

Static and dynamic characterization of MEMS and MOEMS devices using optical interference microscopy

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ABSTRACT

We report on characterization techniques for microstructures using white-light interference microscopy. Capabilities include surface profilometry, integrated profilometry and lateral metrology for full 3D characterization, defect detection, profilometry of thin film structures, stroboscopic interferometry of vibrating samples, and real-time profile snapshots of moving MEMS devices.

Keywords: interferometry, microscopy, white light, thin films, MEMS, MOEMS, stroboscopy, metrology.

INTRODUCTION

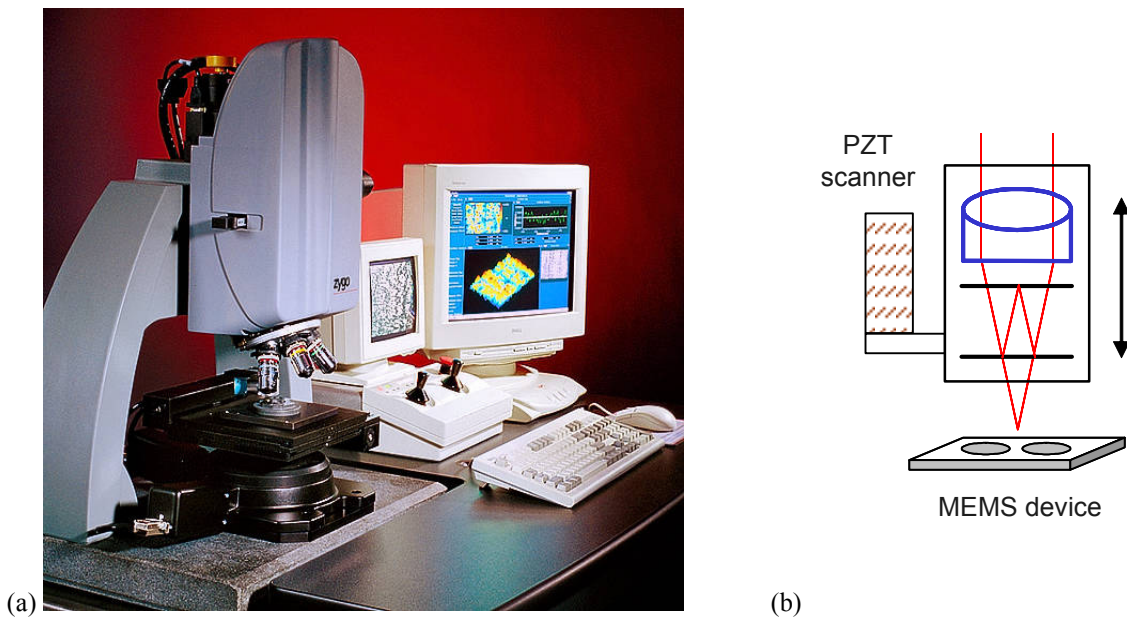


Figure 1: (a) A modern interference microscope for surface profiling and MEMS sample characterization. (b) A high-magnification interference objective of the Mirau type.

The benefits of non-contact, high-data density 3D imaging of surface structures make interference microscopy a preferred metrology technique for microstructures.

Modern interference microscopes are very much like conventional microscopes equipped with an electronic camera, the differences being the rigidity of the overall mechanical structure, the inclusion of a PZT or equivalent mechanical scanner, and an array of interference objectives in a turret (Figure 1a). A moderately filtered white light source is imaged into the pupil of e.g. a Mirau objective, in which the reference mirror is a sub-aperture metal film parallel to the

test surface and the same size as the field of view (Figure 1b). Each objective is optimized for a particular magnification and numerical aperture (NA).

Applications to MEMS, MOEMS and OLED devices have become a major focus of new instrument development. Details of instrument function for MEMS metrology appear in several papers, e.g. by Bossebeuf et al.,¹ Novak et al.² and Hedley et al.³ The present paper is an overview of applications and capabilities, with an emphasis on examples.

SURFACE PROFILOMETRY

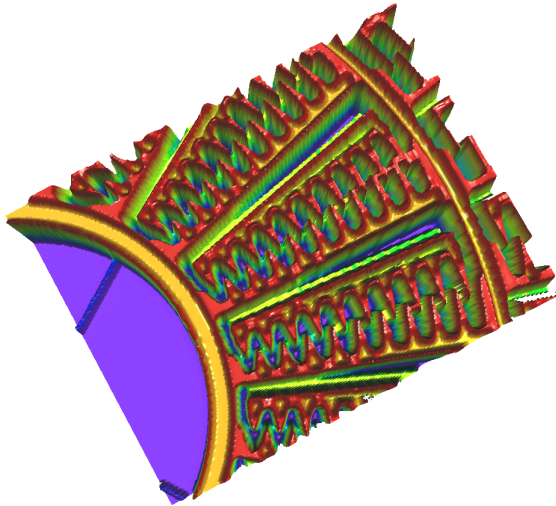


Figure 2: Section of an electrostatic comb drive rotor used in a micro actuator device. The field of view is $250\mu\text{m}$ and the profile range is $20\mu\text{m}$.

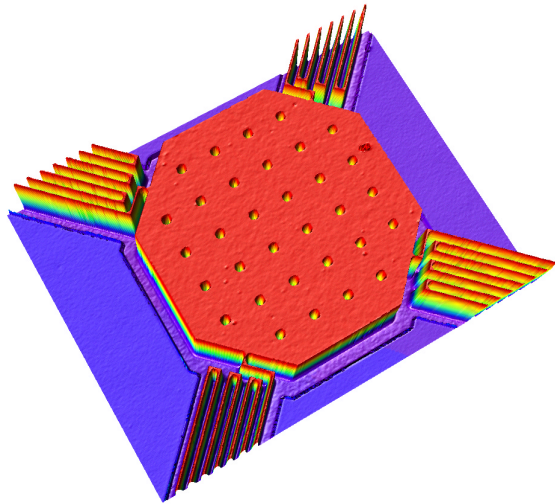


Figure 3: Micromachined accelerometer device. The field of view is 2mm and the profile range is $40\mu\text{m}$.

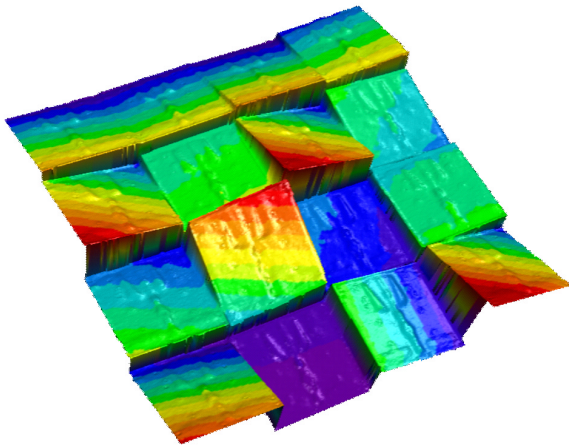


Figure 4: Micro-mirror switch array. The field of view is $500\mu\text{m}$ and the profile range is $40\mu\text{m}$.

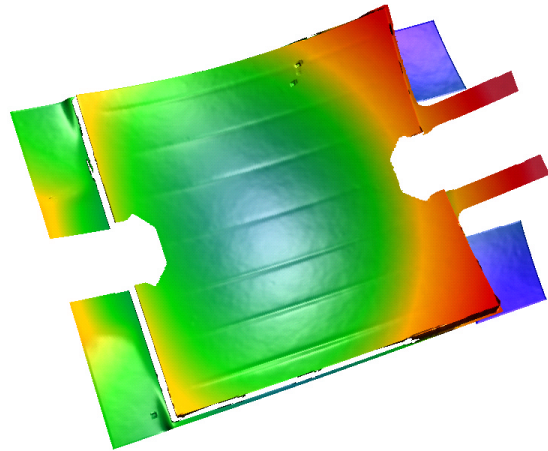


Figure 5: Micro membrane. The field of view is 1mm and the profile range is $100\mu\text{m}$.

The first and still most widely employed capability of interference microscopes is for static surface profile. In this mode of operation, interference fringes are modulated by PZT displacement of the objective shown in Figure 1b in a direction orthogonal to the plane of the sample. Over large measurement ranges, white light techniques remove the fringe order uncertainty, resulting in nm resolution over a total profile measurement range of several mm. One of the key benefits of this scanning white light technique is that it profiles each area of the object at the position of sharpest focus for that area, in much the same way as a confocal instrument but with much higher resolution.

Figures 2-5 illustrate this profiling capability for MEMS structures.

LATERAL METROLOGY AND DEFECT DETECTION

Analysis of lateral distances, areas and dimensions was commonplace long before the widespread use of interference microscopy. With electronic imaging, new software integrates this lateral metrology with 3D imaging for a complete package. As shown in Figure 6, automated area measurement can be performed directly on an intensity image of the object, or alternatively, on the 3D profile. The addition of surface profile in many cases aids in image identification and segmentation. The logical extension of this is defect detection, for example in the micro mirror of Figure 7.

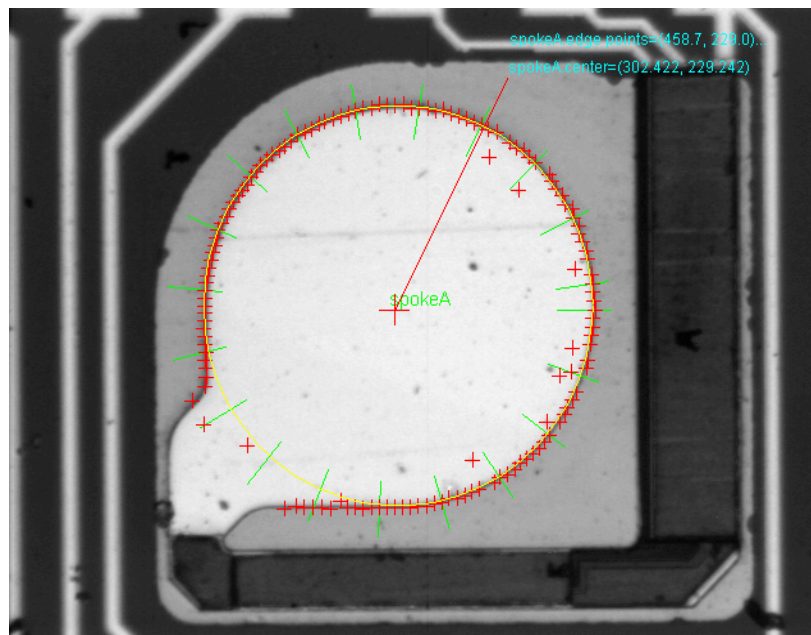


Figure 6: Dimensional Metrology – The round portion of the device has been fit to a circle. The measured diameter is 306.392 pixels or 513.05 μm . The measured area is 0.218907 mm^2

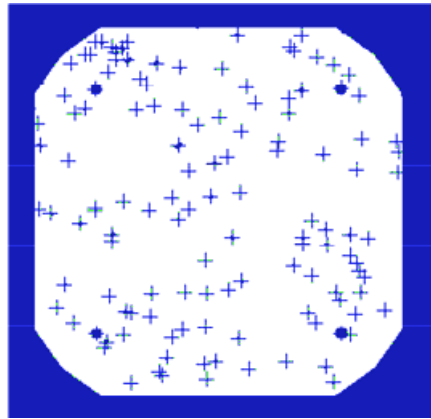


Figure 7: Mirror defects are identified as crosses within this 10.074 mm² area.

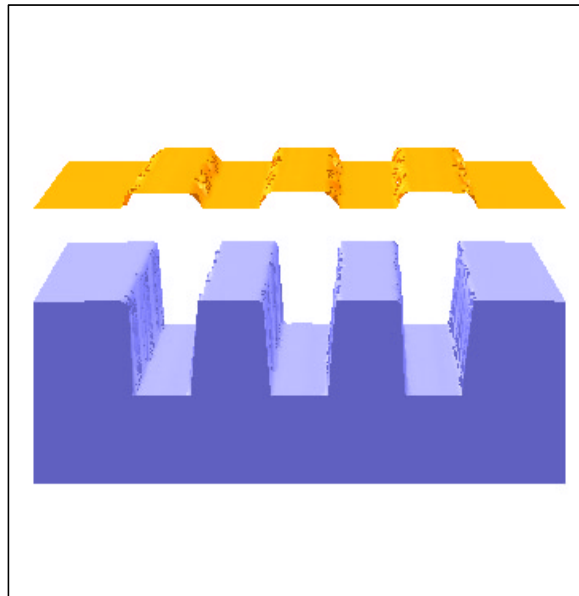


Figure 8: Example scanning white light interference micro image of a thin film structure at 0.8 NA with a 490-nm LED light source. The image shows the top surface and substrate profiles, with the top surface elevated in the figure for clarity. The substrate is Si, and the 2-mm wide, 410-nm deep trenches are filled with SiO₂. The SiO₂ rises 70 nm above the surrounding Si substrate.

THIN FILMS

Samples comprised of thin film structures have posed a significant challenge to interference microscopy. Whether the goal is to measure the film thickness or simply to measure surface profile in the presence of a thin film, new software is being introduced to accommodate the new requirements. Figure 8 illustrates the use of a signal matching algorithm in which a library of predicted scanning white light signals are compared to experimental data in order to extract the contributions from top surface and substrate reflections.^{4,5}

STROBOSCOPIC INTERFEROMETRY OF VIBRATING SAMPLES

Many MEMS and MOEMS devices are specifically designed as actuators, deflectors, motors or other moving systems. The dynamic behavior of these systems is of great interest.

Although vibratory sample motion is detrimental to conventional interferometry, a stroboscopic source illumination can capture repeated images of the sample at the same phase of oscillation so that the interference pattern appears stable.⁶ Eguchi et al.⁷ and Nakano et al.⁸ adapted the stroboscopic technique to a phase-shifting interference microscope for measuring micro-mechanical systems in the early 1990's and there are now a number of commercial instruments that offer this capability, including on scanning white light interferometers (see example profile in Figure 9).

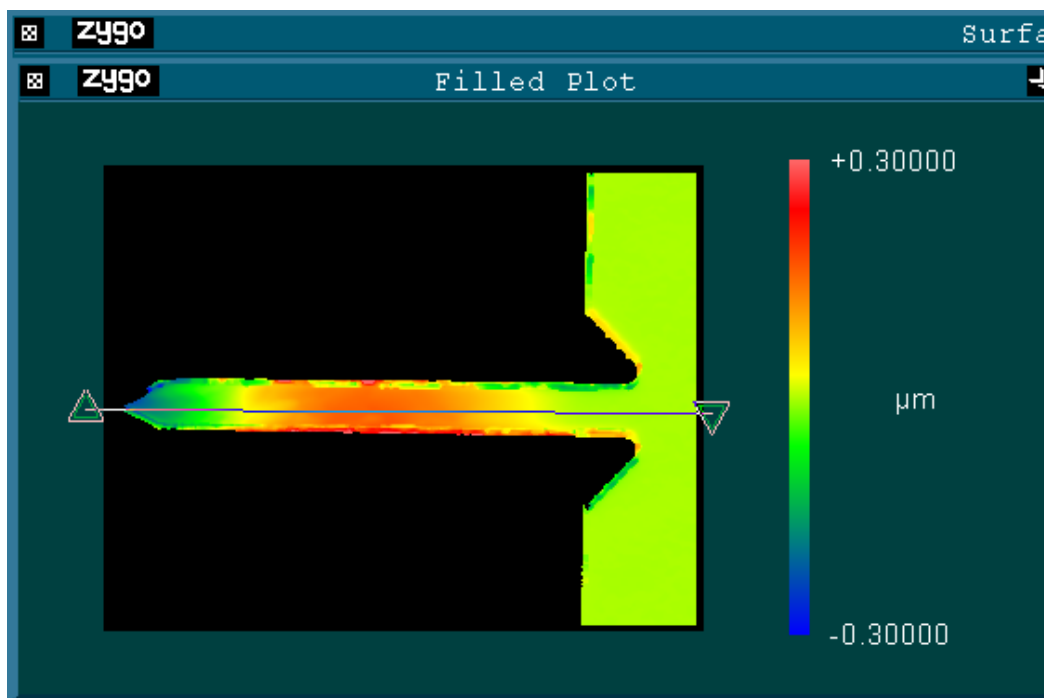


Figure 9: Example image of the 450-kHz vibration mode of an AFM cantilever captured by stroboscopic interference microscopy (see e.g. ref. [8]). The sample was excited by PZT.

INSTANTANEOUS “FLASH” 3D IMAGES OF MOVING MEMS DEVICES

Another approach to interferometry of vibrating devices is to capture an image of the sample with a number of near-parallel interference fringes (Figure 10), using either a single light pulse or an integration of multiple pulses during a single camera frame. Carrier-fringe analysis techniques then allow for a complete profile of the object (Figure 11) without a PZT scan, significantly reducing the time needed to examine e.g. the resonance characteristics of a device (Figure 12).

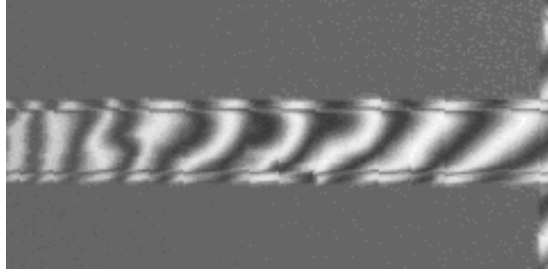


Figure 10: Portion of an intensity image showing interference fringes on a vibrating cantilever similar to that of Figure 9. Analysis of these fringes provides directly the surface profile using only a single camera frame of data, without the need for a PZT scan.

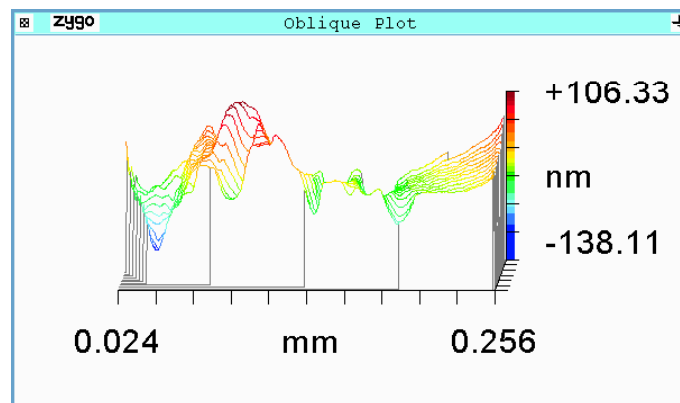


Figure 11: Detailed oblique profile image of the vibrating sample shown above in Figure 9.

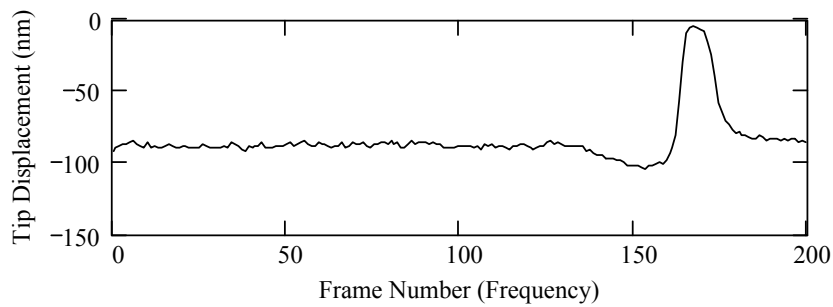


Figure 12: Maximum cantilever tip displacement measured during a continuous change of excitation frequency, using the instantaneous profiling technique of Figures 10 and 11. The plot shows a peak near acquisition frame 170 corresponding to a mechanical resonance.

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