A micro-scanning probe microscope-head with integrated interferometric fiber optic displacement sensor

Sai Gao, Helmut Wolff, Zhi Li, Ludger Koenders, Uwe Brand
Physikalisch-Technische Bundesanstalt (PTB), Germany

Sai.gao@ptb.de

Abstract

A micro-machined SPM-head with embedded optical fiber displacement readout has been developed for dimensional nanometrology. Preliminary experimental investigation proves that a prototype of the MOEMS-based SPM-head can achieve traceable measurement with subnanometric accuracy. It's expected that this MOEMS device, featuring closed-loop nano-Newton force accuracy, can find its applications in the field of nano-force actuation and sensing.

1 Introduction

To enhance the performance of the currently available various long-range nano-measuring machines and effectively reduce the measurement time for large specimen, the concept of a micro-SPM head array [1] has recently been proposed. It consists of a 1×7 micro-SPM head realized in one chip by MEMS fabrication techniques. This device can be further extended to a micro-SPM matrix, if several micro-SPM-chips are configured parallel.

The central unit of each SPM head is an electrostatic comb-drive actuator, whose main shaft protrudes out of the MEMS chip and can be used to sense the surface topography of a specimen under test. The vertical displacement detection of the micro-SPM head is realized on basis of a capacitive sensing technique, featuring nanometric resolution within scanning ranges up to tens of micrometers. The capability of the prototype of the micro-SPM head for surface profiling has been experimentally demonstrated [2].

However, similar to other capacitive displacement sensing systems, one of the important shortages of the current micro-capacitive-SPM is that its measurement results are not traceable to the SI units. Moreover the measurement accuracy of the micro-SPM suffers often from the variations of the ambient conditions.

2 Principle

To further improve the performance of the proposed micro-SPM head, especially to realize traceable surface measurements with the proposed micro-SPM head, one of the natural choices is to integrate an optical interferometer into the micro-SPM head in order to detect the displacement of the main shaft of the micro-SPM unit.

A low-coherence fibre interferometer is integrated into a prototype of a micro-SPM unit. The principle of the micro-opto-electo-mechanical device is illustrated in Fig. 1. The laser light coming from a frequency-stablised laser diode is firstly coupled into a Y-type fiber splitter, and then using a single-mode fibre (SMF) with 125 µm in diameter into the micro-SPM chip. A micro-Fabry-Perot (F-P) cavity is then formed between the front end surface of the single-mode fibre and the back end surface of the main shaft of the electrostatic comb-drive actuator (detailed design, simulation, experimental investigation and specifications of the comb-drive actuator can be found in [1-2]).

The reflected light from the F-P cavity is collected by the same fibre and sent back to the interference signal processing unit.

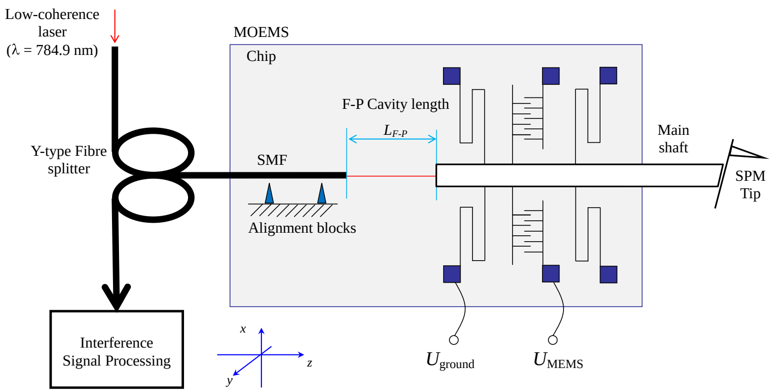
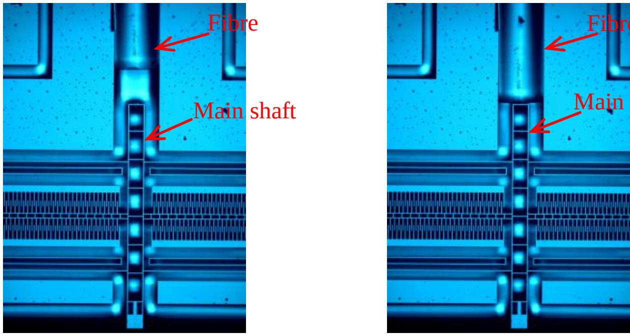


Figure 1: Schematic of the traceable micro-SPM head with embedded interferometric fibre optic displacement sensor

Obviously, the nature of the interference signal of the embedded fibre interferometer is, to a large extent, determined by the relationship between the F-P cavity length $L_{F\text{-}P}$ and the coherence length L_c of the laser light. In the case of $L_{F\text{-}P} << L_c$, typical F-P interference signals can be obtained. On the contrary, typical two-beam interference signals can be acquired, when $L_c/4 < L_{F\text{-}P} < L_c/2$.

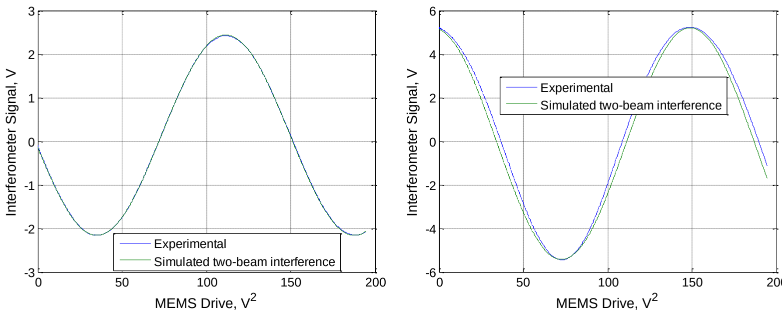
3 First Experiments

A prototype of the proposed MOEMS device has been realized by means of the Bonding-Deep Reactive Ion Etching (B-DRIE) technology (see Fig. 2).



(a) $L_{F\text{-}P} \approx 100$ µm (b) $L_{F\text{-}P} \approx 3$ µm

Figure 2: Prototype of the MOEMS-based traceable micro-SPM head with embedded fibre interferometric displacement sensor.



(a) $L_{F\text{-}P} \approx 100$ µm, $L_c/4 < L_{F\text{-}P} < L_c/2$, two-beam interference signal

(b) $L_{F\text{-}P} \approx 3$ µm, $L_{F\text{-}P} << L_c$, F-P interference signal

Figure 3: Experimental investigation of the optical performance of the MOEMS device under different F-P cavity conditions and for comparison the simulated two-beam interference signals

A diode laser with central wavelength λ_c = 784.9 nm and a coherence length of about 300 µm is employed as the light source for the embedded fibre interferometer. Fig. 3(a) and (b) demonstrate the acquired interference signals when the main shaft of the actuator is moving for $L_{F\text{-}P} \sim 3$ µm ($L_{F\text{-}P} << L_c$, typical F-P interference) and 100 µm ($L_c/4 < L_{F\text{-}P} < L_c/2$, two-beam interference), respectively. It can be seen that the interference signals coincide quite well with the predicted.

In addition, detailed comparison between the acquired fibre interferometer signal (when $L_{F-P} \sim 100$ µm, Fig. 3(a)) and the ideal two-beam interference signal, as shown in Fig. 4, indicates that the measurement accuracy of the embedded fibre interferometer amounts to 0.5 nm (1σ) within the measurement range of about half a micrometer.

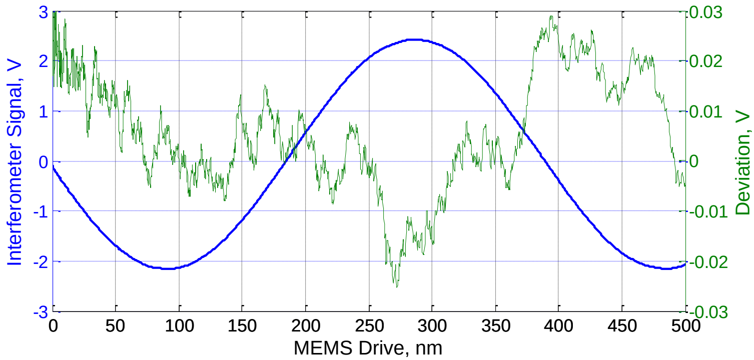


Figure 4: Analysis of the fiber interferometric signal in Fig. 3(a).

It's worthwhile to point out that the stiffness of the MOEMS device has been calibrated to be 2.7 N/m [2], indicating that this device would have a closed-loop force actuation/sensing accuracy of 1.4 nN.

4. Conclusion and acknowledgement

A traceable micro-SPM head integrated with a low-coherence fiber interferometric readout has been realised for surface nanometrology with high accuracy. Preliminary experimental results demonstrate that subnanometric measurement accuracy can be achieved with a prototype of the proposed micro-SPM head.

This research was supported by the DFG (Deutsche Forschungsgemeinschaft) under the number HE 2235/10-1 and ME1657/4-1

References:

[1] S. Gao, Z. Li, K. Herrmann. *Proc.* of Euspen 2010, pp 249-253

[2] S. Gao, H. Wolff, K. Herrmann, U. Brand, et al. Proc. of SPIE 8066, pp. 806626-1-8, 2011.

[3] K. Hiller, M. Kuechler, et al. *Proc.* of SPIE, 5715, pp. 80-91, 2005.