

Spacing Parameters			
Parameters	Profile Type	ISO 4287 & ISO 4288	ASME B46.1
Mean width of profile elements (Psm , Rsm , Wsm)	Primary/ Total Profile	See figure 3. $Psm = (Sm_1 + Sm_2 + \dots + Sm_j)/j$ Where j is a number of profile elements on evaluation length of total profile or primary profile.	
	Roughness	$Rsm = (Rsm_1 + Rsm_2 + \dots + Rsm_n)/n$ Where Rsm_n calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	See figure 3. $Rsm = (Sm_1 + Sm_2 + \dots + Sm_j)/N$ Where j is a number of profile elements on evaluation length of roughness profile.
	Waviness	$Wsm = (Wsm_1 + Wsm_2 + \dots + Wsm_n)/n$ Where Wsm_n calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	See figure 3. $Wsm = (Sm_1 + Sm_2 + \dots + Sm_j)/j$ Where j is a number of profile elements on evaluation length of waviness profile.

Hybrid Parameters			
Parameters	Profile Type	ISO 4287 & ISO 4288	ASME B46.1
Root mean square slope ($P\Delta q$, $R\Delta q$, $W\Delta q$)	Primary/ Total Profile	$P\Delta q = \sqrt{(\Delta_N^2 + Z_N^2 + \dots + \Delta_N^2)/N}$ Where Δ is slope. N is a number of slopes calculated on evaluation length of total profile or primary profile.	
	Roughness	$R\Delta q = (R\Delta q_1 + R\Delta q_2 + \dots + R\Delta q_n)/n$ Where $R\Delta q_n$ calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	$R\Delta q = \sqrt{(\Delta_N^2 + \Delta_N^2 + \dots + \Delta_N^2)/N}$ Where Δ is slope. N is a number of slopes calculated on evaluation length of roughness profile.
	Waviness	$W\Delta q = (W\Delta q_1 + W\Delta q_2 + \dots + W\Delta q_n)/n$ Where $W\Delta q_n$ calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	$W\Delta q = \sqrt{(\Delta_N^2 + \Delta_N^2 + \dots + \Delta_N^2)/N}$ Where Δ is slope. N is a number of slopes calculated on evaluation length of waviness profile.

Note: $\Delta = \frac{(Z_{i+3} - 9Z_{i+2} + 45Z_{i-1} - 45Z_{i-2} + 9Z_{i-2} - Z_{i-s})}{60d}$ where d is a spacing between two data points and Z is data point height of surface profile.

References

1. ISO 4288, Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture.
2. Surface Texture (Surface Roughness, Waviness, and Lay), an American National Standard, ASME B46.1-2002, New York, NY.
3. ISO 4287, Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters, 1997.

Authors

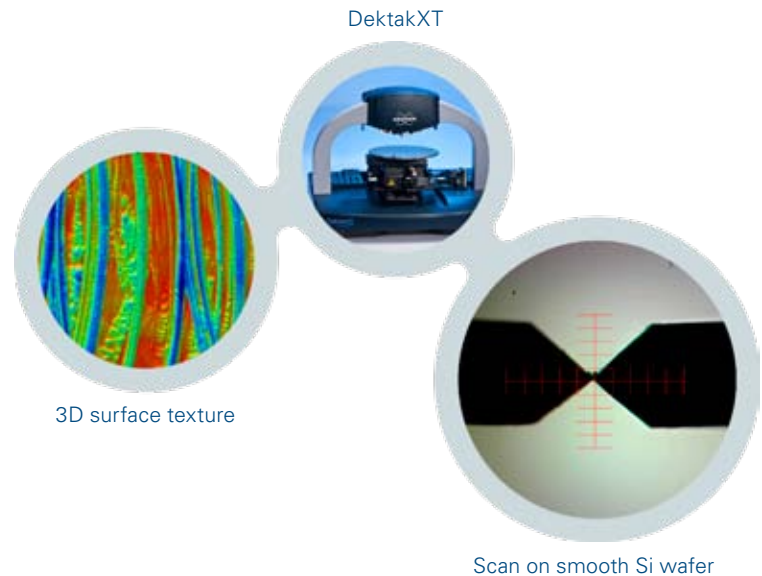
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Application Note #550

ISO-Standardized Filtering for DektakXT Stylus Profilers

The measurement of various parameters of interest for a surface, including roughness, step heights or depths, by any metrology method necessarily provides only a representation of the surface details. The power of proper filtering for data analysis, according to recognized ISO standard methods cannot be underestimated when striving to provide the most accurate and reproducible results for a measuring system. Bruker has designed ISO compatibility to the two-dimensional (2D) profile ISO 4287 and 4288 standards into the versatile Vision64™ software that powers the DektakXT® StylusProfiler. In this application note, we provide information about the setup and application of these standardized filtering methods as well as the implementation within Vision64 software for a specific applications example of scanning a Si wafer for surface roughness.

Stylus Measurement as a Representation of Surface Profile

Consider the image and 3D representation of a machined metal surface shown in Figure 1.

The picture in Figure 1 represents the process of collection of data via stylus trace on a real profile, through the filtering that is done to generate various profiles of interest. The

first profile generated as the representation of the surface is called “total profile.” The short cutoff filter with a cutoff spatial frequency of λ_s is then applied to this total profile in order to produce the “primary profile.” The spatial frequencies that are rejected by the short cutoff are considered noise and stylus deformation (–note that the stylus tip radius is expected to be smaller than the short cutoff frequency for this to be the case).

Once the primary profile is available, the roughness long cutoff filter is applied, with a cutoff spatial wavelength of λ_c . The rejected spatial information that results from application of the roughness cutoff (in other words, spatial frequency content with wavelength less than the roughness cutoff) represents the “roughness profile.” The information that passes represents the “waviness profile.” The waviness profile can be filtered once more, at an even longer cutoff wavelength, in order to separate the waviness and form of the sample under test.

It is important to note that the analysis of stylus traces conforms to standard rules about the traversing and evaluation length, with definitions relative to the cutoff spatial scales of interest. Figure 2 shows a general trace with details of the sampling length and evaluation length.

The “evaluation length” is a length in the stylus scan direction used to evaluate a portion of the “traversing length.” The “sampling length” will be either less than or equal to the evaluation length. For the total profile and primary profile, the sampling length is equal to the evaluation length. For the roughness and waviness profiles, the sampling length is equal to the filter cutoff wavelength used to separate roughness from waviness (λ_c).

Surface Texture Parameters – Filter per ISO 4287, 4288 and ASME B46.1

After applying the desired filters, surface texture parameters are calculated to characterize the surface

profile. There are hundreds of parameters that have been defined for industrial use and many of these appear in standards as well. Surface texture parameters for surface profiles are separated into three categories:

- Height parameters, which characterize the peak, valley, and average of ordinates,
- Spacing parameters, which determine the spacing of peaks and valleys of the surface profile, and
- Hybrid parameters, which combine height and spacing information from the profile.

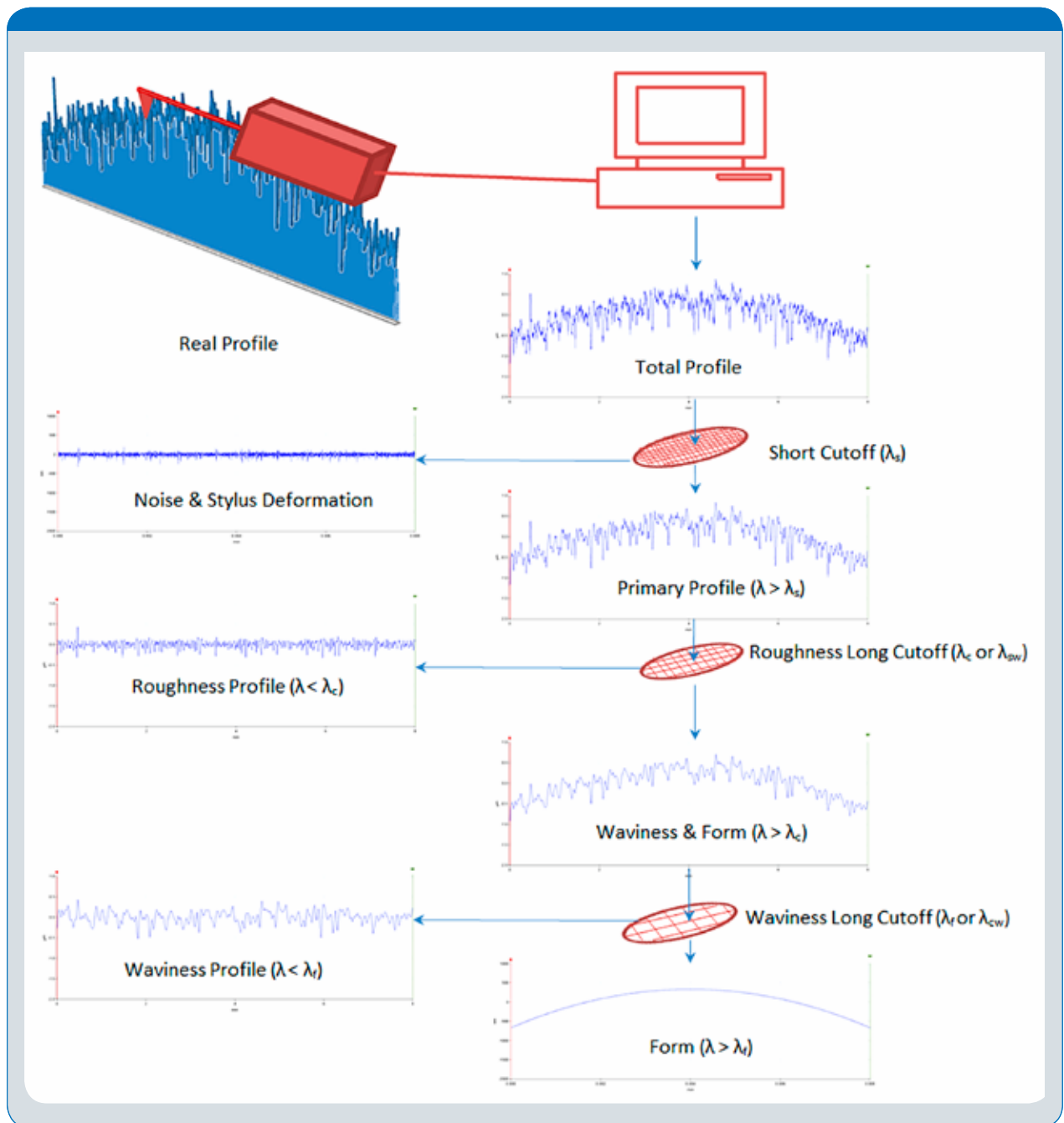


Figure 1. Pictorial representation of affects of application of filters to raw (total) surface profile.

The parameters are differentiated by prefix lettering, where P represents the total profile or primary profile, R represents the roughness profile, and W represents the waviness profile. The method for calculation assigned by ISO 4287 for some parameters is to compute the values over the entire evaluation length, and for others it is to compute the values within a sampling length. The ISO 4288 standard (as well as ASME B46.1) modifies this computation methodology to include estimates of parameters (computed over one sampling length) versus average value of parameters (computed over all available sampling lengths within the

evaluation length). Vision64 software on the DektakXT platform provides an easy method for selecting how these computations and filters are applied. For a complete listing of ISO and ASME parameters, see Appendix.

Figure 3 shows a representation of the separation of a profile into different spacing segments, based on upper and lower limits. The powerful Vision64 software allows for default settings completely in compliance with ISO recommended standards for the measurement analysis.

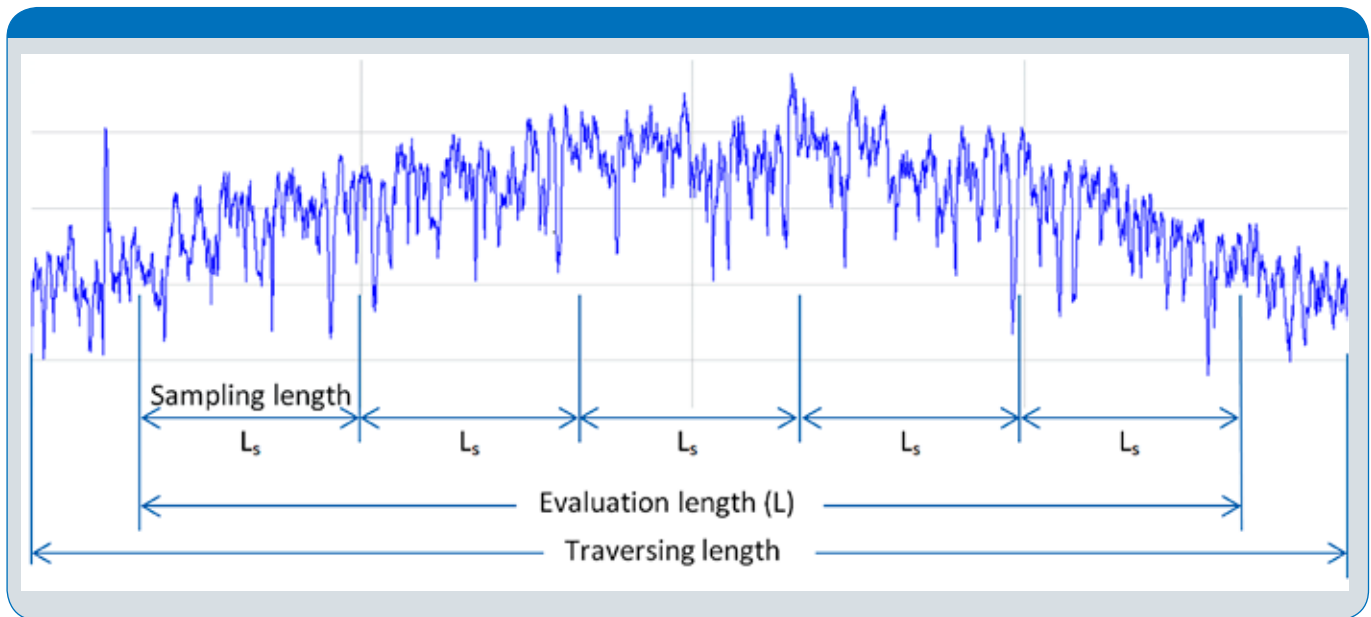


Figure 2. Total Profile with divisions into Sampling, Evaluation, and Traversing Lengths.

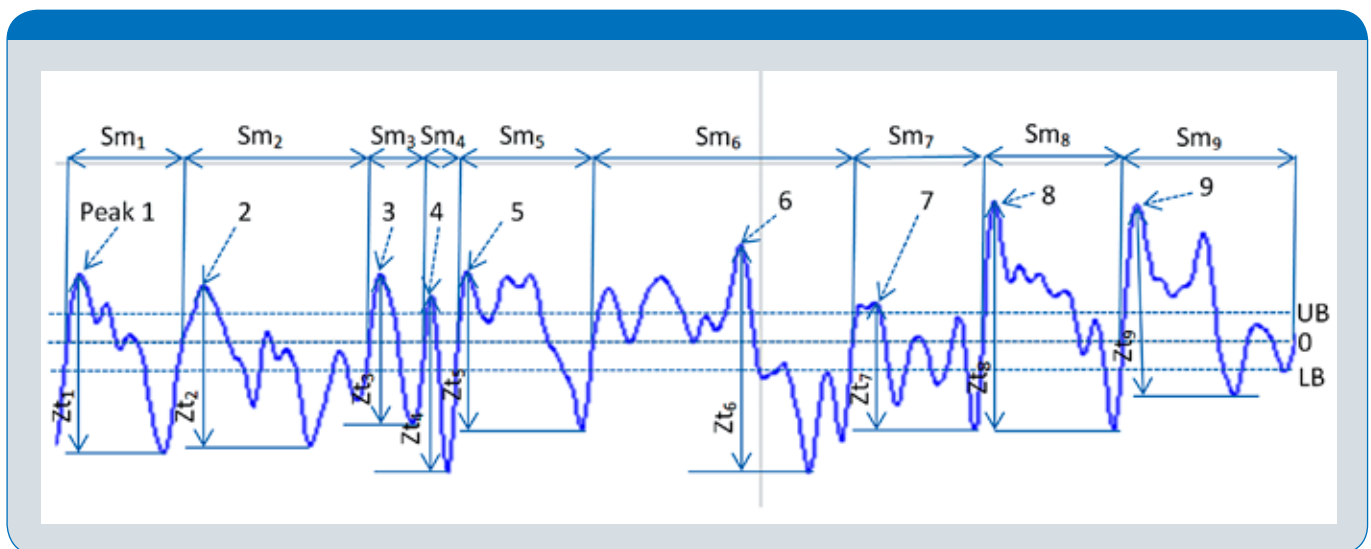


Figure 3. Segments of a profile showing distance between peaks and adjacent valleys, as well as identification of additional peaks based on ISO 4288 standards.

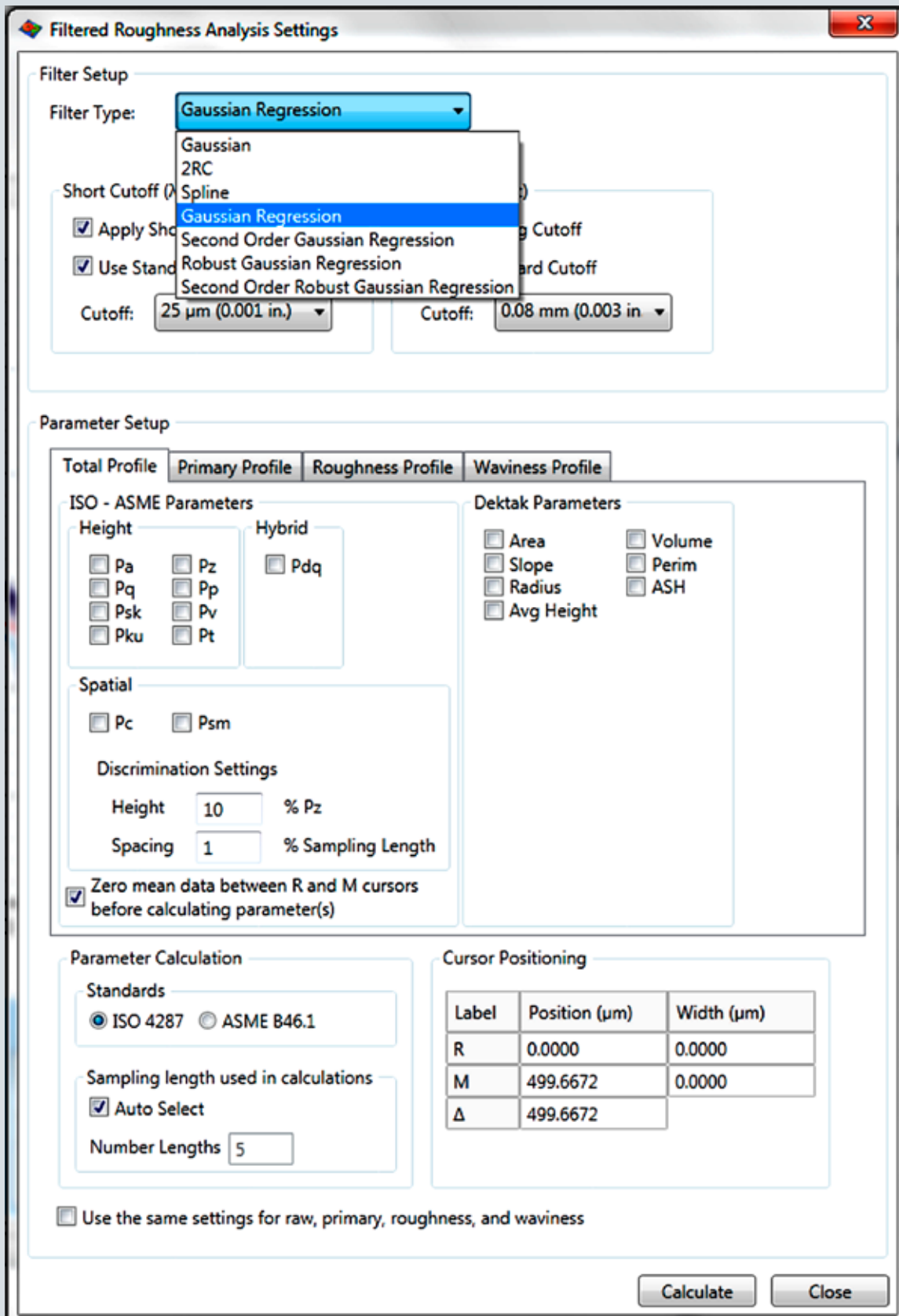


Figure 4. Filtered Roughness dialog settings in Vision64 software for DektakXT.

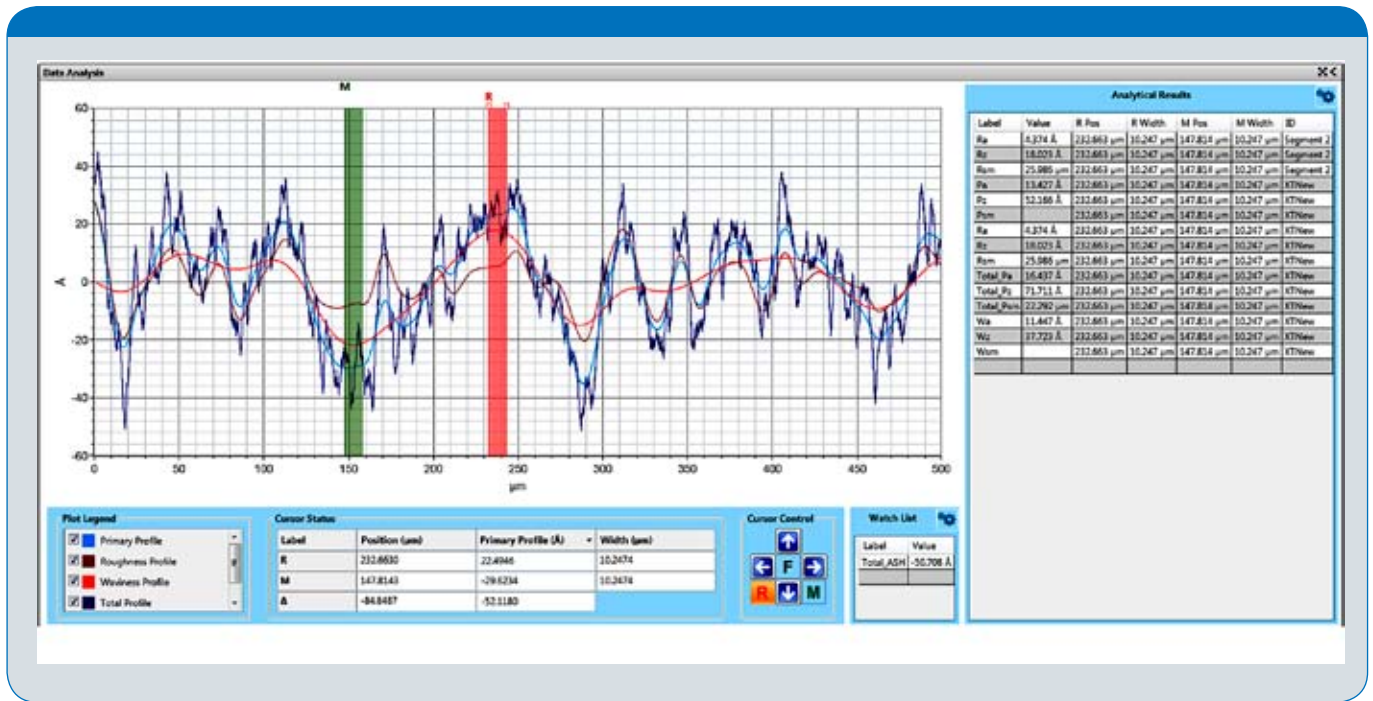


Figure 5. Example 2D profiles on a silicon wafer showing the four profiles (total, primary, waviness, and roughness) according to prescribed filter settings.

The digital filters are applied with specified cutoffs λ_c and λ_s , which stand for the long and short wave cut offs, respectively. The two equations below show the mathematics of modifying a particular signal component by this filtering (Gaussian-filtered roughness and waviness). At $\lambda = \lambda_c, \lambda_s$ the amplitude of the particular component of the signal is attenuated 50%.

$$A_0(\lambda) = A_1(\lambda) * \left(1 - \exp \left(- \pi \left(\frac{\alpha \lambda_c}{\lambda} \right)^2 \right) \right)$$

$$A_0(\lambda) = A_1(\lambda) * \exp \left(- \pi \left(\frac{\alpha \lambda_s}{\lambda} \right)^2 \right)$$

Conclusions

The application of filtering is a straightforward task using Vision64 software when measuring your test articles on the DektakXT platform. ISO or ASME defined cutoff wavelengths can be implemented by checking a box; user-defined cutoffs can also be defined and used by unchecking the standard cutoff box and typing into a dialog for entry. Bruker offers 45° cone angle tips for compliance with ISO specifications for surface 2D profilometry as well as 60° cone angle tips for use on the DektakXT.

Appendix

Extreme Height Parameters			
Parameters	Profile Type	ISO 4287 & ISO 4288	ASME B46.1
Maximum profile peak height (Pp , Rp , Wp)	Primary/ Total Profile	Pp = Maximum peak height of a primary or total profile over an evaluation length.	
	Roughness	$Rp = (Rp_1 + Rp_2 + \dots + Rp_n)/n$ Where Rp_n calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	Rp = Maximum peak height of a roughness profile over an evaluation length.
	Waviness	$Wp = (Wp_1 + Wp_2 + \dots + Wp_n)/n$ Where Wp_n calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	Wp = Maximum peak height of a waviness profile over an evaluation length.
Maximum profile valley depth (Pv , Rv , Wv)	Primary/ Total Profile	Pv = Maximum valley depth of a primary or total profile over an evaluation length.	
	Roughness	$Rv = (Rv_1 + Rv_2 + \dots + Rv_n)/n$ Where Rv_n calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	Rv = Maximum valley depth of a roughness profile over an evaluation length.
	Waviness	$Wv = (Wv_1 + Wv_2 + \dots + Wv_n)/n$ Where Wv_n calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	Wv = Maximum valley depth of a waviness profile over an evaluation length.
Total Height of Profile (Pt , Rt , Wt)	Primary/ Total Profile	$Pt = Pp + Pv $ Pp and Pv calculated over an evaluation length.	
	Roughness	$Rt = Rp + Rv $ Rp and Rv calculated over an evaluation length.	
	Waviness	$Wt = Wp + Wv $ Wp and Wv calculated over an evaluation length.	
Maximum height of profile (Pz , Rz , Wz)	Primary/ Total Profile	$Pz = Pt$	
	Roughness	$Rz = (Rt_1 + Rt_2 + \dots + Rt_n)/n$ Where Rt_n calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	
	Waviness	$Wz = (Wt_1 + Wt_2 + \dots + Wt_n)/n$ Where Wt_n calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	
Mean height of profile elements (Pc , Rc , Wc)	Primary/ Total Profile	See figure 3. $Pc = (Zt_1 + Zt_2 + \dots + Zt_j)/j$ j is a number profile elements over an evaluation length of total or primary profile. Zt is the profile element height.	
	Roughness	$Rc = (Rc_1 + Rc_2 + \dots + Rc_n)/n$ Where Rc_n calculated on a roughness profile over the sampling length n . n is a number of sampling lengths.	See figure 3. $Rc = (Zt_1 + Zt_2 + \dots + Zt_n)/j$ j is a number of profile elements over an evaluation length of roughness profile. Zt is the profile element height.
	Waviness	$Wc = (Wc_1 + Wc_2 + \dots + Wc_n)/n$ Where Wc_n calculated on a waviness profile over the sampling length n . n is a number of sampling lengths.	See figure 3. $Wc = (Zt_1 + Zt_2 + \dots + Zt_n)/j$ j is a number of profile elements over an evaluation length of waviness profile. Zt is the profile element height.

Average Height Parameters

Parameters	Profile Type	ISO 4287 & ISO 4288	ASME B46.1
Arithmetical mean deviation (<i>Pa</i> , <i>Ra</i> , <i>Wa</i>)	Primary/ Total Profile	$Pa = (Z_1 + Z_2 + \dots + Z_N)/N$ Where <i>N</i> is a number of data points of total profile or primary profile over an evaluation length. <i>Z</i> is height value of total profile or primary profile.	
	Roughness	$Ra = (Ra_1 + Ra_2 + \dots + Ra_n)/n$ Where <i>Ra_n</i> calculated on a roughness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Ra = (Z_1 + Z_2 + \dots + Z_N)/N$ Where <i>N</i> is a number of data points of roughness profile over an evaluation length. <i>Z</i> is height value of roughness profile.
	Waviness	$Wa = (Wa_1 + Wa_2 + \dots + Wa_n)/n$ Where <i>Wa_n</i> calculated on a waviness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Wa = (Z_1 + Z_2 + \dots + Z_N)/N$ Where <i>N</i> is a number of data points of waviness profile over an evaluation length. <i>Z</i> is height value of waviness profile.
Root mean square deviation (<i>Pq</i> , <i>Rq</i> , <i>Wq</i>)	Primary/ Total Profile	$Pq = \sqrt{(Z_1^2 + Z_2^2 + \dots + Z_N^2)/N}$ Where <i>N</i> is a number of data points of total profile over evaluation length. <i>Z</i> is height value of total profile or primary profile.	
	Roughness	$Rq = (Rq_1 + Rq_2 + \dots + Rq_n)/n$ Where <i>Rq_n</i> calculated on a roughness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Rq = \sqrt{(Z_1^2 + Z_2^2 + \dots + Z_N^2)/N}$ Where <i>N</i> is a number of data points of roughness profile over evaluation length. <i>Z</i> is height value of roughness profile.
	Waviness	$Wq = (Wq_1 + Wq_2 + \dots + Wq_n)/n$ Where <i>Wq_n</i> calculated on a waviness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Wq = \sqrt{(Z_1^2 + Z_2^2 + \dots + Z_N^2)/N}$ Where <i>N</i> is a number of data points of waviness profile over evaluation length. <i>Z</i> is height value of waviness profile.
Skewness (<i>Psk</i> , <i>Rsk</i> , <i>Wsk</i>)	Primary/ Total Profile	$Psk = \frac{(Z_1^3 + Z_2^3 + \dots + Z_N^3)/N}{P_q^3 N}$ Where <i>N</i> is a number of data points of total profile over an evaluation length. <i>Z</i> is height value of total profile or primary profile.	
	Roughness	$Rsk = (Rsk_1 + Rsk_2 + \dots + Rsk_n)/n$ Where <i>Rsk_n</i> calculated on a roughness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Rsk = \frac{(Z_1^3 + Z_2^3 + \dots + Z_N^3)}{R_q^3 N}$ Where <i>N</i> is a number of data points of roughness profile over evaluation length. <i>Z</i> is height value of roughness profile.
	Waviness	$Wsk = (Wsk_1 + Wsk_2 + \dots + Wsk_n)/n$ Where <i>Wsk_n</i> calculated on a waviness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Wsk = \frac{(Z_1^3 + Z_2^3 + \dots + Z_N^3)}{W_q^3 N}$ Where <i>N</i> is a number of data points of waviness profile over an evaluation length. <i>Z</i> is height value of waviness profile.
Kurtosis (<i>Pku</i> , <i>Rku</i> , <i>Wku</i>)	Primary/ Total Profile	$Pku = \frac{(Z_1^4 + Z_2^4 + \dots + Z_N^4)}{P_q^4 N}$ Where <i>N</i> is a number of data points of total profile over an evaluation length. <i>Z</i> is height value of total profile or primary profile.	
	Roughness	$Rku = (Rku_1 + Rku_2 + \dots + Rku_n)/n$ Where <i>Rku_n</i> calculated on a roughness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Rku = \frac{(Z_1^4 + Z_2^4 + \dots + Z_N^4)}{R_q^4 N}$ Where <i>N</i> is a number of data points of roughness profile over an evaluation length. <i>Z</i> is height value of roughness profile.
	Waviness	$Wku = (Wku_1 + Wku_2 + \dots + Wku_n)/n$ Where <i>Wku_n</i> calculated on a waviness profile over the sampling length <i>n</i> . <i>n</i> is a number of sampling lengths.	$Wku = \frac{(Z_1^4 + Z_2^4 + \dots + Z_N^4)}{W_q^4 N}$ Where <i>N</i> is a number of data points of waviness profile over evaluation length. <i>Z</i> is height value of waviness profile.