Measuring through obstacles with confocal optics

SmarAct GmbH

Abstract
Background signals in interferometric measurements can be efficiently suppressed by using a focused measurement laser in combination with a confocal optical design. Thus, the detection volume is limited and only light that is reflected from the exact measurement position will reach the detector. Both SmarAct's **PICO**SCALE Interferometer and **PICO**SCAN Vibrometer employ a confocal measurement principle which allows accurate vibration measurements of a sample also when it is placed behind a partially reflective window or object.

1. INTRODUCTION

Optical measurements sometimes suffer from disturbances of scattered light at spurious surfaces. This affects the analysis of samples through a window by laser interferometry which is attractive in micromechanical engineering. In general, a fraction of the measurement laser light will reflect off the window and reach the detector resulting in a parasitic signal. Ideally, only light that is reflected from the exact measurement spot should reach the detector while all other light is rejected. Confocal laser scanning microscopy does exactly that. A laser beam is focused into a small measurement spot. Before the reflected light can reach the detector it has to pass through a pinhole which has a size comparable to the focused spot and is placed at a conjugate plane of the focal plane. Thus, only the reflected light that originates from the measurement spot will be detected and all other light will be blocked by the pinhole. Figure 1 shows how this principle is implemented in the focusing sensor heads of the **PICO**SCALE and **PICO**SCAN. Instead of a pinhole a single mode optical fiber is used which entrance is exactly placed in the conjugate of the focal plane [1]. The actual design of the sensor heads is more complicated and also includes the Michelson interferometer optics (not shown in Figure 1) which also add to the suppression of out-of-focus reflections [2].

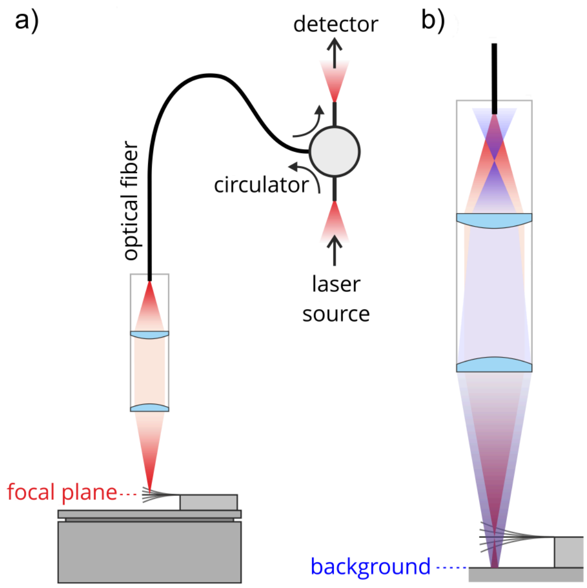

Figure 1. Simplified schematic of the confocal design of SmarAct's sensor heads. a*) Light from a 1550 nm laser source is coupled into the single mode fiber through an optical circulator. After exiting the fiber at the other end, the light is collimated and focused onto the sample. The light that is reflected from the focus follows exactly the same path back and is routed by the circulator to the detector.* ***b****) In case of small or transparent samples a part of the light will be reflected from other surfaces, in this example the underlying substrate. The reflected light, shown in blue, will follow a different path back and not be able to enter the fiber efficiently. As result these out-of-focus reflections will remain largely invisible in the measurements.*

By using a confocal optical design the measurements become insensitive to light scattering objects that are placed in the path of the laser, such as windows or reflective objects. To demonstrate this feature we performed measurements through a window that was actively excited to generate a parasitic background signal. Furthermore, we created a multi-layered sample from AFM cantilevers and show that it is possible to image a structure even when it is hidden from view by other parts of the structure.

2. METHODS

The measurements through a window were performed with a **PICO**SCALE interferometer and a Breakout-Box. Three different sensor heads were tested: C01 (collimated beam), F01 (15 mm focal length) and a sensor head from the **PICO**SCAN vibrometer (6 mm focal length). As sample a small polished titanium plate was placed on a piezo-based shaker stage which was excited at 1 kHz with an RMS amplitude of 1 nm. The distance between sample and C01 sensor head was set at 14 mm. For both focusing heads the distance was adjusted to bring the sample in the focal plane (result-

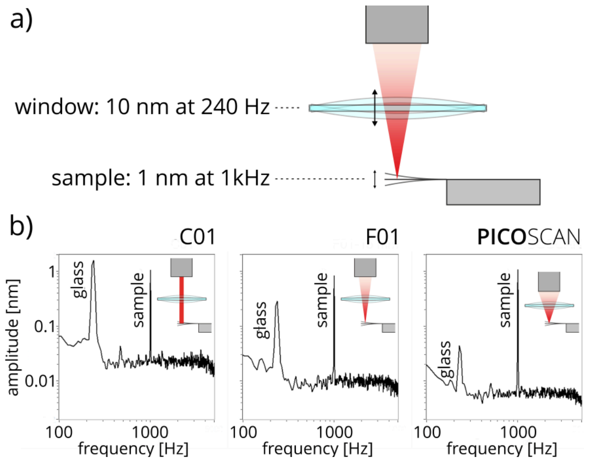

Figure 2. Measuring vibrations through an oscillating window. ***a**) Schematic of the experiment. Vibrations of a sample were measured by directing the measurement laser beam through a glass window. This window, placed halfway between the sensor head and the sample, was brought in oscillation with an amplitude of 10 nm at a frequency of 240 kHz. The sample itself had an amplitude of only 1 nm at 1 kHz.* ***b**) Three different sensor heads were tested. From left to right: C01, a collimating measurement beam accurately reproduces the 1 nm vibration of the sample but fails to suppress the vibrations of the glass window which are visible as a peak of 1.6 nm at 240 Hz. (Strictly spoken this head also follows a confocal design but with a very long focal length). F01, a confocal head with a focal length of 15 mm. The 1 nm vibration of the sample is clearly visible, while the contribution of the glass window is reduced to 0.3 nm, a 30 dB noise suppression.* **PICO**SCAN *the standard sensor head of the vibrometer with a focal length of 6 mm. The contribution of the glass window is further reduced to 0.04 nm, a 48 dB noise suppression.*

ing in maximum signal from the sample). A glass window of 1 mm thickness (microscope object slide) was placed halfway between the sensor head and the sample. The glass slide was clamped at one side and excited at 240 Hz with an additional shaker piezo. The signals for both shaker piezos were obtained from the Breakout-Box and generated by two function generators of the **PICO**SCALE interferometer. The amplitude of the window's oscillation at the position of the measurement laser was adjusted at 10 nm (measurement not shown). The FFT graphs were obtained from 5 s long data recordings at a sample rate of 40 kHz.
The multi-layered sample was created by gluing two AFM cantilever chips on top of each other (TR400 from Olympus, Tokyo, Japan). Bright field imaging was performed with a Proximity series microscope with IF-4 optics and a resolution of 2.9 µm (Infinity Photo-Optical, CO, USA). Confocal imaging and vibration measurements were performed with a **PICO**SCAN Vibrometer.

3. RESULTS

To test the suppression of background signals in interferometric measurements we first performed measurements through a glass window on a sample that was oscillated at an amplitude of 1 nm. To generate a large background signal, the glass window itself was excited with a much larger amplitude of 10 nm (Figure 2a). In a non-confocal measurement

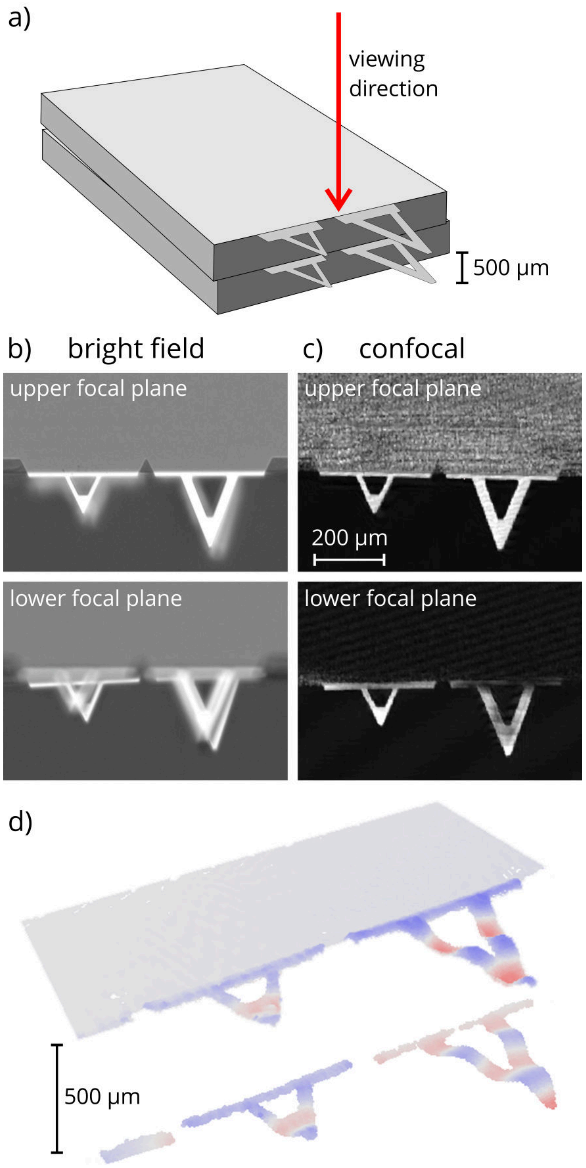

Figure 3. Measuring vibrations of multi-layered samples. ***a**) Schematic of the experiment. Two AFM cantilever chips were positioned on top of each other such that the view of the lower cantilevers is blocked by the upper ones.* ***b**) Imaging of both layers by bright field microscopy does not produce clear images of each layer.* ***c**) Confocal imaging reveals clear images of both layers. The image taken at the lower focal plane shows some variation in intensity caused by the presence of the upper cantilevers in the path of the laser.* ***d**) Vibrations measured of each layer.*

(with the C01 sensor head) both vibrations of the sample and the glass window will contribute to the measured vibrations. In a confocal measurement the vibrations of the glass window are largely suppressed. Figure 2b shows the results obtained with 3 different sensor heads. When a collimated laser beam is used the contribution of the oscillating glass dominates the measured signal. The fact that not the full amplitude of the glass window is recovered is due to the much lower reflectivity of glass compared to that of the titanium sample. With focusing heads the appearance of the parasitic peak is suppressed. Ultimately, a 250 fold reduction is achieved by using the standard sensor head of the **PICO**SCAN Vibrometer. Due to the increased signal quality of the detected signal also the noise floor is clearly reduced when using focusing sensor heads.

In principle it should also be possible to record a confocal image even if a part of the measurement beam is blocked by a non-transparent object. To demonstrate this we created a multi-layered sample by placing two AFM cantilever chips on top of each other such that the view on the lower cantilevers is blocked by the upper ones (Figure 3a). The cantilevers are gold-coated and therefor largely non-transparent for the measurement laser. Figure 3b shows that imaging with a conventional bright field microscope does not allow to produce clear images of both layers. Imaging with a confocal microscope (**PICO**SCAN Vibrometer) shows clear images from each layer (Figure 3c). Figure 3d shows that also vibrations of each layer can be measured.

4. CONCLUSION

With the focusing confocal sensor heads it becomes possible to measure through partly reflective windows while maintaining a high signal-to-noise ratio. The suppression of the background noise is strongest for sensor heads with a short focusing length and reached a factor of 250 in the measured examples. By focusing the laser on the surface of the window it is also possible to accurately measure its vibrations.

Imaging and the measurement of vibrations is even possible when non-transparent objects partially block the view on the sample, a feature which allows the characterization of complex multi-layered geometries.

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