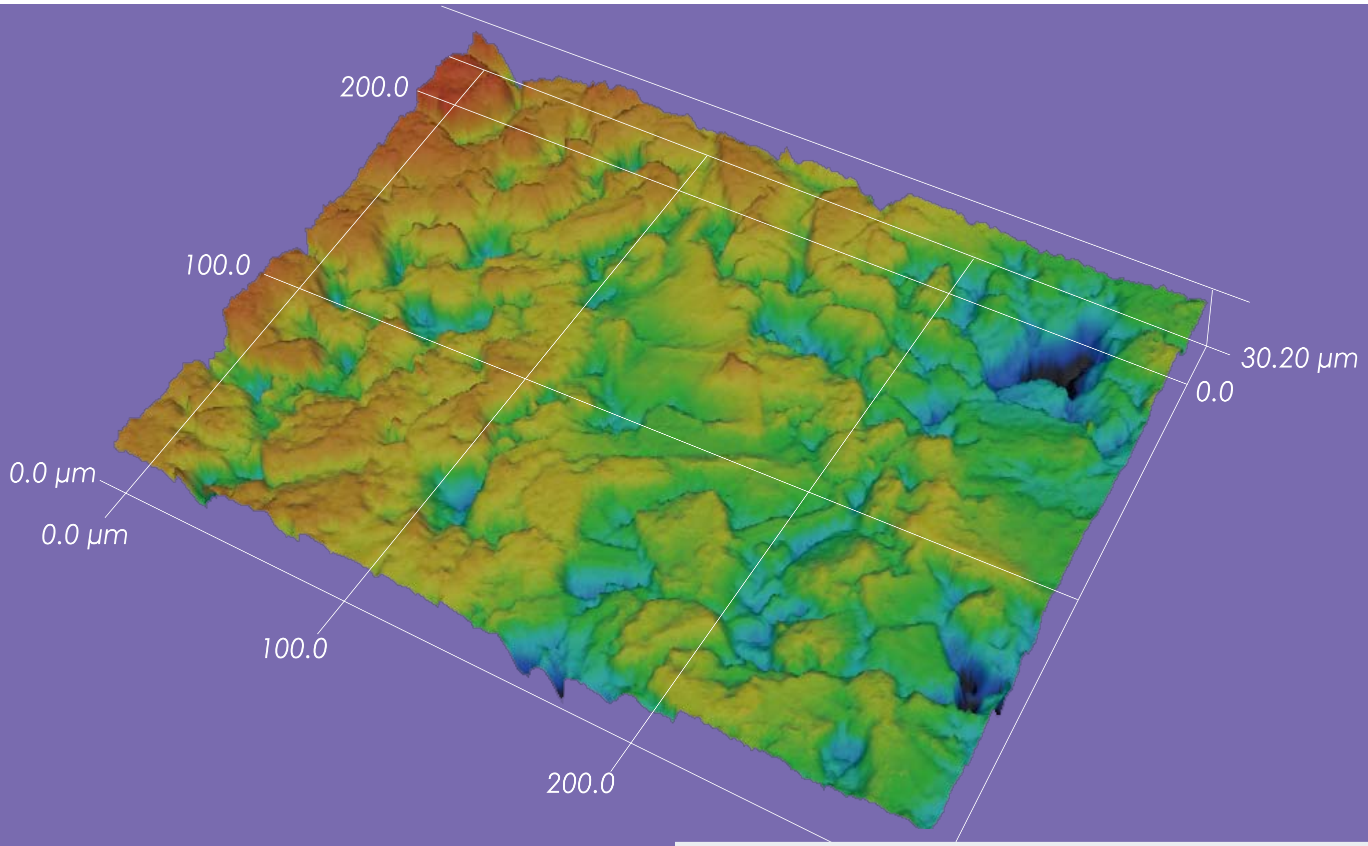
Introduction to Surface Roughness Measurement

Thank you for reading the Introduction to Surface Roughness Measurement.
This document includes the definition of and technical information on the parameters defined in the new standard, ISO 25178 Surface Texture. The content of this document provides explanations that are related to our product specifications.
We hope that this introductory document will help answer your questions regarding the new ISO 25178 measurement module.



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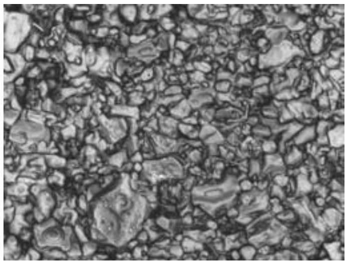
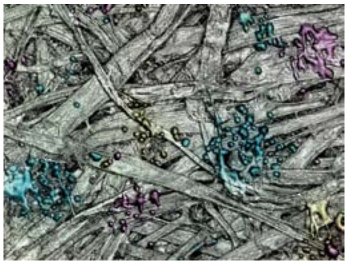
KEYENCE

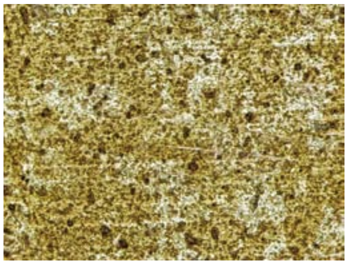
1 About Surface Roughness

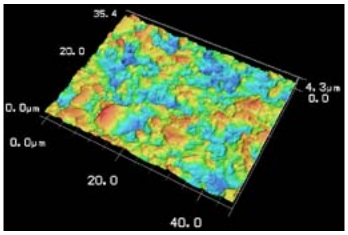
1-1 What is Surface Roughness?

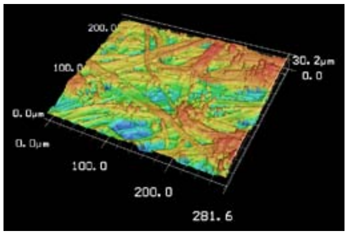
If you look at machined parts, you will notice that their surfaces embody a complex shape made of a series of peaks and troughs of varying heights, depths, and spacing. Surface roughness is defined as the shorter frequency of real surfaces relative to the troughs.
A product's exterior cover, a vehicle's dashboard, a machined panel---the differences in appearance, specifically whether something is shiny and smooth or rough and matte, are due to the difference in surface roughness.
Surface roughness not only affects the object's appearance, but it also produces texture or tactile differences.
Appearance and texture can influence a product's added value such as class and customer satisfaction.
If a part makes contact with something, its surface roughness affects the amount of wear or the ability to form a seal. If the part is to be painted, the roughness also affects the thickness of the paint.
It has therefore been required in recent years to quantify the asperity of a surface.

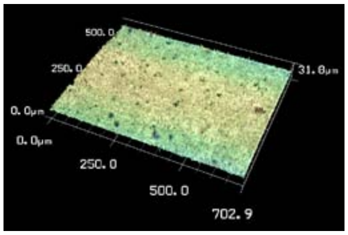

Ceramic surface 6000×


Paper fiber 1000×


Gold-plated surface 400×







1-2 ISO 25178 Surface Texture

ISO 25178 Surface Texture is a collection of international standards relating to the analysis of surface roughness.
While JIS B 0671-1 and ISO 13565-1 (Surface Texture: Profile Method) are based on analysis using the stylus method, ISO 25178 Surface Texture standards support two evaluation methods: contact type (stylus method) and non-contact type (optical probe).
The dual-method approach resolves existing problems in the profile method: variations in measurement results depending on the measurement site and variations due to the scanning direction.

2 Basics of Surface Roughness

2-1 Surface Roughness Terminology

This section explains the terms used in ISO 25178 Surface Texture.

Real surface

Real surface indicates the surface from measurement data in the XY plane direction. Generally, the height data is the subject of processing.

Primary surface

Primary surface is the surface obtained after S-filtering the real surface.

Surface filter

Surface filter is a filtration operator applied to a surface.

S-filter

S-filter is a filter eliminating the smallest scale elements from the surface (low-pass filter). This filter is equivalent to the cutoff value λs in JIS B 0601-2001. In the case of contact-type surface roughness measurement, noise due to edges is removed.

L-filter

L-filter is a filter eliminating the largest scale elements from the surface (high-pass filter). This filter is used to remove undulations and other lateral components from the surface, and thus allows for the extraction of only the roughness components. L-filter is equivalent to the cutoff value λc in JIS B 0633-2001.

F-operator

F-operator removes form from the primary surface. This filter is equivalent to tilt correction, suppressing the nominal surface texture characterization.

S-F surface

Surface filter is a surface obtained after applying an F-operator to the primary surface.

S-L surface

S-L surface is a surface obtained after applying an L-filter to the S-F surface.

Scale-limited surface

Scale-limited surface means either the S-F surface or the S-L surface. It is the equivalent of the roughness profile or waviness profile in the profile method.

Reference surface

Reference surface is the base for the scale-limited surface and represents the plane at the mean height of the evaluation area as per the ISO 25178 Surface Texture function.

Evaluation area

Evaluation area is the portion of the scale-limited surface that is subject to evaluation.

Definition area

Definition area is the portion of the evaluation area that is used for parameter definition.

Height

The height represents the distance between the reference surface and each point on the scale-limited surface. A point lower than the reference plane has a negative value.

Auto-correlation function

Auto-correlation function is used to evaluate the periodicity of surface roughness in the direction of the plane.

Angular spectrum (graph)

The angular spectrum indicates a graph for determining the direction of the lay (or surface pattern; hairline, in the case of metal) comprising a surface.

2-2 Process of Evaluation

The parameters used in ISO 25178 Surface Texture are calculated from the following procedure.

Obtain the primary surface by surface filtering (using S-filter) the real surface.

↓

According to the evaluation result, perform further surface filtering (using F-operator and L-filter) to obtain the scale-limited surface.

↓

Specify the evaluation area from the scale-limited surface.

↓

Obtain the reference surface for the scale-limited surface and calculate the parameters.

2-3 Filtering

The standards for filtering are still under review by the International Organization for Standardization (ISO). This section introduces the filtering methods being evaluated by ISO for the S-filter and the L-filter.

Gaussian filter

The Gaussian filter is one kind of smoothing filter that suppresses noise using the Gaussian function. Gaussian filters that are specified in JIS B 0632:2001 (ISO 11562:1996) and ISO 16610-21:2011 are applied to areal surface roughness measurements.

Spline filter

The spline filter is one kind of filter used to obtain a smooth profile by interpolating the sections between effective adjacent points using the spline function. Spline filters that are specified in ISO/TS 16610-22:2006 are applied to areal surface roughness measurements.

2-4 S-filter and L-filter settings

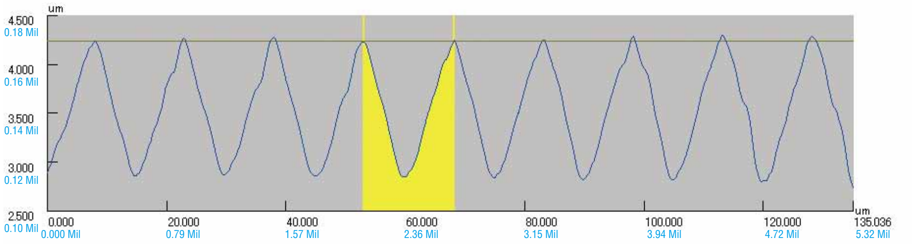
Cutoff wavelength for S-filter

A value equal to or more than 3 times the measurement resolution for the XY plane (horizontal plane) is used. If the set value is not sufficiently effective, increase the set value until the scale-limited surface noise is removed. If a different kind of filtering was applied beforehand, this may not be used.

Cutoff wavelength for L-filter

The cutoff wavelength for L-filter is difficult to uniformly specify based on lens magnification or stylus tip diameter; therefore, it must be adjusted with reference to the real surface. Set a value 5 times the XY-directional length of the profile that you want to remove as waviness.

Example:



Profile 1	Horizontal distance
Section 1	14.678 μm 0.58 Mil

In the example above, the cutoff value is 0.1 mm 0.004".

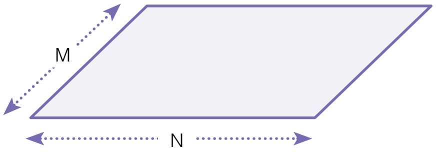
14.678 x 5 = 73.39 ≈ 0.1 mm 0.004"

2-5 ISO 25178 Surface Texture Parameters Explained

The parameters used in ISO 25178 Surface Texture are calculated based on the following concept.

Reference surface

Obtain the reference surface (mean plane) for the measurement area (vertical M pixel, horizontal N pixel) specified on the height screen and calculate the deviation of height distribution when the height of the reference surface is 0.



ISO 25178 Surface Texture Parameters

Parameters are grouped into six categories in ISO 25178 Surface Texture.

1. Height parameters
2. Spatial parameters
3. Hybrid parameters
4. Functional parameters
5. Functional volume parameters
6. Feature parameters

The following evaluation parameters are defined for the categories.

Category	Parameter	Description
Height parameters	Sq	Root mean square height
	Ssk	Skewness
	Sku	Kurtosis
	Sp	Maximum peak height
	Sv	Maximum pit height
	Sz	Maximum height
	Sa	Arithmetical mean height
Spatial parameters	Sal	Auto-correlation length
	Str	Texture aspect ratio
	Std*	Texture direction
Hybrid parameters	Sdq	Root mean square gradient
	Sdr	Developed interfacial area ratio

* Std, the texture direction, is classified in miscellaneous parameters in ISO 25178-2; 2012 (Surface texture parameters).

Functional parameters	Smr(c)	Areal material ratio
	Smc(mr)	Inverse areal material ratio
	Sk	Core roughness depth
	Spk	Reduced peak height
	Svk	Reduced valley depth
	Smr1	Peak material portion (percentage of material that comprises the peak structures associated with Spk)
	Smr2	Valley material portion (percentage of the measurement area that comprises the deeper valley structures associated with Svk)
	Svq	Slope of a linear regression performed through the valley region
	Spq	Slope of a linear regression performed through the plateau region
	Smq	Relative areal material ratio at the plateau to valley intersection
	Sxp	Peak extreme height
Functional volume parameters	Vvv	Dale void volume
	Vvc	Core void volume
	Vmp	Peak material volume
	Vmc	Core material volume
Feature parameters	Spd	Density of peaks
	Spc	Arithmetic mean peak curvature
	S10z	Ten point height of surface
	S5p	Five point peak height
	S5v	Five point pit depth
	Sda(c)	Closed dale area
	Sha(c)	Closed hill area
	Sdv(c)	Closed dale volume
	Shv(c)	Closed hill volume

1 Height parameters

The height parameters below are developed analogously from ISO 4287 and JIS B0601 and focus on the height (displacement) of the evaluation area.

Category	Parameter	Description	Notes
Height parameters	Sq	Root mean square height	This parameter corresponds to the standard deviation of distance from the mean plane. It is equivalent to the standard deviation of heights.
	Ssk	Skewness	This parameter represents the symmetry of height distribution.
	Sku	Kurtosis	This parameter represents the kurtosis of height distribution.
	Sp	Maximum peak height	This parameter represents the maximum value of height from the mean plane of the surface.
	Sv	Maximum pit height	This is the absolute minimum value of height from the mean plane of the surface.
	Sz	Maximum height	This parameter represents the distance between the highest point and the lowest point on the surface.
	Sa	Arithmetical mean height	This is the arithmetic mean of the absolute value of the height from the mean plane of the surface.

Supplementary Notes

Root mean square height (Sq)

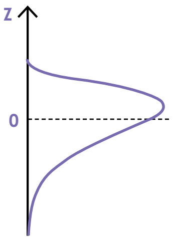
This parameter represents the root mean square value of ordinate values within the definition area. It is equivalent to the standard deviation of heights.

$$Sq = \sqrt{\frac{1}{A}\iint_A Z^2(x,y)dxdy}$$

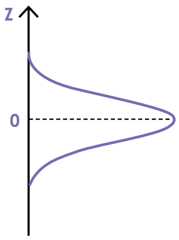
Skewness (Ssk)

Ssk values represent the degree of bias of the roughness shape (asperity).

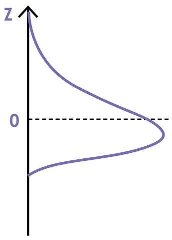
$$Ssk = \frac{1}{Sq^3}\left[\frac{1}{A}\iint_A Z^3(x,y)dxdy\right]$$



Ssk<0



Ssk=0



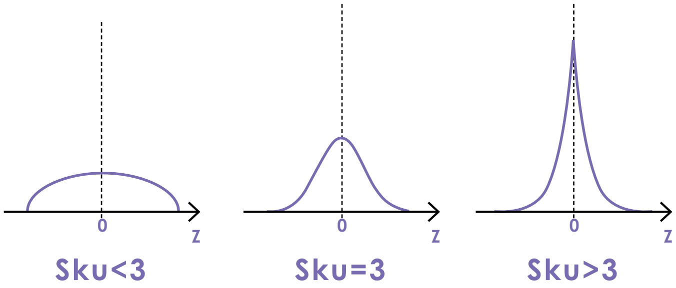
Ssk>0

Ssk<0 · · · · · · Height distribution is skewed above the mean plane.
Ssk=0 · · · · · · Height distribution (peaks and pits) is symmetrical around the mean plane.
Ssk>0 · · · · · · Height distribution is skewed below the mean plane.

Kurtosis (Sku)

Sku value is a measure of the sharpness of the roughness profile.

$$Sku = \frac{1}{Sq^4}\left[\frac{1}{A}\iint_A Z^4(x,y)dxdy\right]$$



Sku<3 · · · · · · Height distribution is skewed above the mean plane.

Sku=3 · · · · · · Height distribution is normal distribution.
(Sharp portions and indented portions co-exist.)

Sku>3 · · · · · · Height distribution is spiked.

Maximum peak height (Sp)

This is the height of the highest peak within the defined area.

$$Sp = \max_A z(x,y)$$

Maximum pit height (Sv)

This is the absolute value of the height of the largest pit within the defined area.

$$Sv = \left|\min_A z(x,y)\right|$$

Maximum height (Sz)

This parameter is defined as the sum of the largest peak height value and the largest pit depth value within the defined area.

$$Sz = Sp + Sv$$

Arithmetical mean height (Sa)

This parameter is the mean of the absolute value of the height of points within the defined area.

$$Sa = \frac{1}{A}\iint_A \left|Z(x,y)\right|dxdy$$

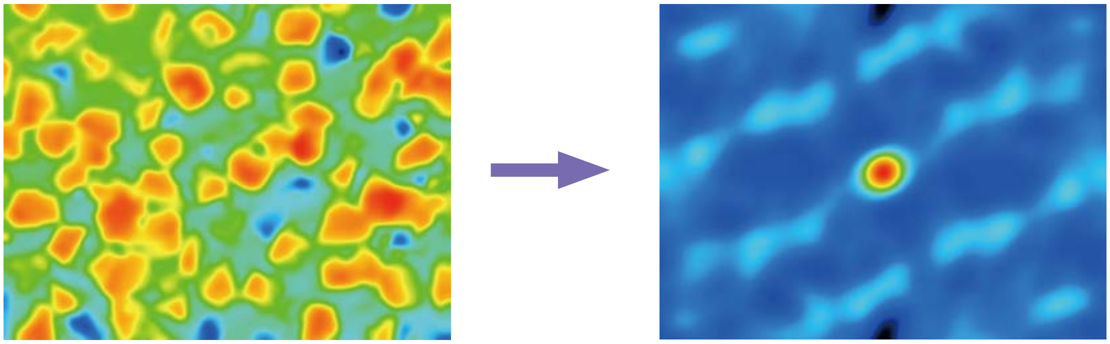
2 Spatial parameters

Spatial parameters are parameters that focus on the direction of the plane (wavelength direction).

Category	Parameter	Description	Notes
Spatial parameters	Sal	Auto-correlation length	This parameter represents the horizontal distance in the direction in which the auto-correlation function decays to the value[s] (0.2 by default) the fastest.
	Str	Texture aspect ratio	This parameter is a measure of uniformity of the surface texture. The value is obtained by dividing the horizontal distance in the direction in which the auto-correlation function decays to the value[s] (0.2 by default) the fastest (equivalent to Sal) by the horizontal distance in the direction of the slowest decay of auto-correlation function to the value[s].
	Std*	Texture direction	This value[s] is the angle with which the angular spectrum fAPS(S) is the largest. It represents the lay of the surface texture.

* Std, the texture direction, is classified in miscellaneous parameters in ISO 25178-2; 2012 (Surface texture parameters).

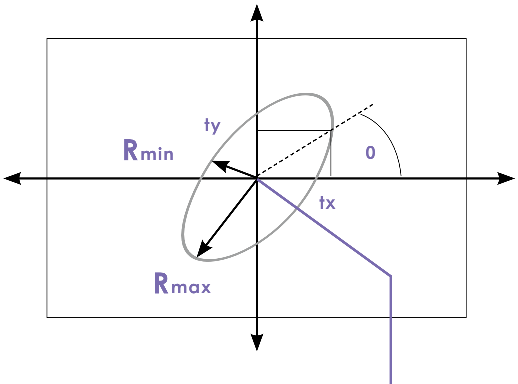
Auto-correlation function used for the calculation of **Sal** and **Str** have the characteristic of allowing you to identify surface features.



Auto-correlation function can also evaluate the periodicity of each surface direction.

The center of the image is the highest point (ACF = 1), and the ACF decays as the amount of shift away from the center increases. ACF falls rapidly to zero along a direction where the short wavelength component is dominant, and falls slowly when shifting along a direction where a long wavelength component is dominant.

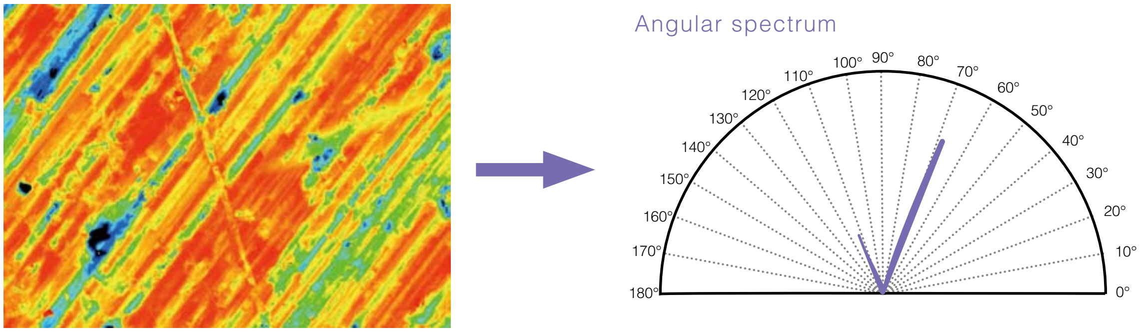
Therefore, the decay is slower along the direction of lay on an anisotropic surface, while the decay is rapid along the direction perpendicular to the lay.



The figure shows wavelength distribution, with the center as 0.

- Frequent long periodic ups and downs: Data concentrates around the center
- Frequent fine ups and downs: Data is dispersed

The angular spectrum graphs used for the calculation of **Std** can be displayed. Angular spectrum graphs allow you to identify the lay (hairline) direction.



The angular direction of lay on the sample surface is reflected in the angular spectrum graph.

- Angle of lay in the image is the same as the angle of peak on the graph.
- Peak size changes according to the intensity of lay.

3 Hybrid parameters

Hybrid parameters are parameters that focus on both the height direction and the direction of the plane (wavelength direction).

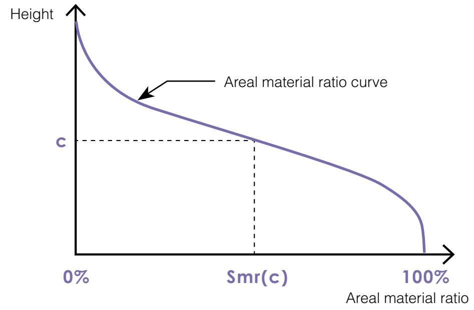
Category	Parameter	Description	Notes
Hybrid parameters	Sdq	Root mean square gradient	This parameter is calculated as a root mean square of slopes at all points in the definition area.
	Sdr	Developed interfacial area ratio	This parameter is expressed as the percentage of the definition area's additional surface area contributed by the texture as compared to the planar definition area.

4 Functional parameters

Functional parameters are calculated using the areal material ratio (bearing area) curve. They are utilized to evaluate the behavior of a surface that comes into strong mechanical contact.

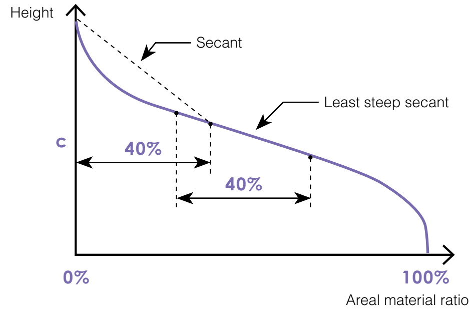
Areal material ratio

The areal material ratio, **Smr(c)**, is the percentage of the cross-sectional area of the surface at a height [c] relative to the evaluation cross-sectional area.



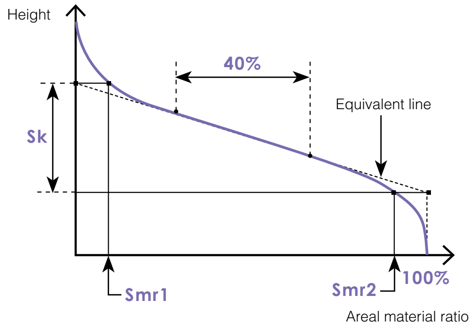
Areal material ratio curve

The areal material ratio curve expresses the heights at which the areal material ratio is 0% to 100%.



Equivalent line

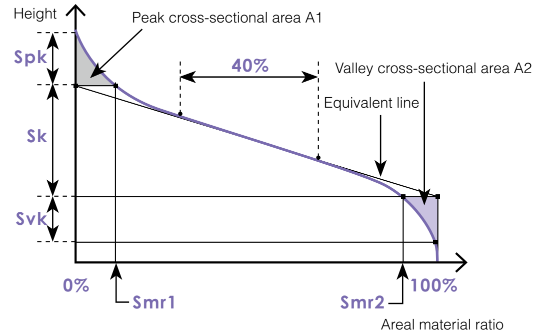
If you shift the secant line of an areal material ratio curve (obtained from subtracting the curve at areal material ratio difference of 40%) from areal material ratio of 0%, the position that has the least steep secant is called the center portion of the areal material ratio curve. The equivalent line is the line where the sum of squared deviation in the vertical-axis direction is the smallest in the center portion.



Core surface

Core surface is obtained by removing the predominant peaks and valleys (portions not included in the range of heights at an equivalent line areal material ratio of 0% to 100%) from the definition area of the scale-limited surface.

The peaks with a height above the core surface are called reduced peaks and the valleys below the core surface are called reduced valleys.



Category	Parameter	Description	Notes
Functional parameters	Sk	Core roughness depth	This parameter is calculated as the difference of heights at areal material ratio values 0% and 100% on the equivalent line; specifically, it is a value obtained by subtracting the minimum height from the maximum height of the core surface.
	Spk	Reduced peak height	This parameter represents the mean height of peaks above the core surface.
	Svk	Reduced valley depth	This parameter represents the mean depth of valleys below the core surface.
	Smr1	Peak material portion (percentage of material that comprises the peak structures associated with Spk)	Smr1 and Smr2 represent the percentage of surface at the intersection of core surface maximum height and areal material ratio curve, and the percentage of surface at the intersection of core surface minimum height and areal material ratio curve, respectively.
	Smr2	Valley material portion (percentage of the measurement area that comprises the deeper valley structures associated with Svk)	
	Sxp	Peak extreme height	This parameter is the difference of heights at the areal material ratio values p% and q%.

5 Functional volume parameters

Functional volume parameters concern volumes that are calculated using the areal material ratio curve. They are utilized to evaluate the behavior of a surface that comes into strong mechanical contact.

Inverse areal material ratio

Smc(p), the inverse areal material ratio, is the height [c] that gives the areal material ratio p%.

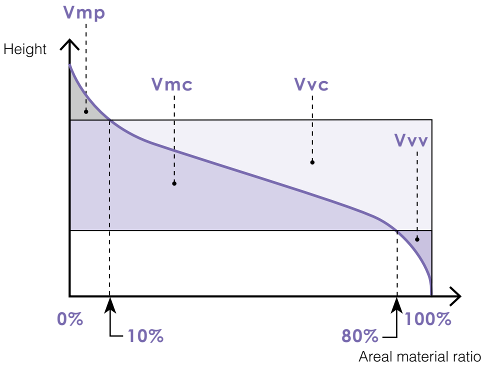
Void volume

Vv(p), the void volume, is the volume of space per unit area that is calculated based on the areal material ratio curve of areal material ratio p% to 100%.

Material volume

Vm(p), the material volume, is the volume of material portion per unit area that is calculated based on the areal material ratio curve of areal material ratio 0% to p%.

Category	Parameter	Description	Notes
Functional volume parameters	Vvv	Dale void volume	This parameter represents the void volume of dale at the areal material ratio p%.
	Vvc	Core void volume	This parameter represents the difference between the void volume at areal material ratio p% and the void volume at areal material ratio q%.
	Vmp	Peak material volume	This parameter represents the volume of material at areal material ratio p%.
	Vmc	Core material volume	This parameter represents the difference between the material volume at areal material ratio q% and the material volume at areal material ratio p%.



6 Feature parameters

Feature parameters are calculated from results of peak and valley regions, respectively, segmented from the scale-limited surface.

Peak

Point on the surface that is higher than all other points within the neighborhood of that point

Hill

Region around a peak such that all maximal upward paths end at the peak

Course line

Curve separating adjacent hills

Pit

Point on the surface that is lower than all other points within the neighborhood of that point

Dale

Region around a pit such that all maximal downward paths end at the pit

Ridge line

Curve separating adjacent dales

Saddle point

Point at which the ridge lines and course lines cross

Local peak height

Height difference between the peak and its nearest saddle point connected by a ridge line

Local pit height

Height difference between the pit and its nearest saddle point connected by a course line

Segmentation

◆ Watershed algorithm

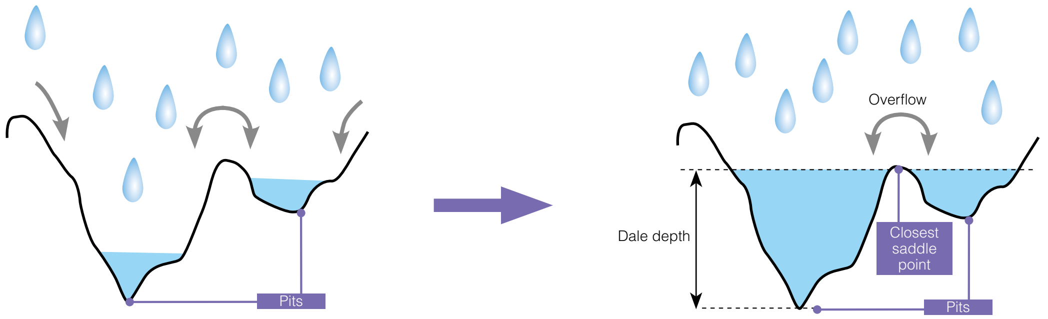
The watershed algorithm is employed to partition regions, which are used in the calculation of feature parameters. Water is poured into the surface landscape and it runs along the surface shape and reaches the pit. Upon continuing to pour water, the water surfaces of water filling different pits make contact with each other. The set of these contact points is the ridge line that partitions the dale region. The same approach can be applied to the hill region by vertically inverting the process.

◆ Wolf pruning

Peaks and pits merely need to be higher or lower that other points in their respective neighborhoods. For this reason, a surface with fine asperity can have a vast number of peaks and pits. Applying the watershed algorithm to such surfaces can result in meticulous segmentation into minute peak and valley regions.

In order to suppress this over-segmentation, the Wolf pruning method is used to remove regions below a certain height/depth threshold.

The threshold is provided as a percentage of the maximum height (**Sz**) of the surface. The default value is 5%.



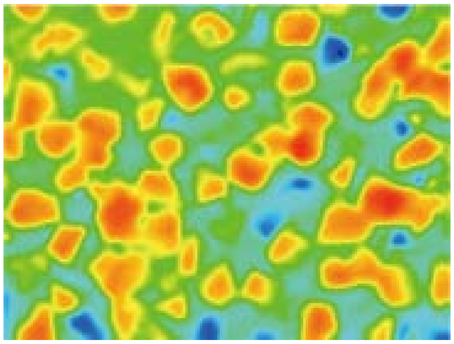
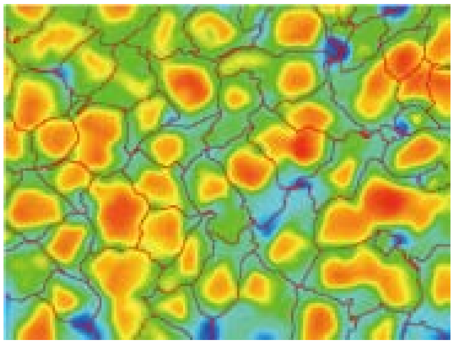


Image of scale-limited surface height


Hill region partition using watershed algorithm (Wolf pruning: 5%)

Closed area

Open area

A region that is in contact with the boundary of the definition area at the material height **c** is called an “open area,” while a region that is not is called a “closed area.” Height **c** is given in areal material ratio and the default value is 50%.

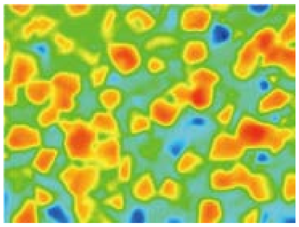
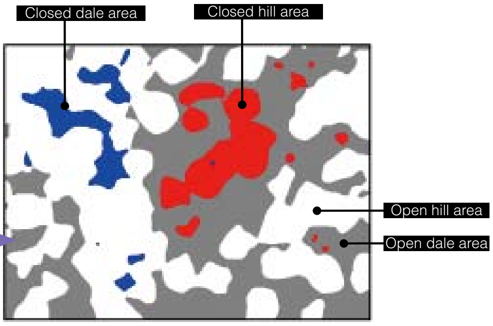


Image of scale-limited surface height



Cross-section image at areal material ratio of 60%

Mean dale area (Sda)

This parameter represents the average of the projected area of a closed or open area at different valley depths **c**.

Mean hill area (Sha)

This parameter represents the average of the projected area of a closed or open area at different hill heights **c**.

Mean dale volume (Sdv)

This parameter represents the average of void volume of a closed or open area at different valley depths **c**.

Mean hill volume (Shv)

This parameter represents the average of material volume of a closed or open area at different hill heights **c**.

Density of peaks (Spd)

This parameter is the number of peaks per unit area.

Arithmetic mean peak curvature (Spc)

This parameter represents the arithmetic mean of principal curvature of peaks within the definition area.

$$Spc = -\frac{1}{2}\frac{1}{n}\sum_{k=1}^{n}\left(\frac{\partial^2 Z(x,y)}{\partial x^2}+\frac{\partial^2 Z(x,y)}{\partial y^2}\right)$$

Ten-point height (S10z)

This parameter is the sum of five-point peak height and five-point pit height.

$$S10z = S5p + S5v$$

Five-point peak height (S5p)

This parameter represents the average height of the five highest hills (including the maximum peak) within the definition area.

Five-point pit height (S5v)

This parameter represents the average height of the five deepest valleys (including the deepest pit) within the definition area.

2-6 Differences between ISO 25178 and JIS B 0601-2001

The chart below summarizes the differences between ISO 25178 and JIS B 0601-2001/JIS B 0671-2002.

Standard Item			ISO 25178	JIS B 0601-2001 (ISO 13565-1)
Instruments			Contact type and non-contact type measuring instruments	Contact type (stylus method only)
Cross-section	Evaluation target		S-F surface	Cross-sectional profile
	Filter		S-filter	λs filter
Roughness	Evaluation target		S-L surface	Roughness profile
	Filter		S-filter, L-filter	λs filter, λc filter
	Height parameters	Maximum peak height	Sp	Rp
		Maximum pit height	Sv	Rv
		Maximum height	Sz	Rz
		Arithmetical mean height	Sa	Ra
		Root mean square height	Sq	Rq
		Skewness	Ssk	Rsk
		Kurtosis	Sku	Rku
	Spatial parameters		Sal, Str, Std	-
	Hybrid parameters		Sdq, Sdr	RΔq

Standard Item			ISO 25178	JIS B 0671-2002 (ISO 13565-1998)
Roughness	Function parameters	Level difference on core surface	Sk	Rk
		Reduced peak height	Spk	Rpk
		Reduced valley depth	Svk	Rvk
		Peak material portion	Smr1	Mr1
		Valley material portion	Smr2	Mr2

Caution The above chart is created based on the definitions of Surface Texture parameters specified in ISO 25178-2:2012. Please note that the above information may be changed via standard revisions after April 2012.

3

Surface Roughness Measuring Instruments

Various measurement tools are available in the market for analyzing and evaluating surface roughness and shape.

This section introduces the principles and characteristics of typical contact-type measuring instruments (surface roughness tester and atomic force microscope) and non-contact type measuring instruments (white light interferometer and laser scanning microscope).

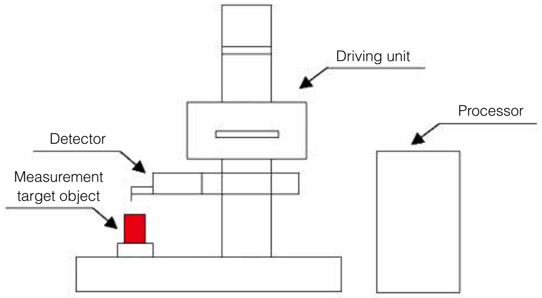
Method	Contact type		Non-contact type	
Measuring instrument	Contact-type roughness tester	Atomic force microscope (AFM)	White light interferometer	Laser microscope
Measurement resolution	1 nm	< 0.01 nm	< 0.1 nm	0.1 nm
Height measurement range	up to 1 mm up to 0.04"	< 10 µm < 0.39 Mil	< a few mm < a few fractions of an inch	< 7 mm < 0.28"
Measurable range	a few mm a few fractions of an inch	1 to 200 µm 0.04 to 7.87 Mil	40 µm to 15 mm 1.57 Mil to 0.59"	15 µm to 2.7 mm 0.59 Mil to 0.11"
Angular characteristic	-	Poor	Fair	Good
Data resolution	-	VGA	VGA	SXGA
Measurement site positioning	-	Optional	Built-in optical camera	Built-in optical camera
Damage to samples	Contact	Contact	Non-contact	Non-contact

3-1 Contact-type Surface Roughness and Profile Measuring Instruments

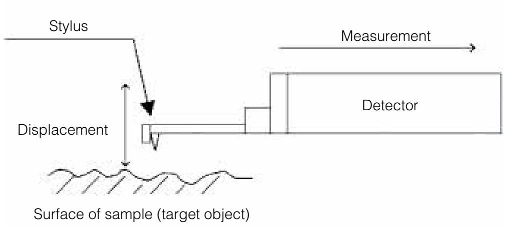
In contact-type instruments, the stylus tip makes direct contact with the surface of a sample.

The detector tip is equipped with a stylus, which traces the surface of the sample. The vertical motion of the stylus is electrically detected.

The electrical signals go through an amplification and digital conversion process to be recorded.



Contact type surface roughness measuring system



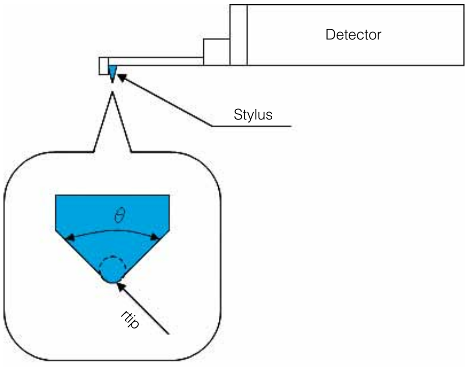
Surface roughness data collection

To precisely measure delicate shapes and roughness with a contact-type surface roughness tester, the radius of the stylus tip must be as small as possible with low contact pressure. Styluses are made of sapphire or diamond and their tip radius is usually about 10 μm 0.39 Mil or smaller. A conical shape with a ballpoint tip is considered ideal for a stylus.

Tip radius: r tip = 2 μm, 5 μm, 10 μm 0.08 Mil, 0.20 Mil, 0.39 Mil

Cone taper angle: 60°, 90°

* Unless otherwise specified, cones on ideal measuring instruments have a 60° taper.



Shape of the stylus tip

<< Advantages >>

- Clear wave profile
- Capable of long distance measurement

<< Disadvantages >>

- Stylus wear
- Measuring pressure can cause scratches on the sample surface
- Inability to measure viscous samples
- Measurement limited by radius of stylus tip
- Measurement takes time
- Difficulties in positioning and identification of subtle measuring points
- Requires sample cutting and processing for tracing by the detector

Contact-type surface roughness testers provide reliable measurement, because they directly touch the sample.

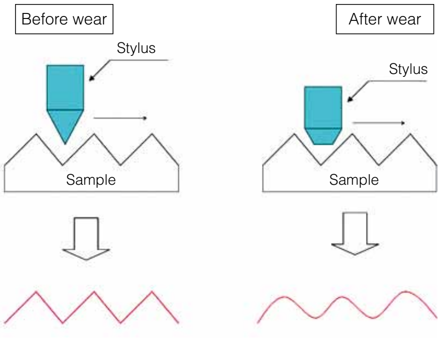
However, direct contact also causes disadvantages as outlined above.

More detailed explanations for some of these points are presented on the following pages.

Stylus wear

The stylus must be polished, because it will wear down over time. The mode of wear varies, making the stylus flat or rounded depending on the material and shape of the measurement target object. Different stylus shapes will naturally generate different wave profiles.

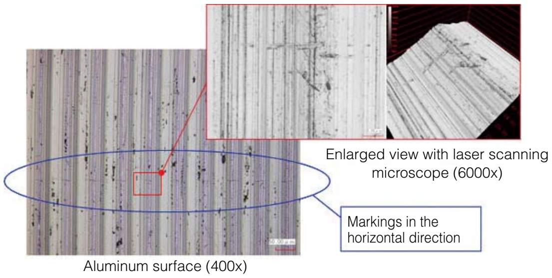
One method for determining stylus wear is to use a commercially available wear inspection test piece. Wear is determined by comparing the data profile (groove width) of the test piece before and after the wear of the stylus.



Differences in measurement results due to wear of stylus

Markings on the sample from measuring pressure

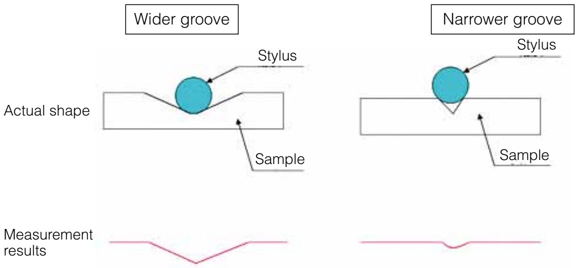
As explained before, styluses are made of sapphire or diamond---such hard materials can scratch the surface of the test object. Especially when repeating parallel adjustments, it is easy for the stylus to scratch the sample during rapid feed.



Markings caused by measuring pressure

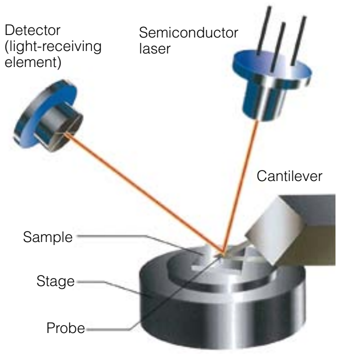
Grooves narrower than the radius of the stylus tip cannot be measured

The tip of the stylus is spherical. The stylus tip cannot trace the shape properly if the width of the groove (scratch, etc.) is narrower than the radius of the stylus tip.



Radius of stylus tip and groove width of sample

3-2 Atomic force microscope (AFM)



The atomic force microscope measures the asperity of a sample using the atomic forces between the tip and the sample. To perform measurement, the user moves the cantilever, equipped with a sharp tip (probe) at its end, into proximity of a sample surface to a distance of several nanometers. In order to maintain a constant force between the tip and the sample (a constant deflection of the cantilever), the atomic force microscope gives feedback to the piezo scanner while scanning. The displacement provided as feedback to the piezo scanner is measured to obtain the z-axial displacement, which is the surface structure.

A common way of measuring the displacement of the piezo scanner is the adoption of the optical lever method in which a laser beam is emitted on the back side of the cantilever and the reflected beam is detected by four-segment (or two-segment) photodiodes.

<< Advantages >>

- High resolution (resolution: minimum distance between resolvable points)
- Capable of 3D measurement with super-high magnification. Collected data can be processed.
- Observation in atmospheric conditions is possible, not needing pretreatment of sample
- Capable of analyzing physical properties (electrical property, magnetic property, friction, viscoelasticity, etc.)

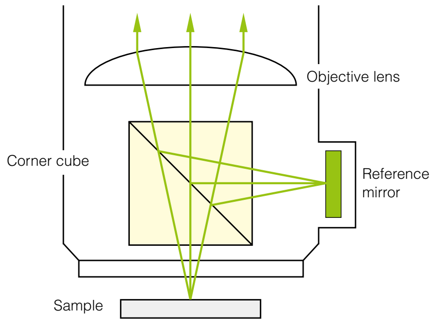
<< Disadvantages >>

- Incapable of low magnification (wide range) measurement. Samples with significant asperity (level difference greater than a few μm = apx. 0.1 Mil) cannot be measured.
- Difficulties in positioning due to the need to narrow down the field of view
  Analysis for each sample takes time
- Inability to measure large samples due to the need for pretreatment and processing
- Relatively difficult operations; Experience required for cantilever replacement, etc.

Very small measurable range

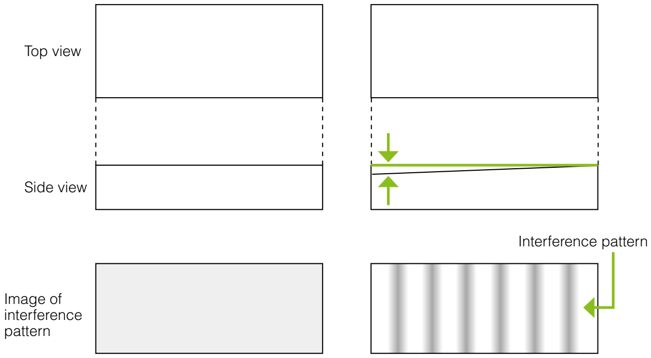
The atomic force microscope (AFM) is a magnifying observation tool capable of measuring 3D textures of a minuscule area. Unlike scanning electron microscopes, it can acquire height data in numeric values, which enable quantification of sample and data post-processing. The AFM also allows for measurements in normal atmospheric conditions and is free from restrictions such as the need for sample pretreatment and electrical conductivity. On the other hand, however, it is subject to the limitation of narrow measuring range (XYZ) due to its high resolution capabilities. The AFM also suffer the difficulties of accurately positioning the probe to the measurement area and the need for knowledgeable operation (correct mounting of the cantilever, etc.)

3-3 White Light Interferometer



Light interference occurs when there is a difference in distance traveled by the light (light path) from the surface of a target object to a certain point. The white light interferometer uses this phenomenon to measure the surface roughness of a sample. The figure on the left is a structural diagram of an interferometer. The light emitted from the source (semiconductor laser, etc.) is separated into reference and measurement beams. While the reference beam is passed to the reference mirror through a half mirror, the measurement beam is reflected and guided to the sample surface. The passed beam is reflected by the reference mirror to the CCD image sensor and forms an interference pattern. The other beam is reflected off the sample surface, passes the half mirror, and forming an image at the CCD image sensor.

The white light interferometer is designed so that the optical path length from the CCD element to the reference mirror and that from the CCD element to the sample surface are the same. The asperity on the sample surface causes these path lengths to be unequal, which results in forming an interference pattern at the CCD element. The number of lines in the interference pattern is translated to peaks and troughs (heights) on the sample surface.



<< Advantages >>

- Capable of measuring a wide field of view.

  Measurement in sub-nanometer range is possible.

- Quick measurement

<< Disadvantages >>

- No or limited angular characteristic
- Use is limited on certain objects

  White light interferometer can only measure when there is good reflection. Therefore, it does not support the measurement of a variety of objects. Measurement may also not be possible when there is significant difference between the light reflected from the reference mirror and that reflected from the measurement area. (White light interferometer handles mirrored surfaces well, but cannot measure spiky or bumpy samples or non-reflective objects.)

- Requires tilt correction

  Prior to measurement, sample tilt correction must be performed using the goniometric stage. Tilted samples can cause closely-spaced interference patterns, which hinders accurate measurement. Some white light interferometry systems are equipped with a tilt mechanism that automatically corrects the sample tilt.

- Low resolution for XY stage measurement

  The resolution for XY stage measurements is low due to the low number of sampling data sets (approximately 300,000). Some white light interferometry systems can scale up to use approximately 980,000 data sets.

- Sensitive to vibrations

  Place of installation is limited due to the equipment’s high sensitivity to vibrations. Shock-absorbing tables are necessary for installation.

3-4 3D Laser Scanning Microscope

① Laser beam emitted from the laser source passes the XY scanning optical system and scans the sample surface.

② Laser light-receiving elements detect the reflection information of the position in the focus of the confocal optical system.

③ A confocal image is created by accumulating the in-focus position information in the Z direction.

④ At the same time, by memorizing the objective lens positions for the in-focus positions, the laser scanning microscope measures the 3D profile of the surface.

<< Advantages >>

- Deep depth of focus; Target object can be observed in color
- Produces 3D profiles and displays color 3D images.
  Capable of measuring film thickness of translucent objects such as resist for semiconductor fabrication
- Analysis in atmospheric conditions is possible, not needing pretreatment of sample
- No limitation on sample size and material; Easy operation makes for excellent general-purpose use.

<< Disadvantages >>

- Incapable of high-definition observation and high-precision measurement (below 1 nm)
- Information of the surfaces of the sample that do not receive laser beam emission (such as the sides) cannot be acquired
- Incapable of measuring materials that absorb laser beam wavelength

A 3D laser scanning microscope is an observation/measuring equipment that enables both the 3D measurement and deep focus depth observation at the same time. It has no restrictions on the size or material of a sample and allows for observation under normal environmental conditions. In addition, the 3D laser scanning microscope features user-friendly operability similar to that of an optical microscope. Samples do not need pretreatment before measurement. Observation can be done in color, which helps accurate analysis of the conditions of the target object. A 3D laser scanning microscope can also be used for measuring the thickness of films, as well as for observing the surface, inside, and back side of a translucent object.

While the 3D laser scanning microscope is better than a scanning electron microscope or an atomic force microscope in terms of operability, it is inferior in observation magnification and measurement resolution. Bottom parts with high aspect ratio and slopes with large angles cannot be measured or observed, because they do not reflect the laser beam.

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