Micromachined scanning proximal probes with integrated piezoresistive readout and bimetal actuator for high eigenmode operation

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Family of novel Scanning Proximal devices have been inspired by an idea of a silicon cantilever integrating piezoresistive deflection sensors and bimetal (bimorph) thermally driven actuator. A cantilever commonly used widely in atomic force microscopy (AFM) offers many opportunities for various novel nanoimaging and nanomanipulation. We fabricate novel type silicon cantilevers using standard CMOS technology fulfilling high reproducibility of electronic parameters [1]. This results in 0.1nm z-measuremnt resolution, nW-actuation power (non-contact mode) and negligible electrical cross-talk between sensor and actuator. A new silicon tip integration technique is proposed. We formed hyperbolic shaped silicon neck using a fluorine based plasma dry etching step. This is followed by field oxide (FOX) growth where a sharp silicon tip is then formed. FOX is usually used to passivate and protect semiconductor surface outside of active device area but does not participate in device function. The field oxide is carried during all technological steps (forming piezoresistors and metal bimorph actuator) and removed after finishing all CMOS procedures opening (formed during the FOX oxidation) sharp silicon tip (Fig.1).

Integration of the thermal deflection actuator with the piezoresitive beam enables very reliable and precise excitation of the cantilever deflection. This is obtained by the reduction of parasitic mechanical vibrations in the microscope measurement head and simplifying of the experimental setup. In contrast to another cantilever deflection detection schemes the piezoresistive method enables quantitative measurement of the tip displacement. In this way forces acting between the tip and the investigated surface can not be detected but also metrologically determined with high accuracy. Due to the differences between thermal expansion coefficients of the metallic layer forming the deflection actuator and silicon spring beam tip deflection can be actuated when heating current passes the microhetear. Using the described method static and resonance vibration actuation can be obtained which enabled us to record surface topography using cantilever arrays [2], [3].

In this work we present additionally for the first time surface measurements, in which the piezoresistive cantilever was excited in the first and the second eigenmode simultaneously using a thermal deflection actuator. Signal corresponding with the amplitude of the first eigenmode tip vibration was fed back to the microscope controller for topography imaging while the phase shift of the first eigenmode, the vibration amplitude and the phase shift of the second eigenmode sensor vibration were recorded during the surface scanning enabling further surface analysis. Information about deflection detector output signal components was taken using two Lock-In amplifiers (Fig. 2). Fig. 3. presents the FFT spectrum of the piezoresistive self-actuated cantilever, when the deflection actuator was driven with a linear combination of sinusoidal currents with $f_{1\ term}$ and $f_{2\ term}$ frequencies corresponding with the first and second eigenmode. Fig. 4. presents high-resolution surface properties measurements made on a highly oriented pyrolytic graphite (HOPG) surface using the described method. Atomic steps on the surface topography image can be clearly seen. Images recorded simultaneously with the topography signal reveal local surface heterogeneity. Moreover, pictures corresponding with changes of tip vibration amplitude and phase shift in second eigenmode are more detailed than amplitude and phase shift pictures recorded in first eigenmode. In our opinion the observed contrasts are connected with heterogeneous growth of a water layer on graphite surface in different regions. Phase contrast images are directly related to energy dissipation processes, consequently the achieved contrast increases with the amount of dissipated energy. In this way the simultaneous excitation of the first two flexural modes of the cantilever increases the compositional sensitivity of the atomic force microscope while reducing the force exerted on the sample. Related to the above approach is the use of higher eigenmodes to extract information about material properties or to improve the instrument sensitivity.

References:

[1] Rangelow et al., Microelectronic Engineering, Vol. 84, Iss. 5-8, 2007, Pages 1260-1264
[2] Woszczyna et al., Microelectronic Engineering, Vol. 86, Iss. 4-6, 2009, Pages 1212-1215
[3] R. Pedrak, et al., J. Vac. Sci. Technol. B 21, 2003, Pages 3102.

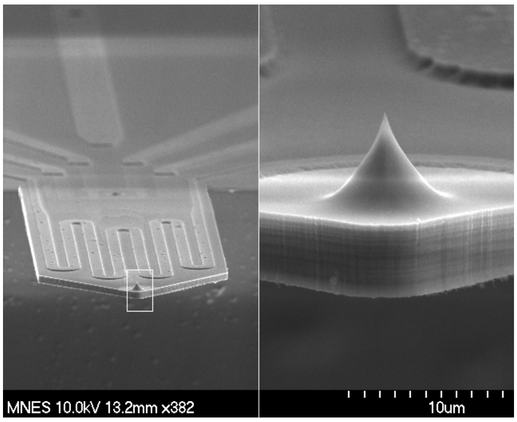

Fig.1 SEM image of self-actuated piezoresistive silicon cantilever and micromachined microtip

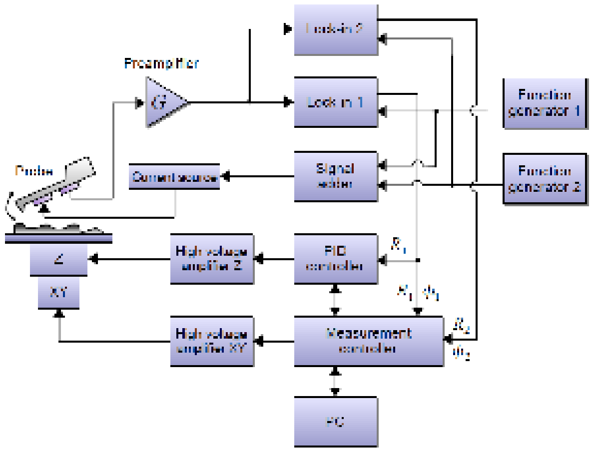

Fig. 2. Schematic diagram of the experiment setup

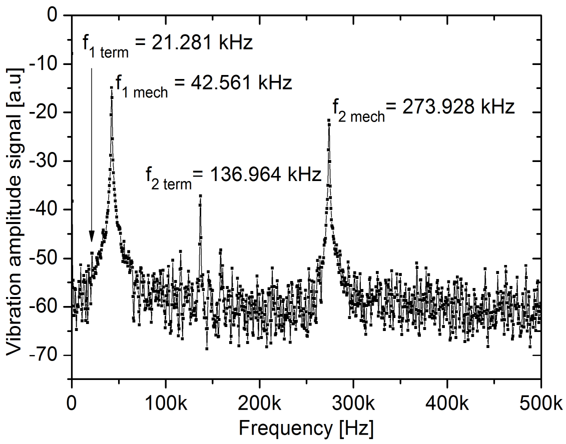

Fig. 3. FFT spectrum of the deflection detector signal of the cantilever vibrating simultaneously in the first two eigenmodes

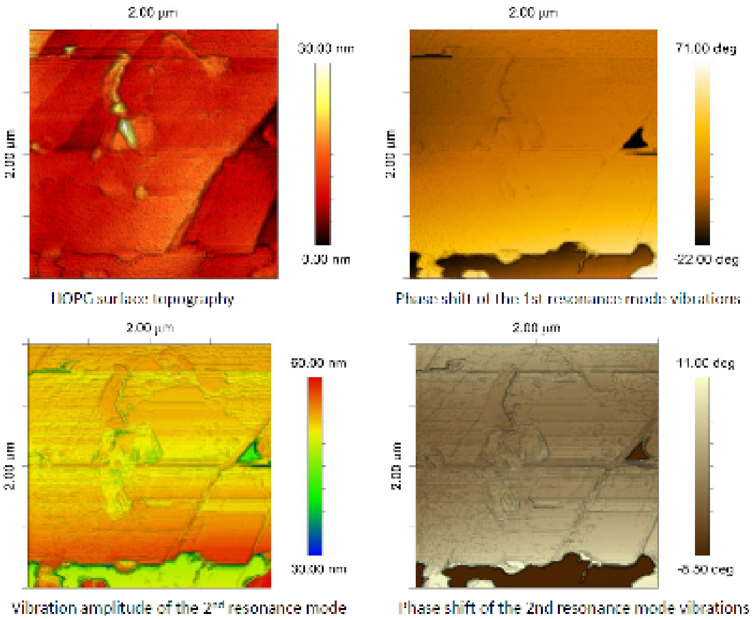

Fig. 4. HOPG surface property measurements obtained with the self-actuated piezoresistive silicon cantilever (sensor force constant:12.9 N/m, estimated deflection and actuation sensitivity of the tip displacement: 3.5 µV/nm and 200 nm/mW)