Micromachined capacitive displacement sensor for long-range nano-positioning

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Abstract

Integrated long-range position sensing with high accuracy will be of paramount importance for high-potential applications in a.o. future probe-based data storage and microscopy applications [1], provided that nm position accuracy can be obtained over a range of tens of micrometers or more. This work presents the design, fabrication and measurements for an integrated incremental capacitive long-range position sensor for nano-positioning of microactuators. For compactness, economical viability and optimal performance, the aim has been to fully integrate sensor and actuator through micromachining technology, without additional micro-assembly.

Two related concepts are presented and evaluated through analysis, 2D-Finite-Element Simulations and experimental assessment. The sensors consist of two periodic geometries (period ≈ 8-16µm) on resp. a slider, movable in x-direction, and sense-structures, movable in y-direction, at both sides of the slider, Fig. 1. In ICMM the displacement of the slider is measured by measuring the periodic change in capacitance \( \Delta C_s(x) \) with a charge-amplifier and synchronous detection technique [2]. Using sense-actuators, the gap-distance between sense-structures and slider is made smaller than is possible with standard available photo-lithography (< 2 µm), thus increasing the capacitance and the S-N Ratio.

In Constant Capacitance Measurement Mode (CCMM) the sense-actuators are closed-loop controlled in order to keep the capacitance \( C_s(x,y) \) constant. The slider-position can be measured with the sense-actuator control voltage, which becomes a periodic signal when the sense-structures closely follow the (sine) pattern on the slider, Fig. 1. Simplified analytic models predict an increase in SNR relative to ICMM of 300x, due to a smaller gap-distance, and a better approximation of the slider pattern (e.g. sine). This is demonstrated with 2D-FE simulations and experiments with a poly-silicon surface-micromachined test-device. Through quasi-static measurements an estimated position reproducibility in the order of ~10 nm over ~30µm range is established for CCMM with a bandwidth BW ~ 1 Hz [3], Fig. 2. Dynamic measurements for ICMM characterized the mechanical resonance frequency (f_res ~1.6KHz) of the test-device with a resolution of 2 nm and BW ~ 1 Hz, limited by the experimental setup without complete EMI shielding.

New experiments with devices made with a novel bulk-micromachining process are underway. This process enables an increase in structure-height and thus an increase in SNR in the order of 25 - 200. With improvements in electronics and setup, actual nano-positioning over a long range and higher bandwidth will be attainable, limited only by electrical noise.

Fig. 1: Micromachined incremental capacitive position sensor. The slider-position is determined by the change in capacitance between two periodic patterns on the slider and the sense structure.

Fig. 2: Measurement result CCMM. The periodic control voltage is a measure for the displacement.

References