DFG Teilprojekt:
Sensor-actuator measurement system with high resolution

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The principle of operation of the sensor-actuator system is comparable to an atomic force microscope (AFM) operated in intermittent contact mode, but here actuation as well as sensing are completely based on electrostatic working principles. The micromechanical sensing device is characterized by a vertical positioning range of about 20 µm. While measuring the sensor's tip is actively placed within this range and enables nanometer-resolution. Based on the small dimensions (800 mm x 1000 mm) an array-like arrangement is realized. The distance between adjacent tips is less then 1 mm. The possible parallel operation mode increases throughput, which is directly proportional to the number of sensors.

The implementation of microtechnologies in the field of precision engineering and micromechanics as well as the down scaling process of structure size in the semiconductor industry has lead to advanced requirements in metrology tools. Increasingly so called resonance-methods are used. A sharp tip is animated to oscillate close to his frequency of resonance. When approach to a surface to a few nanometers a alteration of oscillation evoked by atomic forces can be detected as a phase shift or change in amplitude.
In particular, there was a lot of effort to develop parallel scanning probe microscope (SPM) techniques using arrays, as the throughput of conventional SPM is often inconsistent with commercial purposes
For array-like configurations the size of a single sensor-actuator system defines the density of probes. Therefore, one trend is the fabrication of complex autonomous microstructures including actuators for positioning of the probe relative to the sample as well as sensor elements. The consequent use of the electrostatic principle allows a comparably cost-efficient fabrication. For scanning surfaces the sensor-actuator system has to be included as a sub-system in a x-y-stage, while moving either the sample or the AFM-chip.

The elements have been fabricated using standard single crystal silicon wafers with a near surface bulk silicon micromachining technology. The fabrication of integrated lateral silicon tips has to be performed in parallel to the microstructures using the standard process flow. A skilled variation of the etch parameters can lead to the formation of lateral silicon tips. Up to now lateral tips with a radius of curvature of about 20 nm (measured in the wafer plane) have been fabricated on separate structures. The preparation of probes jutting out over the chip border.

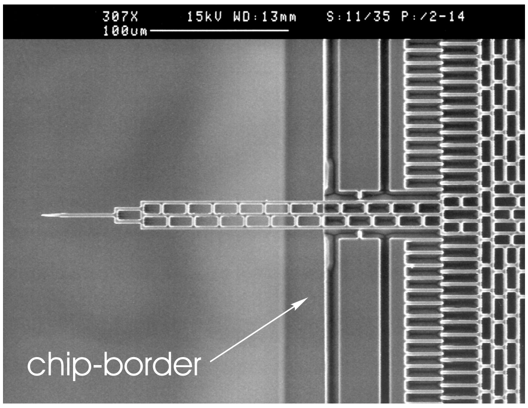

Fig. 1: Detail view (SEM) of a fabricated sensor-actuator system. Probe expands about 200 µm over the chip-border.

Sensor-actuator systems have been fabricated with different layouts, varying spring rates, masses and resonance frequencies (3.5 kHz ... 20 kHz), respectively. The height of the effective electrode area (plate capacitor model) was between 10 µm and 20 µm with trench widths of 3 µm between the electrode fingers. The characterization of the voltage-displacement response of the large range actuator was performed using a light optical microscope and a nano-positioning system. Driving voltages below 80 V generate displacements up to 20 µm. A linear dependence of displacement and square of applied actuation voltage was validated (see Fig. 2).

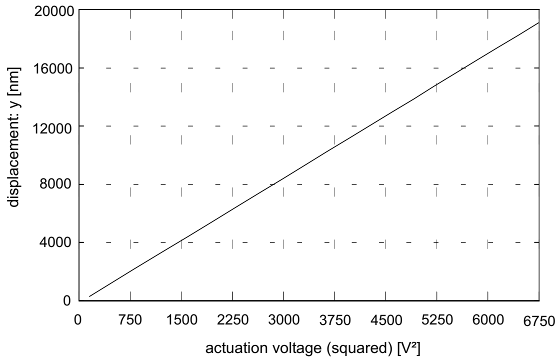

Fig. 2: Displacement vs. square of voltage applied on electrostatic comb system (P) obtained from measurements using a light optical microscope.

As demonstrated in Fig. 3, there is a significant influence on amplitude and phase when the tip interacts with the sample. most important reason for the changes in the signal are atomic forces. The initial decrease of the phase shift is interpretable with the atomic attractive sphere of action. When the tip is moved closer to the sample's surface, the repulsive sphere of action is entered and the phase significantly shifts to large positive values (Δ displacement = 2 nm).

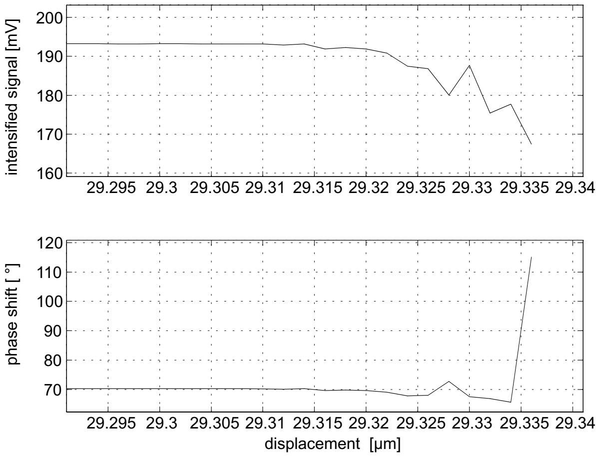

Fig. 3: Measured phase shift and amplitude as function of displacement (movement of probe towards sample). (f_R=18.372 kHz, f_E=18.44 kHz, U_E=10 V_p, Q=40, k=50 N/m)

At this time a phase shift evaluating feedback control has been installed for controlling of the distance between tip and sample in the repulsive sphere of action. Therefore, fine positioning of the tip is achieved by a separate comb drive. To improve the measurement dynamic a new sensor layout was realized. The new sensor-actuator systems are smaller, with a weight of about 2 µg (depending on trench depth) and increased resonance frequencies. The quality factors are between 10 ... 40. The usage of electrostatic field stoppers abated the influence of the electrostatic field on the resonance behavior when an positioning voltage is applied (see Fig. 4).

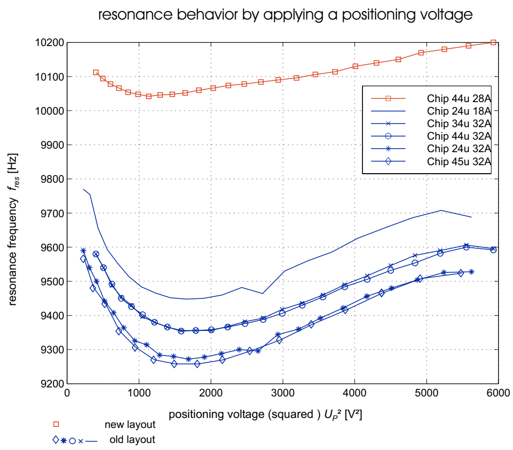

Fig. 4: usage of electrostatic field stopper

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