A Micromachined Nanoindentation Force Sensor

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Summary: *A capacitive force sensor has been designed, manufactured and evaluated for in situ nanoindentation experiments in a TEM. A special feature of the sensor is that it has an integrated fixture for an interchangeable tip. The results show that the force sensor operates well with an off chip read-out circuit.*

Keywords: *Force sensor, Microfabrication, Nanoindentation*

Introduction

Nanoindentation is used for the study of mechanical properties of materials on the nanoscale. The technique utilizes an actuator to press a sharp diamond a few nanometer into the sample while measuring the applied force, typically giving information about the hardness or elastic modulus of the material [1]. Recently, an extension of the nanoindentation method has been demonstrated, using a transmission electron microscope (TEM) for in situ imaging of the entire indentation process [2], giving new opportunities for material characterization. This kind of instrument belongs to a new family of tiny probe instruments placed inside the mm sized pole gap of the TEM, such as the scanning tunneling microscope combined with a TEM [3,4].
To take full advantage of the new TEM-nanoindentation method, however, a proper force sensor, which was not used in [2], is needed. Here we report on such a force sensor fabricated by micromachining methods.

Sensor specifications and requirements

The confined space of specimen holder restricts the dimensions of the sensor to 2x2x1.7mm^3. The sensor will also have an integrated fixture for a tip, interchangeable and commercial though relatively large compared to the sensor itself, see fig 1.

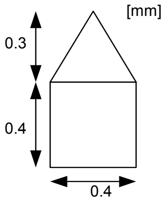

Fig. 1 Geometry and dimension of the nanoindenter tip, the lower part is a cylinder and the upper has a conical shape

The maximum load specified for the nanoindentation is 10mN and the working load range is 0-0.1mN, with a resolution of 0.1µN. In addition it is preferred to have multiple directions sensing to give a better overview of the sample.
To realize these requirements a capacitive read-out was chosen. Other read-out methods such as piezoresistive and piezoelectric were also considered but excluded due to manufacturing and consistency problems.

Sensor description and fabrication

The force sensor consists of a silicon part acting as the top electrode in a capacitive coupling and deposited aluminium on a glass part as lower electrode, see fig 2. Glass is chosen for anodic bonding and its high dielectric property.
The integrated fixture in the silicon part for the interchangeable tip is relatively large and limits the space for a weak membrane. The fixture is therefore suspended with 8 identical springs as seen in fig 2. This yields the required sensitivity.
To sense the direction of the applied force, a variant where the lower electrode is divided in four parts was also manufactured. The relative capacitance change between the electrode parts gives a measure of the force direction.

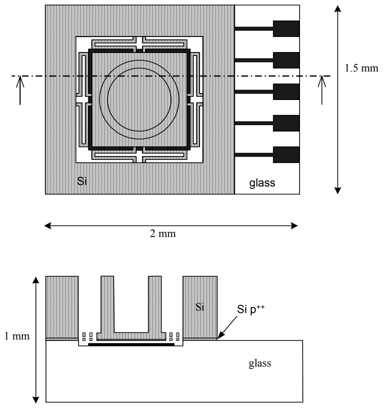

Fig 2. The capacitive force sensor design

The theoretical sensitivity was simulated in FEMLAB using a simplified model. The thickness of the springs was chosen to be around 20µm to fit the intended process, simulated dimension will therefore be in that region. A summary of the simulation results is presented in table 1.

Table1. Simulation results for the force sensor

Spring thickness [µm]	Deflection [nm]	Capacitance change [fF]
15	2.42	2.2
20	1.03	1.4
30	0.83	0.75

Choosing a spring thickness of 20µm yields a theoretical sensitivity of 1.4fF/0.1µN.
The basic processing steps are shown schematically in fig 3. The deep dry etch that forms the fixture and releases the springs is a critical step, fig 3(c),

where the wafer is etched about 500µm, with a ratio of 1:5.

Oxide is grown and masked to later be combined with resist and used as mask during the deep etch, see fig 3(a). The lower part of the silicon is p++ doped to form an ohmical contact between the aluminium contact deposited on the glass and the silicon. The spring structure is etched in the lower part with resist as mask, fig 3(b). Cavities are etched in the glass and aluminium electrodes deposited.

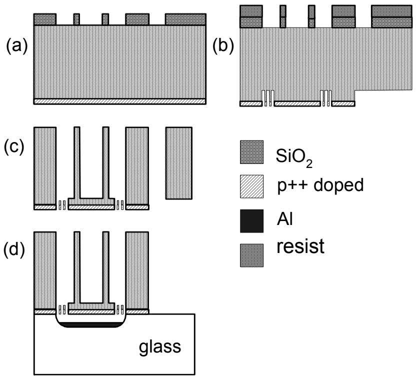

Fig. 3 Schematic of the basic fabrication steps (a) oxide mask and p++ doping (a) enhanced oxide mask and etched spring shaping (c) deep dry etch of the fixture (d) final anodic bonding

When the glass wafer and the silicon wafer are processed they are anodically bonded together, fig 3(d). The anodic bonding was performed with ± 500-700V and 400°C.

The press contact used to connect the silicon part caused problems during the bonding. It was 1µm thick to start with and the bonding was not sufficient, fig 4(a). The aluminium was thinned to 0.45µm, which solved this problem, fig 4(b).

The electrodes were interconnected during the anodic bonding to decrease the risk of unwanted bonding.

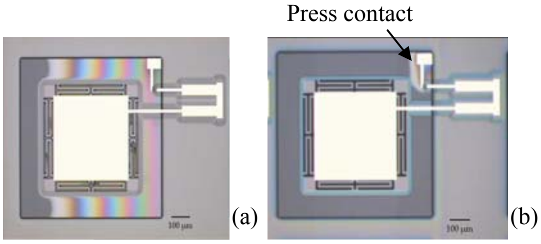

Fig. 4 Anodic bonding (a) A partially bonded device (b) A successful bonded component

Results

The force sensor was successfully manufactured and a photo of the complete force sensor is shown in fig 5.

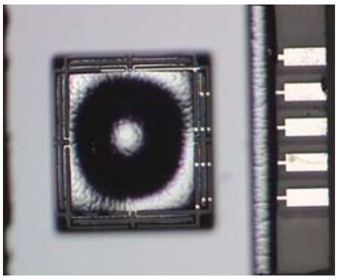

Fig. 5 The manufactured force sensor with four lower electrodes

The sensors were evaluated using a test board with a piezoelectric positioning system. A copper wire attached to the piezoelectric positioning system is pressed against a gold tip glued to the silicon plate. The wire is moved against the sensor tip a certain distance while measuring the capacitance change with a highly sensitive read-out chip [5]. The test was conducted by pressing 500nm to 1000nm. The results were very encouraging and show that the sensor works in combination with a read-out chip while applying a force. A resulting plot is presented in fig 6.

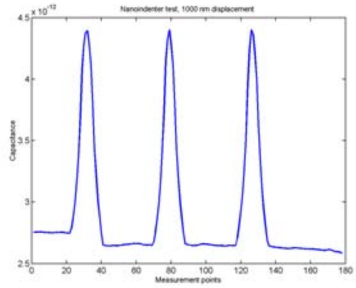

Fig.6 Measured capacitance while the sensor is pressed 1000 nm in and out, axis show capacitance in pF vs measured points

Conclusions

A highly sensitive capacitive force sensor with an integrated fixture for interchangeable tips has been designed, manufactured and evaluated. The sensor is designed to operate in a TEM. Evaluation shows that the sensor is fully operational in combination with the selected read-out chip and an installed tip.

References

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