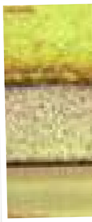

Recent Major Advances
IN 3D OPTICAL PROFILING OF MICRO SURFACES

words | **Ian Holton,** Managing Director,
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The smart way to 3D map micro machined components these days is, without question, to use a 3D Optical Profiler. Quite aside from the phenomenal advantage in speed of acquisition over old-fashioned stylus-profilers (a competent 3D Optical Profiler, for instance, typically acquires a full 3D map in about 30 seconds and is fast and easy to set up for each run) there is a host of other serious benefits, such as true colour mapping and the ability to cover height measurement ranges from sub-nanometre to millimetres (neither of which can be done with interferometers) and to take extremely bulky samples in situ. For many years, indeed, it was a gap in this 'intermediate' length scale which was so neglected, yet which is so absolutely critical for micro machining, and which state-of-the-art 3D Optical Profilers (figure 5) span so competently.

This is the so-called 'focal variation' class of optical instrument. That is, in a nutshell, a form of optical microscope which turns the depth of focus, formerly a limitation, into an advantage and uses it to determine the height of the sample at each and every x,y position on the sample surface (figure 1). This method and the simplicity of microscope optics lends itself to extraordinary versatility. For instance, it is possible to integrate functionality such as Thin Film Measurement by means of reflectometry. It is also possible to integrate Nomarski Differential Interference Contrast to map roughness on scales much smaller than 1 nm (figure 2). Furthermore, it is possible to integrate interferometry in some 3D Optical Profilers in order to push the height resolution even further (figure 3). Images of adjacent areas of sample can be automatically and sequentially acquired and stitched together to 3D-map large areas of sample with extremely high resolution. Additionally, an AFM can also be integrated into the system such that the benefits of the 3D Optical Profiling can be seamlessly married to AFM profiling (where the tip is locatable within the optical Field of View). And so much more. This explosion of powerful functionalities in one 3D Optical Profiling tool has truly revolutionised our ability to characterise (and rapidly) micro machined surfaces.

One company, Zeta Instruments Inc., USA, has come up with an invention which enables a focal variation instrument (sometimes known as 'infinite focus') to measure hitherto

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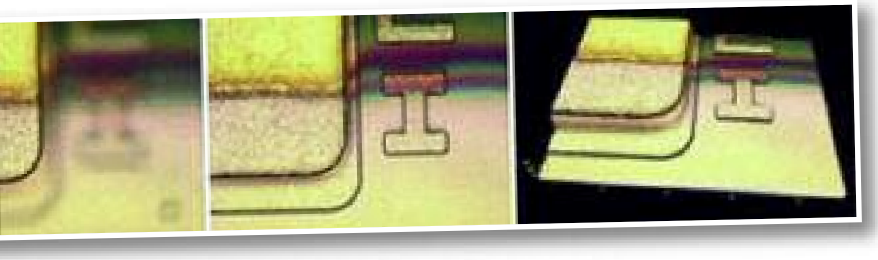
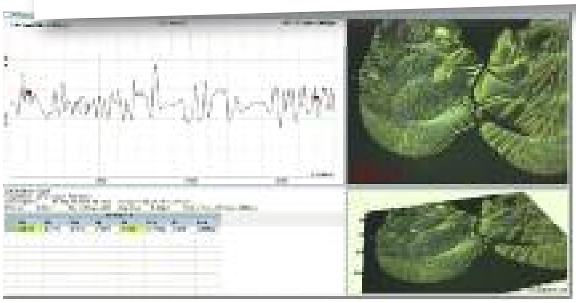
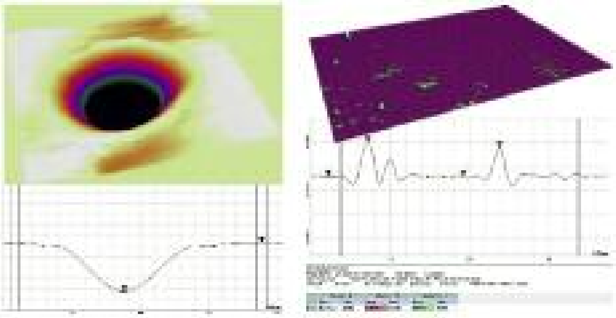


<< **Figure 1:** On the left a conventional microscope image with limited field of view. In the middle there is a focal variation (or 'infinite focus') image in which all depths are in focus, with the resulting 3D representation of that measurement on the right. (Image courtesy of Zeta Instruments Inc., USA.) >>

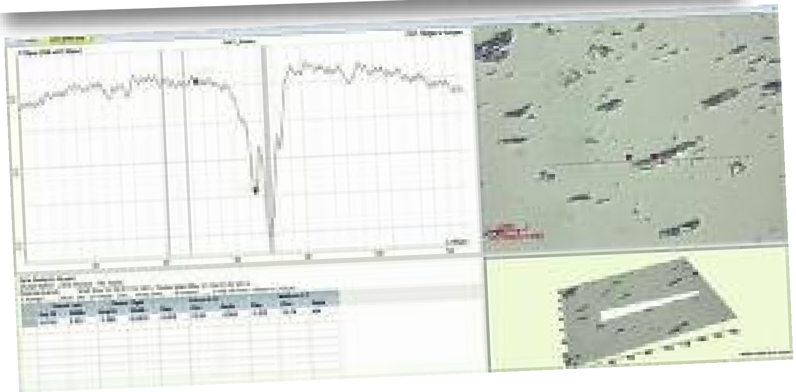
<< **Figure 2:** 3D Measurement of height-variations of the order of 0.1 nm on laser-blasted plastic by means of Nomarski Quantitative Differential Interference Contrast on a Zeta 20 3D Optical Profiler. (Image courtesy of Zeta Instruments Inc., USA.) >>





<< **Figure 3:** Left: 20 nm pit 3D-mapped in false colour using a Shearing Interferometer attachment to a 3D Optical Profiler. Right: 5 nm high stain on a wafer. (Images courtesy of Zeta Instruments Inc., USA.) >>

<< **Figure 4:** A micro machined Calcium Fluoride lens, complete with machining cracks and flaws, is mapped using the ZDot method. The point of interest here is less the cracks and flaws themselves than that this technique accurately and unambiguously 3D-maps the highly-polished and featureless surfaces between those cracks. (Image courtesy of Zeta Instruments Inc., USA.) >>



impossible surfaces. Up until this innovation, a fundamental flaw of the focal variation class of instrument (despite its great advantages) had been that it requires 'something to focus on': that is, the surface under examination required features on which the optics could 'autofocus'. Without such 'native contrast', a focal variation instrument was unable to determine the height of the surface at each and every point. So for instance a surface which contained some areas with such detail and other areas without, could be 3D mapped only for areas with such detail, or native contrast, but would merely return garbage data for the areas that had no such detail. It is pretty much like pointing an autofocus camera at a blank and featureless wall and pressing the shutter: all that happens, as we know, is that the camera lens frenetically shoots in and out, trying in vain to find object features on which it can focus. Only it was worse for the conventional type of focal variation 3D Optical Profiler, because the instrument must find the focal height of each and every pixel in the entire image — and whereas some have detail on which to focus, many do not. Typical examples of very common samples which presented this difficulty include optically polished surfaces, or fractured metal surfaces. The method patented by the Zeta Instruments Inc. (for which they coin the term 'ZDot') actually generates local contrast on the surface where no native sample contrast exists. In this way, it is trivially easy to accurately measure hitherto impossible surfaces, such the CNC diamond micro machined Calcium Fluoride lens in Figure 4, optical flats and metals which have areas of high polish. The most featureless smooth and polished surfaces are 3D mapped unambiguously.

Perhaps one of the most impressive examples of the utility of this feature is the ability of the ZDots to measure the internal dimensions of different surfaces of a sealed micro fluidics device. The instrument is now able to measure each of the transparent surfaces by selecting it and differentiating it from the others (see figure 6). Of course, given that the internal dimensions of micro fluidics cells change upon sealing, that ability to measure the internal dimensions of a sealed cell is proving of critical interest to companies such as IntegenX and others which develop micro fluidics devices. Another example of a measurement which is enabled by the use of ZDots is the ability to measure micro needles (see for instance the paper on 3D maps of micro needle arrays by Prof. Y. Makino et al).

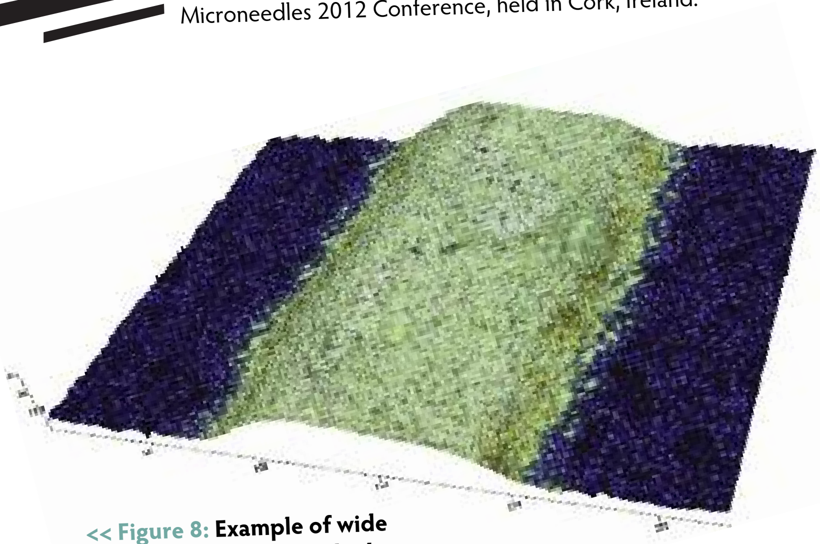
Once it is required to 3D map features of only a few nanometres height then a piezo stage can be used to enhance the Z translation capability: yet the optics can still map down to this level with no problem. For instance it is always required to accurately check the 3D profiles of LED PSS bumps (as in "Light Emitting Diode Patterned Sapphire Substrate"), where arrays of these bumps are manufactured on exactly such a demanding scale. Figure 7 shows a typical quality check on such a semiconductor wafer.

There are occasions when the surface to be measured is inconsiderate enough to reflect almost no light at all. There exist medical MEMS which are required to be black, for instance, and of course solar cells are purposely designed not to reflect light (having a reflectivity of less than 0.5%) and yet which must be 3D profiled on the micro scale for quality and for research and development purposes. Happily, one of the figures of merit (the Numerical Aperture) which gives 3D Optical Profilers ability to measure height with greater accuracy also enables easy acquisition using the pitiful levels of reflection that there are (Figure 8). A critical concomitant of sensitivity for such large dynamic range is, however, the ability to measure within the same image features of extreme reflection such as the silver contacts without either saturation of the high reflectivity or loss of the low reflectivity areas, and good 3D Optical Profilers have the ability to do this.

In summary, 3D Optical Profiling, Imaging and Metrology functionalities, which have so far been mutually exclusive in an instrument can now be combined in one instrument, and recent innovations enable the measurement of hitherto difficult or impossible surfaces.

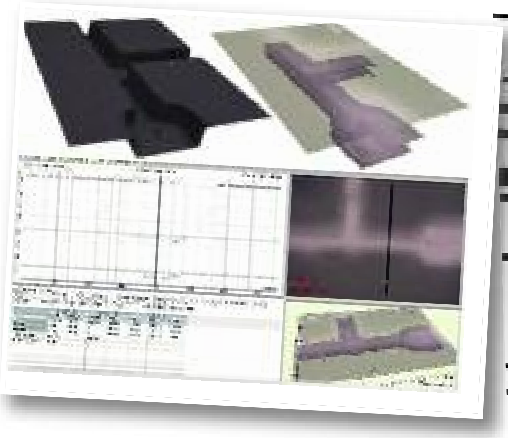
References:

"3D image analysis of microneedles" Y.Makino, T.Kurita, M.Ishibashi, K.Kobayashi, H.Hamamoto, K.Toyohara and M.Kiyoki of Tokushima Bunri University, Japan, MEDRX Co., Ltd, Japan and TEIJIN Limited, Japan. Presented at Microneedles 2012 Conference, held in Cork, Ireland.

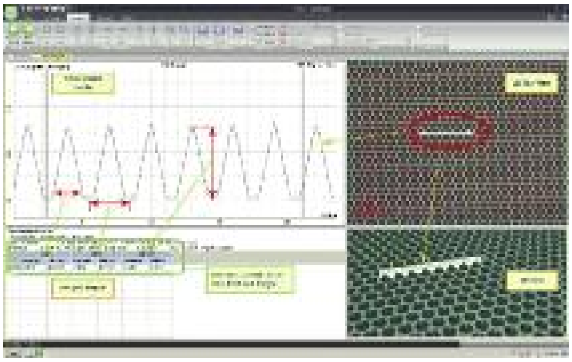


<< Figure 8: **Example of wide dynamic range — a high-reflectivity metal contact on Silicon Nitride, which has reflectivity of less than 0.5%. There are now systems which can handle a very large dynamic range of reflectivity within one image without either saturation or loss of low intensity data. (Image courtesy of Zeta Instruments Inc., USA.)** >>

<< Figure 5: **Structured micro fluidics MEMS. (MEMS Image courtesy of IMTEK, Laboratory for MEMS Applications, Freiburg, Germany. 3D Optical Profiler image courtesy of Zeta Instruments Inc., USA.)** >>



<< Figure 6: **3D-mapping an open micro fluidics channel (top left) is straightforward. 3D mapping a sealed micro fluidics cell (top right) in order, for instance, to account for distortions upon sealing has not been possible until the advent of Zeta's ZDot method. Top right and below we see a full map of all three surfaces in one single sample scan, together with the three surface profiles. (Images courtesy of Zeta Instruments Inc., USA.)** >>



<< Figure 7: **An example of enhancement of stage height-resolution by means of piezo-drives, in this case for measurement of LED PSS bumps of less than 2 nm in height. (Image courtesy of Zeta Instruments Inc., USA.)** >>