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Abstract
A tactile probe has been designed at the Eindhoven University of Technology to measure a translation of its tip with a 3D uncertainty of 20 nm or better. The suspension of this probe and the electrical connections are manufactured in a series of etching and deposition steps and can be considered to be a Micro Electro-Mechanical System (MEMS). It will be shown that hysteresis effects can have a dominant influence on the probe measurement uncertainty. Several sources of hysteresis within the probe system are investigated experimentally.

Introduction
One of the most common causes for hysteresis in a precision construction is friction combined with a finite stiffness, as shown in Fig. 1 [1,2,3,4]. The left-hand picture shows a block, which exerts a friction force F_f in the direction opposing the driving force F. This block is connected to the frame via a spring with stiffness c.
For a system in equilibrium the force F needs to increase above the friction force F_f, before the block will be displaced. A further increase in the force F leads to a displacement x, where $\alpha = \tan(c)$, as shown in the right-hand picture of Fig. 1. When the force F is than decreased, the block will remain stationary until the decrease in F is two times the friction force F_f. In this way an increasing and decreasing force F leads to the hysteresis loop shown in the right-hand picture of Fig. 1.

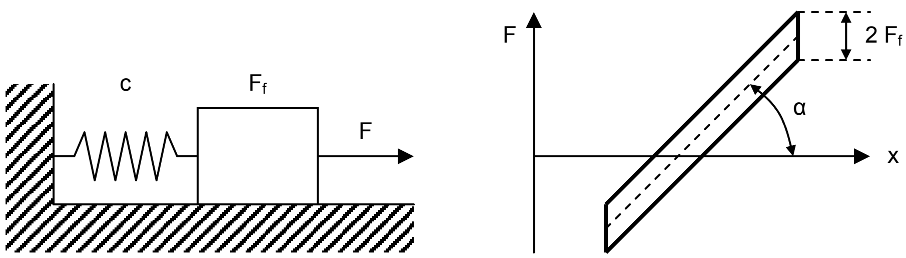

Fig.1 Hysteresis loop due to friction force F_f.

It is well known that the area enclosed by the hysteresis loop equals the energy dissipated during the movement of the block (in this case due to friction). It should be clear from this figure that hysteresis should be minimized in precision equipment. In the abovementioned picture this can be done by decreasing the friction force F_f (e.g. low-friction materials, smooth surfaces, lower weight, lubrication, etc.) and increasing stiffness c.
The design of the nano probe will briefly be discussed in the next section. Then several other sources of hysteresis will be addressed. It will be shown theoretically and

experimentally that these may significantly influence the uncertainty of the nano probe and similar systems.

Original design of the nano probe

The probe consists of a stylus with a ruby sphere, as shown in Fig. 2. It is attached to a silicon chip via a three-legged star using epoxy glue. To avoid damage to the work piece the dynamic mass of the probe is less than 20 mg and the stiffness of the suspension is lower than 200 N/m [5].

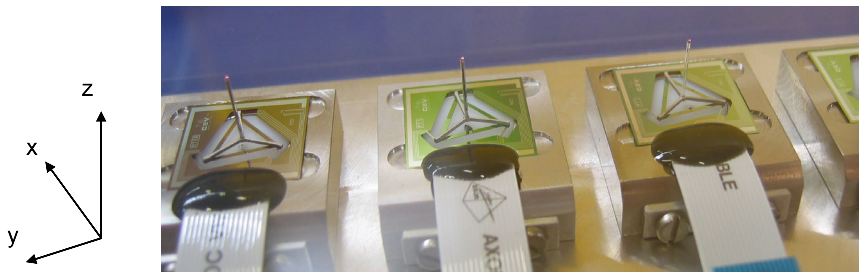

Fig.2 Nano probe [3].

The suspension used in the probe system consists of three slender rods (as seen in Fig. 3) that enable motion of the probe tip in z-direction and pseudo translation in x- and y-direction. The remaining degrees of freedom are fixed.
The displacement of the probe tip is measured using strain gauges attached to the slender rods. Their influence on the measurement uncertainty of the probe system will be discussed in the next section. For a more in-depth discussion on the measurement principle, the reader is referred to [6,7].

Piezo electric effects

The features of hysteresis, creep and relaxation are common to many materials such as polymers [8,9]. However, the silicon base material and the poly- silicon strain gauges have very low hysteresis [10,11]. Experiments with strain gauges have shown that hysteresis is most often caused by the connection of the strain gauges to the base material [12], for example when it is glued to the surface.

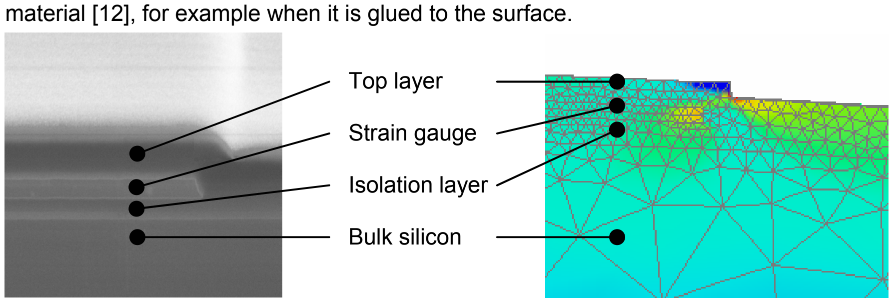

Fig.3 Cross-sectional SEM view of strain gauge and FEM analysis.

The strain gauges are deposited on the silicon base material, with an intermediate layer of Silicon Nitride, as shown in the left hand picture of Fig. 3. It is therefore

expected that the hysteresis due to the connection of the strain gauges to the base material can be neglected.
However, the polysilicon layer does add to the local stiffness of the slender rod on which it is deposited. The magnitude of this effect is increased by the construction of the slender rods, in which the strain gauge is encaged by two Silicon Nitride layers, as shown in the left hand picture of Fig. 3. The resulting decrease in strain of the strain gauges can be as high as 10%, depending on the thickness of the poly-silicon layer. A Finite Element Analysis of this effect is shown in the right hand picture of figure 3.

Globtop

An electrical connection between a MEMS device and package is often created using wire-bonds, as shown in Fig. 4. A wire-bond offers a reliable connection, but can easily be damaged. To protect the wire-bonds in the nano probe a globtop (glue) is used, as shown in Fig. 2.

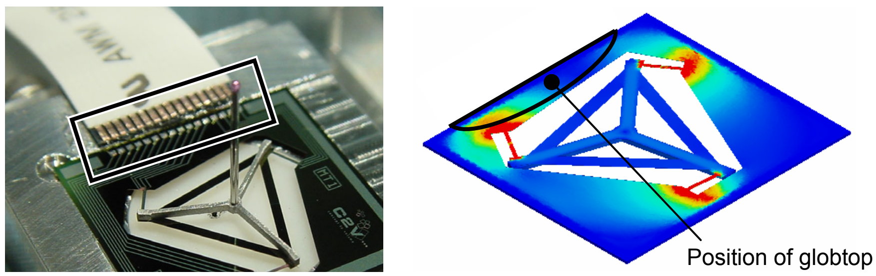

Fig.4 Probe without globtop with highlighted wire-bonds (left) and FEM of the stress in the membrane during probing in z-direction (right).

Using Finite Element Modelling (FEM) the strain in the chip during a displacement of the probe in z-direction is shown in the right-hand picture of figure 4. It can be seen that the deformation of the membrane at the position of the globtop is considerable. The globtop material is known to dissipate energy when deformed, as mentioned in the previous section [9]. A displacement of the probe tip thus leads to energy dissipation in the globtop and hysteresis during probing.

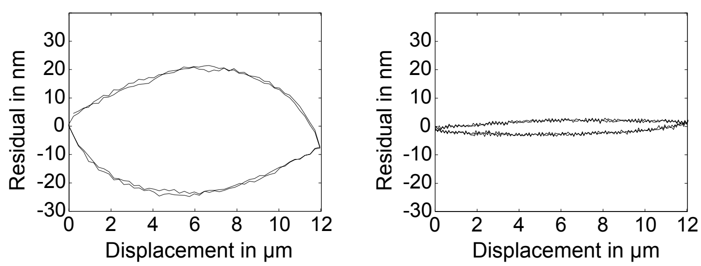

Fig.5 Measurement results for a probe with globtop (left) and without globtop (right).

This can be observed in the left-hand picture of Fig. 5 in which the measurement results for a probe with globtop during a measurement in the z-direction are given. The right-hand picture of figure 5 shows the results for a probe without globtop. It can be seen that the hysteresis has been reduced significantly. It should therefore be prevented that the globtop attaches itself to deforming parts, like the membrane in the nano probe. Another factor influencing the measurement uncertainty of the probe system is drift. One possible cause for this drift is a parasitic resistance between the strain gauges and the bulk silicon, as will be discussed in the next section.

Drift

It has been investigated by Pril [13] that part of the drift in the nano probe could be caused by a varying parasitic resistance between the connection pads, on which the wire-bond threads are attached, and the bulk silicon. This may be caused by the wire-bond process in which a high frequency vibration and pressure is used to attach the gold wire to the substrate. As a result the isolation layer between the bond pads and the bulk silicon can locally be damaged, causing the parasitic resistance.
By careful bonding using less energy and applying an extra isolation layer, the mean drift for a freely suspended probe has been reduced from 4 to 3 nanometres per hour. The remaining drift is most likely caused by differences in the coefficient of thermal expansion between the probe and connecting components (in particular its holder and the intermediate body between chip and stylus).

Conclusion

Removal of the globtop and implementation of an extra isolation layer has lead to a significant reduction of the probe hysteresis and drift. To reduce the hysteresis further, the probe assembly and design should be analysed as well. This will be discussed in a future extended paper.

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