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In-situ characterisation of nanomechanical measurement instruments using a force transfer standard with interferometric deflection measurement

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Abstract

To improve the capability of cantilever, beam and membrane-based force transfer standards for in-situ force characterisation with relatively broad measurement range and high resolution, a laser interferometer with sub-nanometer resolution is added to a silicon force transfer standard, whose bending stiffness has been well calibrated. The fast data acquisition system of the laser interferometer enables not only quasi-static force measurement, but also dynamic force characterisation for nanomechanical measurements. The fundamental principle of the proposed system is detailed. A prototype of the closed-loop force standard is realized. In-situ characterisation of the indentation force of a nanoindentation instrument using this prototype is reported in this manuscript.

Keywords: Force calibration, micro-force measurement, nanomechanical instrument, interferometric deflection measurement

1. Introduction

Requirements on quantitative determination of the mechanical properties of small volumes of materials, including ultra-thin films, micro- and nano-structures and nano-objects, demand that the test force resolution and uncertainty of nanomechanical characterisation systems and instruments have to be unceasingly improved. [1]. In-situ force characterisation is especially desired, since the working condition of a nanomechanical instrument might be varying for different measurement tasks.

To date, in-situ quasi-static force calibration with a resolution down to the nN range is generally realized by means of utilization of (silicon-based) passive force transfer standards, owing to their small size, ease of use, and relatively wide measurement range [2, 3].

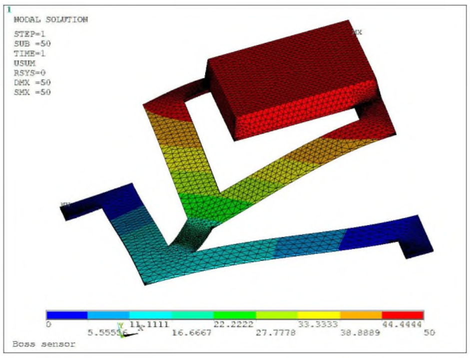
Despite the aforementioned features of such kind of passive force standards, e.g. reference silicon cantilevers, however, the drawbacks related with these force transfer standards are also quite clear for the end users, e.g. sensitive to environmental instability, potential systematic deviation due to misalignment, etc.

To further improve the capability of cantilever/beam/membrane-based force transfer standards for in-situ force characterisation with a resolution down to sub-µN, a laser interferometer readout system with sub-nanometer resolution is proposed to real-timely measure the deflection of the silicon force transfer standard.

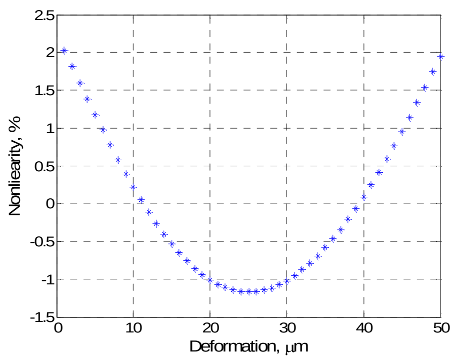
2. A silicon boss-membrane force sensor used for force and displacement sensing

To demonstrate the feasibility of our proposal, here a boss membrane based force sensor [4-5] is used. Compared with cantilever-like force standards [2], this kind of mechanical sensors for force/displacement measurement feature purely vertical (out of plane) deflection of the boss, as shown in Fig. 1(a). They can be therefore conveniently coupled with a conventional laser interferometer.

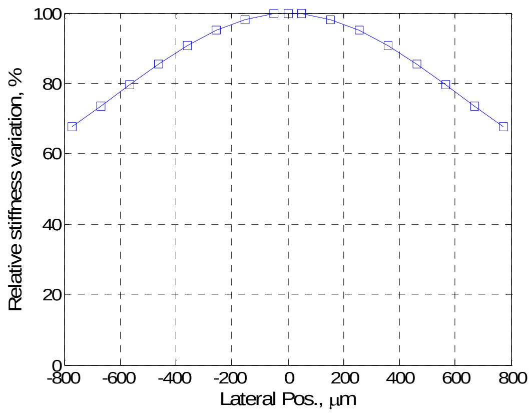
Detailed finite element analysis (FEA), as illustrated in Fig. 1(b), indicates that a nonlinearity less than 2% can be achieved with this boss membrane suspending system for a vertical displacement up to 50 µm.



(a) Finite element simulation of the vertical deformation of the silicon force sensor (1/4 model for symmetric loading along z-axis)



(b) Nonlinearity of the force sensor over the maximum deformation of 50 µm.



(c) Stiffness variation with respect to the lateral misalignment.

Figure 1. Numerical investigation of the force transfer performance of the silicon force standard.

In the meantime, numerical investigation also reveals that the actual bending stiffness of such kind of force sensors is relatively sensitive to the lateral contact position on the boss of the force sensor. It can be seen from Fig. 1(c) that the actual membrane stiffness will have about 2% deviation, when the contact point on the boss is about 200 µm away from the central position of the membrane boss.

3. A force transfer standard with interfereometric readout

The measured force of a mechanical force transfer standard is actually deduced by multiplication of the bending stiffness of the force sensor with its deflection under external force.

3.1. Configuration

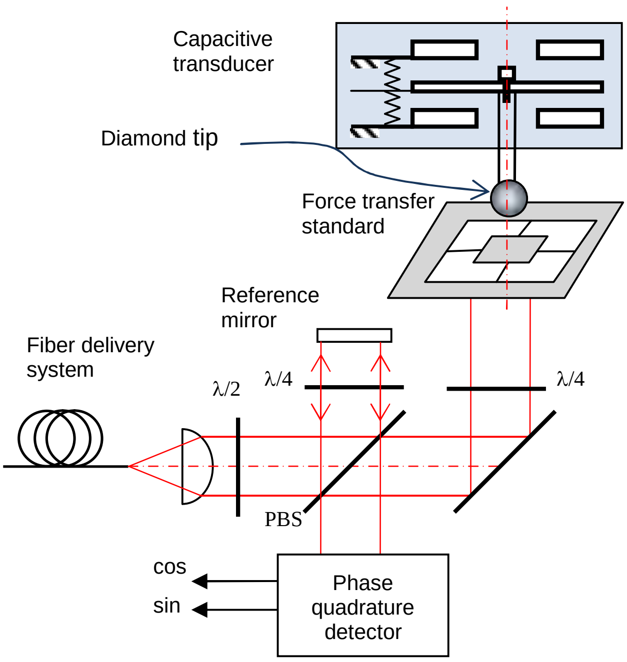


Figure 2. Principle of the interferometric force transfer standard and its application for characterisation of a nanoindentation instrument.

To real-timely measure the displacement of the membrane boss, a home-developed laser interferometer is used. As shown in Fig. 2: the laser light coming from a frequency-stabilized He-Ne Laser is delivered to the interferometer block using a polarization maintaining fiber. The measuring beam is sent to sense the out-of-plane deflection of the force sensor by means of a 90°-folding mirror. Since the boss back surface of the force sensors might have slightly varying reflection ratio, a λ/2 waveplate is inserted in the interferometer block to adjust the illumination intensity of the measuring beam.

3.2. Experimental investigation

The prototype of the interferometric force transfer standard is used to in-situ characterise the depth and force sensing system of a commercial nanoindentation instrument (Triboscope TI 950, Hysitron Inc.). In the experiment, a spherical indenter with a nominal tip radius of 100 µm is used to contact the membrane boss, so as to minimize the surface deformation on the force sensor.

Since the electronic signals from the transducer under calibration are not accessible, direct acquisition of the displacement of the transducer is not possible. During the calibration procedure, after engagement the force transducer is driven to produce step-like indentation force, the indentation depth and the boss displacement will be measured by the transducer and the interfereometric force sensor separately. Histrogram analysis is then used to analyze the measurement data and correlate the measurement results from both systems.

One of the typical measurement results is shown in Fig. 3. The transducer's displacement readout is found to have a scale deviation of 2.5%, which coincides well with the report in [6].

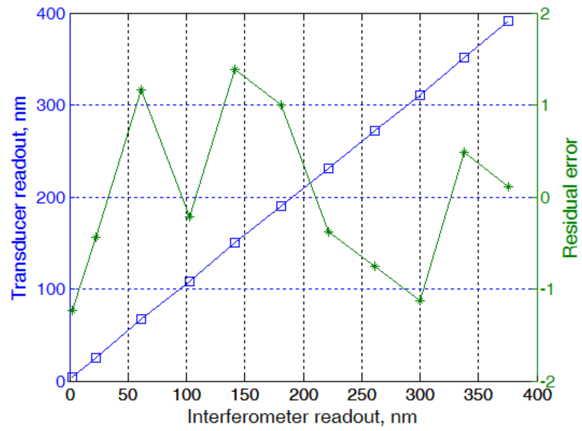


Figure 3. Characterisation of a capacitive transducer using the interferometric force transfer standard.

5. Summary and outlook

An interferometric force transfer standard is proposed in this manuscript, with the aim for in-situ characterisation of the force and depth sensing system within nanomechanical instruments.

First measurements prove the feasibility of this proposal. However, detailed data analysis and measurement error estimation should be done in the near future.

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