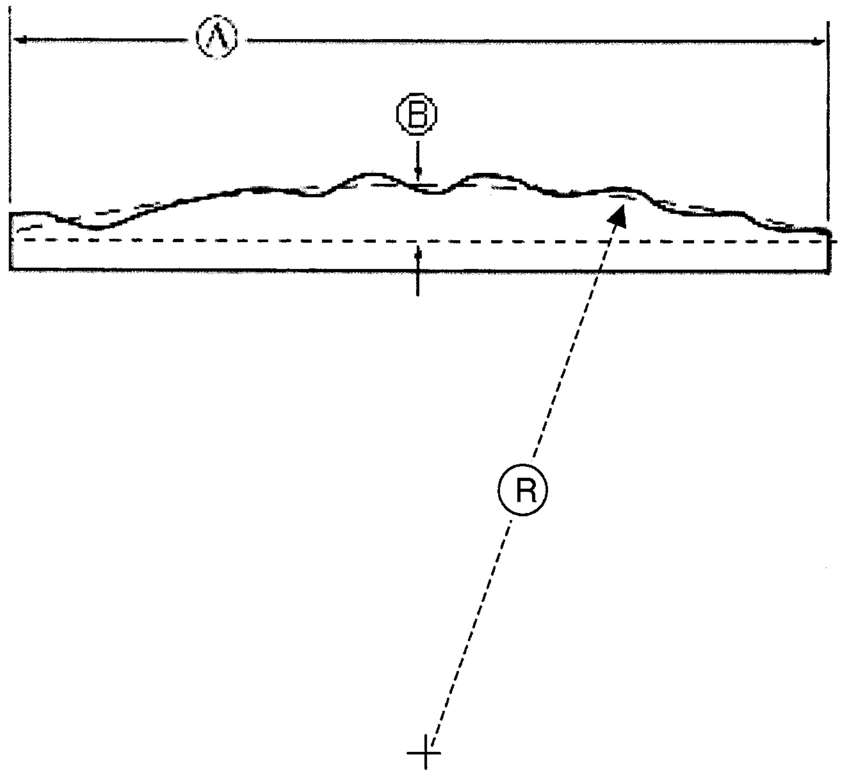
3.3.1 *front-to-front deviation (FFD)*—the maximum distance above, plus the maximum distance below the front surface best-fit plane of a substrate, measured with the back surface restrained. See Fig. 3.

3.3.2 *taper*—the linear component of the variation in thickness across a substrate, indicated by the angle between the best-fit plane to the front surface and the ideally flat back surface of the substrate. See Fig. 4.

[1] This guide is under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.15 on Compound Semiconductors.

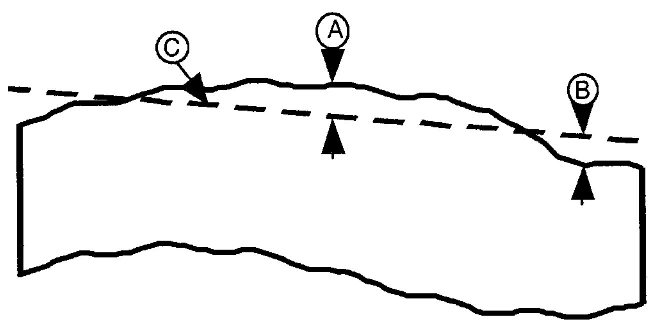
Current edition approved May 1, 2004. Published June 2004.

[2] Available from Semiconductor Equipment and Materials International (SEMI), 3081 Zanker Rd., San Jose, CA 95134.



A – Diameter of quality area
R – Radius of best-fit sphere

FIG. 1 Sag, B = $R - \frac{1}{2}\sqrt{4R^2 - A^2}$
(positive if convex, negative if concave)



A – Maximum distance above the best-fit front-surface plane
B – Maximum distance below the best-fit front-surface plane
C – Best-fit front-surface plane

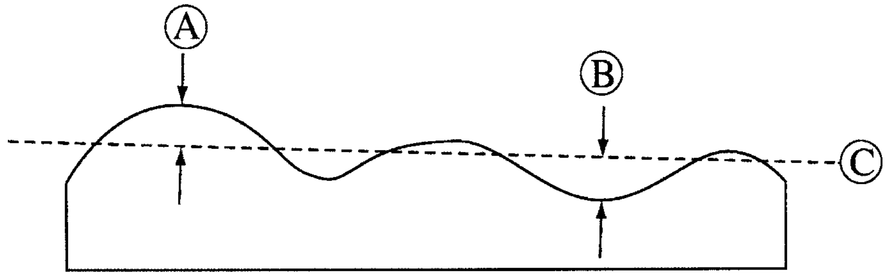
FIG. 2 Sori = |A| + |B|

3.3.3 *total thickness variation (TTV)*—the difference between the maximum and minimum values of the thickness of the substrate. See Fig. 5.

NOTE 1—Even though the above parameters define the variation of a theoretically restrained substrate, the measurements may be performed in the unrestrained state, with calculations performed to simulate the restrained condition.

4. Summary of Guide

4.1 The surfaces of samples under test may be measured using optics, interferometry, or any other technique that effectively characterizes the form of the sapphire sample. It is important to hold the sample properly to achieve accurate measurements.



A – Maximum distance above the best-fit plane
B – Maximum distance below the best-fit plane
C – Best-fit plane

FIG. 3 Front-to-Front Deviation (FFD) = |A| + |B|
(back surface restrained)

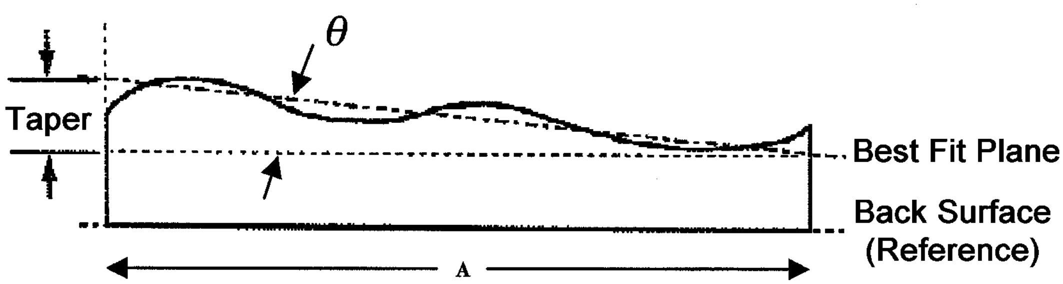
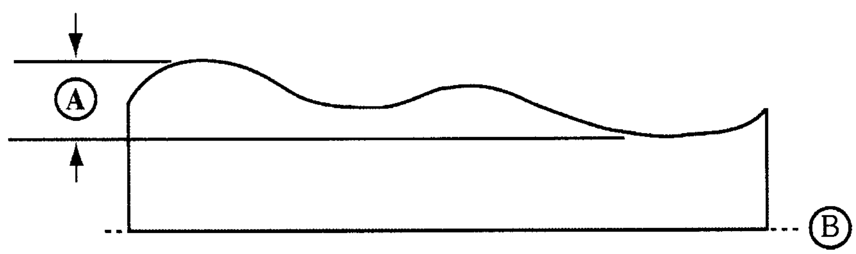


FIG. 4 Taper = A · tanθ



A – TTV
B – Back reference surface

FIG. 5 TTV = |A|
(shown measured in the restrained condition)

4.1.1 *Condition of Unrestrained Substrate Under Test*—The sample shall be supported in such a way as to represent as closely as possible a stress-free state of the substrate.

4.1.2 *Condition of Restrained Substrate Under Test*—The sample shall be supported such that it represents as closely as possible the back surface of the substrate in the restrained state, when one side of the substrate is clamped to an ideally flat surface.

5. Significance and Use

5.1 The measurements described in this guide can significantly affect the function of the sapphire substrate.

5.2 Substrates with excessive form errors in the free state may cause processing errors in production.

5.3 The restrained state of the substrate is intended to simulate as closely as possible the form that the substrate will take in one of its intended uses. During processing, one surface of the substrate is sometimes forcibly restrained to a flat state through either vacuum or adhesion to a flat surface. The measurements in the clamped state are intended to model the form of the front surface of the substrate when the back surface is constrained to the reference plane. The form in the clamped state may have a direct impact on the performance of the substrate in use.

5.4 The user should determine whether the unrestrained or restrained measurements are most pertinent to the application and specify the appropriate parameters accordingly.

5.5 Knowledge of these characteristics can help the producer and consumer determine if the dimensional characteristics of a specimen substrate satisfy given geometrical requirements.

5.6 This guide is suitable for sapphire substrates in the as-sliced, lapped, polished, or other condition. Refer to SEMI M3 for substrate specifications.

5.7 Until the results of a planned interlaboratory evaluation of this guide are established, use of this guide for commercial transactions is not recommended unless the parties to the test establish the degree of correlation that can be obtained.

6. Interferences

6.1 An extremely thin substrate that is measured in the unrestrained condition, but is not positioned in a state that minimizes distortion due to gravity, may require the user to mathematically compensate for the effect of gravity. Appendix X1 provides a guideline for how and when to apply a correction to compensate for deformation due to gravity.

6.2 Mechanical variations in substrate holding devices between systems may introduce measurement differences.

6.3 The quantity of data points and their spacing may affect the measurement results.

6.4 The temperature of the substrate under test may affect the measurement. The measurements described herein should generally be performed at room temperature.

7. Suitability of Test Equipment

7.1 The suitability of the test equipment shall be determined with the use of a reference substrate and its associated data set, or by performance of a statistically-based instrument repeatability study to ascertain whether the equipment is operating within the manufacturer's stated specification for repeatability.

7.2 The more points and the more accurate the method of collection of points on the surface of the part, the more accurately the surface characterization can be made.

7.3 Determination of degree of suitability is currently under investigation.

8. Sampling

8.1 This guide is nondestructive and may be used on either 100 % of the substrates in a lot or on a sampling basis.

8.1.1 If samples are to be taken, procedures for selecting the sample from each lot of substrates to be tested shall be agreed upon by the parties to the test, as shall the definition of what constitutes a lot.

9. Calibration and Standardization

9.1 Calibrate in accordance with the manufacturer's instructions.

10. Procedure and Apparatus

10.1 This section defines typical methods of holding the sapphire substrate under test, depending on whether the substrate is to be measured in the unrestrained or restrained condition. Sori and sag are measured with the substrate held in the unrestrained state. Taper, TTV, and FFD are typically measured in the restrained condition. However, as stated in 3.3, taper, TTV, and FFD may be measured in the unrestrained condition provided that the backside form is compensated for.

10.2 The following examples are not intended to exclude other similar techniques. Other methods besides those described below are permissible, provided that they satisfy the definition of restrained or unrestrained.

10.2.1 *Measuring a Substrate in the Unrestrained Condition*—Some typical methods of data collection are described below. Any other technique should be designed to represent as closely as possible a stress-free state.

10.2.1.1 Support the part by a single vacuum port from the back side and hold the part vertically. This method will minimize the influence of gravitational forces on the flatness of the substrate. For very thin substrates, it may be necessary to compensate for deflections induced by the vacuum port. Supported in this state, the front surface is measured and a mapping of the surface is created.

10.2.1.2 Support the part mechanically (for example, support on three points with no vacuum, support on a flat plate such as a granite block, and so forth) and measure the surface from above or below or both, creating a map of one or both surfaces of the substrate. In this horizontal orientation, it is desirable and in some cases necessary to calculate and remove the influence of gravity on the measurement (see 6.1). Thinner substrates are more sensitive to the influence of gravity than are thicker substrates.

10.2.1.3 For sufficiently stiff samples, the substrate can be supported on its edge with the substrate nominally vertical. This method also reduces the influence of gravity and is a suitable substitute for the method described in 10.2.2, especially for perforated wafer carriers unable to be held by vacuum.

10.2.2 *Measuring a Substrate in the Restrained Condition*—Some typical measurement techniques for the clamped state are described below. Any other technique should be designed to represent as closely as possible the back surface of the substrate in the restrained state. Taper, TTV, and FFD may be measured in either the restrained or unrestrained condition, as described below. If measured in the unrestrained state, both sides must be measured concurrently, and the clamped state must be simulated mathematically by subtracting out the height of the backside of the wafer. Figs. 6 and 7 show how a wafer measured using both techniques will produce the same result.

10.2.2.1 Constrain the back surface of the substrate to a flat vacuum chuck surface, and measure the front surface of the substrate compared with the surface of the vacuum chuck. This method requires the user to accurately determine the plane of the vacuum chuck so that chuck alignment error can be removed from the restrained measurement. This method is effective because it accurately simulates one method of clamping the substrate during use.

10.2.2.2 Support the sample and measure both sides concurrently either by scanning the full part or by taking localized measurements of the two surfaces at various points across the substrate. If performed in this manner, then the clamped state must be simulated mathematically by subtracting out the height of the backside of the wafer.

11. Calculations

11.1 *Sori* (see Fig. 2)—The maximum distance above the best-fit plane plus the maximum distance below the best-fit plane.

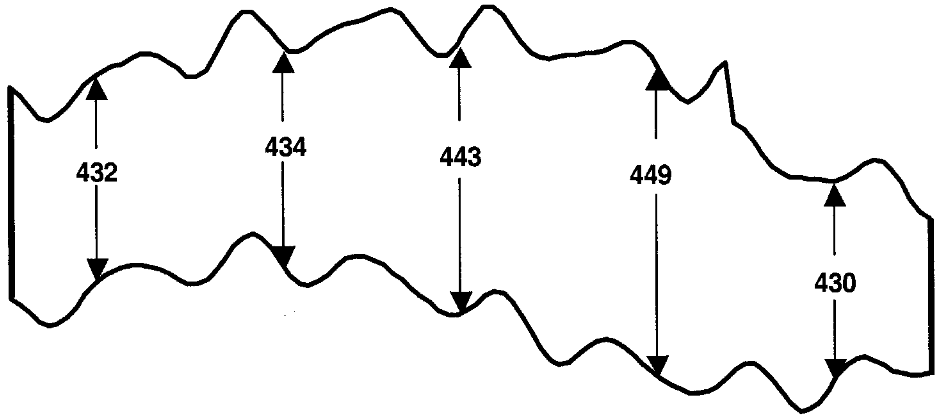


FIG. 6 Unrestrained Condition
(will produce same result as Fig. 7)

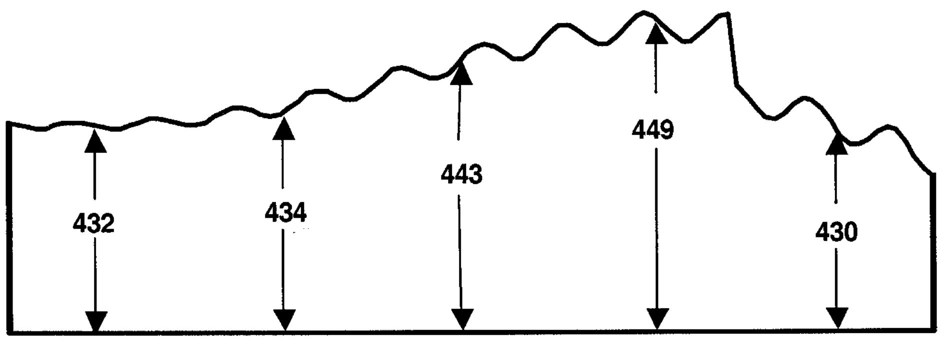


FIG. 7 Restrained Condition
(will produce same result as Fig. 6)

11.2 *Sag* (see Fig. 1):

$$\text{Sag} = R - \frac{1}{2}\sqrt{4R^2 - A^2} \quad (1)$$

where:
R = radius of the best-fit sphere, and
A = diameter of the circle defining the quality area.

11.3 *Taper* (see Fig. 4)—The diameter of the quality area times the tangent of the angle between the best-fit front surface plane and the restrained back surface plane.

11.4 *Total Thickness Variation (TTV)* (see Fig. 5)—The maximum thickness minus minimum thickness.

11.5 *Front-to-Front Deviation (FFD)* (see Fig. 3)—The maximum distance above the best-fit front surface plane plus the maximum distance below the best-fit front surface plane.

12. Report

12.1 Report the following information:

12.1.1 Date of test,

12.1.2 Identification of operator,

12.1.3 Identification of measuring instruments, including substrate holding device and, if necessary, gravitational correction method,

12.1.4 Lot identification, and

12.1.5 Measurements of each substrate measured.

12.2 For referee tests, the report shall also include the standard deviation of each set of substrate measurements.

13. Precision and Bias

13.1 The precision and bias of the techniques mentioned in this guide have not yet been determined. Interlaboratory round robin tests will be conducted in the future to quantify precision and bias of the techniques.

14. Keywords

14.1 backside processing; compound semiconductors; flatness; form; front-to-front deviation (FFD); measurement; restrained; sag; sapphire; sapphire substrates; sori; taper; total thickness variation (TTV); unrestrained

APPENDIX

(Nonmandatory Information)

X1. GUIDELINE TO COMPENSATE FOR THE INFLUENCE OF GRAVITY ON UNRESTRAINED, FREE-STATE MEASUREMENTS

X1.1 For free-state measurements, the goal is to measure the parts in a "stress-free" state. Therefore, it is important to be aware of the way in which gravity will affect the free-state measurements, particularly for wafers that are very thin relative to their part diameter. Both the customer and supplier should be aware of the impact of gravity on the free-state measurements. This appendix is intended to serve as a guide on when and how to compensate for the influence of gravity for free-state measurements.

X1.2 If the part under test is supported and measured in the vertical orientation, then the influence of gravity on the sample becomes negligible and can be ignored. If the part is supported and measured in the horizontal orientation, then the deformation due to gravity should be calculated to determine whether it is a significant percentage of the sag limit. If the calculated deformation due to gravity (γ) exceeds 10 % of the allowable sag, then one should consider mathematically compensating for it, using the method described in this appendix.

X1.2.1 Governing equation:

$$\gamma = \text{Sag Correction} = \frac{5+\upsilon}{1+\upsilon}\left[\frac{P_o R^4}{64D}\right] \quad \text{(X1.1)}$$

where:

υ = Poisson's ratio,
R = $\text{Radius}_{\text{wafer}}$,
P_o = weight / area = ρtg,
ρ = density,
t = thickness,
g = gravitational constant,
D = Et^3 $/$ $12(1 - \upsilon^2)$, and
E = modulus of elasticity (Young's Modulus).

X1.3 After establishing that the deformation due to gravity must be accounted for, one must determine whether the sag correction must be added or subtracted from the measured sag. This will depend on how the part under test is supported, and whether the surface being measured is the top surface or the bottom surface.

X1.4 The two models shown in Figs. X1.1 and X1.2 illustrate the two possible methods of supporting the part. In reality, the wafer may not exactly match either of these conditions, however, using these simplistic models will result in a worst-case calculation. Therefore, the results attained with these calculations will be conservative.

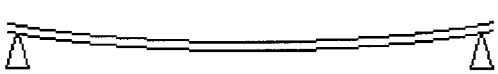


FIG. X1.1 Wafer Simply Supported by its Edges

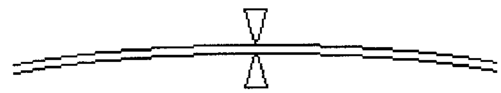


FIG. X1.2 Wafer Simply Supported by its Center

X1.5 The sag due to gravity (γ) will either increase or decrease the measured sag (*S*) depending on how the part is held. Therefore, it is important to apply the sag correction in the appropriate direction. The four possible conditions are shown in the table below, with the associated formula:

Condition	Wafer Supported Horizontally by its:	Surface Being Measured	Formula for Corrected Sag
I	edges	top	$S' = S + \gamma$
II	edges	bottom	$S' = S - \gamma$
III	center	top	$S' = S - \gamma$
IV	center	bottom	$S' = S + \gamma$

where:

S = measured sag (will be positive for a convex surface and negative for a concave surface),
γ = calculated sag due to gravity, and
S' = sag of measured surface after compensating for deformation due to gravity.

X1.6 If the sample is resting on a flat surface, such as a wafer chuck or a granite flat, then the wafer will always measure lower absolute sag values than the actual value, since the influence of gravity will cause it to more closely conform to the chuck surface. While the exact influence of gravity on the wafer is very complicated, since the contact between the wafer and the chuck is variable, the impact can be approximated by using the formulas of Conditions I or III, depending on whether the part is concave or convex.

X1.7 The graph shown in Fig. X1.3 may be used to approximate the magnitude of the sag due to gravity, for various wafer dimensions. The following constants for sapphire were used in calculations for the graph:

Poisson's Ratio	$\upsilon = 0.29$
Density	$\rho = 3970\ kg/m^3$
Modulus of Elasticity	$E = 4.70E + 11\ N/m^2$

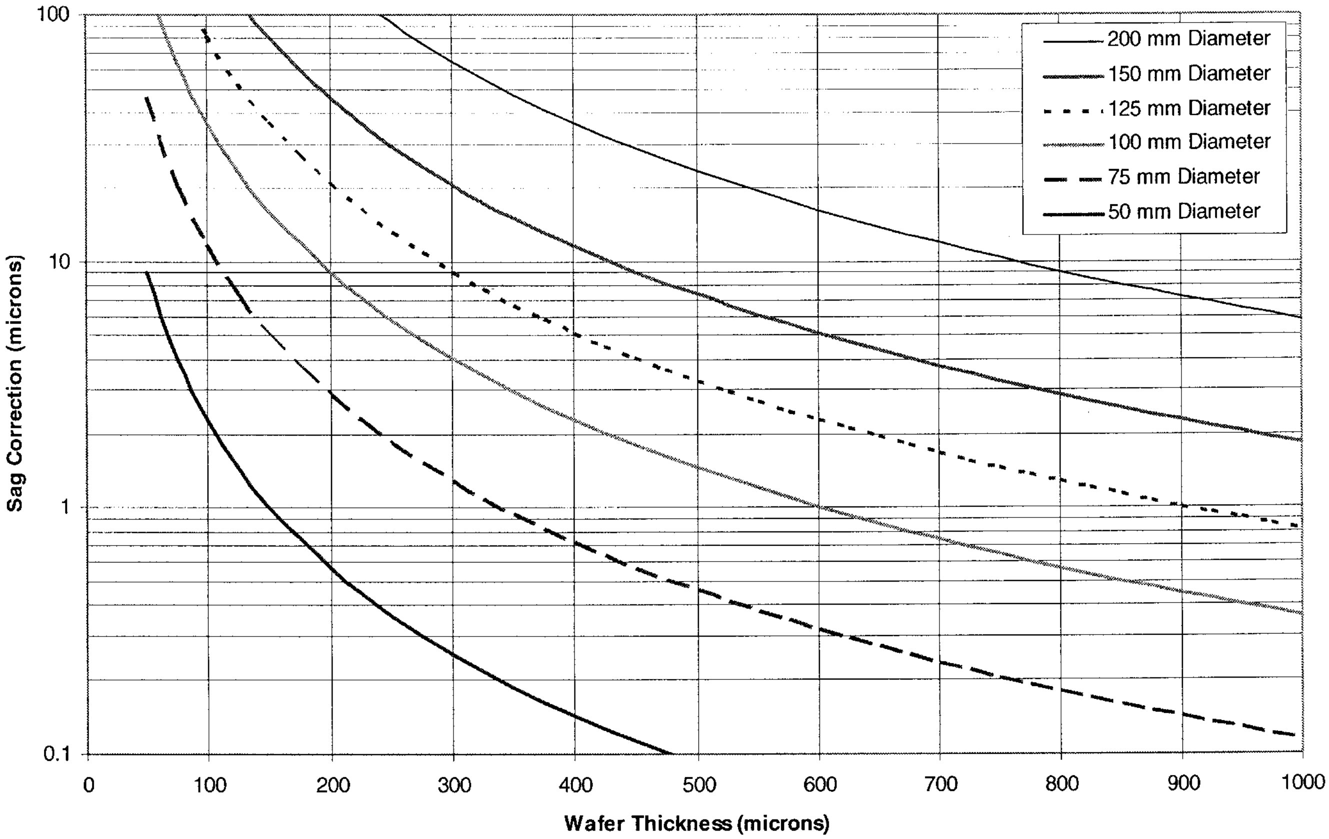


FIG. X1.3 Gravitational Influence versus Thickness for Sapphire Wafers