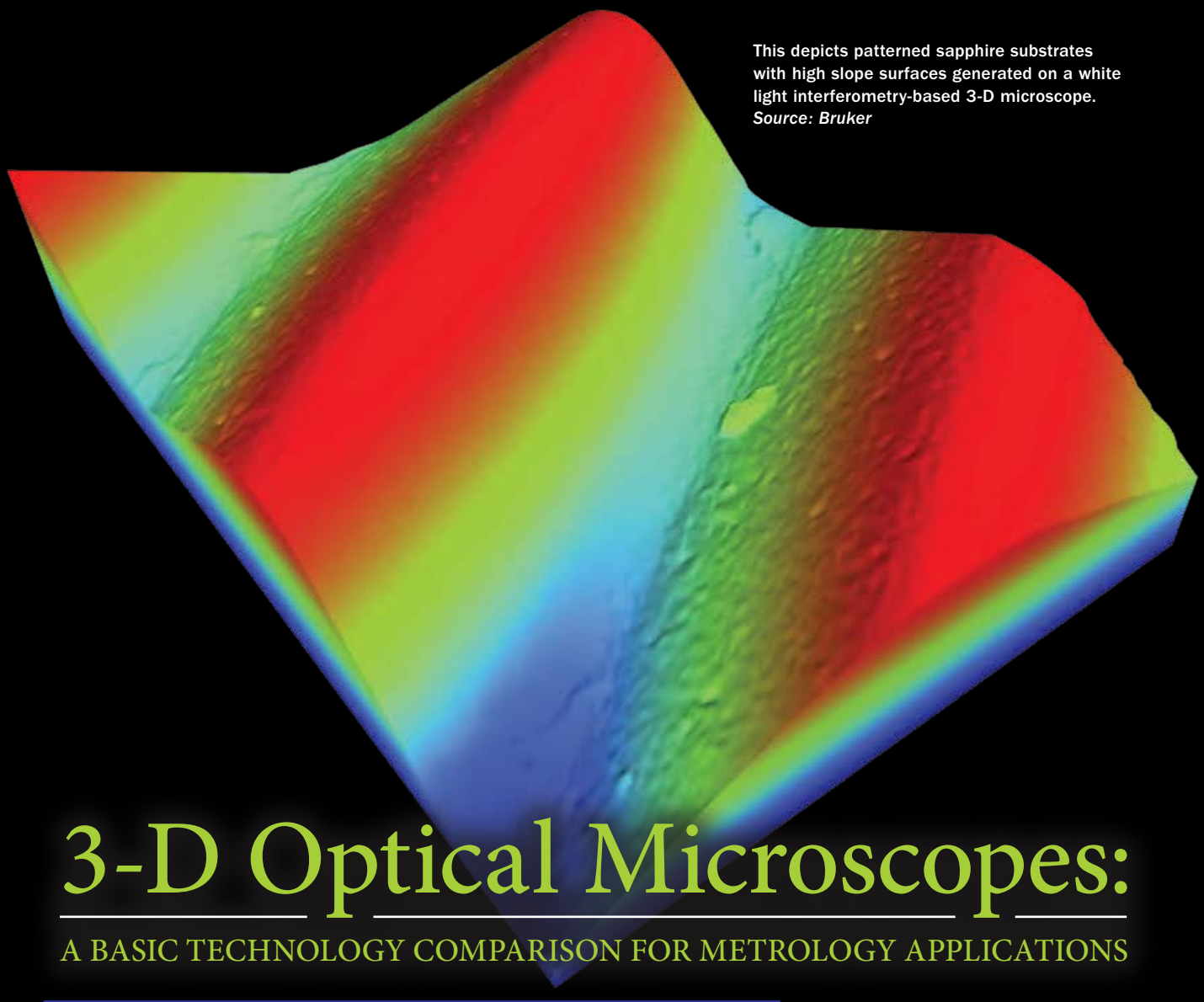

This depicts patterned sapphire substrates with high slope surfaces generated on a white light interferometry-based 3-D microscope. *Source: Bruker*

3-D Optical Microscopes:

A BASIC TECHNOLOGY COMPARISON FOR METROLOGY APPLICATIONS

Learn more about 3-D techniques such as white light interferometry and confocal microscopy.

BY MATT NOVAK AND DEEPAK SHARMA

Three-dimensional optical microscopy is a metrology mainstay serving needs across a wide range of industries. There are a few basic technologies that enable a 3-D surface representation to be built from a microscope image: two key techniques are white light interferometry (WLI) and confocal microscopy, also known as laser scanning confocal microscopy (LSCM). These two methods are ubiquitous for measuring surface heights on the scale of nanometers to millimeters.

PRINCIPLES OF MEASUREMENT

Confocal microscopy was originally developed for imaging of biological cell and tissue samples, an application having very little to do with metrology. This method's main strength continues to reside in the imaging area, as opposed to critical industrial metrology applications. In confocal microscopy, the sample is advanced vertically in steps such that each point on the surface passes through focus. A very small aperture is placed in front of the detector to admit light from a single point as it passes through focus. In LSCM, only one point is measured at a time, raster scanning in the X and Y directions as well as in the Z axis to obtain data for each point on the surface. A limitation of this approach is that it becomes very time-consuming to capture data over a large field of view. With 3-D microscopy based on WLI, a vertical scan along the Z axis is made so that each point of the test surface passes through focus and the X and Y data are captured with a single acquisition at each Z axis step. This provides a speed advantage over confocal methods where each point needs to be scanned in both X, Y and Z (see figure 1). It should be noted that some confocal microscopes using alternative technologies (such as spinning disk

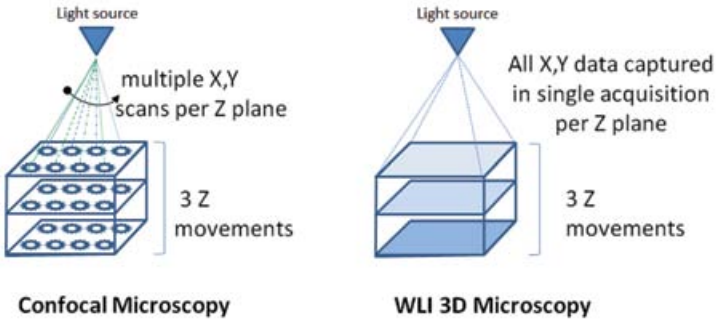

Figure 1. Diagram outlining different scanning methods used by confocal microscopes and 3-D microscopes. *Source: Bruker*

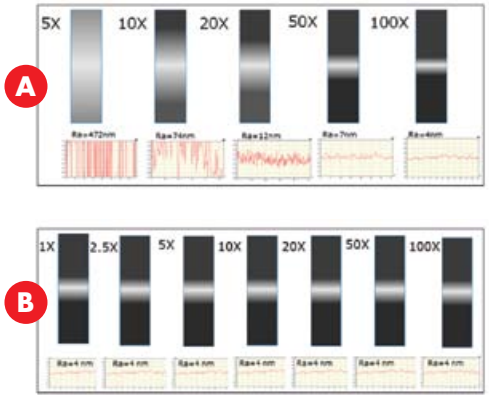

Figure 2. (A) Confocal microscopes produce only a strong and narrow signal at high magnification and wider, weaker signals for lower magnification objectives. (B) WLI microscopes provide a constant, narrow signal for all objectives. *Source: Bruker*

multiple pinhole) can image multiple points simultaneously, but all 3-D microscopes based on WLI capture X,Y data simultaneously.

ORIGINAL APPLICATION AREAS

Confocal microscopy development has been led by the need to image colorful fluorescent biological samples and these origins are reflected in several of the key strengths of this measurement method. Confocal microscopy is known as an excellent method for generating rich and colorful graphical images. It is also more suited to high magnification of very small areas, due to the nature of biological samples (tissues, cells, subcellular compartments and proteins). This high magnification also enables confocal microscopy to generate data on highly angled steep smooth surfaces due to the very tight focal plane generated at such high magnifications (see figure 1, left). When used in industrial applications, the confocal range finding system, which uses laser reflection intensity for detection, can measure shapes that have high angular characteristics with low noise.

WLI-based 3-D optical microscopy, on the other hand, was developed specifically for industrial metrology applications. WLI 3-D optical microscopes use closed-loop scanning in the Z-axis to provide sub-nanometer vertical resolution and 0.01-nanometer RMS repeatability. These systems maintain this high resolution regardless of the magnification or field of view (see figure 2B). Current WLI-based microscopes can be used to measure the surface profile at any magnification. Stitching is only necessary for areas larger than 5x5 millimeters and can be done very rapidly with today's computing capabilities.

LATERAL RESOLUTION

Confocal systems offer the advantage of an effective wavelength typically of 408 nanometers versus a wavelength on the order of 500 nanometers for WLI-based 3-D optical microscopes. The lower wavelength of confocal tools offers a slight advantage at higher numerical apertures and magnifications, however, both microscopy technologies meet diffraction limits for the vast majority of applications. In practical application, the resolution enhancement provided by the confocal microscope makes no difference until feature sizes are below 400 nanometers.

There are two possible limits on the lateral resolution of an optical system. The first is pixel-limited resolution where two adjacent features are imaged into a single camera pixel and thus there is no way to distinguish between the features in the final digitized image. Another possible limitation to lateral resolution is diffraction, where there are at least two camera pixels for each feature but multiple features are blurred by the optics so that they still cannot be readily distinguished from each other. For visible light microscope systems, whether WLI or confocal, this limit is usually about 350 to 400 nanometers. High-magnification objectives, such as

TECH TIPS

- Confocal and WLI-based 3-D microscopes are both excellent solutions for surface investigation.
- Confocal microscopes were originally developed for biological imaging while WLI-based microscopes dominate the industrial metrology field.
- To select one for your application, consider resolution, desired field of view, and desired throughput of data.

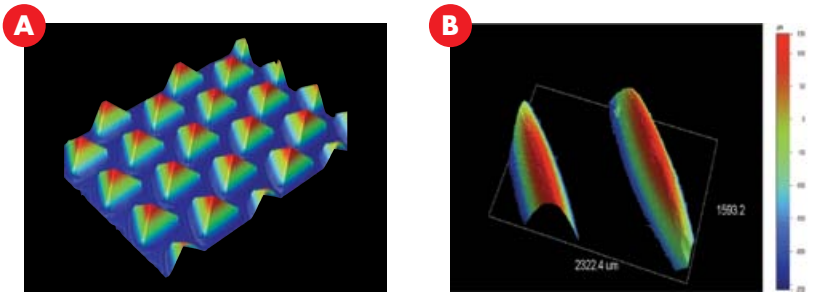

Figure 3A. Image of PSS with high slope surfaces generated on a WLI-based 3-D microscope. 3B. 5x thread image of sloped surface generated on a WLI-based 3-D microscope. *Source: Bruker*

3D Microscope Basis Technology	Area of Interest [mm square]	Ra - Metal Sample [nm]	Time to Data [seconds]
LSCM - 50x Objective	0.1	7	1
Stitch 50x - 100 sections	1	7	100
Stitch 50x - 2500 sections	5	7	100
WLI - 50x Objective	0.1	4	1
5x Objective	1	4	1
Stitch 5x - 4 sections	5	4	5

Table 1. Comparison of time to data for best metrology (vertical) resolution for LSCM and WLI. This data assumes a 0.3 megapixel per second image for LSCM, interline transfer rate for image acquisition and subsequent processing for WLI systems. WLI-based systems can produce higher quality data in much less time. Example roughness (Ra) data is from given sample area of interest. *Source: Bruker*

20x, 50x and 115x, typically produce diffraction-limited images.

MEASUREMENT SPEED

Confocal microscopes typically achieve data acquisition speeds on the order of 0.3 megapixels per second, in units of sections, or images. In order to achieve higher speeds with a confocal microscope, the field of view must be reduced (e.g., for greater than 10 microns/second a single line profile must be taken rather than a whole image). Three-dimensional microscopes based on WLI, on the other hand, provide scan speeds up to 100 microns per second vertically, with the entire field of view imaged in a fraction of a second. To illustrate this point, table 1 estimates best resolution data for equivalent inspection areas measured by LSCM and WLI-based 3-D microscopes.

MEASUREMENT OF DIFFICULT SURFACES: SLOPED AND VARYING REFLECTANCE

The range-finding system in confocal microscopes is based on laser reflection intensity and provides low-noise measurement of shapes that have high angular characteristics. When initially developed, WLI 3-D optical microscopes were limited in their ability to detect steep angles. However, today's top 3-D optical microscopes can measure slopes up to 87 degrees. When using WLI-based systems to measure very steep angles present on very smooth surfaces, such as in the patterned sapphire substrates (PSS) used to improve performance of high-brightness light-emitting diodes (HB-LEDs), data is mathematically calculated, and the height, pitch and pyramid volumes are characterized (see figure 3A). They can also measure steep angles on a dull/diffuse reflecting surface, such as a screw thread (see figure 3B).

Confocal microscopes typically use a photomultiplier with a sensitivity range that allows for accurate measurement of targets with areas of both high and low reflectivity. WLI-based 3-D optical microscopes can also measure a wide range of surfaces from highly specular to diffuse surfaces with reflectance as low as 0.05% and as high as nearly 100%.

COLOR IMAGES

As you would expect for a technology originally designed for imaging of biological samples, confocal microscopes capture fully focused color images with accurate height information associated with each pixel. Because they were originally designed for industrial metrology, WLI-based 3-D microscopes developed such capabilities later, and the latest generation of high-performance WLI-based microscopes offer color imaging options that address the specialized applications where color is needed, such as the characterization of copper wire bonding.

Confocal and WLI-based 3-D microscopes are both excellent solutions for surface investigation. Confocal microscopes were originally developed for biological imaging applications and retain advantages in this area while WLI-based microscopes dominate the industrial metrology field. To determine the best fit for a particular application, it is best to be aware of the specific characteristics of each method in terms of resolution, desired field of view, and desired throughput of data.

Figure 4: Image from a WLI 3-D microscope of a wedge bond on a lead frame. *Source: Bruker*

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