Measuring MEMS vibrations through a packaging of silicon

SmarAct | metrology

INTRODUCTION

MEMS allow the miniaturization of devices that generate and detect motion. Here, we have tested the MPU-6050 multi-axis motion sensor from InvenSense, a TDK Group Company. This motion sensor is widely used in consumer and automotive electronics to track motion, a function that has become indispensable for many applications. The actual testing of the mechanical motion within MEMS plays an essential role during their development and allows to find causes for unexpected responses. Deviations from calculated behavior can for example originate from production tolerances. The need for testing continues when MEMS are to be integrated in an appliance. Here, performance can be affected by mechanical stresses from mounting the sensor on a printed circuit board and by vibrations caused by active components such as loudspeakers and switched power supplies.
The ideal test of the vibrational behavior of MEMS is performed under conditions that disturb the device as little as possible. Laser interferometry and vibrometry are widely accepted methods for the contactless modal analysis of micromechanical systems. However, such instruments predominantly use a light source within the visible wavelength range. The MPU-6050 is packaged in a silicon enclosure to provide it with a controlled micro-environment, which makes it inaccessible for any technique that operates with visible light.
Because silicon becomes nearly transparent at higher wavelengths, infrared (IR) light can be used to 'look' through silicon. SmarAct's **PICO**SCALE *Vibrometer* employs an IR laser (1550 nm wavelength) in combination with a confocal microscopy technique. Thus, selected planes of the MEMS can be imaged with minimal disturbance of semi-transparent layers that do not lie in the focal plane, such as the silicon package. In this application note we show how the moving parts of an MPU-6050 sensor can be imaged with the **PICO**SCALE *Vibrometer*.

RESULTS

For the experiments, the molded plastic enclosure was removed from the top of the motion sensor in order to gain access to the silicon package (Figure 1A). By moving the focused measurement laser beam of the confocal microscope down while recording the reflection signal, the different interfaces can be detected. Figure 1B shows that 2 main peaks can be distinguished, one for the silicon window and one for the MEMS structure. Within the silicon peak, two subpeaks can be distinguished that represent the upper and lower side of the silicon window. By adjusting the focus of the microscope to the respective peaks both the top of the silicon window and the actual MEMS structure can be imaged (Figure 1C). Fine structural details can be resolved on the MEMS structure which allows for a more detailed study of the vibrations of its moving parts.
To study the moving parts of the sensor, the image

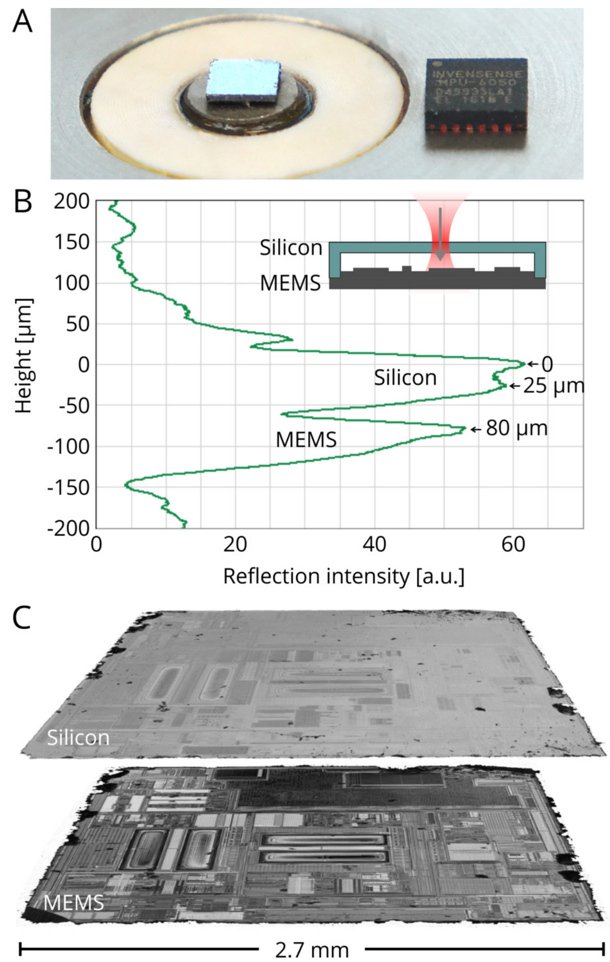

Figure 1. Confocal imaging through silicon. *A) The MPU-6050 motion sensor without its plastic enclosure, mounted on the shaker stage. For comparison, the intact chip is shown at the right. B) With confocal microscopy the multiple interfaces of the sample can be detected. The peaks that show the top and bottom of the silicon window are ≈25 µm apart, which has to be multiplied by its refractive index to obtain the thickness of the silicon window of ≈90 µm. The distance between the lower surface of the silicon window and the MEMS is ≈55 µm. C) 1 megapixel images of the top surface of the silicon window and the underlying MEMS structure.*

size was reduced and the local motion was measured by positioning the measurement laser at the indicated point (Figure 2A) while the sensor was mechanically actuated from 1-600 kHz. The measured response shows multiple pronounced resonance peaks (Figure 2B). To image the associated bending modes the sensor was actuated at these frequencies while recording an image of the vibrations. The inset figures in Figure 2B reveal bending modes of increasing complexity.
Thanks to the large scan area and megapixel imaging capability the **PICO**SCALE *Vibrometer* can also compare the motion of different part of the MEMS. Figure 3 shows that, although their amplitude was comparable, the motion of the different structures was phase shifted by ≈70°. Such a phase can originate from different resonance frequencies of the structures.

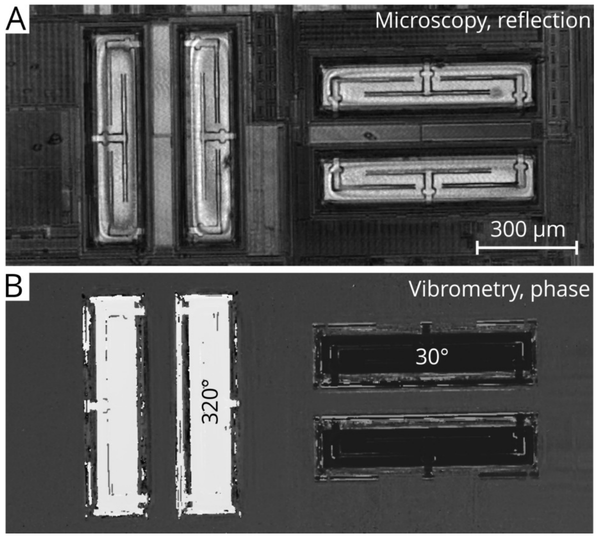

Figure 3. Relative motion of multiple objects. *A) Confocal microscopy image showing a total of 4 mobile structures. B) The motion sensor was actuated at 37.4 kHz and the phase image shows the phase with respect to the shaker stage signal. The phase is gray-scale coded (0° is black, 359° is white), the difference in phase between the mobile structures is ≈70°.*

CONCLUSION

Both SmarAct's **PICO**SCALE Interferometer and **PICO**SCALE *Vibrometer* are based on an infrared 1550 nm laser source in a confocal configuration. A unique advantage of this combination is that it allows to 'look' through silicon windows to measure vibrations of underlying structures. Nevertheless, also objects that are made out of silicon can be imaged and their vibrations can be measured.
The specific advantage for packaged MEMS is that it is now possible to directly measure the vibrations of moving parts through the silicon enclosure, a feature that will help to test and to improve MEMS design.

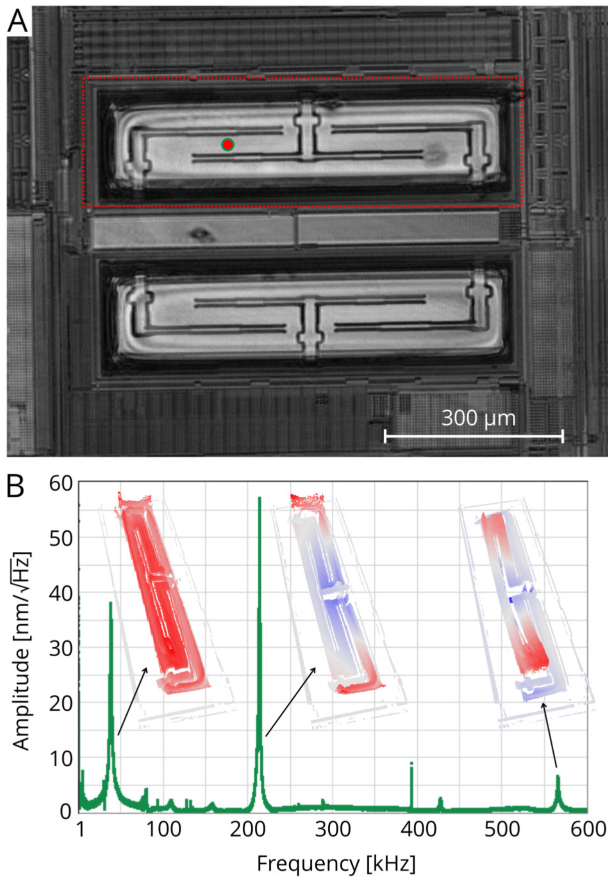

Figure 2. Modal analysis of the motion sensor through a silicon window. *A) The vibrations were first measured at the indicated point. B) The amplitude spectral density plot shows multiple resonance peaks. At the indicated peaks a modal analysis was performed of the part of the structure that is indicated by the red box in A). The inset figures show a 3D rendering of the motion of the structure.*

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