AL 2010- Nov/Dec 2010

New Solutions for Surface Texture Analysis

[Barbara Foster](bfoster@the-mip.com)

For the original (with zoomable images), visit www.americanlaboratory.com (Nov-Dec 2010 issue) or http://new.americanlaboratory.com/913-Technical-Articles/576-New-Solutions-for-Surface-Texture-Analysis/?adpi=2

MONDAY, NOVEMBER 01, 2010

Most microscopists are familiar with confocal microscopy from neuroscience or cell biology. However, very quietly and abruptly, confocal has jumped the fence into industry, becoming a major tool-of-choice for measuring surface texture and wear as well as evaluating thin film thickness and counting, sizing, and defining distribution of particles in epitaxial films. Twenty years ago, when confocals first became commercially available, white light confocals were rare. **LaserTec** (San Jose, CA) and the K series from Technical Instruments of San Francisco (TISF, now**Hyphenated-Systems, Inc**., Burlingame, CA), were the only real competitors. Today, the field is crowded and highly competitive. Recent estimates by T**he Microscopy & Imaging Place, Inc.**(McKinney, TX) put the market for this version of confocal microscopy at about $80 million/year, with a projected growth rate of 20% per year each year for the next three years.[1]

As with conventional biological confocal microscopy, industrial confocals scan the specimen surface with a pinpoint of light, then, at the detector, limit the diameter of the resulting image forming beam. As seen in *Figure 1a*, the resulting image has shallow, well-defined depth of field and an image free of haze and glare. Scanning the stage in the Z direction produces a series of these well-defined planes (Figure 1*a*–*e*), which can then be combined in software to create 3-D reconstructions (1f).

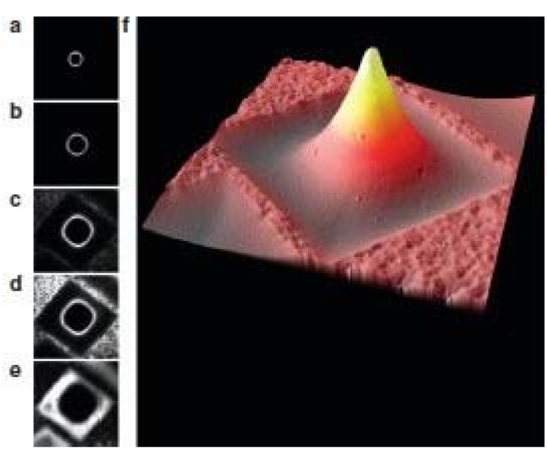

*Figure 1 - a–e) A series of confocal sections acquired at defined Z locations moving from the top of the structure to the bottom. (f) The resulting 3-D reconstruction. (Images courtesy of **Leica GmbH**, Wetzlar, Germany.)*

Biological confocals often use lasers as the light source and scanning mirrors to scan and descan incoming and resulting sample beams. Initially, industrial confocals primarily used white light sources and acoustic-optical tunable filters or spinning disks with arrays of pinholes or slits to scan and descan the beam. Also, while most biological confocal systems use fluorescence to generate images, their industrial cousins use reflected light.

Today, industrial confocals span both the laser scanning and white light spectrum. **Keyence's** VK-9700 (Woodcliff Lake, NJ) and Olympus Industrial's LEXT 4000 (Center Valley, PA) use a white light source for true-color confocal imaging and a violet light-emitting diode (LED) as a secondary light source to enhance resolution. As seen in the equation below*, to calculate the Rayleigh limit of resolution, resolution is directly related to wavelength: Shorter wavelengths enhance the imaging of finer detail. **Carl Zeiss** (Thornwood, NY) offers two versions of confocal: the more industrial ASM 700, which is a white light system, and the more traditional laser-based LSM 700. While the ASM 700 operates in reflected light mode used in most industrial applications, the LSM 700 offers a combination of both fluorescence and reflected light mode, making it an interesting solution in situations in which fluorescence can be applied to image and measure defects, contamination, or special particles of interest.

**Resolution = 0.6l/NA, where l is the wavelength of light, and NA is the numerical aperture related to the collecting angle of the objective.*

Two- and three-dimensional parameters describe complex structure:function relationships

The world of surfaces is a complex domain. Characterizing surfaces is critical. The way a surface behaves, wears, or changes over time or in the presence of a specific environment determines how the things around us function, whether it is the polymeric coating that maintains crispness in a bag of potato chips or the smooth ball bearing that keeps airplanes aloft.

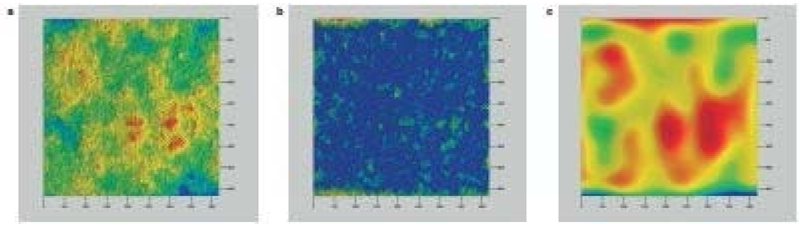

*Figure 2 - Ceramic floor tile: a) Composite image of surface texture, b) roughness component, and c) underlying waviness. Each image was taken with an EC Epiplan Neofluar® (**Carl Zeiss**), 10×/0.25. Single plane: 4163.9 µm × 4163.9 µm × 159.0 µm. Image size: 1024 × 1024 pixels × 54 planes. (Image courtesy of **Carl Zeiss, Inc**.)*

For decades, surfaces have been described in terms of 2-D roughness parameters such as average roughness, peak-to-valley ratios, and peak heights. However, underlying the 2-D characterization may be larger, 3-D influences such as waviness or bow. Both have an impact on how a surface will perform. *Figure 2*illustrates the level of today's roughness characterization. Figure 2*a* shows the composite roughness characterization of a ceramic tile, while Figure 2*b* and *c* depict the roughness and waviness components, respectively.

Traditional profilometry sets the standards

Table 1 Sample comparison of roughness measurements offered by traditional white light interferometers (A) and today's industrial confocals (B)*

A) Traditional profilometry		B) Industrial confocal	
Roughness and waviness:	Bearing parameters:	Roughness and waviness:	Bearing parameters:
Ra, Rku, Rmax, Rp, Rq, Rt,	Rk, Rpk, Rvk, Rsk	Ra, Rku, Rmax, Rp, Rq, Rt, Rv,	Rk, Rpk, Rvk, Rsk
Rv, Ry, Rz, Pc, Pa, Pt, Wa, Wq, Wy	Hybrid parameters:	Ry, Rz, Pc, Pa, Pt, Wa, Wq, Wy	Hybrid parameters:
	Rvolume, RSa, WSa		Rvolume, RSa, WSa

*SWLI data courtesy of **ZYGO, Inc.** (Middletown, CT); confocal list courtesy of **Olympus Industrial**.

For decades, terminology in this arena has been set by more traditional stylus and scanning white light interferometers (SWLIs). As seen in *Table 1*, industrial confocals are catching up. The Olympus LEXT is a case in point. Its graphical user interface (GUI) has been designed to represent roughness, waviness, and bearing ratio parameters in the same terms used by conventional optical profilometry.

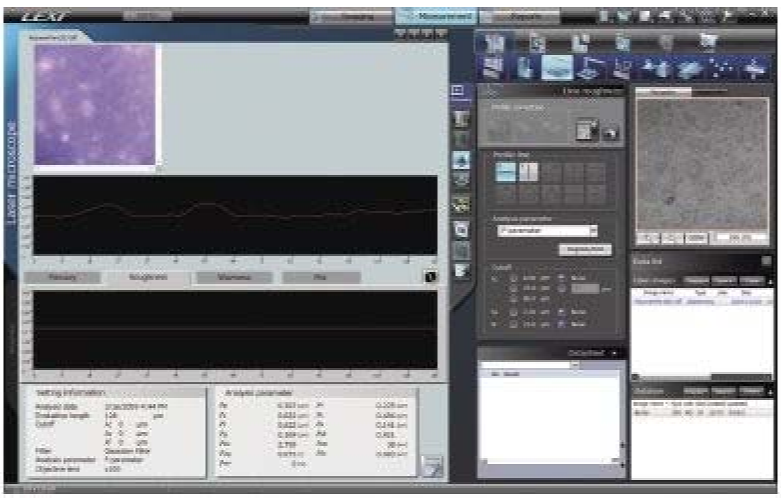

Figure 3 - The user interface for LEXT confocal mirrors a typical SWLI interface. (Image courtesy of ***Olympus Industrial****.)*

Not only are the parameters parallel, but presentation and reporting mimic stylus and SWLI formats. As shown in*Figure 3*, **Olympus** has designed a special GUI to replicate a profilometer menu, including all ISO parameters. In addition is the ability to filter the data to match a profilometer for correlation.

Piecing together the world at large

Unlike interferometry, the field of view (FOV) in confocal microscopy is determined by magnification of the objective. In the simplest terms,

$$FOV = FN_{ep}/M_{objective}$$

where FN = field number of the eyepiece and M = magnification of the objective. As magnification increases, the field of view under observation decreases. How, then, does one compute roughness parameters that are representative of the material at large? Most of the confocal companies now offer stitching programs, which, as depicted in *Figure 4*, combine a sequence of smaller scans into a larger whole.

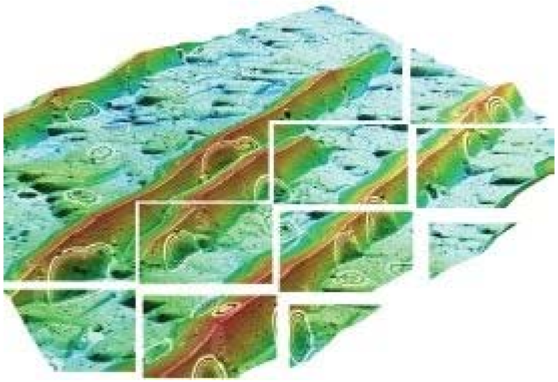

Figure 4 - Special stitching software allows smaller areas to be combined to provide large-area analyses. (Image courtesy of ***Leica****.)*

Stitching presents challenges both mathematically and empirically. Microscope stage movement is not always exact, requiring stitching algorithms to seek information about what was really at the edge of Plate 1 to match it properly with some similar fiduciary structure at the edge of the adjoining plate. Moving from 2-D to 3-D makes the process even more challenging. In its Zen software, Carl Zeiss has instituted next-generation stitching that not only matches segments in XY, but also in Z.

Who's doing what?

Industrial confocals are offered in a variety of configurations and capabilities. Generally, they fall into two categories: more traditional configurations versus hybrids. The **Zeiss** ASM 700, **Keyence** VK-9700 series, and **Olympus** LEXT all fit neatly into the more traditional mold. Each has unique tweaks, but as a group, they offer ease of use, excellent 3-D imaging, and a wide range of surface metrology capabilities. **Hyphenated-Systems** (now distributed as the **Bruker AXS** [Tucson, AZ] VCM™ confocal microscope) is also a member of this cadre, but differs somewhat in its advanced 3-D reconstruction capabilities.

Figure 5 - ***FRT's*** *open architecture combines field-of-view confocal microscopy (right objective) with a chromatic white light confocal point sensor (left) for large area raster scans.*

Among the hybrids, each group member is radically different. As shown in *Figure 5*, the open architecture in the MicroProf 200® **(FRT**, San Jose, CA) architecture allows the user to configure the microscope to fit the measurement need. In this case, the right objective provides an optical path for conventional field-of-view confocal microscopy. The left "objective" is actually a chromatic white light confocal point sensor for large area raster scan measurement. This system can also be extended to include SWLI and atomic force microscopy (AFM), all on a variety of stages ranging from conventional microscope format to very large gantry formats.

Leica is now offering a customized version of **Sensofar's**(Barcelona, Spain) dual core system as the DCM 3D Measuring microscope, combining interferometry and confocal on one stand. This combination is intriguing in that it offers phase shifting and white light interferometry for characterization of very smooth surfaces (<1 nm in roughness) with confocal's higher XY resolution. **Leica** has extensive experience in bullet analysis, and this new offering presents another important tool in that arsenal.

*Figure 6 - **LaserTec's** Optelics offers six different wavelengths to selectively image components. a) Red filtration highlights the circuitry. b) Blue filtration highlights substrate. c) Overlay of the red and blue images illustrating context. Subject: circuit board. (Image courtesy of **LaserTec** and **Nikon Metrology, Inc**.)*

LaserTec, one of the original pioneers in this field, now distributed through the**Nikon Metrology group**(Brighton, MI), has gone a step further with WIDE. Offered on the Optelics H1200W system, WIDE provides two distinctive contrast enhancement mechanisms that can operate simultaneously with its confocal mode. The "W" refers to wavelength. Integrated into the confocal light path is a high-intensity discharge lamp that generates six monochromatic wavelengths ranging from 405 nm (purple) to 630 nm (red) as well as white light. As shown in *Figure 6*, the wavelengths can be tuned to the subject under study to enhance or suppress contrast while taking confocal images. The "D" in "WIDE" refers to DIC (aka "Nomarski"), a well-known optical microscopy approach for enhancing edges in fine detail.

In addition to contrast enhancement, the H1200W has two mechanisms to extend the confocal's surface metrology capabilities. The "I" in WIDE refers to a built-in interferometry system (both Mirau and Linnik interferometers are available), while the "E" stands for "Exceed," and refers to a scanning probe option, realized through the addition of an objective-based AFM (only available outside the U.S.). With a combination of powerful optical microscopy, confocal, interferometry, and AFM on one stand, the Optelics sets a new level for hybrid instrumentation.

From traditional metals and polymers to exotic microfluidics

Traditional SWLIs have an edge when it comes to speed, large scan areas, and ultrafine Z resolution (1 nm or less). However, applications involving steep side walls (>~20°) and higher XY resolution are a better fit for confocals.

*Figure 7 - Changes in metal surface during processing: a) prior to machining, RSa = 18.853 µm; b) after turning, RSa = 5.543 µm; and c) after final polish, RSa = 0.034 µm. (Images courtesy of **Carl Zeiss, Inc**.)*

Figure 7 shows a routine surface roughness application that can be handled by either SWLI or industrial confocal. The average roughness, RSa, of an unmachined part (7*a*) changes dramatically after turning (7*b*) and after the final polish (7*c*).

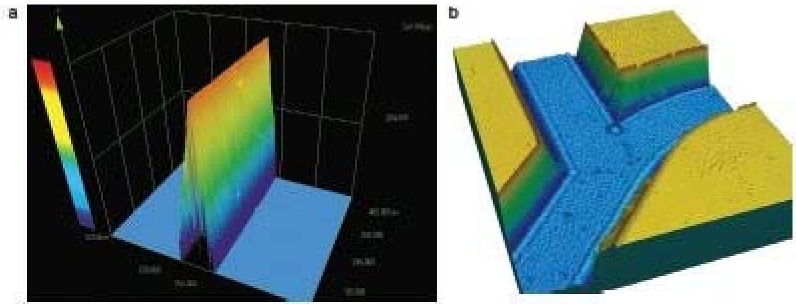

*Figure 8 - a) Measurement of roughness and cutting angle of a razor blade. (Image courtesy of **Olympus Industrial**.) b) Microfluidics channel intersection. (Courtesy of **Bruker AXS** and **Hyphenated-Systems, Inc**.)*

Figure 8 clearly demonstrates the ability of industrial confocals to measure steep angles. The angles on the razor blade (8*a*) measured with the**Olympus** LEXT are 85°. Because they can measure deep channels as well, industrial confocals are finding a happy home in the new arena of microfluidics. Figure 8*b* characterizes the junction between multiple channels in a microfluidics cell, providing the side wall-angle measurement as well as channel depth and width.

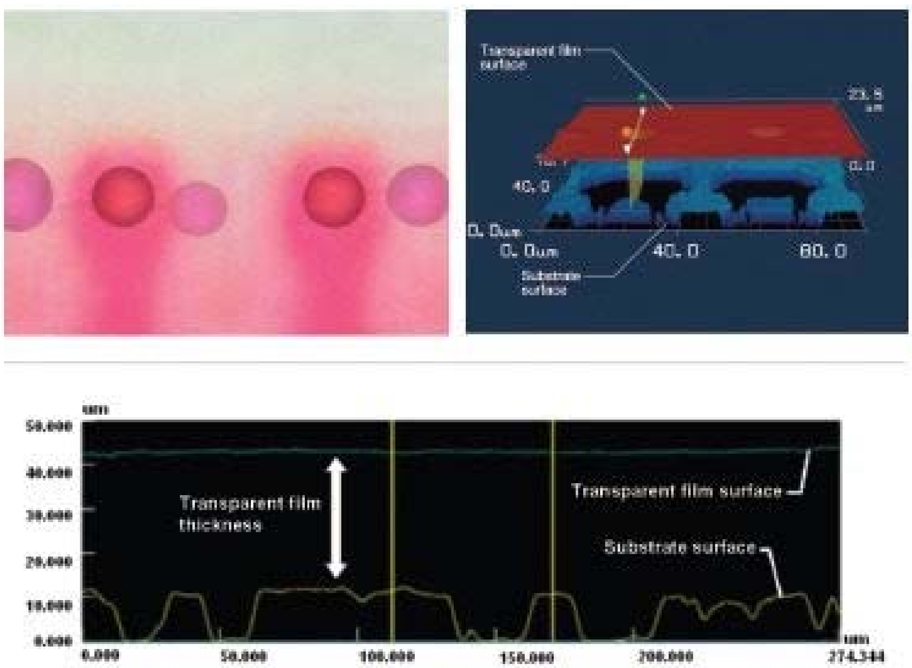

*Figure 9 - Measuring thickness of film on metal substrate. Upper left: Brightfield image of an inkjet printer nozzle. Upper right: 3-D confocal image revealing placement of film over metal substrate. Lower image: Surface profile of metal substrate with measurement bars depicting film thickness at unique points. (Images courtesy of **Keyence**.)*

Because industrial confocals behave like microtomography devices, they can readily define the top and bottom of films on reflective substrates, providing an excellent method for measuring film thickness (*Figure 9*). In addition, they can image particles within the film, providing a unique tool for counting, size, and determining the distribution of inclusions such as bubbles or particles such as the metallic flakes in clear coat.

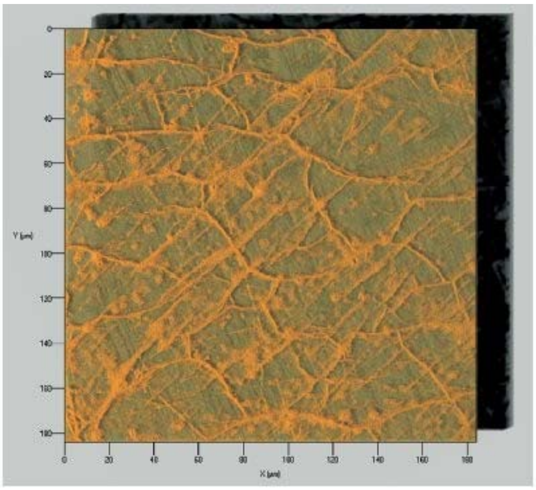

Figure 10 - Fluorescence + confocal: 3-D image of cracks in polymer laminate over metal (488 nm excitation, 3-D shadow projection, LD Epiplan® 50×/0.5 NA, 184.3 µm × 184.3 µm × 24.0 µm. Image size: 512 × 512 pixels. Sample: Dr. S. Rastogi, Dept. of Technical Engineering, TU, Eindhoven, The Netherlands. (Image courtesy of ***Carl Zeiss, Inc****.)*

Figure 10 demonstrates the advantages of adding fluorescence to confocal. In this particular example, the cracks were illuminated using a fluorescent dye. Twenty-one sections were collected and then reconstructed using a 3-D shadow projection. The resulting image clearly depicts the crack structure using the fluorescent component of the image and the underlying metal surface using the reflected light component.

Broader reach and a bright future

The new generation of industrial confocals is a practitioner's dream. Easy to use, sleeker, faster, and more capable, they embody the current "lab to fab" movement, providing research-level capabilities for engineers and researchers as well as the ability to program simplified recipes for more routine analyses and use by less experienced operators. Finally, smaller players are moving into the mainstream, distributed by well-known microscope vendors with extensive reach. **Hyphenated-Systems** is now distributed by **Bruker AXS**, **Sensofar** by **Leica**, and **LaserTec's** Optelics by **Nikon Metrology**. From paper to microfluidics, multilayered packaging materials to semiconductors, industrial confocals have a bright future.

Reference

1. *The Industrial Confocal and Scanning White Light Market*. The Microscopy & Imaging Place, Inc., [in press]

Ms. Foster is President and Chief Strategic Consultant, ***The Microscopy & Imaging Place, Inc****., 7101 Royal Glen Trail, Ste. A, McKinney, TX 75070, U.S.A.; tel.: 972-924-5310; e-mail: bfoster@the-mip.com. The author welcomes questions and comments.*