Subproject B2: Experimental characterization, modell adaption and reliability: "On the search of charges in MEMS"

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1 Introduction

At the characterization of a micro electro mechanical system (MEMS) a plenty of parameters has to be determined. Aside from the geometry and the surface properties like warp and roughness the electro mechanical characteristics are very important technical features. Thereby it could be observed that the presence of charges strongly influences the static deflection and the dynamic behavior of capacitive sensors or actuators [1, 2, 3]. An example to illustrate this effect is the acceleration sensor shown in Fig. 1. The aluminum electrodes are placed on glass wafers. A single crystalline silicon wafer is used to realize the seismic mass and its supporting bending beams. While assembling the wafers by an anodic bonding process voltages up to 400 V have to be applied. The consequential electrostatic force deflects the seismic mass towards the opposite electrode until it hits. To prevent sticking and an electrical short circuit spacers are deposited on both sides of the seismic mass. Because the spacers have to be dielectric materials they carry charges deposited during the bonding process for a very long time. One important property of the acceleration sensor is the static deflection curve. It is obtained by applying a voltage on one capacitor and measuring the capacitance of the opposite capacitor. The same measurement is performed the other way round. The two obtained curves are given in the C-V plot of Fig. 2. They are shifted towards higher voltages. These offset voltages typically are caused by the presence of charges within the sensor. If the charge density changes the static deflection is changing too. Consequently, the characteristic of the acceleration sensor is influenced by charges.

To investigate the behavior of charges in MEMS devices it is necessary to characterize the charge distribution on a sample surface. The information is obtained by measuring the surface potential or the capacitance. Therefore different methods are applicable. For instance Kelvin probe force microscopy [4, 5], electrostatic force microscopy [6] and force microscopy [7] are used to measure the surface potential and capacitance distribution. An overview about electrometers and electrostatic fieldmeters developed at the University of California, Berkley is given in Riehls dissertation [8].

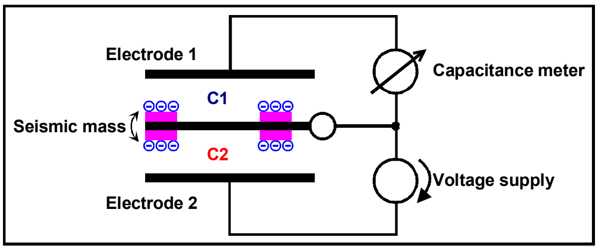

Fig. 1: Characterization of the acceleration sensor

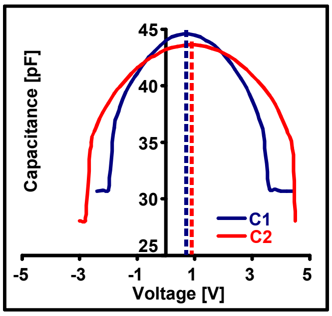

Fig. 2: C-V plot of the sensor

At the Chemnitz University of Technology an electrostatic field sensor was developed that measures the surface potential and the topography simultaneously. The acquisition of the topography enables to control the distance between sensor and sample so that its influence becomes negligible. Compared to the techniques mentioned in [4-7] the realized setup has a very large scan range of some 10 mm^2 which is essentially for the planed investigations. The in-plane resolution is about 50 µm.

2 Sensor and function principle

To characterize the behaviour of charges on dielectric layers in the region of driving or sensing electrodes of capacitive MEMS a measurement technique was developed that is related to the Kelvin method. This means, the effect of the charge induced surface potential is compensated. Fig. 3 shows a scheme of the realized electrostatic field sensor. The micromechanical part is a cantilever-like bending beam with a cubic tip. Its lower surface is the sensing area. A sinusoidal voltage with the frequency ω and an adjustable offset voltage is applied between the cantilever and the sample. The resulting electrostatic force leads to an oscillation of the beam tip that is recorded by a Laser Doppler interferometer.

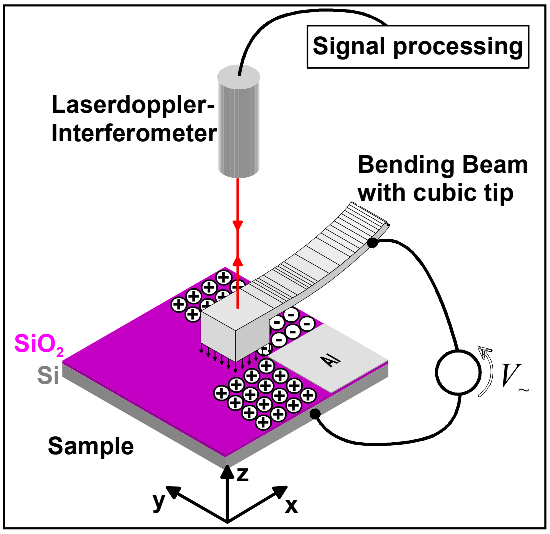

Fig. 3: Scheme of the electrostatic field sensor

The calculation of the electrostatic force on the sensing area will be described using the simplified model of a plate capacitor with a dielectric layer or layer stack on one electrode as shown in Fig. 4.

In assumption of a homogeneous field within the capacitor without interactions with the surroundings the arrangement is electrical neutral, e. g.:

$$\sigma_1 + \sigma_2 + \sigma_P = 0 \qquad (1)$$

Furthermore the Kirchhoff's law is valid and the applied voltage divides into:

$$V_\sim = E_1 \cdot d_1 + E_d \cdot d_d \qquad (2)$$

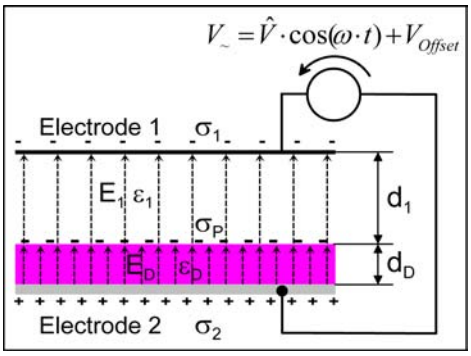

Fig. 4: Simplified model of a plate capacitor

Using (1) and (2) and the usually used equations to calculate electrostatic forces (3) the resulting force on electrode 1 and the sensing area, respectively can be described using equation (4).

$$dF = -\frac{E_1 \cdot dQ_1}{2} \qquad (3)$$

$$F = \varepsilon_0 \cdot \varepsilon_1 \cdot E_1^2 \cdot A$$

with A … the area of the electrode 1

$$F = \frac{\varepsilon_0 \cdot \varepsilon_1 \cdot A}{2 \cdot (\frac{d_D \cdot \varepsilon_1}{\varepsilon_D} + d_1)^2} \cdot [\frac{\hat{V}^2}{2} \cdot (1 + \cos(2 \cdot \omega \cdot t))$$
$$+ 2 \cdot \hat{V} \cdot V_{Offset} \cdot \cos(\omega \cdot t) + 2 \cdot \hat{V} \cdot \frac{d_D \cdot \sigma_P}{\varepsilon_0 \cdot \varepsilon_D} \cdot \cos(\omega \cdot t) \qquad (4)$$
$$+ V_{Offset}^2 + (\frac{d_D \cdot \sigma_P}{\varepsilon_0 \cdot \varepsilon_D})^2 + 2 \cdot V_{Offset} \cdot \frac{d_D \cdot \sigma_P}{\varepsilon_0 \cdot \varepsilon_D}]$$

Because of the linear spring stiffness of the bending beam the motion of the tip of the beam is proportional with the stimulating electrostatic force. Consequently it will deflect statically and dynamically at the frequencies ω and 2ω. On the condition that the applied offset voltage V_{Offset} is equal to $-\frac{d_D \cdot \sigma_P}{\varepsilon_0 \cdot \varepsilon_D}$ the equation to calculate the electrostatic force on electrode 1 reduces to:

$$F = \frac{\varepsilon_0 \cdot \varepsilon_1 \cdot A}{2 \cdot (\frac{d_D \cdot \varepsilon_1}{\varepsilon_D} + d_1)^2} \cdot \frac{\hat{V}^2}{2} \cdot (1 + \cos(2 \cdot \omega \cdot t)) \qquad (5).$$

It is to be seen that the tip of the beam oscillates only at the frequency 2ω. The amplitude at this frequency depends on d_1 and it is used to control the distance between the tip and the sample. Consequently the surface topology is taken into consideration. The applied offset voltage is equal to the surface potential. Furthermore it can be used to calculate the charge density on top of the isolation but therefore the parameters of the dielectric layer like thickness and dielectric constant has to be known (6).

$$\sigma_P = -\frac{V_{Offset} \cdot \varepsilon_0 \cdot \varepsilon_D}{d_D} \qquad (6)$$

3 Results

The samples used for the investigations are similar to MEMS structures. That means, the assembly of silicon, dielectric layer or layer stacks and metal layer is like that of driving or sensing electrodes. The sample shown in Fig. 5 consists of silicon with a 300 nm thermally grown silicon dioxide layer. On top of the dielectric a sputtered aluminum layer is deposited. The experiments are done as follows. The Si-SiO_2-Al capacitor is charged by applying a DC-voltage between silicon and aluminum for some seconds. After that, the potential of the aluminum layer is left free and the surface potential distribution on the Al and the adjacent SiO_2 was measured using the micromechanical electrostatic field sensor.

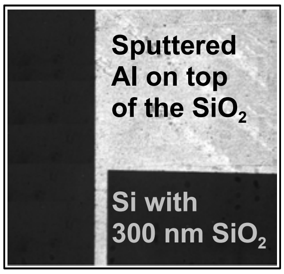

Fig. 5: Sample top view

The measurement results shown in Fig. 6 are obtained after charging the aluminum at +12 V. Fig. 6a is the surface potential distribution of the sample measured immediately after the charging procedure. The potential of the aluminum is +12 V. This is caused by the free charge carrier of the aluminum and the large Si-SiO_2-Al capacitance compared to the capacitance generated by the sensing area of the cantilever and the sample. The adjacent silicon dioxide has a surface potential of about -0.7 V which is a result of experiments performed some weeks before. After 24 hours the measurement was repeated (Fig. 6b). The obtained result strongly differs from the previous one (Fig. 6a). The extracted line scans in Fig. 6c illustrate this change. Depending on time the surface potential on the aluminum decreases while it increases on the adjacent silicon dioxide.

Immediately after performing the measurement shown in Fig. 6b the aluminum was charged at -12 V. The same area of the sample was scanned as before and the results are given in Fig. 7. The surface potential distribution measured 20 minutes after the charging process (Fig. 7a and 7c) shows a rapid discharge of the aluminum to ca. 8.5 V. The results on the silicon dioxide are comparable to those of the last measurement in Fig. 6c (after 24 h). Fig. 7b shows the surface potential distribution after 24 hours. As in the previous experiment, the result strongly differs from that given in Fig. 7a. Fig. 7c shows that the change occurs faster than in the previous measurement (Fig. 6c).

The measurement results show a strong change of the surface potential distribution and consequently of the charge distribution after 24 hours. This can be explained by existence of a thin water film on top of the sample caused by the air humidity. It enables the charge carrier movability on the silicon dioxide surface for in-plane motion. Another reason is the ionization of the adjacent air and deposition of the ions and electrons on the sample. Within the continuation of the experiments the influence of climatic factors e. g. light, temperature and air humidity will be investigated.

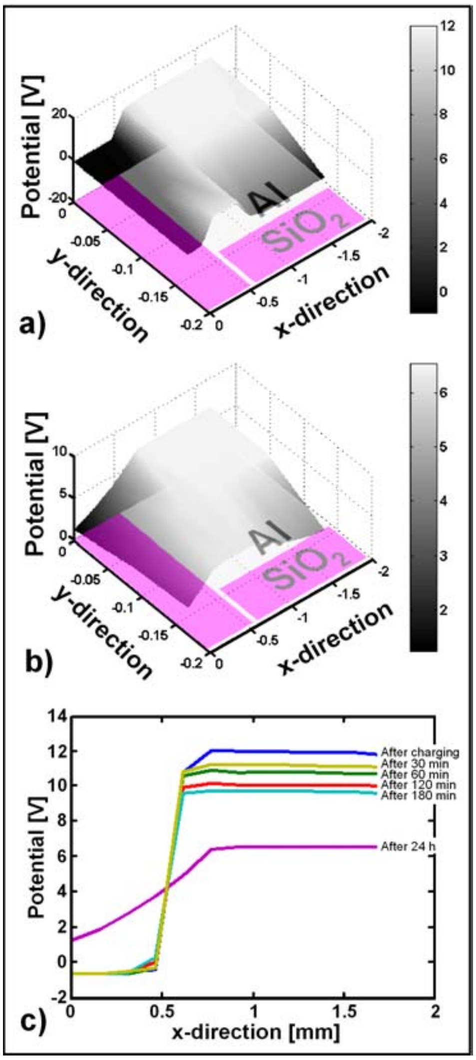

Fig. 6: Measured surface potential distribution after charging the Al at +12 V, a) immediately after charging, b) 24 h later, c) extracted line scan at different times after charging

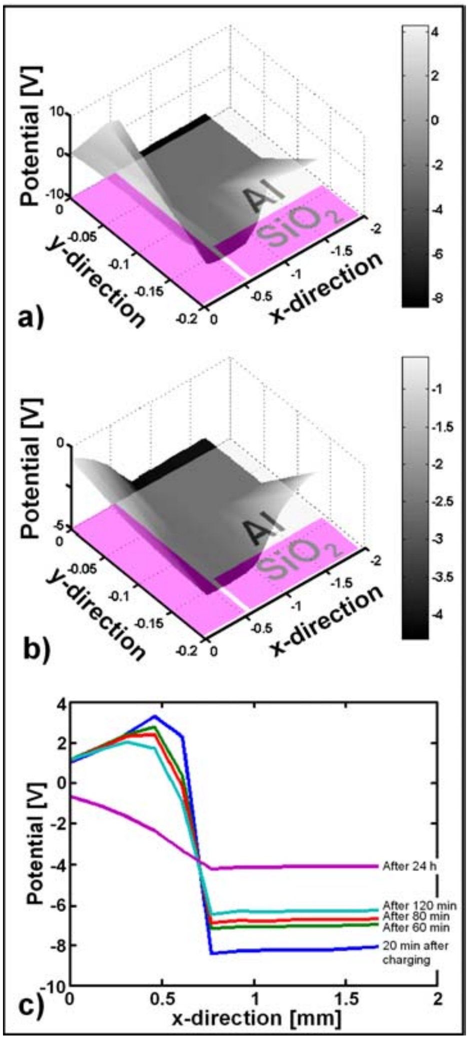

Fig. 7: Measured surface potential distribution after charging the Al at -12 V, a) 20 min after charging, b) 24 h later, c) extracted line scan at different times after charging

4 Summary

The presence of charges strongly influences the characteristics of capacitive MEMS devices. If the charge density changes the static deflection and the dynamic behavior of the sensor or actuator are changing too. Consequently, it is very important to investigate the behavior of charges in MEMS devices to derive rules for the design and fabrication process. The presented micromechanical electrostatic field sensor is used to measure the surface potential distribution which is significant for the charge density. The presented results show the practicability of this sensing technique. It could be demonstrated that after charging a sample the surface potential distribution changes depending on time. Investigations about the influence of climatic factors and the patterning of the dielectric layer are subject of the future work.

5 References

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