The Challenge of Dimensional Metrology on High Aspect Ratio Micro Structures

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The 4M-Multi Material Micro Manufacture Network of Excellence initiative [1] is concentrating its efforts on non-silicon materials, i.e. metals, polymers and ceramics. For metrology of micro-components this material choice has a big impact on the possibility of making accurate measurements [2], although vision based metrology problems are already very obvious in high aspect ratio MEMS manufacturing[3]. This paper will report some specific findings related to the measurement of high aspect ratio microstructures of polymers and metals.

When the lateral (X,Y) dimensions of components shrinks to micrometers and the thickness dimension (Z) increases and even surpasses the lateral dimensions by large factors, we end up in so called high aspect ratio structures. This is where the big metrology challenges sets in if we need to measure in all three dimensions with high accuracy as standard scanning electron microscopes are not accurate enough to be used as a metrology tool. They suffer from drifts and image aberrations.

Traditional coordinate measurement machine (CMM) metrology based on a contacting sphere can not normally be applied for two reasons. The trigger force necessary for detecting "contact" is typically of the order of 50 mN, which will cause considerable measurement errors for tiny pillar type structures, see Fig.1. The other reason is the size of the ball. The smallest probes have balls with a diameter of about 30 – 50 micrometers, which will prevent access to micro channels in some micro-fluidic components. (See Fig.2) Standard atomic force microscopes (AFM) are not capable of measuring height-variations larger than about 6-10 micro-meters.

The alternative would then be an optical non-contacting probe, e.g. a confocal microscope, a white light interferometer, an optical head on a CMM or a laser triangulation unit. At a second thought they are not obvious choices either. As seen from Fig. 3. an accurate measurement along the Z-axis (height) based on focusing requires a large numerical aperture of the imaging objective. But measuring in narrow high aspect ratio holes and trenches will cut off this cone of light. The strange thing is that optical profilers or microscopes are not tested and specified at high vertical measurement ranges with the condition of also having a high lateral resolution.

To illustrate what happens, Fig. 4 shows an image obtained with a 20X objective in a standard optical microscope of an X-ray LIGA structure [4]. The leftmost image is focused at the top of a 190 micro-metre Ni-mould with different channels in it. The rightmost image is obtained when focus is set to the bottom of the channels. The leftmost horizontal channel is 100 micrometer wide, yielding an aspect ratio of ~2. Already at this limited aspect ratio the image is very blurred by the out-of-focus top surface having a high reflectance.

Optical systems designed for metrology applications should be optimised for small distortions, to be as accurate as possible in the linear imaging. Some also make use of telecentric objectives to prevent magnification changes for out of focus details. In this presentation we will for the first time present experimental data of how well different commercial optical 3D-measuring systems perform with regard to high aspect ratio features of micro-components.

References
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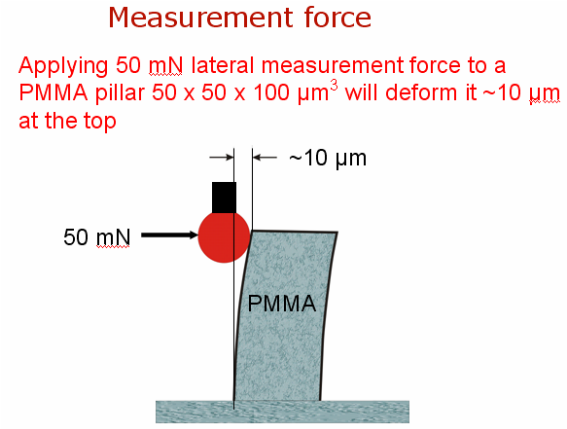

Fig. 1 Effect of CMM probe

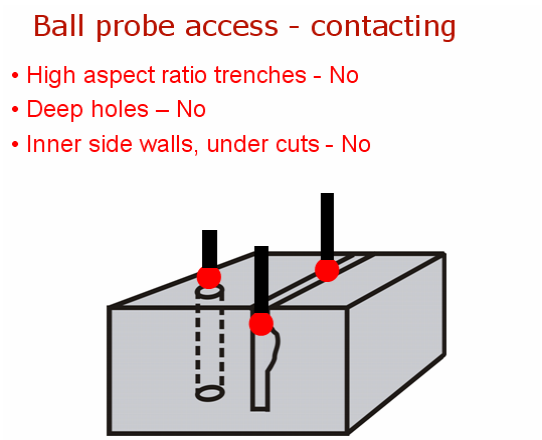

Fig. 2 CMM ball probes are too large

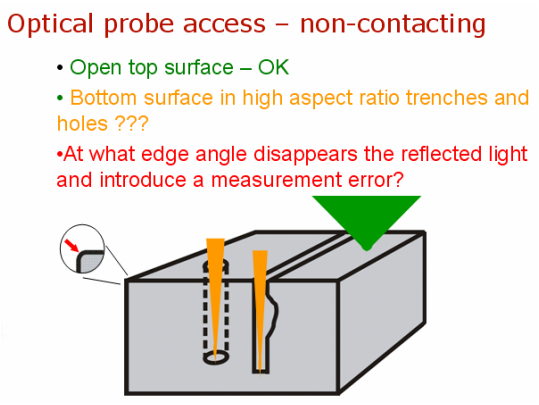

Fig. 3 Optical probes have limited accuracy

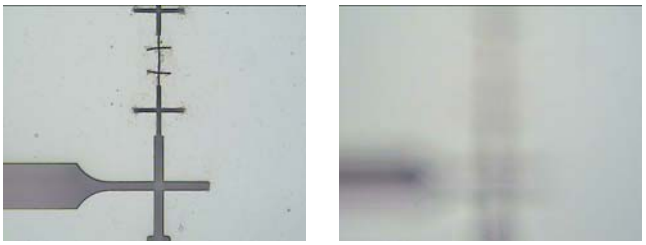

Fig. 4. Out of focus blur limits performance