Interferometric measuring microscopy applied to miniature machines, structures, and surface features

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INTRODUCTION - THE NEED FOR 3D SURFACE ANALYSIS

MEMS are complex microstructures such as data storage read-write heads, accelerometers, ink jet printer heads, sensors and micro-mirror arrays. Typically, measuring microscopes control and monitor MEMS fabrication, including the silicon micro-machining process. Metrology tools measure a wide variety of devices at various stages of device fabrication, including wafer, die, and packaged-level, and require flexibility and automation to meet the varied needs of R&D and production [1].

The large diversity of devices, materials, and processes, and the wide range of surface parameters create unique challenges for MEMS metrology tools. The physical dimensions and geometries of MEMS encompass a large range, from tens of millimeters down to the angstrom level. Ideally, surface characterization yields quantitative information over a variable field-of-view covering the x, y and z dimensions. Additional procedures and controls characterize mechanical parameters such as deformations.

For the past decade, optical profilers based on scanning white light interferometry (SWLI) have enabled leading edge development and commercial success of advanced MEMS devices. We review the special requirements for MEMS metrology, the general principles of SWLI microscopy, and show several examples of expanded capabilities including integrated lateral metrology, long working distance objectives, and closed-loop deflection measurement.

SCANNING WHITE LIGHT INTERFEROMETRIC MICROSCOPY

A natural candidate for non-destructive 3D surface structure analysis of a MEMS device is an interference microscope, which provides surface height detail with sub-nm resolution. The instrument of choice is the scanning white light interferometer or SWLI microscope [2]. SWLI, also known as coherence scanning or vertical scanning interferometry, is fundamentally a multiple-wavelength technique, relying on a spectrally broadband source to remove the interference fringe order ambiguity characteristic of the previous generation of monochromatic interferometers.

In a typical application (Figure 1), a PZT or similar mechanical transducer scans an interference objective towards or away from the object surface, gathering data by electronic camera during the scan. The data are then transformed by coherence and phase analysis into a surface profile. The scan direction orthogonal to the part surface can be several mm in length, accommodating tall step heights and disconnected regions characteristic of MEMS devices. SWLI has the interesting and important property that it has the sub-nm resolution of conventional interferometers on polished surfaces [3], but is nonetheless capable of handling rough surface textures that generate complex speckle patterns that traditionally were considered inaccessible to interferometric metrology [4]. Surface profiling microscopes are ideal for form and roughness measurements on small parts. Figure 2 illustrates an example surface topography measurement of a MEMS device using the measurement geometry of Figure 1.

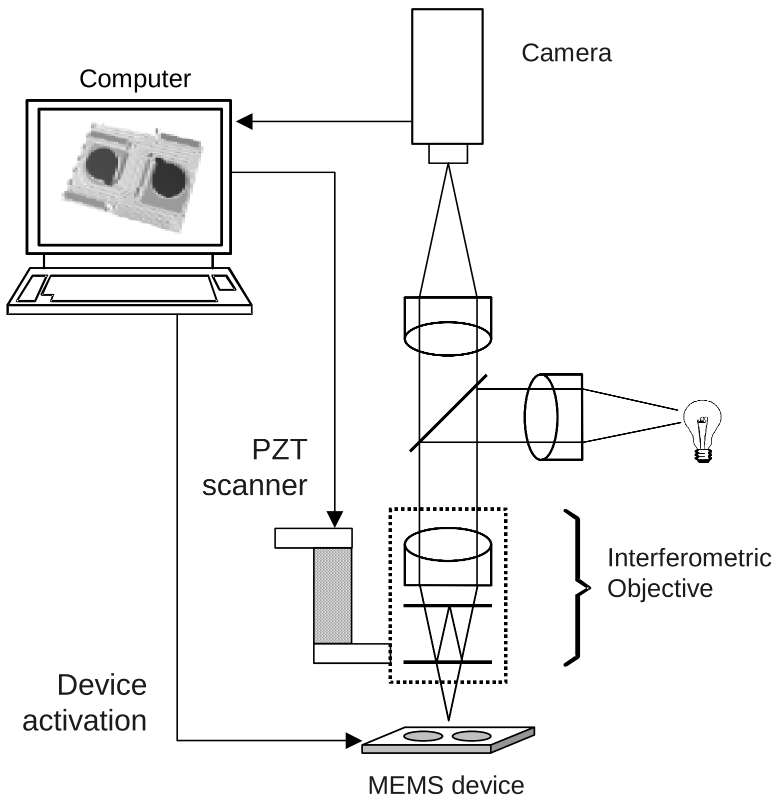

Figure 1: Typical MEMS metrology geometry for a SWLI type measuring microscope.

OUT OF PLANE PARAMETERS

The function of a many MEMS devices relies on out-of-plane deflections. Wafer-level characterization of controlled deformations allows device fabrication verifies performance prior to the investment of additional processing such as dicing, packaging and bonding, leading to increased yields and cost savings. Examples include actuators, pumps, and membranes, as well as pop-up, tilt-able, and deformable mirrors. In other cases, any out-of-plane deflection is highly undesirable, for example in accelerometers and gyros.

For some MEMS devices, the objective is to characterize the micro-mechanical system as a function of applied voltage. A simple set-up performs a series of individual measurements after actuation of the device in repeated steps, without the need of mechanical contact. The data can be rapidly visualized and processed to yield quantitative information.

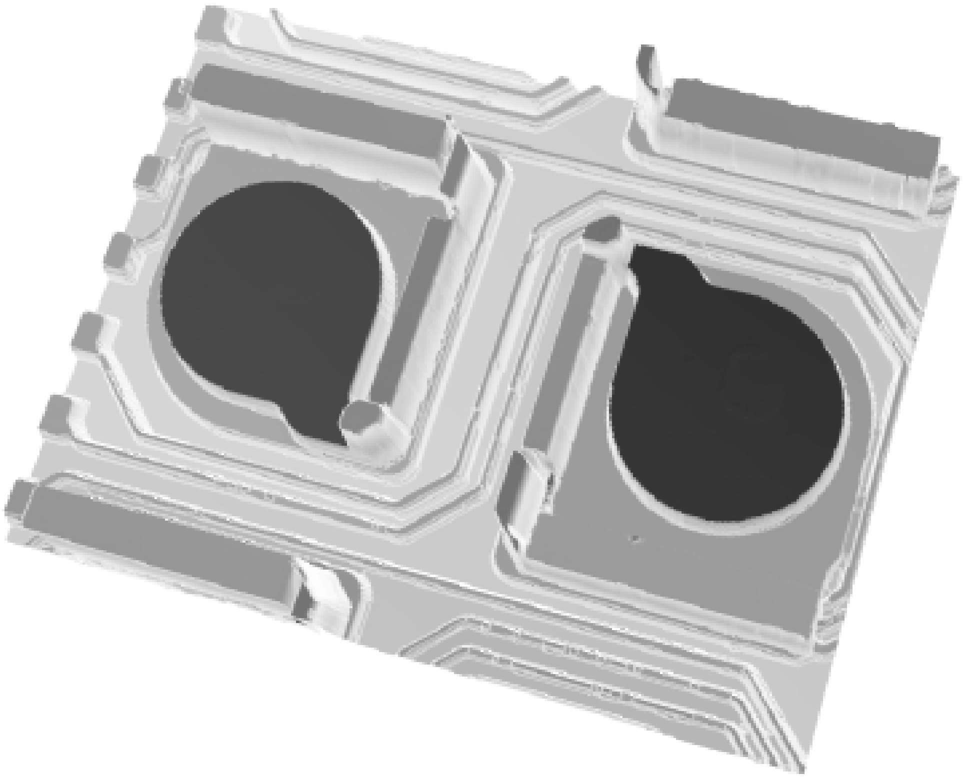

Figure 2: Surface topography map of a MEMS micromirror device. The lateral dimensions are 1.6 X 1.8mm, and the height range is 10 μm.

A typical scenario is a measurement tool in concert with a MEMS controller, using a flexible scripting language as the programming environment. In one example developed in collaboration with an end User, the microscope measures out of plane tilt as a function of applied voltage. The measure cycle begins with the MEMS device at the zero state, with no voltage applied. At the completion of this measurement, the profiler contacts the MEMS controller and requests a new voltage level. After applying the new voltage, the controller sends a signal back to the profiler indicating completion of its task and prompting the profiler to continue with its measure sequence. Repeating this cycle and logging the numerical data generates an applied voltage response curve for device calibration.

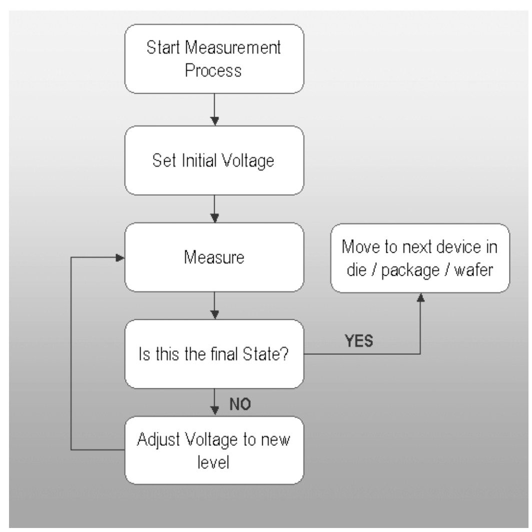

Figure 3: Flowchart depicting closed loop response measurement

A special consideration in these measurements is a long working distance to accommodate packaged devices and provide room for electrical probes, vacuum chucks, thermal plates, and manipulators for characterization and actuation of devices under test. Ultra-long working distance objectives (>15mm) simplify the integration of the measurement system with other experimental apparatus. It is also possible to image through a glass window to enable characterization of the device within a vacuum or sealed package.

IMAGE ANALYSIS AND DIMENSIONAL METROLOGY

Since MEMS devices rely on mechanical properties, lateral dimensions such as size, location, diameter, shape and offset are equally as interesting as surface topography. With the complete integration of an image processing vision system, the SWLI profiler is easily used to determine x-y dimensions as well as heights in the z direction. Such a system can also perform higher-level tasks such as device rotation during activation.

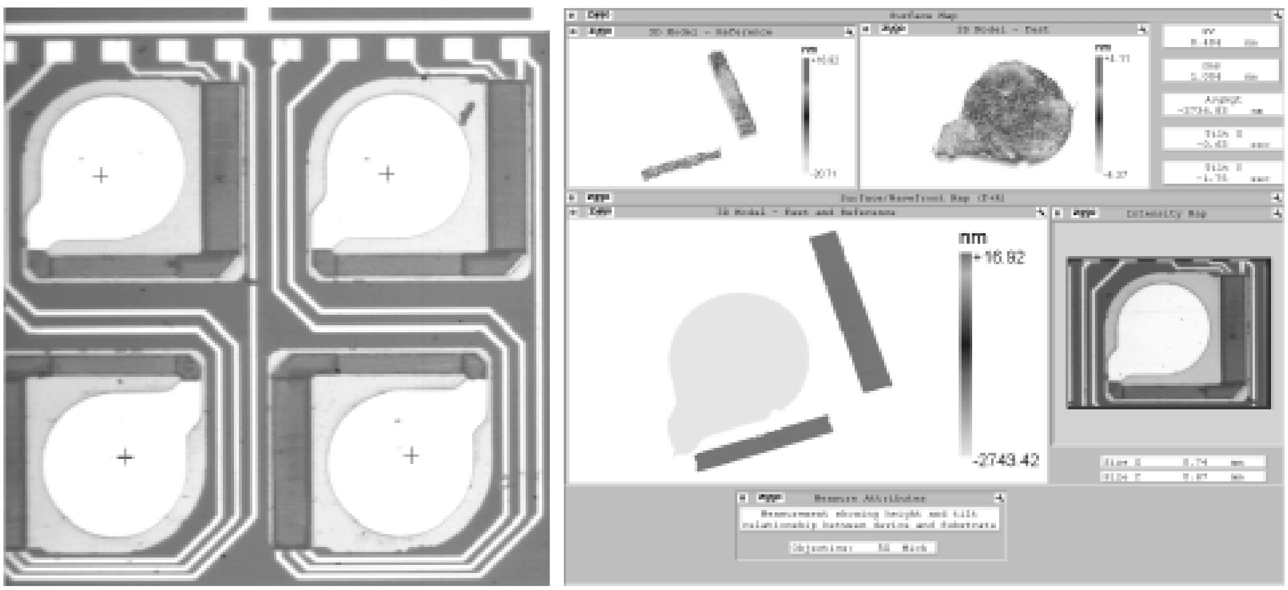

Figure 4: Automated feature finding. Left: The crosses indicate the defined centers of the six features identified by image analysis. Right: Image segmented by height relationships.

Advanced algorithms locate and segment complex data over a given field-of-view, without the need for hardware or software masks. The segmentation relies either on image intensity data (Figure 4a) or relative surface profile (Figure 4b). Automatic segmentation allows for several process enhancements including automation of individual and wafer level device metrology, increasing throughput and eliminating subjectivity introduced by manual masking.

Once identified, x-y metrology of specific features proceeds as illustrated e.g. by Figure 5, to determine the diameter of a round feature by detailed edge finding.

The vision system that is an integral part of a SWLI microscope also performs defect analysis. By teaching the vision system what an ideal part should look like, the actual test part can be compared to determine how closely ideal and actual parts match. The image analysis also locates defects such as pits, scratches and contaminants (Figure 6).

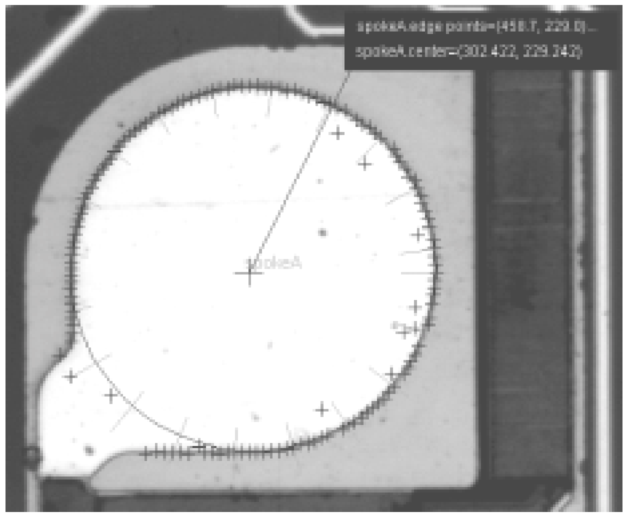

Figure 5: Dimensional Metrology – The round portion of the device has been fit to a circle. The measured diameter is 306.392 pixels or 513.05 µm. The measured area is 0.218907 mm^2

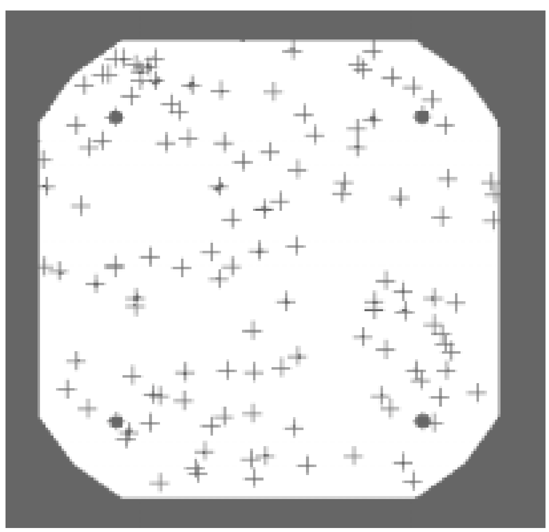

Figure 6: Defect analysis – 125 defects are identified as crosses within this 10.074 mm^2 area.

REMOTE ACCESS

As a final note, while much of the design of MEMS devices is performed in high technology environments with high costs of manufacturing, the actual manufacture of these devices is often contracted out to a MEMS foundry. These foundries are often in a distant geographic region as compared to the design center. In order to keep manufacturing processes under control or to monitor manufacturing progress, it is often convenient to set up a profiler at the foundry which can be controlled remotely via a high-speed internet connection from anywhere in the world.

Using PC remote control software and application sharing, it is possible to access the surface profiler's GUI from a remote location (Figure 7). Operations such as moving a programmable stage or changing the position of a motorized objective turret can be programmed to occur when a button on the interface is pressed. This sort of application is quite useful when great distances separate foundries and designers and measurement turnaround time is a premium.

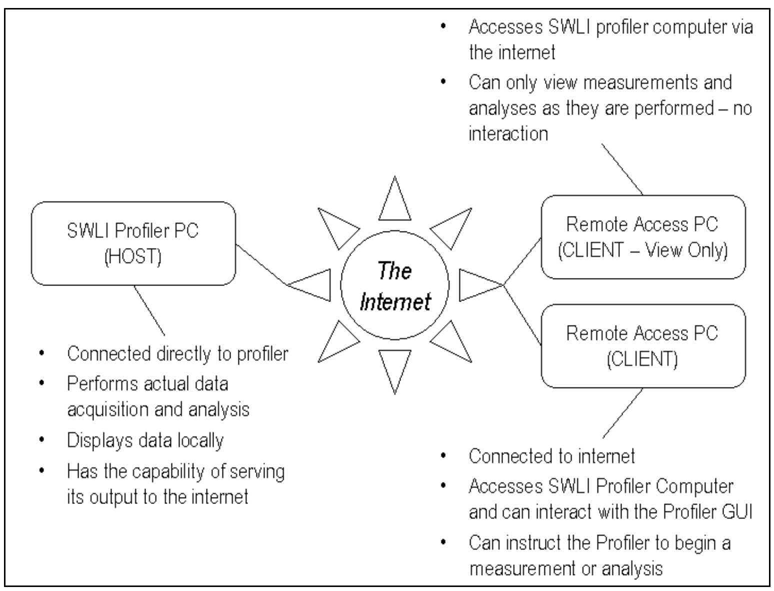

Figure 7: Example Remote Control Architecture allowing for remote viewing and remote use of SWLI Profiler.

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