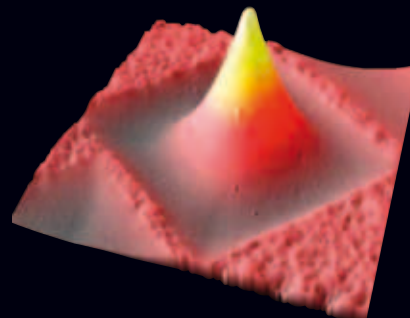


CUSTOMER MAGAZINE FOR MATERIALS SCIENCE & TECHNOLOGY
SPECIAL EDITION SURFACE ANALYSIS



reSOLUTION

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Collecting "Funny Money"

Digital Microscope Helps Detect Counterfeit Currency

How Much "Digital" Do You Really Need?

Trends in Microscopy

A Marriage of Two Technologies

3D Measuring Microscope Combines Confocal and
Interferometry Techniques

SPECIAL EDITION



Dear readers,

Technical surfaces are not just rough or smooth. It is the special surface structures that give components and materials their functional properties. The lotus effect that is becoming a feature of more and more products is only one example of how complex micro- and nano-geometries can have a specific influence on surface characteristics. These structures can only be seen under high-resolution microscopes.

There are innumerable components and materials which require surface inspection to an accuracy of a few microns or even nanometers in order to avoid malfunctioning or failure. As well as being highly precise and reproducible, measurements usually have to be taken quickly to avoid interruptions to production processes. The demands made of modern microscopic imaging systems and quantitative analysis methods are correspondingly high.



In this special issue of reSOLUTION for Industry and Material Sciences, we present two innovative microscope systems that have been specially designed for sophisticated 3D surface measurements: the new Leica DVM5000 – 2000 Digital Microscopes which offer unparalleled flexibility and speed, and the dual-core 3D Measuring Microscope Leica DCM 3D with integrated confocal and interferometry technology. We have included articles on sample applications. Also, we report on a software solution for surface quantification, and a new LED illumination system for reflecting samples, both of which are used in combination with high-end stereomicroscopes.

We hope you find this special issue interesting. We intend to feature more exciting surface measurement applications in the next issues of reSOLUTION. If you would like us to report on your application, we would be pleased to hear from you.

Anja Schué
Communications & Corporate Identity

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Digital Microscope Helps Detect Counterfeit Currency

Collecting “Funny Money”

Nobody wants counterfeit money in their wallet. Even counterfeiters want to get rid of their own creations as quickly as possible. However, experts work intensively to identify counterfeit money on behalf of the law. Martin Weber of the National Analysis Center of the German Bundesbank (Federal Bank) in Mainz is such an expert on forged banknotes. Although anyone can spot most counterfeit euro notes just by looking at them, microscopes are needed to detect the signature of the counterfeiters and convict them. The Bundesbank now uses a new Leica DVM5000 Digital Microscope, as well as stereomicroscopes, to examine counterfeits with even greater precision and enhance the effectiveness of training.

Mr. Weber, what role do you and your colleagues play in the National Analysis Center of the Deutsche Bundesbank?

As a National Analysis Center, our legal mandate is to be concerned with forged banknotes and coins. We also handle damaged money and repay the person who submitted it, provided the reimbursement criteria are met. My team specializes in banknote forgeries. In addition, on behalf of the police, we monitor everything that is treated as legal tender: payment cards, securities, traveler's checks, and currency in gold and silver coins.

Our core task is not, as you might suppose, to determine whether banknotes are real or fake. Our trained eyes can tell this at first glance. We examine whether a counterfeit matches one we already know of and the technique it has been manufactured with. A counterfeiter leaves behind a unique individual “trademark,” always using the same technique and mostly concentrating on certain security features he considers important or believes to have mastered particularly well.

He will usually then make easily recognizable mistakes in other places. In this way, we can normally clearly assign forgeries to a perpetrator, who is initially unknown. If the perp is caught, our expert's reports not only allow us to prove in court that the criminal originated the fakes and how it was done, we can also indicate the time frame and extent to which he did it.

We get most of the counterfeit money from the police. Occasionally, banks submit suspicious cash directly. After we have examined the forgeries, we give our reports and results to the police, who pass them on to the public prosecutor. The judge of the court hearing may request our presence in court to explain the reports.



Photo: © Deutsche Bundesbank

How do you examine the counterfeits?

We concentrate almost exclusively on visual examination, using stereomicroscopes of up to 100x magnification with various light sources and filters. We also need to know as much about forging as the forgers themselves. All the five experts in our group have a degree in printing engineering. When we view a counterfeit under the microscope in incident, transmitted or UV light, we can tell exactly how it was produced.

Fig. 1: Martin Weber, expert in counterfeit banknotes at the National Analysis Center of the German Bundesbank, can spot a fake at first glance.

Photo: © Deutsche Bundesbank



Fig. 2: Analyzing a banknote with the Leica DVM5000: with the instrument's high magnification levels, versatile zoom optics, and large depth of field, experts can discover how counterfeit money was produced and match a forgery to a known "trade-mark."

How do you benefit from the digital microscope?

The new digital microscope is a much-needed addition. In terms of magnification, we are brushing up against our limits with the stereomicroscopes. Now, with higher magnification levels and better depth of field, we can examine paper structures, inks, and pigments, for instance effect pigments and diffraction structures in holograms, with greater accuracy. Another reason we need high magnification levels is that the counterfeiters' inkjet printers deliver ever-finer resolution.

The flexibility of the digital microscope is also a great advantage for us. For example, the tilting stand enables us to record the effect of movement on the security features. The versatile zoom optics allow us to verify in much finer detail whether counterfeits were produced with printers or paper confiscated from suspects by the police.

The digital technology is also great for documenting our work. We record every single result in digital images, which may be used as conclusive visual material to support written evidence in court or for discussions among colleagues. Pictures of forgery details are also useful in our well-functioning European

network for tracking down perpetrators. Relatively few forgeries are committed in Germany. They are mostly the work of internationally organized groups.

You also hold training courses for the police, businesses and banks. What do you teach and what advantages does the digital microscope provide?

Training sessions represent an increasing proportion of our work. One of our responsibilities is to show staff of the criminal investigation police and state investigation bureaus how forgers work. The second target group are checkout staff in shops or bank cashiers who are trained on the job by the nearest branch of the Bundesbank. We show them a sample set of forgeries to demonstrate the problems that forgers have with the security features.

However, we are often surprised at how little some course participants know about the security features of the euro banknotes. These features are designed to make forgeries easy to identify without technical equipment. But without the knowledge of how a genuine banknote should look and the security features on a genuine note, the person receiving the currency will not be able to distinguish a genuine banknote from a forgery.

We are organizing more and more seminars on an international level to share experience with experts from other central banks. Our Technical Central Bank Cooperation department also helps to set up and develop money analysis centers in other countries. We have installed a large flat screen in our laboratory for in-house training that we can directly connect to the digital microscope. All the participants are thus able to watch a live demonstration of what we examine under the microscope and the methods we use. So the new technology helps us make lectures and training courses more lively and effective.

Have forgeries become more common over the last few years?

The Federal Bank registered 60,000 counterfeit euro notes in the year 2010, which was 14 per cent more

Photos: © Deutsche Bundesbank



than the year before. Damage resulting from forgery increased from 3.1 to 3.4 million euros. The highest increase can be recorded for the counterfeit 50 euro notes. The number of counterfeits of other denominations, however, is declining. Statistically, there are seven forgeries in Germany per year for every 10,000 members of the population, which puts us well below the European average. The figure also indicates the low risk of coming into contact with counterfeit money. Even though this means people don't pay much attention to the security features, it doesn't worry us that much in view of the low risk for private individuals and the success of the police in solving forgery crimes. Our main aim is to reach as many people as possible with our ongoing awareness-raising work and copious information material on the Internet which is available to everyone free of charge.

Contact

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Fig. 3: Foil element of the 500 euro note, image acquired with the digital microscope's swing stand at a 45° angle.

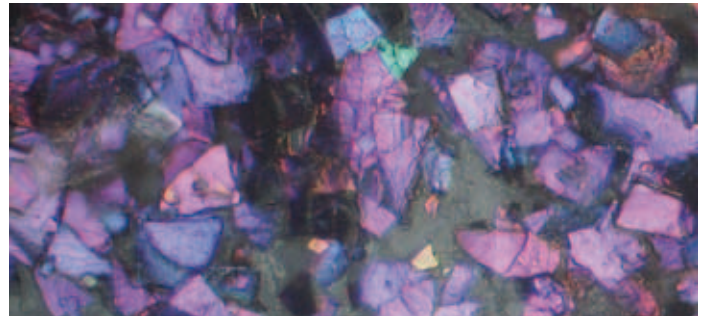


Fig. 4: Special OVI pigment only found on genuine notes of 50 – 500 euro denominations. This photograph was taken at a magnification of 1000x.



Fig. 5: Toner particles and paper fibers of a forgery.

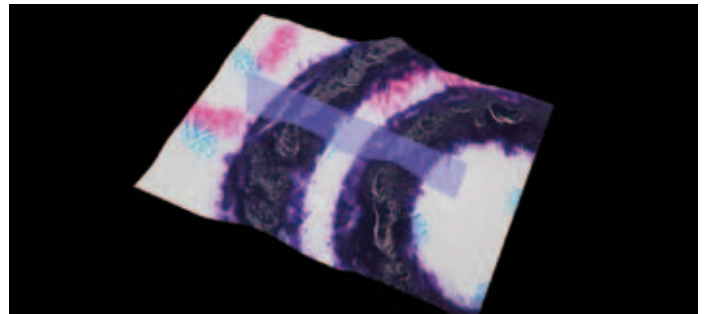


Fig. 6: 3D image capture of the intaglio printing on a genuine 500 euro bill. A section was made through the profile.

Photos: © Deutsche Bundesbank



Money Museum of the Deutsche Bundesbank

Interesting facts on the history of money and how it is produced and used are presented in the Money Museum in the Frankfurt headquarters of the Deutsche Bundesbank

www.geldmuseum.de

Security features

The Bundesbank provides clear information on the security features of euro banknotes on its website. Brochures and CD-ROMs can also be ordered.

www.bundesbank.de

Digital Microscopes Leica DVM5000 – 2000

The New Benchmark for Optical Profiling

Digital technologies have revolutionized both our work and everyday lives in many respects, and there is no end to these innovations in sight. In particular, industrial quality control – which places the most stringent requirements on macroscopic and microscopic imaging and image processing – benefits from innovative, reliable digital technology. Digital Microscopes from Leica Microsystems open new horizons in terms of mobility and speed. For many applications, they offer an ideal supplement to traditional inspection and analysis.

Three Digital Microscope solutions, the Leica DVM5000, DVM3000, and DVM2000, provide a wide range of different configurations – from the “intelligent,” portable, all-in-one system to the modular basic model. The microscopic image is displayed directly on a high-resolution monitor. This means that the user does not have to look through an eyepiece. The streamlined zoom optics reach extremely difficult-to-access surfaces, which allows non-destructive inspection of even the largest stationary parts that can be examined using traditional microscope techniques only with great effort. Leica Digital Microscopes not only feature outstanding, high-quality optics, they also offer a wide variety of quantitative analysis options – whether 2D analyses or advanced 3D surface measurements. Each system can be configured for specific applications and individual requirements using an extensive range of components and accessories.

Portable all-in-one-system

Some products cannot be transported and do not allow a sample to be taken for microscopic analysis; only non-destructive inspection is possible, such as production machines or airplanes. The Leica DVM5000 is specifically designed for such situations. Here, you can bring the microscope to the sample. The Digital Microscope, including the optics, monitor and computer, can convert into a compact, portable system with just a few hand movements. The Leica DVM5000 is a highly integrated system that features outstanding performance capacity and speed. Within a very short time, the Leica DVM5000 provides the desired results – even complex 3D models are available in mere seconds.

Flexible in every

The Leica DVM3000 features outstanding flexibility. It includes all the elements needed for digital microscopy: zoom with encoded magnification,

respect

features. It includes all the elements needed for digital microscopy: zoom with encoded magnification,

Fig. 1: The portable all-in-one-system Leica DVM5000 is a highly integrated system that features outstanding performance capacity and speed.



high-performance digital camera, integrated metal halide lamp, and standard interfaces for computer and monitor to enable all sample-related data to be sent to the computer for subsequent evaluation. Its “open” design makes the Leica DVM3000 a compact, versatile Digital Microscope for a wide variety of applications – from simple imaging to 2D measurements to highly specific roughness measurements in 3D with subsequent documentation using conventional Microsoft® Office programs.

Focused on the basics

With the Leica DVM2000, Leica Microsystems offers the ideal entry-level digital microscope. This modular system is composed of zoom optics, digital camera, and software and is based on standard components. However, the Leica DVM2000 also provides plenty of options from a comprehensive range of products and accessories to configure the ideal digital solution for your needs. Also, Leica Application Suite (LAS) offers a wide variety of software modules for different analyses and evaluations.



Fig. 2: The 360° rotating head offers an all-around view that provides entirely new ways of looking at samples. As an added benefit, rotating the view creates a 3D impression of the sample. In this way, Leica Digital Microscopes open up new perspectives – in the truest sense of the word – and possibilities for viewing and analysis.

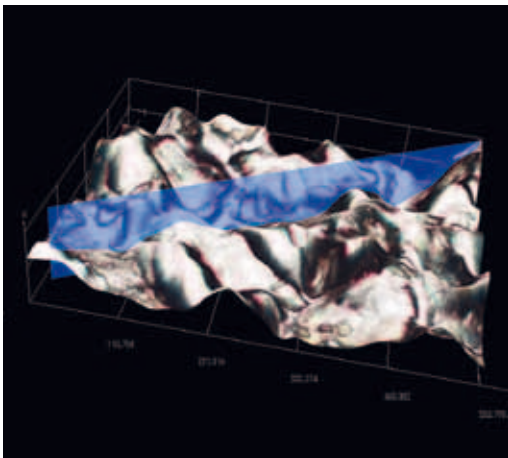


Fig. 3: 3D profiling in all variants: 3D profiles of height, width, and surface irregularities; display as texture, color depth encoding or grid model; height difference and volume measurements; combined 2D and 3D profiling.

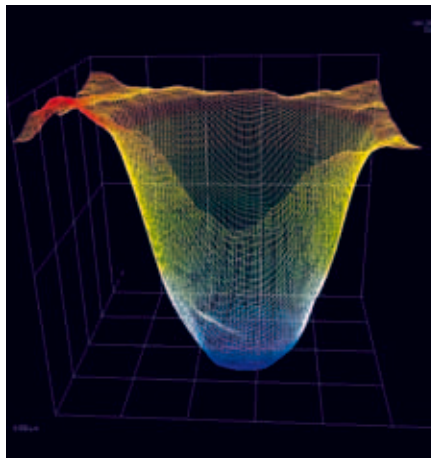


Fig. 4: 3D models in seconds: visualizing desired 3D models within a few seconds and further analyses, such as profile measurement or roughness measurement, with just a few mouse clicks.

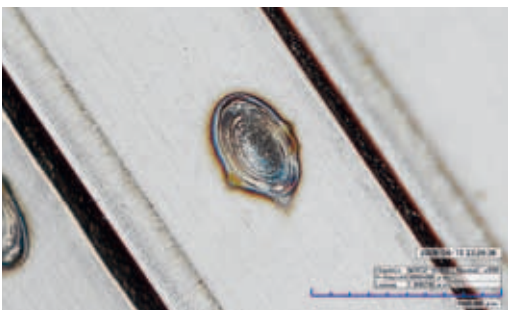


Fig. 5: High Dynamic Range (HDR) provides outstanding images. Leica Microsystems has long used state-of-the-art 16-bit individual color detection to provide highly dynamic images, no under- or over-exposed image areas, and clearly display difficult surfaces such as metal sections.



Fig. 6: Mosaic – Capture every detail: Simultaneously analyze the smallest details and document large surface without an encoded or motorized stage. An intelligent algorithm generates perfect mosaic images.

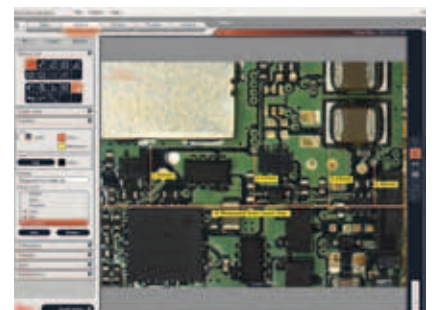


Fig. 7: LAS – Measurement without limits. The Leica Application Suite (LAS) measurement module for a wide variety of evaluations: From simple point-to-point measurements to intelligent image recognition algorithms. With the LAS measurement module it is possible to do automatic image analysis for determining phase proportions, grain sizes, particles, and much more.

Trends in Microscopy

How Much “Digital” Do You Really Need?

There are digital cameras, digital TV sets, digital picture frames, digital schools on the internet. Cryptologists design digital signatures, communication researchers speak of digital identity. Digital may be an overused buzzword, but digital technology has undeniably revolutionized our world ever since the invention of the computer and will continue to do so in future. The digital revolution has also had a radical impact on the field of microscopy. The beginnings were made by digital cameras, which provided users in all fields of microscopy with better documentation and analysis facilities. Today, there are digital microscopes on the market which are a far cry from traditional microscopy methods. New technologies always attract plenty of attention, and after all, digital microscopes offer a host of advantages. However, this does not mean they can simply replace all the world's traditional microscopes. It's worth taking a closer look to identify the limitations of digital microscopy as well as the benefits.

Digital microscopy offers clear advantages for a large number of industrial quality inspections, particularly for surface analysis. Fracture analysis and the analysis of inclined or vertical surfaces, or in situ inspection of large components such as turbine rotors are just a few examples of applications where digital microscopes can show their full potential. For some applications, however, a traditional solution with stereo- or light microscopes is more practical and cost-effective. Qualified advice and extensive application know-how are therefore essential for choosing the right solution. But what are the key criteria for the successful use of digital microscopes, and what are the differences between digital and traditional microscopy?

What is a digital microscope?

First of all, a digital microscope has no eyepiece to look through. The sample is directly imaged on the monitor. This enables the user to view and analyze the sample in a single pass using the software, sitting in a comfortable and relaxed position. The individual components of a digital microscope are chosen according to the particular application: zoom optics for low to ultra high magnifications, stands, sliding stages, etc. A digital microscope system should have a modular design so that it can be exactly configured to suit its intended use and flexibly adapted to changes in general conditions. To offer users real value added compared with traditional set-ups, a digital microscope has to meet the five following technological requirements:



Fig. 1: Digital microscopes with a flexible tilting stand and a rotary x/y stage allow reliable inspection and analysis of the sides of samples or inclined surfaces.

1. Optimized digital imaging
2. Dynamic viewing of processes or objects
3. Qualitative and quantitative sample analysis
4. Display and analysis of samples with high dynamic range
5. Lean optics for flexible orientation to sample and for mobile use

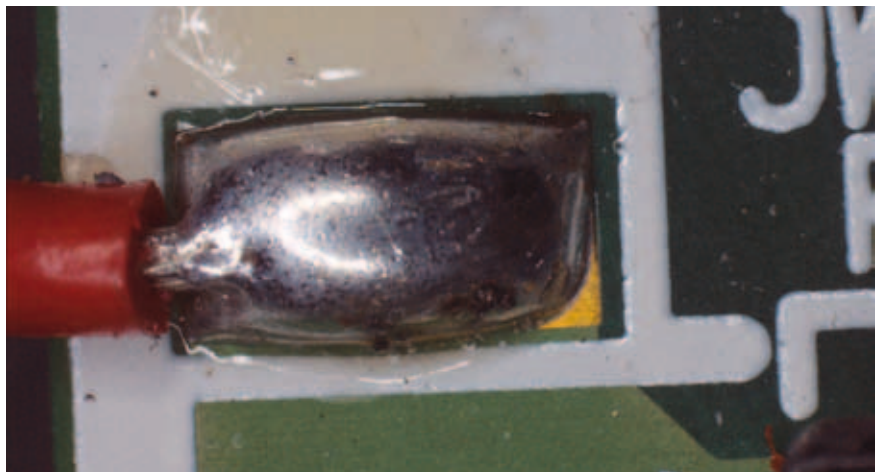
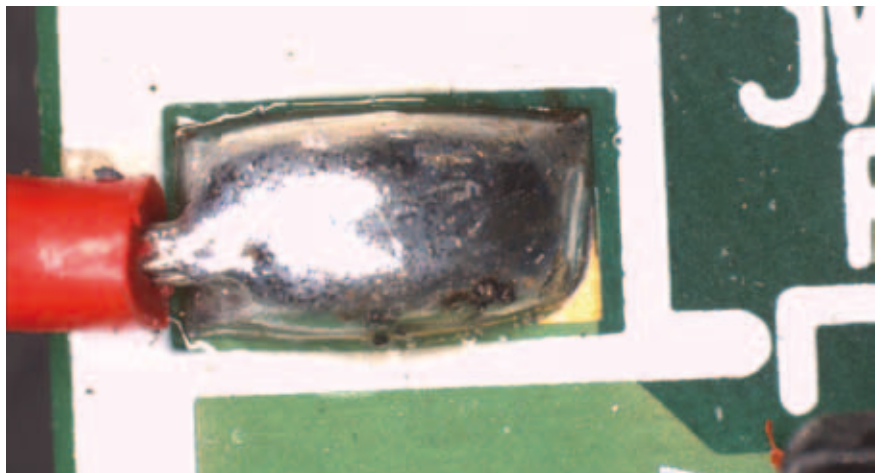
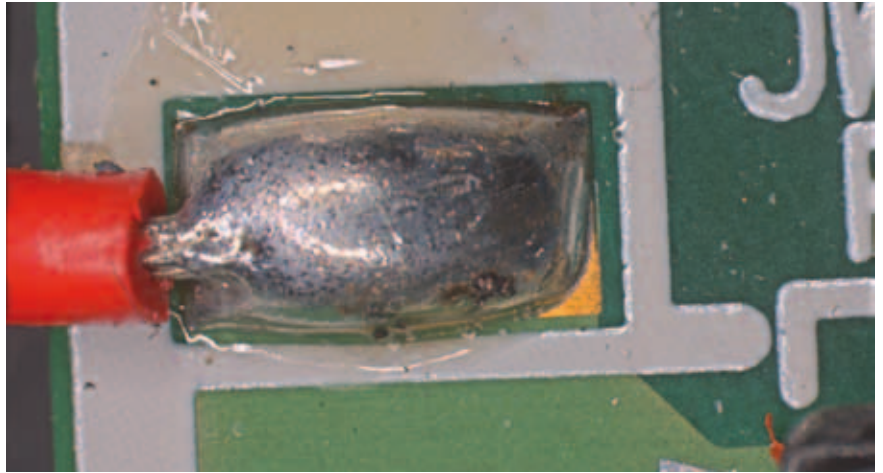
Optimized digital imaging

Typical digital microscopes are equipped with a 2.11 megapixel CCD camera that is perfectly tuned to the high-resolution optics. The camera delivers the best possible information yield while keeping the amount of data of each picture manageable. However, digital cameras tend to be judged by the number of megapixels they offer. The more the better, many people think. But in microscopy, the camera with the most megapixels is not necessarily the best. The key criteria for deciding which camera will produce the best imaging results are the application and the optical performance of the microscope. Long before the triumph of digital photography, the US-American scientist Harry Nyquist proved that cameras in the double-digit pixel range do not offer more image information, but only fill the hardware with useless data more quickly.

A measure of the resolution in a digitized image is the maximum number of black-and-white line pairs that are imaged in sharp focus. The rule of thumb for calculating the line pairs per millimeter for microscopes is $3000 \times \text{NA}$ (numerical aperture). This number is divided by the reproduction ratio of the object on the camera sensor to obtain the number of line pairs per millimeter that are actually captured by the camera sensor. This shows that a camera with, for instance, 12 megapixels, is no advantage at high magnifications. The resolving power of such a camera is then higher than that of the optical system. The image produced would be larger, but not better. Instead of resolving additional detail, the camera just produces more data.

As a digital microscope does not have an eyepiece, it has to be able to display the live image on the monitor at a high refresh rate. An ideal refresh rate is at least 15 frames per second, which ensures that the image can be viewed in comfort even when the stage is moved in xy direction. The faster image processing offers a further advantage during an experiment: The image capture rate is accelerated and therefore the overall sample processing time is shorter.

Illumination is another important issue for a microscope without an eyepiece. The light source should be as powerful and durable as possible and should have a color temperature similar to that of daylight to



ensure that a realistic image of the sample is obtained. Metal-vapor lamps are ideal for this job. The long-life, maintenance-free LED-based systems now available on the market offer a convincing alternative.

Fig. 2: High Dynamic Range imaging reveals all the details of a solder joint (top). Long exposure times are better for visualizing dark areas (center), while bright areas show up better with short exposure times.

Dynamic viewing of processes or objects

Compared with traditional stereomicroscopes, zoom systems have the disadvantage of not being able to provide a three-dimensional image. With a digital

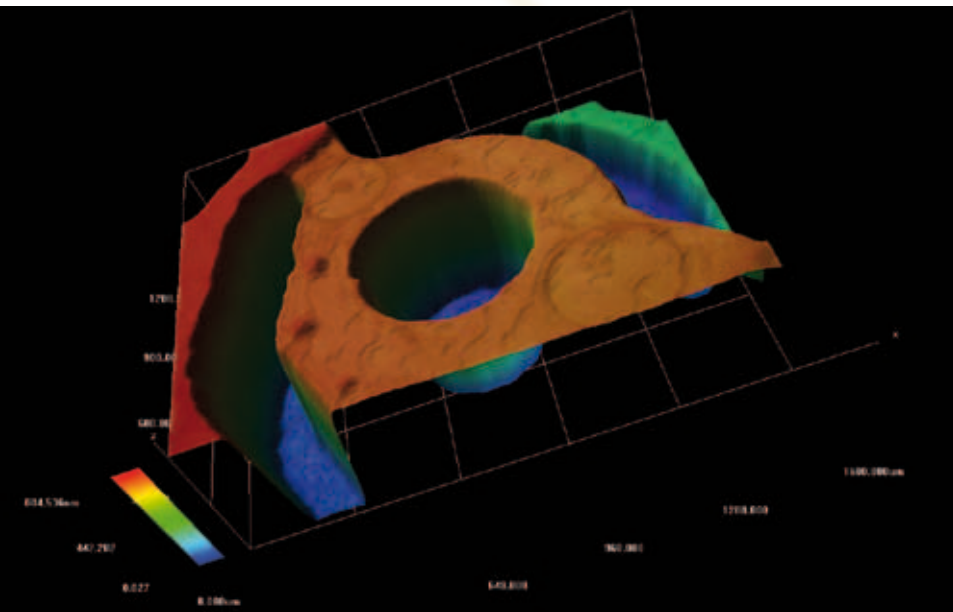


Fig. 3: 3D model of a plastic component, displayed in pseudo colors



Fig. 4: HDR image of an electronic component

microscope, this can be more than compensated with a smart accessory: A 360° rotary head enables the user to view the sample from all sides and even record this panorama view as a movie. This literally opens up new perspectives and viewing opportunities. Also, the 360° rotation clearly shows the three-dimensionality of the sample. The standard software suite should also feature time series recording to document dynamic processes.

Qualitative and quantitative sample analysis

One of the key strengths of digital microscopy is the fast creation and analysis of 3D surface models. Using the motorized focus drive, an image is recorded in every focal plane in z direction. Then the focus is determined in every single image and for each pixel. The pixel with the best definition determines the focused texture, from which an optimized 3D model is computed. In addition, a topographical profile can be produced from the information on the distance from which the sharply focused points were recorded.

This method is versatile and can be used at low magnifications (macro objective) as well as high magnifications (high-performance 7000x objective) for precise topographical surface measurement. Besides 3D profiles it is also possible to measure roughness, geometries and volumes.

In the interests of reliability as well as precision, digital microscopes should be equipped with an electronically coded zoom. The digital image is then automatically given the correct calibration during the recording. Incorrect image values are a frequent source of error with conventional systems.

Display and analysis of samples with high dynamic range

Most digital microscope cameras use 16-bit single color capture (equivalent to 65,536 colors) to exploit the entire dynamic range of the image. The problem is that most computer screens and printers can only display 8 bits per channel, which is equivalent to 256 brightness levels. This means that all the natural nuances in brightness that our eye is able to differentiate are not always reproduced.

For capturing images with a high dynamic range, the HDR (High Dynamic Range) method is used. These high-contrast images capture the whole range of natural brightness nuances. The pixel values are in proportion to the actual luminous density. Despite the fact that HDR images have to be adapted to the lower brightness range which is still a feature of almost all screens, they offer advantages nevertheless. In particular, details remain visible even in extremely dark and bright areas of the screen image.

Lean optics for flexible and mobile use

For examinations of extremely small structures on inclined or vertical surfaces, conventional microscopes come up against their limits. For example, a sideways view of a solder joint on a large circuit board can only be obtained with an adventurous setup of equipment. Previously inaccessible areas of samples are no problem for digital microscopes.

A flexible tilting stand combined with the rotary x/y stage allows reliable inspection and analysis in virtually any position. Some products, however, can neither be transported, nor can samples be taken from them. For modern, portable digital microscopes, non-destructive inspection even of stationary objects poses no challenge. And of course, mobile digital microscopes are also useful for performing quality control tasks at multiple sites.

Conclusion

Digital microscopes are a particularly good alternative to traditional microscopes for the frequent inspection of difficult-to-document samples or fast 3D surface quantification. However, if optical brilliance and variety of contrasting techniques are more important, stereo- or light microscopes are superior. Before investing in a new instrument therefore, it always pays to weigh up the benefits carefully and obtain comprehensive and objective advice on the alternatives.

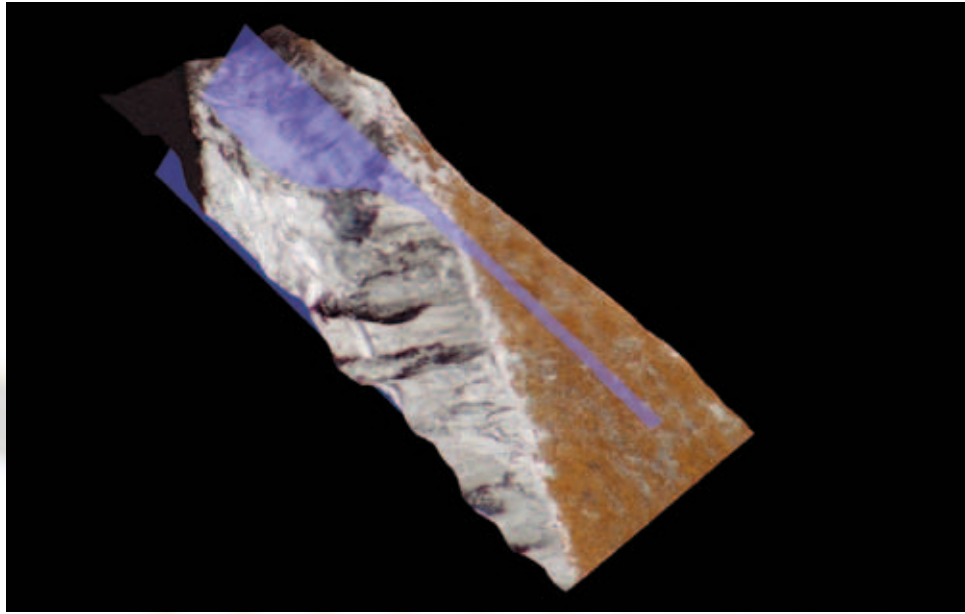


Fig. 5: Measurement of wear on a hard metal indexable insert

3D Measuring Microscope Combines Confocal and Interferometry Techniques

A Marriage of Two Technologies

In recent years, interferometers and optical imaging profilers based on confocal technology have been competing fiercely to conquer the non-contact surface metrology market. They are both capable of accurately and reliably measuring surface topographies on a millimeter to nanometer scale. Today, Leica Microsystems presents a new complete solution which combines both confocal and interferometry techniques: the Leica DCM 3D Dual-Core 3D Measuring Microscope. In addition to its compact and robust design, the Leica DCM 3D is a complete tool that is ideal for obtaining a super fast, non-invasive assessment of the micro- and nanogeometry of technical surfaces, in multiple configurations: From R&D and quality inspection laboratories to robotic driven systems during online process controls, the new Leica DCM 3D is able to serve a wide range of applications where high-speed and high resolution measurements down to 0.1 nm are needed.

Fig. 1: Leica DCM 3D dual core 3D measuring microscope



Unique combination

The Dual-Core 3D Measuring Microscope Leica DCM 3D offers a unique combination of confocal and interferometry in a single sensor head. The core technology is based on a fast reaction microdisplay placed in the position of the field diaphragm. Bright field, interferometric and confocal images can be generated by the control of the microdisplay. The non-moving part concept, the confocal microdisplay (MD), two light sources and two cameras (one color and one monochromatic) achieve high accuracy 3D measurements and unlimited depth of focus.

Confocal MD technology allows measurements of smooth to rough surfaces, of topographical differences ranging from 1 nm to several mm, and up to 70 degrees of local slope. In comparison to Laser Scan based systems or Spinning Disc, MD confocal technology needs no moving mechanical parts, increasing both image stability at high magnifications and light efficiency, and enhancing reliability and flexibility. Along with a LED based light source, MD technology prolongs instrument lifetime, reducing servicing and avoiding the cost of expensive spare parts.

Surface measurements are achieved in seconds. The system is easy to use. Just place your sample under the microscope, focus and click "Acquire". It only takes a few seconds (typically less than 5) to get a 3D view of the surface comparable to those acquired with a scanning electron microscope, in a fraction of the time.

3D profiling and unlimited depth of field

As an example, the paint adhesion ability on a steel surface was characterized. After polishing, the steel was too smooth to allow good adhesion of an enamel-based composition. To increase the adhesion the steel is processed with an acid attack to create micro-valleys. This enables the paint to penetrate further into the surface, increasing the effective contact area and improving adhesion to the upper layers. As a result the paint is fixed hard. If the micro-valleys are too deep, however, the upper layer of the paint tends to follow the shape of the valleys in the underlying steel surface. On the other hand, if the microstructures are not deep enough, there is no adhesion effect.

With the Leica DCM 3D it is possible to inspect the surface and obtain suitable quality parameters to

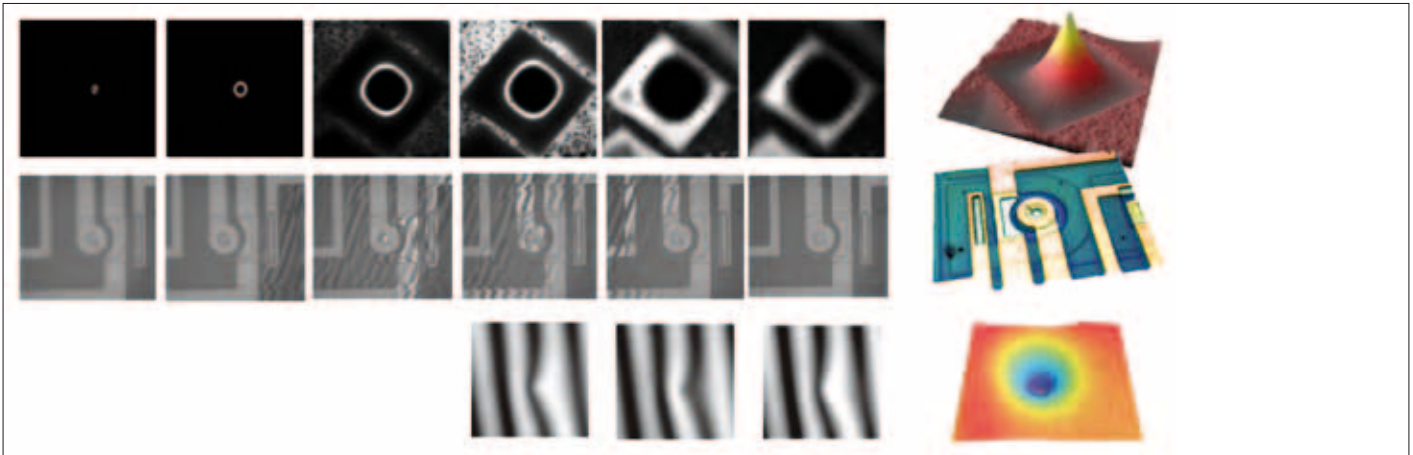


Fig. 2: Examples for Confocal, VSI and PSI optical profilometry

decide if the surface treatment is adequate or not. Already after placing the surface under the microscope, it is easy to get a good idea of the depth of the micro-valleys. The real-time confocal image allows you to focus on top of the surface, move the focus down to the valleys and take a direct reading of the depth. After clicking the “Acquire” button to get a 3D view, the confocal scan was so fast that I didn’t get time to follow what was happening. A pseudocolor display of the topography was shown on the screen with clear presentation of the micro-valleys. Figures 3 and 4 show the result of such a measurement. In order to get a quantitative analysis of the micro-valleys, the 3D analysis software included with the system, called LeicaMap, was used.

The software automatically segments the regions of the upper structures and the regions of the valleys. The volume distribution of the segmented regions (Fig. 5) was a suitable indicator for this purpose. Another useful parameter is Sdr. This parameter represents the proportion of the 3D surface that has been formed to the vertical projection of this area. Thus, a plane surface has a ratio of 1:1, while a surface with valleys increases the 3D area and thus this value. In our case we concluded that the optimum value should be 1:1.33, that is, a 33% increase of effective area.

Outperforming any profiling technology

A unique benefit of the Leica DCM 3D is the fact that it incorporates two CCD cameras. One is a color camera used for bright field inspection, while a high-quality monochromatic CCD is used as a metrological detector. During the 3D measurement of an area, a high resolution and high contrast confocal image and an infinite focus color image are acquired simultaneously. The analysis software allows 3D imaging of the surface in different color modes such as pseudocolor display of the topography, confocal stack, infinite focus color image and high resolution confocal luminance with the chrominance signal of the color camera.

One of the main confocal benefits for 3D profiling is its flexibility to use microscope objectives originally designed for bright field microscopy. This means that the ideal optics are generally available to match the desired application, such as objectives with long free working distances for large topography variations within the sample or for sample geometries that would collide with conventional objectives, objectives with an adjustable collar ring designed to focus through coverslips, objectives for LCD inspection, and objectives for water immersion. Nevertheless, the numerical aperture of the objective limits the depth of focus and thus the height resolution. Low magnification objectives have lower NAs and confocal 3D measurements tend to be noisier. The DCM 3D achieves the highest measurable surface height range by its unique combination of confocal and interferometry technology.

In contrast to confocal technology, depth discrimination of phase shift interferometry (PSI) and vertical shift interferometry (VSI) does not depend on the objective’s NA but on the light source properties. While PSI delivers maximum height resolution down to 0.1 nm, the VSI algorithm overcomes the intrinsic height limitation of that algorithm, equalling the Z resolution of the highest magnifying confocal objectives, independently of the magnification used for interferometry. The confocal + interferometry combination allows measurements from 0.1 nm to several mm and offers the user always the best technology for each sample. Figure 9 shows the result of measuring a 10 nm step height standard with PSI technology, a height resolution not possible with conventional confocal technology.

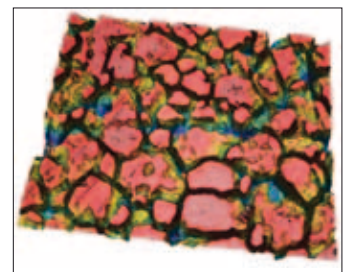


Fig. 4: Three dimensional view of the surface under inspection

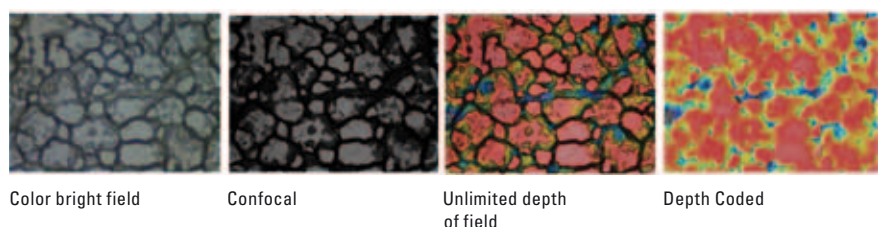
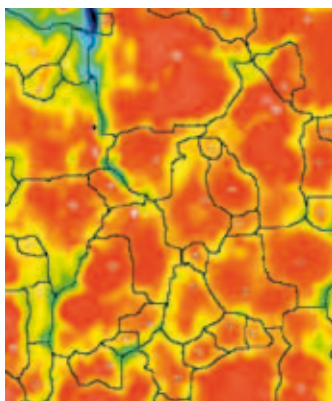


Fig. 3: Microscope modes



Leica interferometry objectives and powerful analysis software

The Leica DCM 3D uses Leica Interferometry Objectives to provide additional benefits to cover customers' needs. The full range of interferometry objectives (5x, 10x, 20x and 50x) can be used for both interferometry techniques PSI and VSI. A unique system of tip-tilting (tilting at right angles to the optical axis) is integrated on each objective, dramatically improving the time and the ease of alignment between the surface of the sample and the optical axis in order to obtain interference fringes with the best contrast. In addition each objective is equipped with a dial with four different positions to change the amount of light reaching the sample. It is therefore possible to analyze samples with all kinds of reflectivity, increasing the flexibility of the whole system.

The Leica DCM 3D is driven by field-proven LeicaScan software. This package controls the whole system and also allows several 2D/3D measurements. In addition, the system is fully compatible with Leica-Map, one of the most advanced 3D analysis packages for microscopic analysis of surfaces. When automatic 2D analysis is needed, the system is also compatible with the well known Leica Imaging Analysis Systems: Leica Application Suite, Leica QWin and Leica Material Workstation.

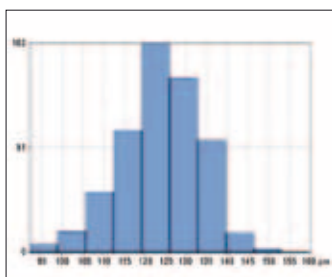


Fig. 5: Microvalley segmentation (top) and volume distribution of the microfragmentations

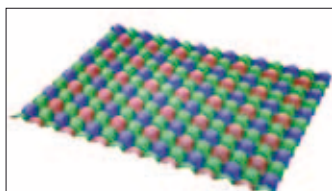


Fig. 6: Application: 3D view of the bayer filter on the microlens array of a CCD

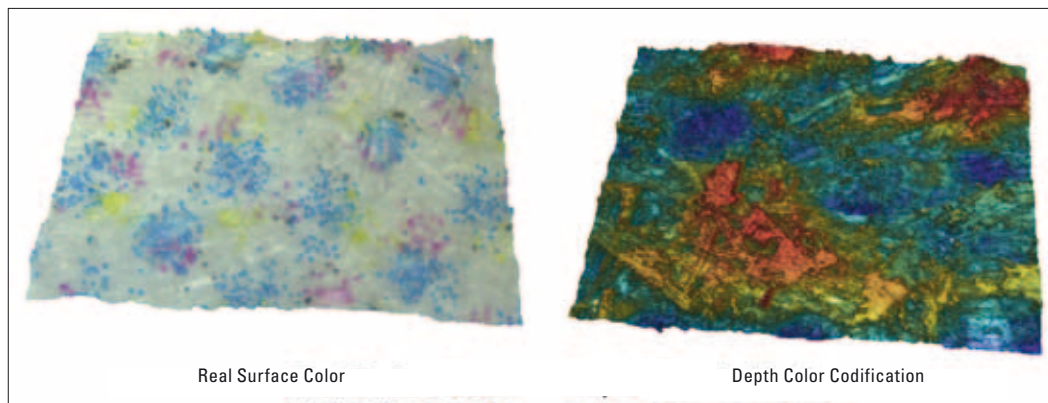


Fig. 7: Paper portion after ink-jet printing. Left: 3D view with bright field color information, right: the same 3D view with pseudocolor display of topography.

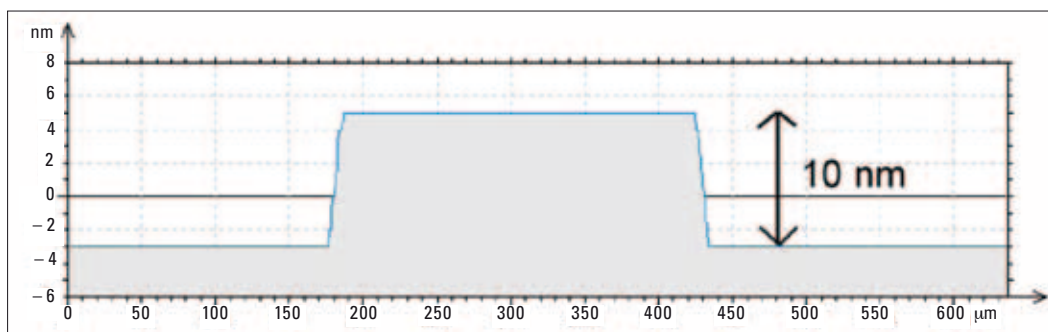


Fig. 8: Step height standard of 10 nm measured with PSI technology, a measurement not possible with conventional confocal technology.

Nanometer Precision and Lightning Speed

Characterization of Solar Cells

Solar energy is becoming more and more important all around the globe. Not only is it available in unlimited supply, it also offers key advantages for protecting the climate and the environment. Every year, many thousands of solar cells are produced worldwide for new photovoltaic plants. An important criterion for quality control is 3D characterization of the light-absorbing surface. In the past, this required time-consuming SEM analysis. The new Dual-Core 3D Measuring Microscope Leica DMC 3D offers non-contact, high-precision analysis of the surface texture of solar cells in a matter of seconds.

Monocrystalline and polycrystalline silicon

The most frequently used basic material for solar cells is silicon. In large-scale solar power generation, thick-film cells are most common, with a differentiation being made between monocrystalline and polycrystalline. Monocrystalline cells are made of monocrystalline silicon wafers like the ones used for semiconductor fabrication. Polycrystalline cells consist of wafers with varying crystal orientation. For one thing, they can be manufactured by casting and cost less than monocrystalline cells.

The efficiency of the solar cell depends on the silicon dopant, the light intensity and the wavelength range used, the optical thickness and surface texture. Currently, the energy efficiency of a solar cell is about 20 per cent. Applying specific but extremely expensive surface texturing processes, the solar cell can absorb more light, increasing its efficiency by up to 50 per cent. The application that demands the greatest cell efficiency is space travel.

Surface texture enhances energy efficiency

Numerous techniques have been tested for increasing cell efficiency, for instance light focusing with Fresnel lenses, solar concentrators or anti-reflection coatings. The most effective way to increase light absorption is by increasing the effective optical thickness of the silicon surface. This method, called surface texturing, depends to a large extent on the type of silicon. Monocrystalline silicon texturing is accomplished by a wet anisotropic etching process based on sodium hydroxide solution. The crystallographic silicon plane {111} is slowly etched, and the result is squared pyramids grown randomly with equal angled surfaces. The quality of the surface and the amount of pyramids depend on the temperature and the composition of the etching solution. The light absorption of this surface texture is extremely effective by increasing the number of internal light reflections.

In comparison, polycrystalline silicon texturing is not quite as effective due to the fact that most of the grains have incorrect orientation. Different grains etch at different rates, causing the formation of steps at grain boundaries, which may lead to problems with soldering zones and contacting structure in the subsequent metal screening process.

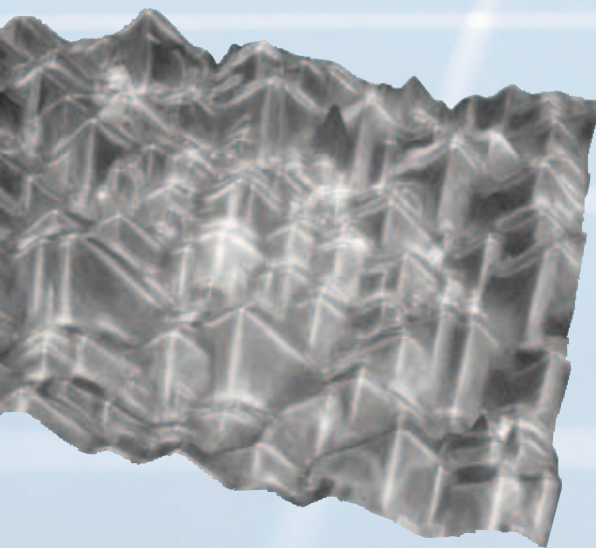


Fig. 1: Monocrystalline silicon surface after crystallographic wet etching {111}. The pyramidal surface texture increases light trapping up to 50 times, thereby increasing the cell efficiency.

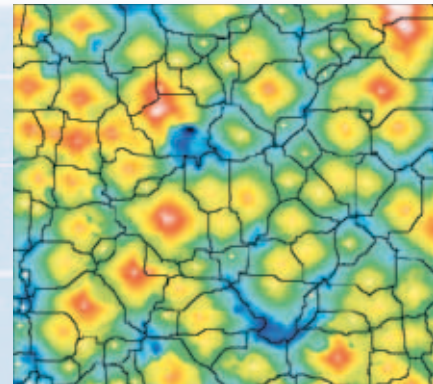


Fig. 2: Automatic segmentation using the intelligent watershed segmenting algorithm in individual pyramids

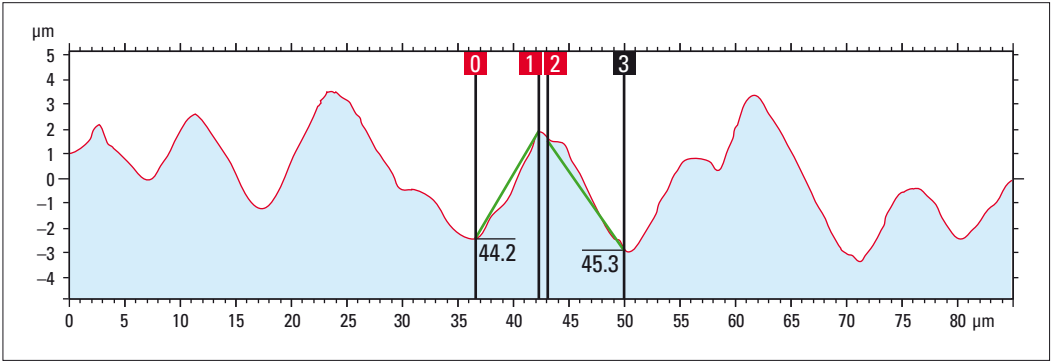


Fig. 3: Profile section of the pyramids on a monocrystalline silicon surface

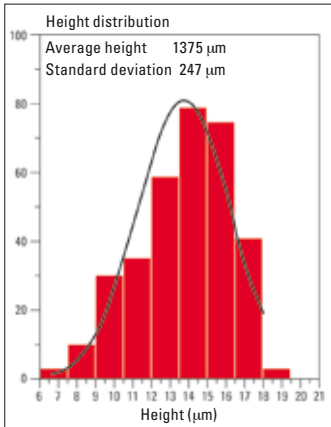


Fig. 4: The height distribution statistics of the segmentation are used for surface structure characterization.

3D surface measurement in a few seconds

Solar cell quality control is done at the end of the production chain, testing each individual cell for efficiency. The dual-core technology Leica DCM 3D Optical Imaging Profiler offers the possibility to check silicon surface texture, roughness, pyramid statistical characterization and metal contact in a few seconds.

Unlike the time-consuming scanning electron microscope method, the wafer is simply placed under the Leica DCM 3D and a 3D measurement taken in less than 10 seconds. The high local slope of the pyramid faces demands the use of objectives with a high numerical aperture, which are only available in confocal technology.

Figure 1 shows a 3D measurement of a monocrystalline silicon wafer after pyramid etching. For a 3D measurement of this kind, a 150x objective with a numerical aperture of 0.95 was used. As a result, the size of the visual field was reduced to a few tens of microns, which is roughly equivalent to the visual field of an SEM. The surface is scanned a few microns along

the focus position of the objective, collecting the confocal images plane by plane. The result is a high-resolution image similar to that generated by an SEM with infinite focus and precise 3D information on the height of the pyramids.

For the statistical pyramid characterization, a special watershed segmentation algorithm is used. This algorithm uses the height information to separate each individual pyramid into segments and then calculates the area, volume, mean and maximum height of each individual segment. In Figure 3, a profile section shows the characterization of a single pyramid with the height, base area and face angles.

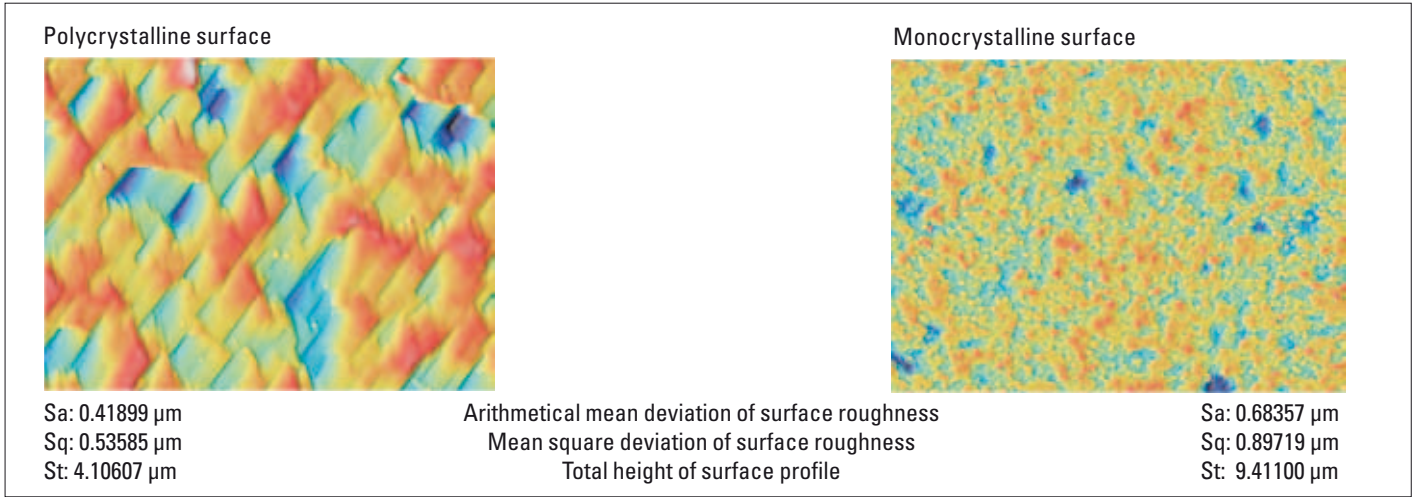


Fig. 5: Comparison of the typical surface parameters (e.g. roughness) of monocrystalline and polycrystalline silicon

Inspection of Micro-optic Components

No Defect Goes Undetected

Micro-optic components are used in a host of products concerned with illumination or imaging. Quality control of these components is challenging, as inspection has to be highly accurate yet non-invasive. Combining confocal and interferometric technology, the Leica DCM 3D Measuring Microscope is equipped to characterize these components with nanometer precision and ultra fast speed, despite the fact that they often have polished and curved surfaces that are difficult to examine.

Micro-optic components serve a wide range of applications. In front of the LCD display of a beamer, for example, there is a microlens array, so that a microlens is active in front of each pixel of the display. This makes it possible to use economical lamps, including semiconductor light sources such as LEDs. Another example are Fresnel lenses for concentrating the light from powerful white-light LEDs. The resulting design is extremely small and compact, yet offers a high light yield, high transparency and low power consumption. These white-light LEDs are therefore an ideal substitute for flash light in digital cameras. Micro-optics also help to improve the imaging performance of endoscopes for biomedical applications or support the realization of LOC (lab-on-chip) systems for comparing tissue samples or chemical substances. Microlenses are indispensable today for concentrating light in microscopic wave guides, for optic couplers (e.g. VCSEL) and in microsystems known as MOEMs.

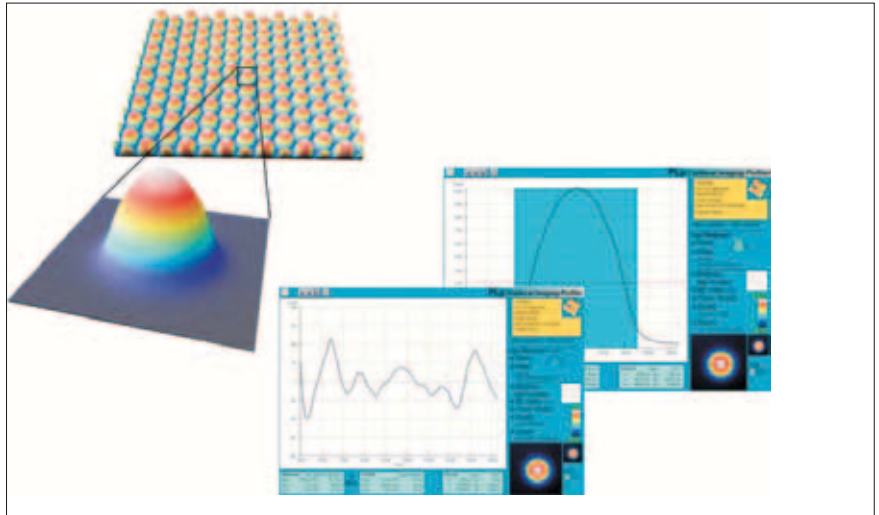


Fig. 1: Copy of a microlens array on Borofloat® glass. A single lens can be used to set the radius of curvature and correct deformations.

Lithography, fusion or replication

The technology for producing micro-optic components depends on the specific application, the required surface quality, desired reliability and final cost of these components. The three most common production techniques are lithography, fusion and replication. The lithographic method was originally developed in microelectronics for the production of structured coatings or surface profiles. With this method, a laser or electron beam is used to write 3D patterns in a photoresistant film which, after development, are applied to the substrate by means of a reactive ion process. This lithographic technique is suitable for wave guide structures, micro-optic free-space elements and diffractive optic elements.

The fusion technique is used to produce refractive components. It delivers high-quality results and is appealingly simple. Small cylinders are made in a traditional lithographic method. Due to the surface tension caused by the melting process, small plano-convex lenses of extremely high quality are produced. Lithography and fusion are extremely precise methods. In

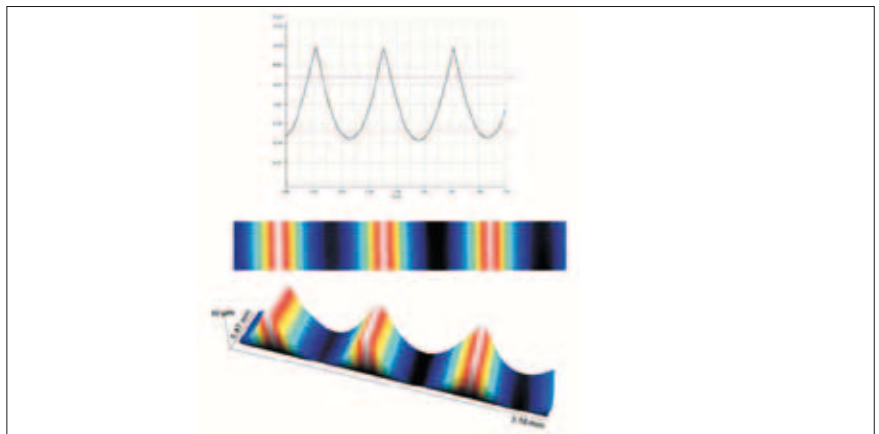


Fig. 2: Linear lens array. Copy of an array of cylindrical lenses on epoxide material (ion etch master). The data were recorded with a 50x, 0.8NA objective using the topography stitching method. The total field of view of the sample measures 0.4 x 3.18 mm and the surface slope is more than 30° in places. Topography stitching is therefore necessary to depict the entire lens group. The spacing between the lenses is 1 mm, the total height is over 90 µm.

view of the rising demand for microlenses however, some manufacturers use the replication technique to obtain higher quantities. As a rule, molding processes are applied to produce replicas in silicon oxide or epoxy resin on hard glass with a high-quality master.

Contact-free, high-precision measurement

Instruments for measuring micro-optic components have to meet two important criteria: they must enable contact-free and at the same time highly precise measurement. Contact profilometers are not non-destructive, but are able to record the profile of a complete lens irrespective of reflectivity and slope steepness. For surface features with an average height ratio or for wave guides under a coating, white-light interferometry is used. Due to the design of interferometers, however, the maximum measurable slope is limited by the numerical aperture of the objective, which is normally under 0.5 for a high magnification.

The Leica DCM 3D Dual-Core Measuring Microscope uses objectives with a numerical aperture of up to 0.95 NA and a high light yield, enabling structures even on polished surfaces to be measured with a reproducibility of 1 nm and with up to 70° of slope. Another alternative for measuring a complete lens or lens array is topography stitching. An objective with a high numerical aperture usually also provides a high magnification, which reduces the field of view to a few hundred μm . To enlarge the field of view, the software of the Leica DCM 3D controls a motorized stage fully automatically and measures several separate topographies. Finally, the software generates, again automatically, a final topography with an extended field of view, retaining the original properties of the single fields.

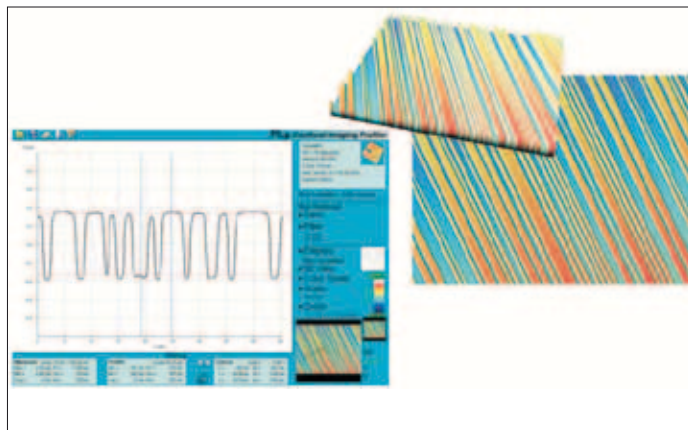


Fig. 3: Pattern generator. The average height is 700 nm, the line width varies from 1 μm to 7 μm . The wall inclination is 50°. A 100x, 0.9NA objective was used for this measurement.

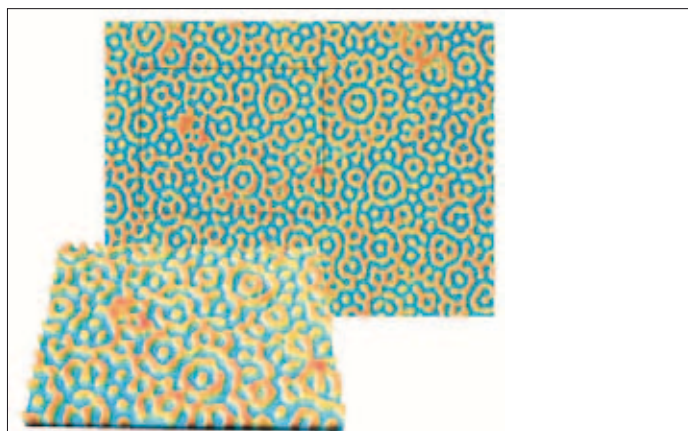


Fig. 4: Optic diffuser with random diffraction pattern. Measurement with a 100x objective. Average height 700 nm.

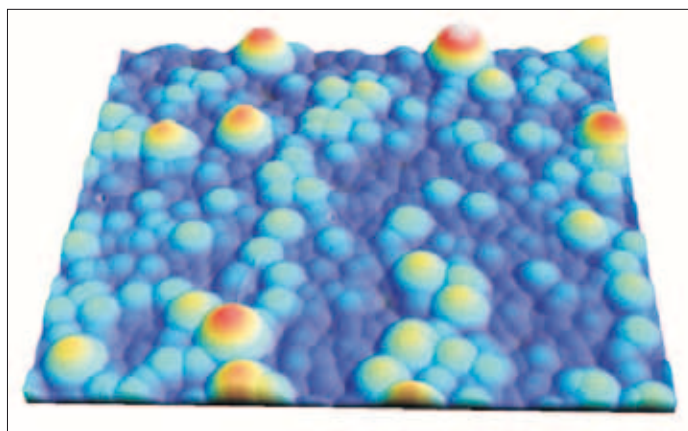


Fig. 5: Optic diffuser made of randomly arranged microlenses on an epoxy substrate. Measurement with a 20x objective on 10x10 mm fields. Total field of view 7 x 5 mm.

The Stereomicroscope as a 3D Measuring Device

Mathematical Genius

We only need one eye to see. But we need both eyes for seeing in three dimensions and finding our way in the world. In principle, stereomicroscopes work like an extension of our eyes. Two separate light paths each record an image from a slightly different angle. Our brain then composes a three-dimensional image from the two. For a long time, however, it was considered impossible to transfer this ingenious achievement of the brain to the image recording and processing technology of stereomicroscopy. This has now been achieved by innovative software combined with the necessary camera technology.

Although stereomicroscopes have always enabled three-dimensional viewing of samples with large depth of focus, they only used to provide two-dimensional images. Realizing the countless stereomicroscopic applications which would greatly benefit from the possibilities of 3D image recording and quantitative analysis, scientists and engineers tried to find a practicable solution for years without success.

Leica Microsystems has now developed software that – combined with a special digital camera – transforms a conventional stereomicroscope into a 3D measuring device. With the unique Leica StereoExplorer and the Leica IC 3D camera, a wide variety of 3D surface measurements can be performed, such as profile, roughness, area and even volumetric measurements. The Leica 3D system is useful in all fields of science, industry and forensics in which representation of spatial depth information means having more, and more valuable, information.

3D Stereo Reconstruction

The stand-alone software package Leica StereoExplorer automatically calculates a 3D data record from a pair of stereo images for reconstruction, documentation, analysis and quantitative measurement of three-dimensional surface structures. The realistic image, which appears in relief and can be freely rotated on the monitor, makes it easier for the user to identify complex surfaces and enables better diagnosis. The Leica StereoExplorer is also excellent for education and training purposes. Top-quality, true-to-detail stereopair images are essential for precise 3D reconstructions. The integrated digital Leica IC 3D stereo camera creates a perfect high-resolution stereopair without the need for complex adjustments. To obtain good results with conventional stereoscopic setups, a precisely matched optical system is required. Building on this precision, the combined software/camera solution of Leica Microsystems additionally features an instrument calibration achieving an accuracy of a few microns, depending on the zoom setting.

The software is optimized for the coded stereomicroscope Leica M165 C, controlling not only the Leica IC 3D stereo camera, but also the motor focus, and updating the data on the display. The camera and focus settings can be saved and retrieved as required. This makes work ergonomic and efficient, particularly during repetitive experiments, and ensures reproducible results.

Quantitative measurements

Once the surface information of the object has been captured, the 3D data can be visualized and analyzed in the Leica StereoExplorer. All analysis routines are designed for modular combination and intuitive operation. It would go beyond the limits of this article to describe all the possible analytical capabilities. One example is the profile analysis module, which permits the extraction of a height profile along user defined paths that can be used to calculate relative height measurements as shown in figure 2. All established



Fig. 1: The optical concept of 3D image capture: The Leica IC 3D digital stereo camera (1) is integrated between the binocular tube (2) and optics carriers of a Leica M Series stereomicroscope (3) and takes a high-resolution image of each optical beam path.

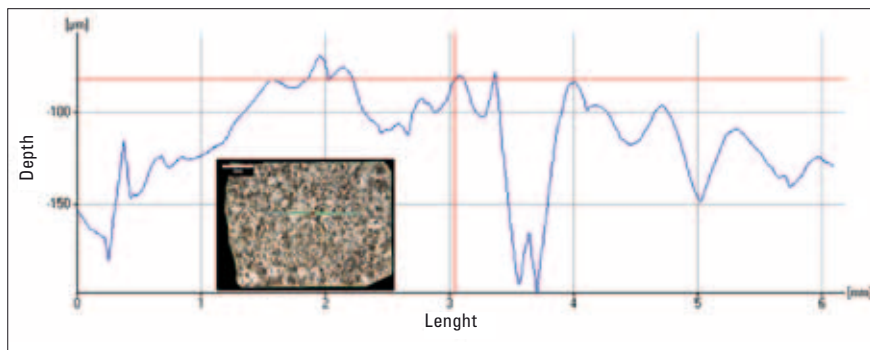


Fig. 2: Profile of a geological specimen

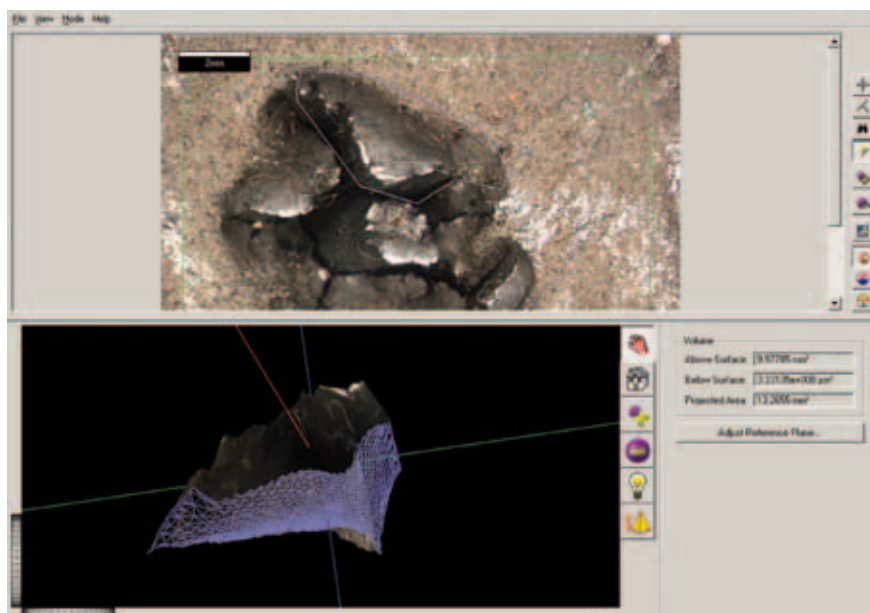


Fig. 3: Volume measurement in fracture analysis. A 3D model visualizes the volume of interest.

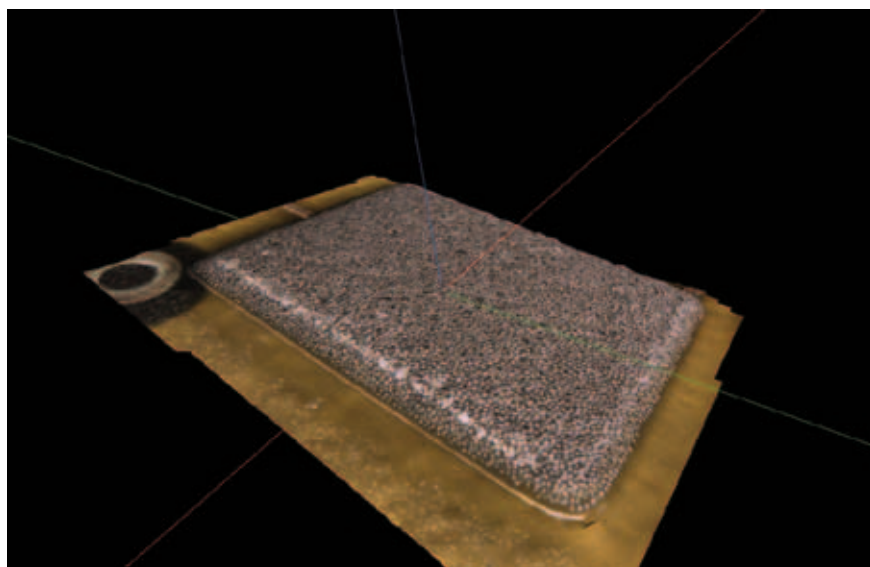


Fig. 4: 3D model of a solder paste with axes of coordinates, visualized by the Leica StereoExplorer

roughness, profile and waviness measurements can be performed with the Leica StereoExplorer as well as various statistical calculations. For example, the area analysis module calculates parameters such as the ratio of true-to-projected area, also termed the bearing area curve. The volume analysis module shown in Figure 3 enables direct volumetric measurements relative to freely definable polygon lines.

Wide range of applications

The Leica StereoExplorer and the Leica IC 3D camera can be applied in any field of study where the surface structure of a specimen is important. This may include documentation of surface roughness for affinity calculations, the analysis of fractured surfaces from mechanical parts, or the volumes of impressions and uprisings of formed surfaces. The advantages of the innovative technology from Leica Microsystems are particularly apparent in the following applications:

- Fracture analysis
- Semiconductor inspection
- MEMS (Microelectromechanic systems)
- Materials development
- Geology
- Drug discovery and production
- Life sciences research
- Entomology

Easily retrofittable

The development of the Leica StereoExplorer and the Leica IC 3D digital camera has enabled, for the first time, direct quantitative measurements of three-dimensional surface parameters in stereomicroscopic images. Precise profile, area and even volumetric calculations can be performed in reconstructed 3D images. All the measured values, 3D models and other parameters can easily be exported to standard files, integrated and further processed in reports. All these analysis tasks can be performed with the Leica M165 C stereomicroscope, which can be easily retrofitted with the necessary system components such as tubes, objectives, stands and illuminators. In this way, the capacity of a laboratory can be enhanced tremendously for a relatively small outlay.

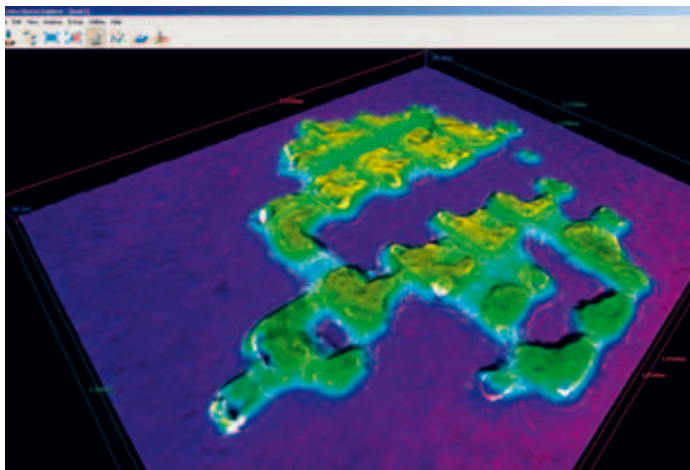


Fig. 5: Height-encoded phantom color view of a surface

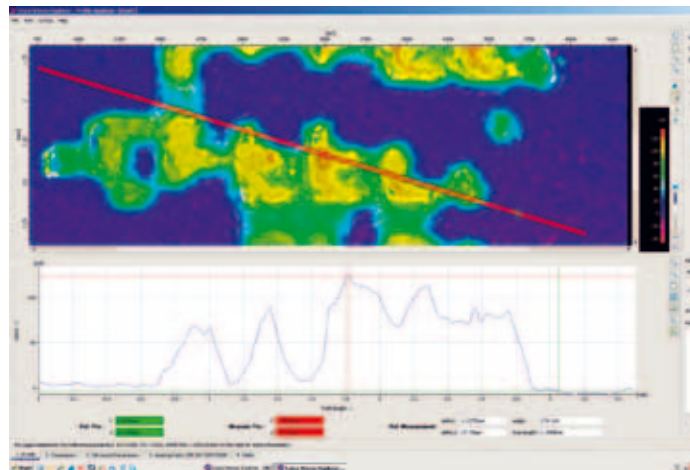


Fig. 6: The profile analysis module shows the height profile along a user-defined line (red). This profile allows various further evaluations.

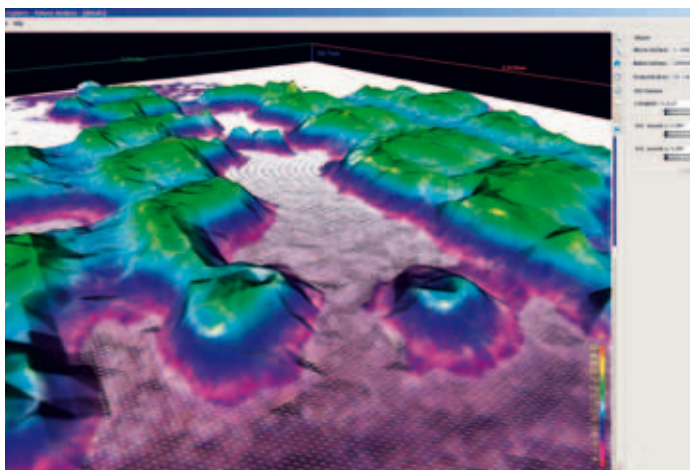


Fig. 7: The Leica StereoExplorer makes precise volumetric calculations above and below a reference plane.

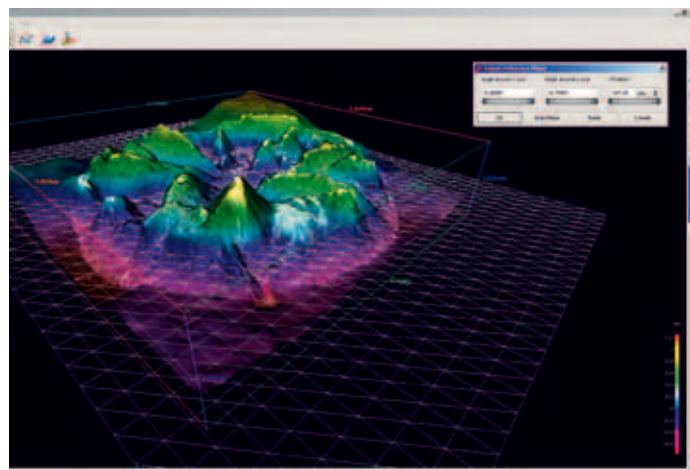


Fig. 8: The user can define any reference plane, which can be rotated round all axes. It determines the point of reference for all subsequent measurements.

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Homogeneous Dome Illuminator for Difficult Samples

The Reflection Tamer

Modern microscope and camera technology has generally made stereomicroscopic inspection and quantitative analysis of industrial samples a lot easier. Some materials, however, continue to give even microscopy specialists a hard time. When characterizing metal surfaces, for example, reflections frequently prevent satisfactory image recording. To remedy this problem, Leica Microsystems has developed a simple, but ingenious solution: the Leica LED5000 HDI™ dome illuminator.

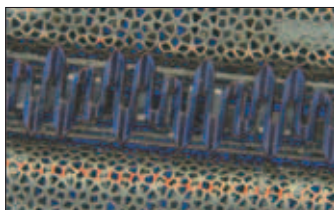
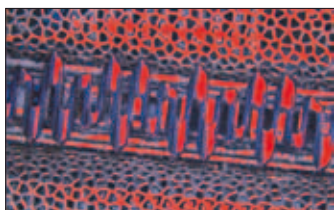


Fig. 1: Top: Foil cutter head, recorded with ring light. The red, overexposed areas do not provide any image information. Bottom: Foil cutter head, recorded with the Leica LED5000 HDI™. The dome illuminator provides uniform illumination and complete information on the structure of the sample.

Visualizing samples with reflecting surfaces via stereomicroscopes and digital microscope cameras is a problem that has beset users for a long time. Most illuminators shine directly at the sample, causing strong reflections of metal surfaces in particular. These often overtax the dynamic range of digital cameras, making it practically impossible to obtain a well-balanced image of the sample. The image then contains over- and underexposed areas which do not supply any useful analysis and measurement data.

Creativity called for

Talking to customers confronted with this problem, Leica Microsystems' product specialists were often shown bizarre setups the customers had constructed themselves in an attempt to suppress the reflections. Some users had improvised by removing the bottom from a white plastic cup and putting the cup over the sample. The sample could then be fully viewed through the microscope objective while the white, semi-transparent plastic shielded the sample from the direct irradiation of gooseneck light guides, generating an indirect light.

In principle, the new Leica LED5000 HDI™ works in a similar way, although it is far more sophisticated. It is based on the idea of an illuminating dome, the shape of which produces an extremely homogeneous, indirect light of constant intensity. At the same time, ambient light is effectively blocked out. The Leica LED5000 HDI™ therefore provides uniform light distribution with no disturbing reflections and harsh shadows.

Unique flexibility

The idea of dome illumination is not completely new – it is often applied in automated, camera-controlled quality assurance inspections. However, this dome illumination is designed for machines and uses rigid domes. These would be impractical for microscopy, as access to the sample would be extremely awkward – as in the case of the plastic cups. The illumination dome of the LED5000 HDI™ (Leica FlexiDome™) is made of flexible silicone rubber, and can be opened and closed with a simple hand movement.



Fig. 2: Leica FlexiDome™ in lower position: Diffuse illumination from all sides suppresses nearly all reflections and shadows. Stray and ambient light are eliminated, the illumination intensity remains constant throughout the microscopic inspection.



Fig. 3: Leica FlexiDome™ in upper position: Maximum sample accessibility. The light characteristic is equivalent to a fluorescent ring light.

When it is pulled up, the sample can be accessed and re-aligned without altering the focus. In the up position, the Leica LED5000 HDI™ delivers a light characteristic comparable to that of a fluorescent ring light. In the down position, the sample is illuminated with homogeneous, diffuse light from all sides. The soft, longlife silicone rubber affords the sample extra protection. The flexible and easy handling makes the Leica LED5000 HDI™ unique.

Fully integrated

Like all LED illuminators from Leica Microsystems, the Leica LED5000 HDI™ is fully integrated in the complete system of microscope, camera and software. The dome illuminator is either controlled via the built-in membrane keypad, the Leica Application Suite

software or the external Leica SmartTouch™ control. All the illumination settings are repeatable. The LEDs offer the additional benefits of low power consumption and extremely long lifetimes, which make lamp change unnecessary.

The advantages of the Leica LED5000 HDI™ reach their full potential in combination with the Leica StereoExplorer, the Leica Application Suite module "Montage" and the high-end stereomicroscopes Leica M125, M165 C, M205 C and M205 A.

A motorfocus is also recommended, particularly for reproducible surface measurements.

Advantages of LEDs in microscope illumination

- Long life – approx. 30,000 hours
- No need for lamp change
- Up to 90% lower power consumption
- Color-neutral imaging of sample
- Constant color temperature, even at different brightness levels
- No ventilator required
- Flicker-free illumination due to DC components
- Insensitive to voltage fluctuations in grid

Advantages of Leica LED illumination systems

- Controls on the instrument
- Robust membrane keypad
- Easy installation
- No need for additional control devices
- Integrated in LAS software
- Reproducible settings
- Illumination setting stored with the image
- Good access to sample due to compact illuminator design
- Saves space at the workplace

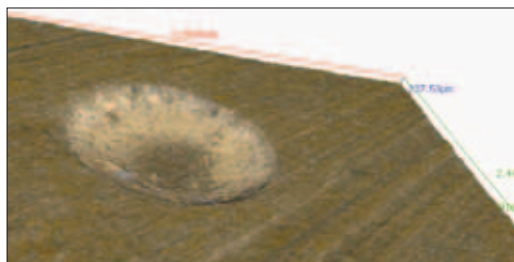
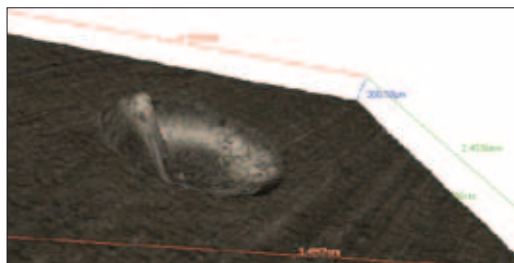


Fig. 4: Top: Indentation in a workpiece, recorded with the Leica StereoExplorer and a fluorescent ring light. Bottom: A far better image is obtained with the Leica StereoExplorer and the Leica LED5000 HDI™.

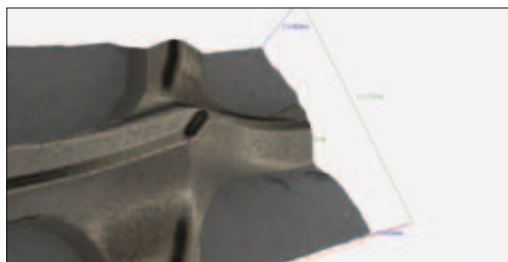
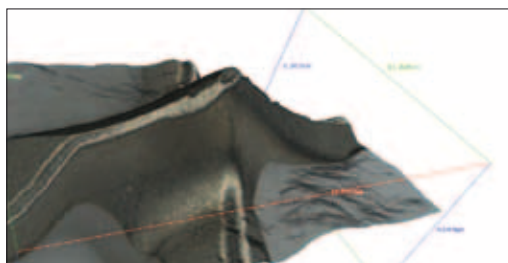


Fig. 5: Top: Drill head, recorded with the Leica StereoExplorer and a fluorescent ring light. Bottom: Here, too, the better result obtained with the Leica StereoExplorer and the Leica LED5000 HDI™ is evident.

IMPRINT

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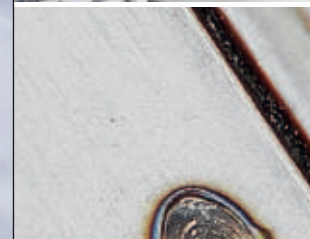
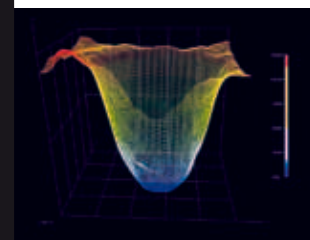
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