3D MEMS Metrology with Optical Profilers

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Introduction

Faster product development and reduced time-to-market have made optical surface profilers essential tools for three dimensional metrology of MEMS. Veeco Metrology Group's Wyko NT Series Optical Profilers, available in a range of automation options, from the benchtop model NT1100 to the highly automated MEMS3500, utilize three distinct techniques for 3-D imaging and measuring of MEMS:

- Phase-Shifting Interferometry (PSI)
- Vertical Scanning Interferometry (VSI)
- Enhanced VSI (EVSI)

PSI measures height variations of several micrometers with angstrom-level resolution, on continuous surfaces that have no abrupt (pixel-to-pixel) height changes greater than ¼ the wavelength of light, which is typically 160nm. White light interferometry, or VSI, was invented at Veeco, and measures nanometer-level surface roughness as well as larger height variations, including step heights up to several millimeters. EVSI brings the best of PSI and VSI together: angstrom level height resolution and millimeters of height range.

Advantages of Optical Profilers for MEMS Metrology

One key advantage of the optical techniques PSI and VSI is that they are non-contact. For many applications, non-contact measurement is preferred, even required. Optical profilers are routinely used to measure out-of-plane deflection of fixed beams, cantilevered beams, or suspended membranes, as well as tilt angle of micro-mirrors (see figures 1-5).

White Light Interferometric Optical Profiler

Provides fast, non-contact three dimensional measurements. Captures an area up to 6mm x 8mm in a single image, and a much larger area by stitching images together. Out-of-plane range exceeds 8mm (model NT8000). Resolution: in-plane about 0.5µm (high-magnification objective lenses) in a single-image field of view about 50µm x 60µm; out-of-plane, better than an angstrom (rms roughness measurement).[1]

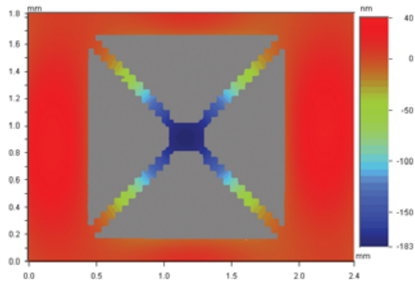


Figure 1. Veeco NT Series optical profiler image (topview perspective) of a bulk micromachined, suspended structure that is deflected (out-of-plane) under compressive stress. Some suspended structures can be extremely sensitive to applied mechanical loads; optical profilers are routinely used to measure these free of mechanical contact. 1.8 x 2.4 mm image; 230nm height range (color scale).

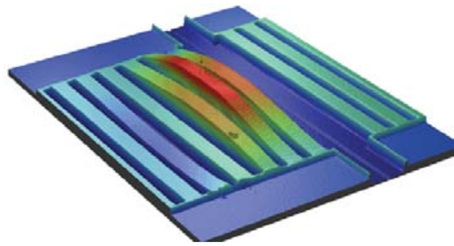


Figure 2. Optical profiler image of surface-micromachined poly-crystalline silicon fixed beams. Out-of-plane bending of beams here is a result of stress, and, possibly stiction in the case of the second beam from the left which is bent down (darker blue in the mid-section of beam). The image can be viewed from many angles, and allows accurate measurement of in-plane dimensions, as well as out-of-plane deformation of the beams, while also revealing defects, like on the 4th beam from the left. 460µm x 600µm area; ~13µm height range (color scale).

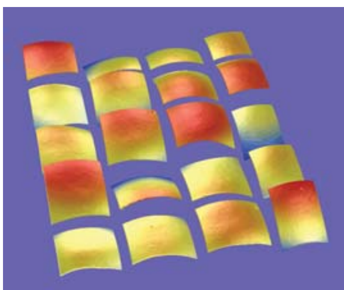
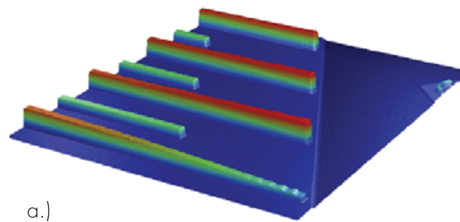
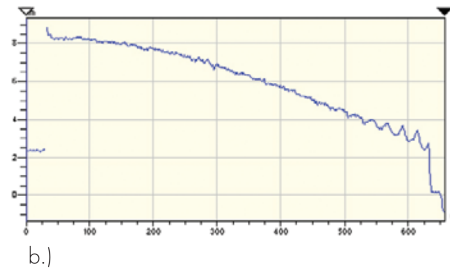


Figure 3. Optical profiler image of an array of micro-mirrors. Typical measurements include mirror planarity (tilt angle and bow), mirror spacing, and surface smoothness. 1.2mm x 1mm area; ~600nm height range (color scale).

Figure 4. Topview perspective of a single (not stitched) optical profiler image, depicting twenty cantilever beams all at once. 1.4mm x 2.1mm area; 17µm height range (color scale).



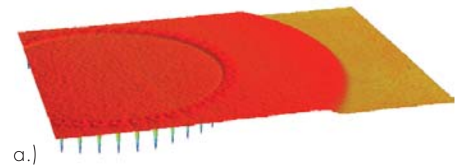
a.)



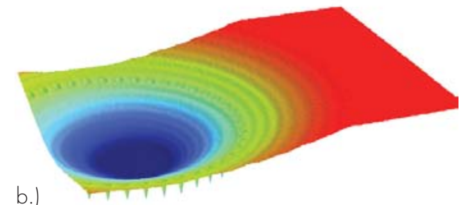
b.)

Figure 5. To make measurements on an image, a large array of software features is available, including cross sections. a.) optical profiler image of one pinned (to substrate) and several free-standing surface micromachined poly-crystalline silicon cantilever beams. 750µm x 650µm area; 12µm height range (color scale); b.) a cross section measures the downward deflection along and the ripples at the end of the pinned-down beam.

Figure 6. Foreground: a single high magnification (50X objective lens) optical profiler image with a lateral spatial sampling interval (pixel size) of 0.3µm. The Veeco NT3300 and MEMS3500 optical profilers can stitch several such images into a mosaic, combining large field of view and high lateral resolution. Background: composite stitched together from 49 individual images (with some overlap at the boundaries); 580µm x 640µm area, 15µm height range.



a.)



b.)

Figure 7. Optical profiler images of a micromachined membrane a.) without, and b.) with 30V electrostatic actuation voltage applied. Out-of plane deflection is captured in several successive images (only two are shown here) as the actuation voltage is varied in steps. 1.2mm x 1mm area; 2.2µm height range (right image).

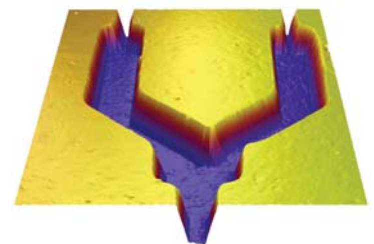


Figure 8. Optical profiler image of micro-fluidic channels reveals detail, including defects, and measures step height, and surface roughness. 1.5mm x 2.5mm area; 33µm height range.

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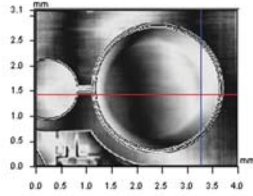

Top view optical profiler image (4mm x 3mm area) and cross section analysis of the 3D data from a micro-sensor membrane. Veeco's user-configurable Vision32 software analyzes NT optical profiler, Dektak stylus profiler, and Digital Instrument NanoScope AFM images, all on the same footing.

Another advantage of optical profilers is the large field of view of the images. In a single image, an NT Series optical profiler can record the 3D topography of an area as large as 6mm by 8mm, capturing several devices spread over a large area, as shown in figure 4, or an entire system, as shown in the sidebar.

In addition, several images can be "stitched" together to visualize and measure on yet a larger field of view (Figure 6). Much of this can be automated in the Veeco NT Series optical profilers, including the NT1100, NT3300, NT8000 (offers >8mm scan range), and the MEMS3500, optimized for 3D MEMS metrology.

Optical profiling is fast. An individual profile (image) is often complete in about a minute or less. The speed also makes it easy to take and average repeated (duplicate) measurements of a quantity to improve upon the already low-noise measurement capability of the instrument. In some applications, this averaging leads to a meaningful improvement in the repeatability of measurements.

The combination of large field of view and speed make the NT Series optical profilers ideal for high-throughput applications. This combination, together with the non-contact nature of optical profiling, enables yet another set of applications with entirely different requirements: measuring the moving parts of a MEMS in different stages of actuation; that is, making a measurement, actuating the structure into a new position, and measuring it again (and repeating the procedure). For example, a membrane's out-of-plane deflection is measured as an electrostatic actuation voltage is applied stepwise (see figure 7).

The large range of out-of-plane (height) measurements—up to several mm—is another feature of optical profilers that suits the needs of MEMS metrology well. Since optical profilers can cover this large range and also offer high resolution, they are often used for measuring microfluidic components for cavity dimensions, sidewall angles, and surface roughness, as well as for locating defects (see figure 8).

Vision®32 Brings Data Portability to Veeco Metrology Tools: Optical Profilers, Stylus Profilers, Atomic Force Microscopes (AFM).[2]

The 3D image visualization and measurement features of Veeco the Vision32 software, which controls all aspects of the Wyko NT Series optical profilers, has been received very will by our users worldwide. Vision32 offers a flexible, customizable user interface for individual measurements, as well as a wide range of automated measurements and analysis options for pools of data gerated from multiple images. The popularity of Vision32 resulted in the expansion of the software. Users can now

- capture profile data on Veeco's Dektak stylus profilers, and process and analyze that data similarly to NT Series optical profiler data. [Reference 1]
- import Veeco's Digital Instruments NanoScope AFM images and analyze them on the same footing as optical profiler images.

This data portability helps fast, easy comparison and correlation of measurements made on three very different tools, thereby helping to improve productivity beyond what is possible with each tool separately.

Summary

Optical profilers offer fast, non-contact three dimensional measurement for MEMS. With a change of the objective lens, the field of view of a single image can be adjusted from a few micrometers up to 6mm x 8mm. The field of view can be substantially increased by stitching of individual images. The combination of speed, non-contact, and large field of view makes the optical profiler an ideal metrology tool for a vast majority of MEMS. Several levels of automation are available to fit the needs of a production fab, or an R&D lab. The three dimensional image analysis software Vision32 of Veeco's NT optical profilers also handles profiling data from Veeco's Dektak stylus profilers, and Veeco's Digital Instrument NanoScope AFM images, adding to the value of these three classes of metrology tools far beyond the sum of the parts.

References

[1] For an example of optical and stylus measurement correlation, involving SU-8 photo resist, please see the article by L. E. St. Clair, A. R. Mirza, P. Reynolds in Sensors Magazine (an Advanstar publication), Volume 17, No. 7, July 2000, pp. 24—33.

Footnotes

1. To learn how optical profilers work , please see the application note "Interferometry: Technology and Applications" from Veeco Metrology Group.
2. For more information on measuring MEMS with stylus profilers and AFM, please see the application notes "3D MEMS Metrology with stylus profiling and atomic force profiling" and "3D MEMS Metrology with the Atomic Force Microscope" from Veeco Metrology Group.

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