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Ultra-Sensitive Force Gauge Accessory for Microscope Micromanipulators

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Summary:

Micromanipulators equipped with sharp needles are now indispensable tools for ultra-sensitive operations under the optical or electron microscope, which are mainly visually guided. Measuring the local mechanical forces acting on probe tip can give another important feedback to the operator, or to the closed-loop actuators in automated systems. However, measuring contact forces, especially as a vector quantity, is highly challenging. In this work, we present a lightweight, compact, two-dimensional piezoresistive MEMS sensor-based system, that can be mounted on the tip of a commercially available 3-axis piezo-actuated micromanipulator. As the calibration with an atomic force microscopy probe reveled the sensitivity of the sensor is a few μN at an electric response of 29 μV/μN. To demonstrate the capability of system, in-situ static tests were carried out on an Pt micorwire.

Keywords: Piezoresistive force sensor, add-on tool, AFM probe, Pt micorwire, Young modulus

Motivation and Objective

Micromanipulator is a robotic tool with extremely precise position control along three to six degrees of freedom for transferring micro- and nanometer sized objects under an optical or scanning electron microscope (OM/SEM). It is used in various fields, such as specimen fabrication for transmission electron microscope (TEM lamella), electrical probing during IC failure analysis, cell biology, robotic surgery etc. [1]. These manipulations are usually controlled by the operator using real-time optical camera or electron detector image. For many applications, however, local sensing of the force would be an effective tool to provide direct feedback to the operator. In addition, in automated industrial processes direct feedback is essential for the closed-loop actuators.

Over the last three decades, a number of techniques have been used to force sensing in the range below pN up to several mN [2]. Among them piezoresistive force sensors have several advantages: such as high signal-to-noise ratio, wide measuring range, low cost, and compact size. Until now, piezoresistive and the strain-based manipulator sensors have been mainly applied for one-dimensional force sensing in the mN to sub mN range.

Our aim was to demonstrate a compact, lightweight 2-dimentional piezoresistive force sensor system which can be mount on a tip of an ultrafine piezoelectric manipulator and to increase the sensitivity down to the few micronewton force range.

Description of the System

The system was adapted to our ultrafine 3-axis piezo-actuated SEM micromanipulator (Kleindiek Nanotechnik MM3A-EM) (Fig. 2c). The center of the system is a 3 dimensional piezoresitive force chip [3] (Fig. 2a), which is extended with a sharp W needle having a diameter/length/radius of of 250 μm/15 mm/~100 nm (Fig. 2b) to manipulate microscopic objects. Due, to elongated lever arm, the sensitivity of the force measurement is enhanced along the transversal direction and remained unchanged for the normal direction, resulting in a quasi-two-dimensional force gauge. Conventional flexible as well as purpose designed polyimide cabling were used to avoid interference with the movement of the inchworm-type piezomotor. The analog signals from the four bridges of the piezoresistive force sensor chip are digitalized by the electronics located under the manipulator and transmitted to the controller notebook via the SEM feedthrough.

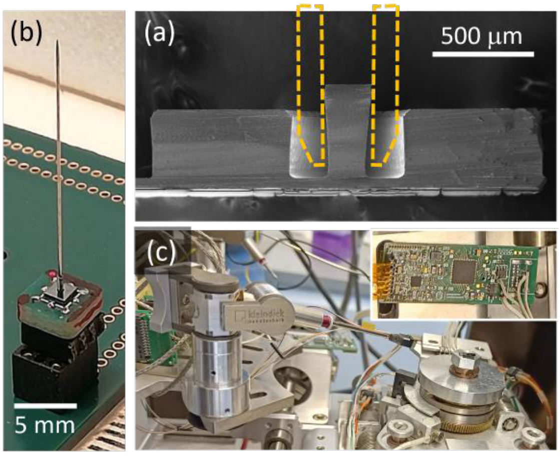

Fig. 1. (a) SEM image of the bisected piezoresistive chip; yellow dashed line indicates the position of the probe adapter (a). Force gauge chip mounted on the PCB and equipped with an ultrasharp probe (b). Force sensing system set up inside the SEM, ready for in-situ nanomechanical test (c). Inset shows the purpose-built readout electronics

Results

Prior to the nanomechanical tests, the force response of the sensor accessory was determined by standard atomic force microscopy (AFM) probes in an in-situ static bending test (Fig. 2a, lower inset) where the tip of the force sensor was pressed against the cantilever, while both sensor signals and the cantilever deflections were recorded. The force constants of the calibrating AFM probes were determined by Sader method in the AFM apparatus (AIST-NT) (Fig. 2a upper inset) [4]. To cover a wider range of the calibration a standard (k=48.8 N/m) and a relatively soft (k=2.8 N/m) tapping mode AFM probes were selected. The force calibration data obtained for the two sets of measurements are in good agreement (R≈29 µV/µN). According to the tests ultralow load forces, down to the 1-2 µN range, can be consistently detected.

In order to demonstrate the capability of the add-on force sensor tool, we carried out a nanomechanical bending test on Pt microwires created by ion beam assisted deposition (IBAD) in a cross-beam SEM/FIB system (FEI Scios). As shown in Fig. 2b, by recording the static bending deflection (Fig. 2b) as a function of the measured load force, the nanoelectromechanical properties of the microwire can be evaluated. By performing finite-element analysis (Fig. 2b, upper inset), we obtained a Young-modulus of Y≈70 GPa for the IBAD microwire which is significantly lower than that of the pure bulk Pt (168 GPa). The softening of the microwire can be attributed to the high carbon content of the IBAD microstructure.

In summary the demonstrated compact piezoresistive force sensor is a power ad-on tool for micromanipulators to measure the local force during the manipulation of microscale objects.

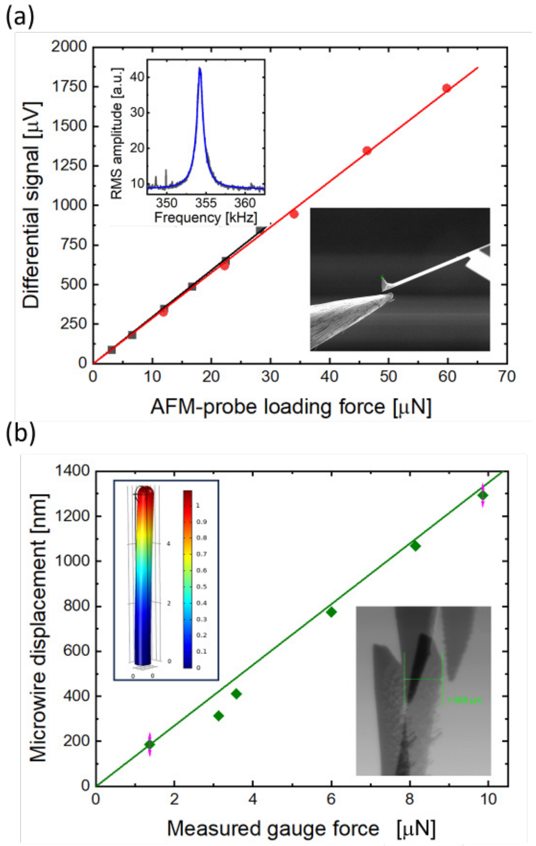

Fig. 2. (a) SEM force sensor calibrated by AFM probes with static bending experiments (lower inset). The force constant of the calibrating probe was beforehand determined (upper inset). (b) In-situ SEM nanomechanical bending test of a Pt microwire (lower inset). Finite element analysis of the wire (upper inset) revealed a Young-modulus of 70 GPa.

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