SOFTWARE FOR THIN FILM DATA ANALYSIS

Absolutely no hardware or Operating system lock. Combine data from different sources, model them together or separately, add pictures and data from Imaging ellipsometer, mapping data, AFM pictures, etc. Use your favorite computer and operating system- don't worry be happy

TFCompanion Software:

Complete data analysis for Standard & Imaging ellipsometry, reflectance and transmittance measurements

TFCompanion™ *is a powerful and user-friendly software application for thin film analysis and metrology. It is a fusion of optical metrology, material science, and process development experience with the latest computer technology.*

- **Calculate filmstack parameters based on measurement results**
- **Simulate measurement sensitivity and optical response from the filmstack**
- **Estimate measurements repeatability and optimize measurement recipe**
- Measurements data can be imported from the text (ASCII) file in SOPRA, Woollam, Beaglehole Instruments, Nanofilm, Jobin-Yvon and many other formats. Manual data input, other instruments formats, direct data acquisition and network data transfer (TCP IP) are also supported.
- TFCompanion includes extensive library of material's optical properties. New materials can be added by user manually or imported from the text files (TFCompanion, SOPRA, Rudolph and other materials formats are supported)
- Wide range of parameterized materials supported (Cauchy, Sellmeier, EMA, Lorentz oscillator, Lorentz-Drude, Tauc-Lorentz, etc.)
- Results can be presented in tabular form; 2D or 3D (surface, contour, 3D lines) plot

Optical measurements are indirect in that they are measuring optical response of the physical properties not the properties themselves. One needs to solve an "inverse problem" in order to find the value of actual physical properties ((like thicknesses of the layers and optical properties of the materials) of interest. The "inverse problem" is solved numerically by finding the best fit between measured and calculated data and physical properties are inferred from the model that gives the best fit. It is important to check the validity of the model, understand the sensitivity of the measured data to parameters of interest, and the correlation of these parameters in the context of specific measurement recipe, in order to get reliable results. TFCompanion simplifies this task by combining versatile analytical tools for interpretation of measured data. It includes simulation and sensitivity analysis, gives the ability to estimate measurement/calculation errors, create and optimize measurement recipes. In research environment this allows to develop reliable and comprehensive measurement strategy; in production environment it helps mitigate tradeoffs between measurement accuracy and throughput.

TFCompanion provides flexible configuration of access level, feature set and capabilities. It supports both standalone and connected mode. In connected mode it can provide direct data acquisition and control of the measurements, in a standalone mode the measured data can be imported and analyzed off line. It supports Operator, Engineer and Administrator user levels with different access privileges and features available. TFCompanion is suitable for R&D and production environment.

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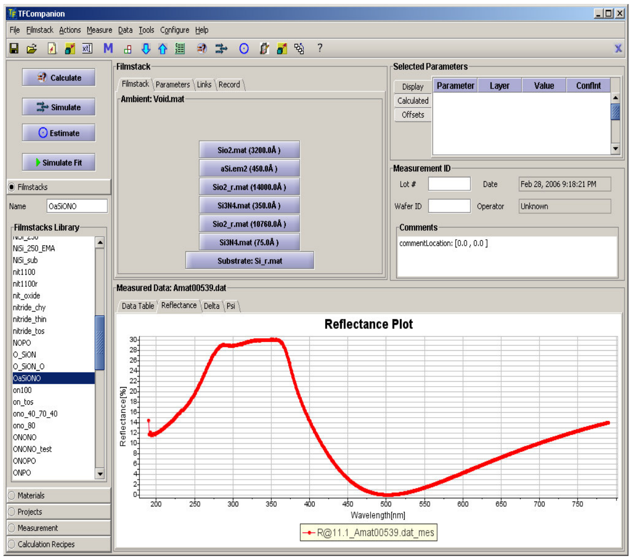
SOFTWARE FOR THIN FILM DATA ANALYSIS



Name: OaSiONO

Ambient: Void.mat

- Sio2.mat (3200.0Å)
- aSi.em2 (450.0Å)
- Sio2_r.mat (14000.0Å)
- Si3N4.mat (350.0Å)
- Sio2_r.mat (10760.0Å)
- Si3N4.mat (75.0Å)
- Substrate: Si_r.mat

Selected Parameters

Parameter	Layer	Value	ConfInt

Measurement ID

Lot #:

Date: Feb 28, 2006 9:18:21 PM

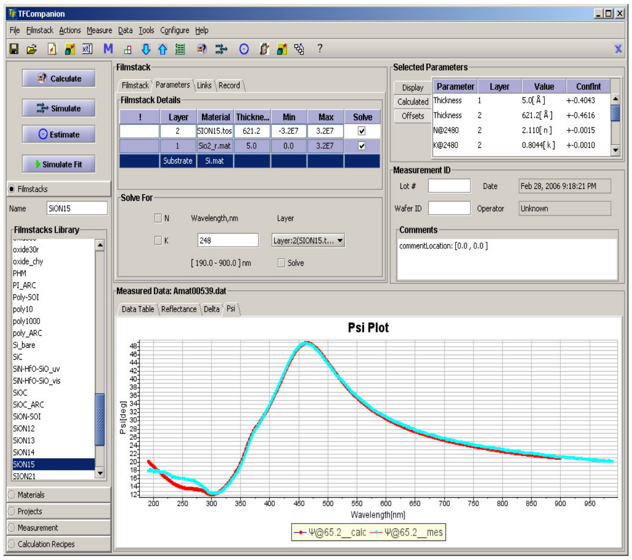
Wafer ID:

Operator: Unknown

Comments: commentLocation: [0.0 , 0.0]

Measured Data: Amat00539.dat

Main window view (Engineer/Administrator level)



Name: SION15

Filmstack Details

!	Layer	Material	Thickne...	Min	Max	Solve
	2	SION15.tos	621.2	-3.2E7	3.2E7	☑
	1	Sio2_r.mat	5.0	0.0	3.2E7	☑
	Substrate	Si.mat				

Solve For

☐ N Wavelength,nm: 248 Layer: Layer:2(SION15.t...

☐ K [190.0 - 900.0] nm ☐ Solve

Selected Parameters

Parameter	Layer	Value	ConfInt
Thickness	1	5.0[Å]	+-0.4043
Thickness	2	621.2[Å]	+-0.4616
N@2480	2	2.110[n]	+-0.0015
K@2480	2	0.8044[k]	+-0.0010

Measurement ID

Lot #:

Date: Feb 28, 2006 9:18:21 PM

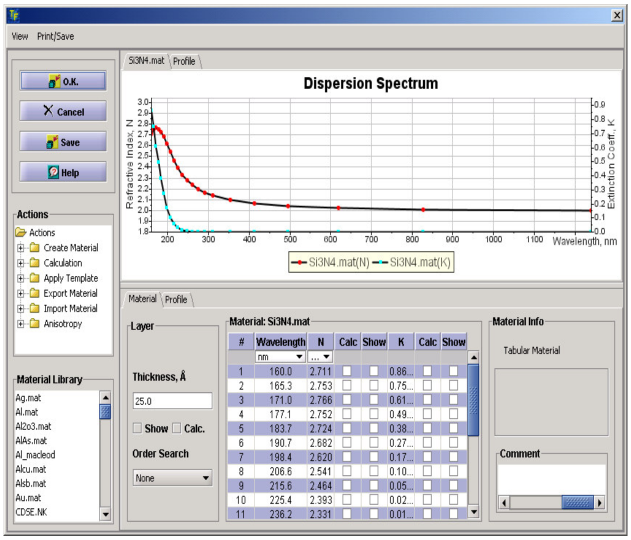
Wafer ID:

Operator: Unknown

Comments: commentLocation: [0.0 , 0.0]

Measured Data: Amat00539.dat

Main window view (data fit and calculated parameters)



Layer

Thickness, Å: 25.0

☐ Show ☐ Calc.

Order Search: None

Material: Si3N4.mat

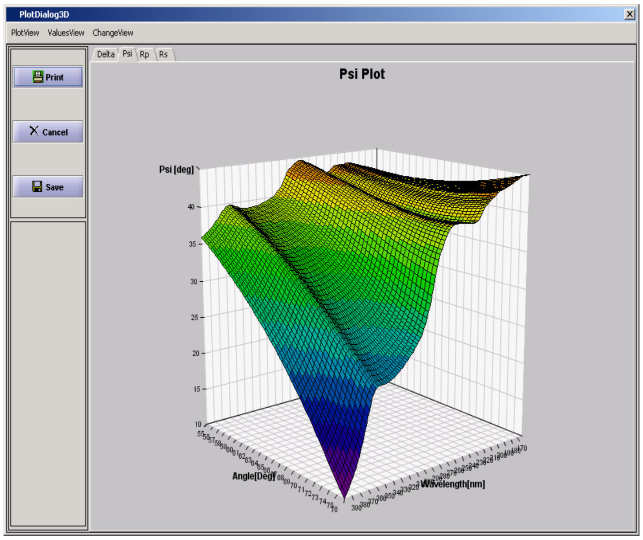
#	Wavelength	N	Calc	Show	K	Calc	Show
	nm	...					
1	160.0	2.711	☐	☐	0.86...	☐	☐
2	165.3	2.753	☐	☐	0.75...	☐	☐
3	171.0	2.766	☐	☐	0.61...	☐	☐
4	177.1	2.752	☐	☐	0.49...	☐	☐
5	183.7	2.724	☐	☐	0.38...	☐	☐
6	190.7	2.682	☐	☐	0.27...	☐	☐
7	198.4	2.620	☐	☐	0.17...	☐	☐
8	206.6	2.541	☐	☐	0.10...	☐	☐
9	215.6	2.464	☐	☐	0.05...	☐	☐
10	225.4	2.393	☐	☐	0.02...	☐	☐
11	236.2	2.331	☐	☐	0.01...	☐	☐

Material Info

Tabular Material

Comment

Layer–detailed view (Engineer/Administrator level)



Simulated data plot (3D)

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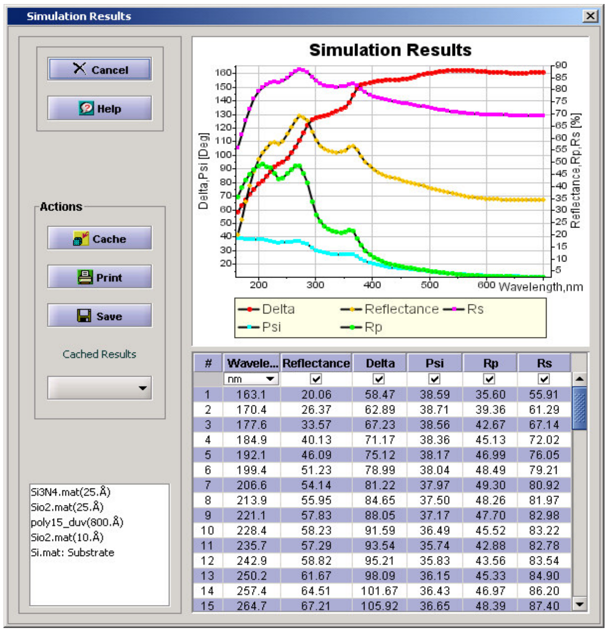
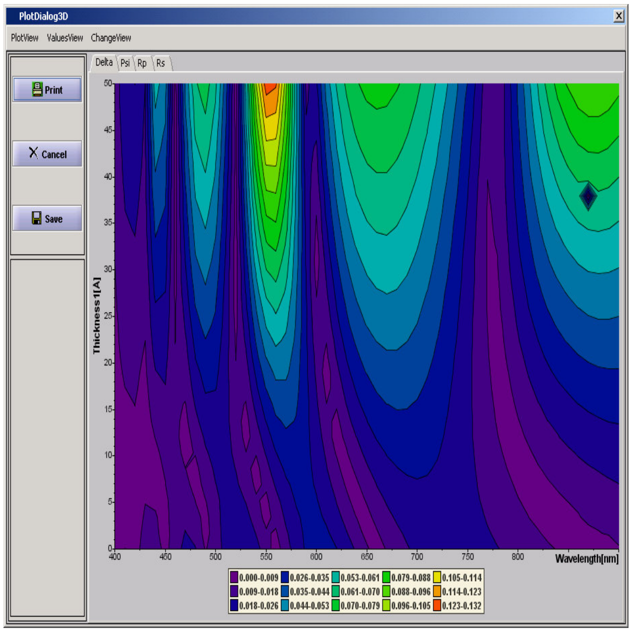


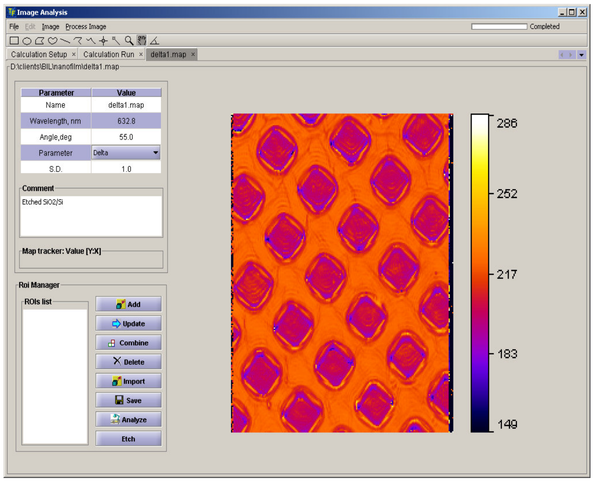
Si3N4.mat(25.Å)
Sio2.mat(25.Å)
poly15_duv(800.Å)
Sio2.mat(10.Å)
Si.mat: Substrate

#	Wavele...	Reflectance	Delta	Psi	Rp	Rs
	nm	☑	☑	☑	☑	☑
1	163.1	20.06	58.47	38.59	35.60	55.91
2	170.4	26.37	62.89	38.71	39.36	61.29
3	177.6	33.57	67.23	38.56	42.67	67.14
4	184.9	40.13	71.17	38.36	45.13	72.02
5	192.1	46.09	75.12	38.17	46.99	76.05
6	199.4	51.23	78.99	38.04	48.49	79.21
7	206.6	54.14	81.22	37.97	49.30	80.92
8	213.9	55.95	84.65	37.50	48.26	81.97
9	221.1	57.83	88.05	37.17	47.70	82.98
10	228.4	58.23	91.59	36.49	45.52	83.22
11	235.7	57.29	93.54	35.74	42.88	82.78
12	242.9	58.82	95.21	35.83	43.56	83.54
13	250.2	61.67	98.09	36.15	45.33	84.90
14	257.4	64.51	101.67	36.43	46.97	86.20
15	264.7	67.21	105.92	36.65	48.39	87.40

Simulation data window (2D)



Sensitivity of Delta to thickness (contour plot).



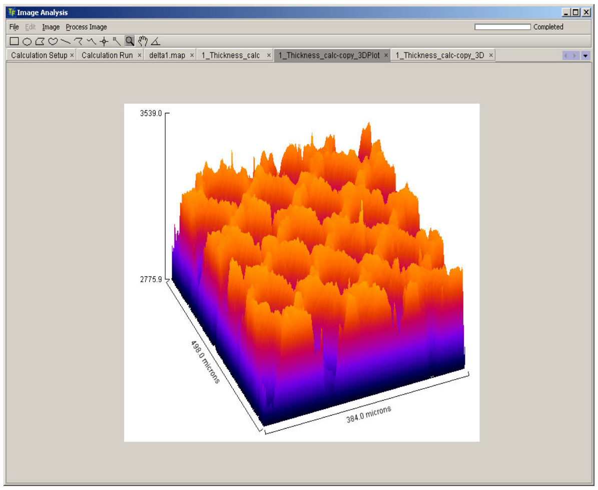
D:\clients\BIL\nanofilm\delta1.map

Parameter	Value
Name	delta1.map
Wavelength, nm	632.8
Angle,deg	55.0
Parameter	Delta
S.D.	1.0

Comment: Etched SiO2/Si

Map tracker: Value [Y:X]

Imaging calculation dialog (Imported measured data)



Thickness map (calculation results)

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TFCompanion Versions and Features Guide

Several versions and capability levels of TFCompanion are available. Available versions (in ascending order of features) are **Basic, Standard, Advanced, Imaging, ImagingPro**, and **Enterprise**:

- **Basic** is introductory version that supports only simulation features. It is intended as educational and reference tool, e.g. reviewing dispersions of different materials, doing simulation and sensitivity analysis;
- **Standard** version has most commonly used features of thin-film data analysis
- **Advanced** version adds support for batch processing, error estimator and additional advanced features;
- **Imaging** version supports analysis of the image or mapped data, in particular imaging Ellipsometry and Reflectometry data analysis. Basic image analysis of regular (intensity) images is also included;
- **ImagingPro** version supports additional advanced features: batch image processing, multiple ROIs analysis, etc.;
- **Enterprise** version includes Performance estimator features that enables optimization of the measurement recipes and qualification of metrology equipment

Version features are cumulative - each version has all the features of the lower version plus extra, e.g. Advanced version has all the features of Standard version + extra, Imaging version has all the features of Advanced version +extra.

All versions (except Enterprise) are available in three capability levels: **-R** (only reflectance, transmittance and absorbance); **-E** (only ellipsometry); **-RE** (all parameters). See list of parameters in **Table 1** below.

Table 1. TFCompanion capability levels matrix

Parameter	Description	Capability level			Comment
Description in User Guide (Appendix III)		-R	-E	-RE	All ellipsometry parameters are available in Transmission/Reflectance ellipsometry mode
Δ, Ψ, Cos Δ, Tan Ψ	Delta, Psi angles	-	✓	✓	
X, Y	Alternative to Delta/Psi	-	✓	✓	
Absolute Phase of Rp, Rs, Tp, Ts		-	✓	✓	
α, β 1)	RAE, RPE measured values	-	✓	✓	Directly measured quantities in RAE or PRE (rotating polarizer/analyzer) ellipsometry systems
a2, b2, a4, b4 1)	RCE measured values	-	✓	✓	Directly measured quantities in RCE (rotating compensator) ellipsometry systems
Reflectance	Rp, Rs, normal	✓	-	✓	
Transmittance	Tp, Ts, normal	✓	-	✓	
Absorbance	Ap, As, normal	✓	-	✓	

[1] System dependent parameters are available for simulation/sensitivity analysis only. Can be customized for specific system to use in calculations

Table 2. TFC Standard & Advanced versions – Features Matrix

Technical Feature	Standard Version	Advanced Version	Comments
Data Import			
Text file import: Woollam, Sopra, Beaglehole, Nanofilm, Jobin-Yvon (Horiba), Rudolph, TFCompanion	✓	✓	Batch data import requires Advanced version. Imaging and mapped data import requires Imaging version
Manual input	✓	✓	
Direct data acquisition (control and data acquisition module is included)	–	✓	Available for Ocean Optics and Avantes spectrometers for reflectance/transmittance data only
Simulation/Sensitivity analysis			
Spectral variables: Wavelength, Angle, any filmstack parameter	✓	✓	2D and 3D (two variables) plots
Sensitivity variable: Wavelength, Angle, any filmstack parameter	✓	✓	2D and 3D (two variables) plots
Finite Wavelength, Angle resolution simulation	–	✓	
Calculation			
Modified Marquardt-Levenberg (global) method	✓	✓	
Order (grid) search	✓	✓	
FFT (Power Spectral Density) for thick layer	–	✓	Thickness estimate
Unlimited number of layers	✓	✓	
Linked layers and/or materials (e.g. Layers grouping)	–	✓	LH and superlattice grouping of repeated layers etc.
Multisample calculation	–	✓	Simultaneous fitting of the data for several samples
Thick layers (incoherent layers), substrate backside reflection correction	–	✓	
Inhomogeneous layers (optical properties profile)	–	✓	Linear, Gaussian, etc. profiles of optical constants
Surface roughness correction	✓	✓	Reflectance, Transmittance only
Batch calculations	–	✓	Sequence of measurements (e.g. in situ measurement data) or production batch. Trend chart and statistics output.
Full control of calculations conditions	✓	✓	

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Technical Feature	**Standard Version**	**Advanced Version**	**Comments**
Confidence intervals and correlation coefficients for all calculated parameters	✓	✓	
Support separation of calculated and displayed parameters	✓	✓	e.g. one can calculate Cauchy coefficients and display corresponding optical constants at specified wavelength
Materials	Supported materials dispersion types		
Tabular (NK Table)	✓	✓	
Cauchy	✓	✓	oxides
CauchyK	✓	✓	With light absorption
Cauchy Exponential	✓	✓	
Sellmeier	✓	✓	Glasses
Sellmeier2	✓	✓	
EMA (2 and 3 component)	✓	✓	Physical mixture (polySi, roughness layer)
Harmonic oscillator	--	✓	Crystaline (Si, GaAS)
Tauc-Lorentz Oscillator	--	✓	Amorphous (aSi, SiON)
Drude-Lorentz oscillator	--	✓	With metals/free carriers
Cody-Lorentz oscillator	--	✓	Amorphous with UV
Cody-Lorentz-Urbach oscillator	--	✓	Dopants, bandgap region
Exciton approximation	--	✓	For polymer materials
Binary Compound approximation	--	✓	Compound/multi-component materials(e.g. CIGS)
Import/Export materials From/to text file	✓	✓	SOPRA, TFCompanion text formats
Parameterized models to a Tabular (NK table)	✓	✓	Export data to text file
Tabular material to parameterized model	✓	✓	Fitting of parameterized model to tabular data
Anisotropic materials (uniaxial, biaxial)[1]	–	✓	Tabular and all parameterized models
Materials database	✓	✓	Extended database is also available free of charge
2D interactive plots	✓	✓	plots (dispersion, results of simulation/calculation, etc.)
3D interactive plots (surface, contour and 3D line)	✓	✓	Simulation, sensitivity results
Printing and exporting plots	✓	✓	

Technical Feature	Standard Version	Advanced Version	Comments
Error estimation	Estimation of filmstack parameters measurement precision		
Error Estimator	–	✓	One parameter variation only
PSE Wizard	–	–	Enterprise version
PSE Batch	–	–	Enterprise version
Productivity features			
Project/workspace environment	✓	✓	Save and load all project info in database
Templating mechanism	✓	✓	One click operation
Software configuration	✓	✓	Units, resolution, appearance, etc.

[1] Custom module by request

Table 3. TFC Imaging – Features Matrix

Technical Feature	TFC Imaging	TFC ImagingPro *	Comments
Data Import/Export			
Standard images (gif, jpeg, png, tiff, fits, bmp, raw, dicom)	✓	✓	
Data Images (Different text formats: Text image (map), PicoScan, etc.)	✓	✓	All leading imaging ellipsometry/Reflectometry formats are supported. Other formats are added on request free of charge
Data Images transfer over network (TCP IP)	-	✓	
Multiple images (image sequence)	-	✓	Loading files from directory, zip archive and URL are supported
Import/Export ROI files (templates, grids, data)	Only TFC exported ROIs	✓	Popular formats are added on request free of charge

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Technical Feature	TFC Imaging	TFC ImagingPro	Comments
Direct data acquisition from camera/ image grabber board [1] (special module provided on customer request)	-	✓	PixelSmart frame grabber, Bruxton framegrabber (Andor, Princeton instruments, Hamamatsu..)
Calculations (Ellipsometry/Reflectometry/ Transmittance/Absorbance)			All filmstack, material models, calculation control options and measured data types of Advanced version are supported
Full map calculation	✓	✓	
LineScan calculation (straightline, polyline, freeform)	✓	✓	
Combination of several maps in one calculation set (e.g. different wavelengths or AOI measurements of the same sample)	✓	✓	Number of maps in the calculation set is unlimited
Image point or ROI average data calculation	✓	✓	Data is extracted from all images in specified calculation set
Using different models (filmstacks) for different ROIs	✓ (only one ROI per calculation)	✓	
Batch processing of multiple ROIs (with optional different models)	-	✓	
Batch processing of multiple maps (Image sequence)	-	✓	Full map, selected ROIs, averaged ROIs
Kinetics analysis (from image sequence calculation) [2]	-	✓	Special module to customer specification
Image Processing			
Calibration (pixels width, height and density)	✓	✓	Density distributions fitted to commonly used function (polynomial, log, etc.)
Angular distortion, Angle of incidence value & cone angle correction	-	✓	
Background correction and normalization	-	✓	Including correction for uneven illumination
Threshold setting	✓ (only manual)	✓	Manual and automatic (different strategies including maximum entropy, Otsu, etc.)
Smoothing, Sharpening, Edge detection	-	✓	
Filtering: Convolution, FFT, Kalman, LoG, 2D Gaussian, etc.	-	✓	
Histogram	✓	✓	Including color histogram for RGB images (separate histogram for each color)
Dynamic Linescan	✓	✓	Data is updated as user moves line in the image

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Technical Feature	TFC Imaging	TFC ImagingPro	Comments
Co localization of images	-	✓	Using Correlation analysis
Measure and Label	-	✓	Area, perimeter length, s.d., mean, min, max and other standard parameters
Zooming and rotation of images	✓	✓	
Image math	-	✓	Add, subtract, multiply, divide on another image or constant. Can apply also some predefined equations
Image adjustment	✓	✓	Leveling contrast, brightness, histogram equalization, etc
Utilities			
Scale Bar	✓	✓	Place calibrated scale bar on the image
Change Colors, hues, Lut	✓	✓	
Managing ROIs	✓	✓	Rectangular, oval, polygon, freestyle, lines
Surface plot	✓	✓	Interactive surface plot with animation
Creating/editing ROI grids	-	✓	
Macro script support (option)	-	✓	Recording, execution, etc

[1] customer may need to provide hardware for integration testing - additional charge for testing may apply

System requirements:

TFCompanion uses Java™ technology and can be installed on MS Windows, Linux, Unix, MacOs and other operating systems that have Java ports.

Standard requirements: 64MB RAM (available to software), CPU 1Ghz+, 30MB of hard drive space.