# EFFECTS ON IMAGING BY TILTING ELECTROSTATIC ACTUATORS IN ELECTRON MICROSCOPY.

A.J. Been, R. Vermeer, L.A. Woldering and L. Abelmann

*MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands.*

***Abstract* — In this paper we investigate the influence of tilted electrostatic actuators on the imaging in electron microscopes. Previous studies have shown image deformation by electrostatic actuation in electron microscopes, and suggested a strong influence of the tilt angle on the deflection of the electron beam. Our model suggests an influence of 1 µm/° of the tilt angle on the amplitude of deflection. Preliminairy experimental results indicate an influence of the angle on the amplitude of deflection, but the observed effect is two orders of magnitude smaller than simulations predict. However, there are still some variables we have not explored that might influence the strength of the influence of tilt.**

***Keywords:* MEMS, Electron microscopy, Electrostatic actuation**

## I – Introduction

Micro Electro Mechanical System (MEMS) devices are used in numerous applications, yet are still very scarcely employed in electron microscopy. We investigate the potential of using MEMS devices inside electron microscopes and the influence of their actuation on the imaging in these microscopes. One of the forseen applications of a MEMS device in an electron microscope is moving a small aperture with nanometer precision.

The disadvantage of imaging a MEMS device in an electron microscope is that electrostatic actuation can strongly affect the path of the electron beam, and thus deform the image that is obtained by the microscope. An extensive study on this subject was reported by us at MME 2011 [1].

We have continued our research to investigate the influence of several configuration parameters in a SEM on the amplitude of deflection of the electron beam, which is observed as a deformation in the images. The amplitude of deformation in the SEM images was measured and compared with simulation results. These results show that the measured values are about four to five times larger than the actual simulated values [2]. Our suggested explanation for this observation is that a tilt of the device with respect to the horizontal plane, see Figure 1 for a situation overview, increases the measured deformation significantly. Indeed simulations of this effect show a dependence of about 1 µm per degree of tilt on the amplitude of deformation. The results of the simulations of the device under different tilt angles can be found in Figure 2 (taken from [2]).

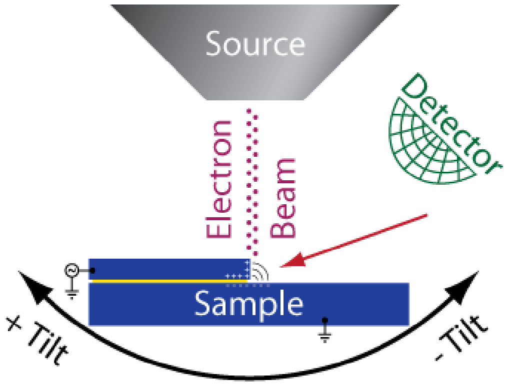

Figure 1: *Illustration of the situation inside the SEM. The electron source emits electrons at the sample, which is actuated. Electric fields generated by the actuation are indicated by the red arrow. The detector on the right counts the number of secondary electrons emitted from the sample. The sample can be tilted as shown, with the tilt axis perpendicular to the image.*

To confirm that tilt has a great influence on the amplitude of deflection, we are performing tests in a SEM. Preliminairy results of these tests are presented in this abstract. In order to take into consideration any effect the detector position may have, we also vary the experimental situations such that the observed edge is oriented towards and away from the detector.

## II – Experimental Details

To measure the amplitude of deformation, we used MEMS devices as described in [3]. These devices have a symmetrical nature, with a suspended table that is actuated by two identical combdrives on either side of the table. This device is shown on the left in Figure 3. The device is mounted on a custom home-built device holder and installed on the sample table of the SEM. Experiments were performed in a FEI Quanta 450 SEM, with an Everhart-Thornley Detector at 250 V bias to detect the secondary electrons [4]. The SEM is fitted with wiring that enables us to control the device from outside the vacuum chamber. The voltage applied to the combdrive is generated by an Agilent 33120A waveform generator, amplified by an ESyLAB LM3325 8 channel HV Amplifier with an ESyLAB LM3322 HV Power Supply. Connecting coax cables are of the RG58c/u MIL-C-17f and RG174/u MIL-C-17f lf types. Follow up measurements using biased actuation were performed using a P-265 HV amplifier (100 ×) and an Agilent 54622D oscilloscope. We measured the amplitude of deformation in the SEM images under a constant working distance

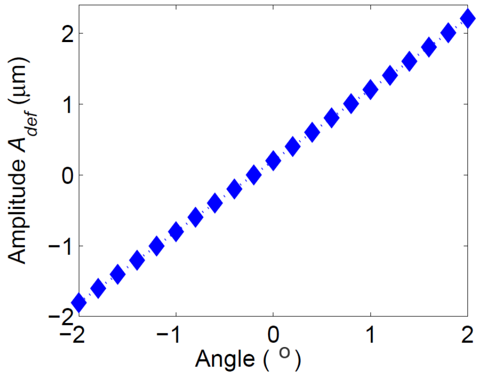

Figure 2: *The simulated amplitude of the deformation* $A_{\mathrm{def}}$ *as a function of the angle of the SEM sample table with respect to the horizontal plane. A negative amplitude means a phase shift of* 180° *with respect to the positive amplitude at an angle of the table of* 0°.

of 12 mm and magnification of 20 000 ×.

In order to see a large effect of the electrostatic actuation on the SEM imaging, we chose a low acceleration voltage of 2 kV. Accross all measurements, we kept the beam current of 57 pA constant. SEM images were taken for four actuation and measurement situations, see Figure 3. These situations were chosen to investigate the influence of the detector on the amplitude of deformation for tilted devices. In addition we investigated whether the amplitude of deformation depends on the location of actuation. For each situation we varied the tilt of the sample between −4° and 4° with respect to the horizontal plane.

To determine the amplitude of deflection from the image, we measured the distance between the peaks by hand. Since we align the device perpendicular to the detector at the beginning of the experiment, we can take the horizontal position of the two extremes and divide the difference by the scale of the image to obtain the amplitude of deformation in micrometers.

### III – Results and Discussion

As we performed the measurements of the four different situations, we came across two situations where the edge of the structure could not clearly be measured. These are indicated as situation two (for positive angles) and situation four in Figure 3. When observing the actuated side, the contrast difference is too large to be able to see the edge throught a full cycle, see Figure 4. Observations of the unactuated side are much more clear, see Figure 5. Our solution was to apply a bias to the actuation, such that the applied voltage never changed sign. Using the oscilloscope we measured that the applied voltage was from −18.0 V to −55.3 V.

We were unable to obtain clear images for experimental situation four, despite applying a bias to the actuator. The images for experimental situation two were clear enough for some measurements for both the biased

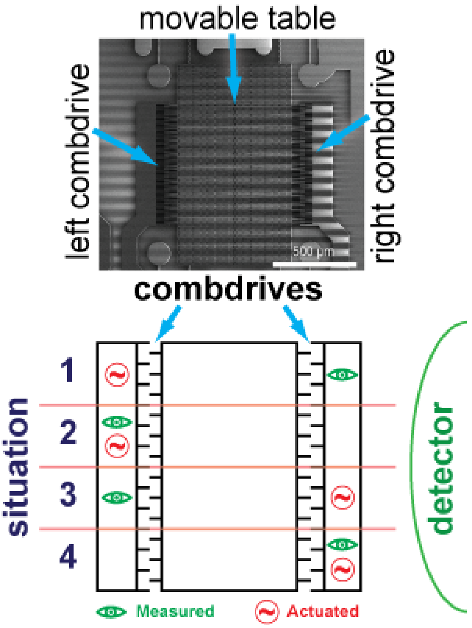

Figure 3: Top: *Scanning electron micrograph of the device that was used for our experiments. In the middle a movable table is shown that can be actuated by the electrodes on the left and the right side. Contrast changes in the image are caused by the electrode on the right that is connected to a* 1 Hz, 40 $V_{\mathrm{pp}}$ *sine wave.*
Bottom: *This schematic drawing shows the four different measurement situations. For each situation the eye symbol shows the side which is observed and the source symbol which side is actuated.*

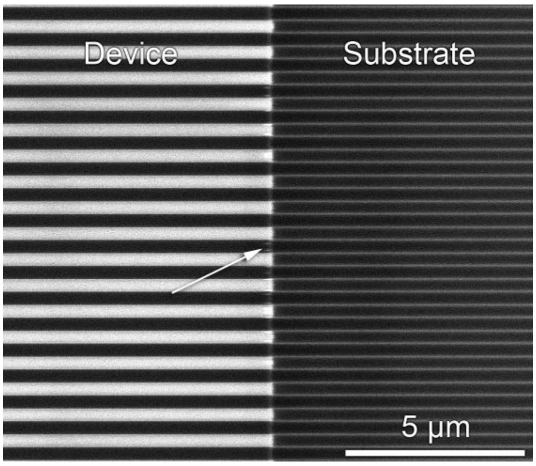

Figure 4: *Scanning electron micrograph of the actuated side of the combdrive on a* 1 Hz 40 $V_{\mathrm{pp}}$ *sine. On the left side the device layer is shown, while on the right side the supporting substrate is observed. The device is tilted by* 1.5° *towards the detector and the observed edge is oriented towards the detector. No clear edge can be defined to determine the amplitude of deformation, see arrow.*

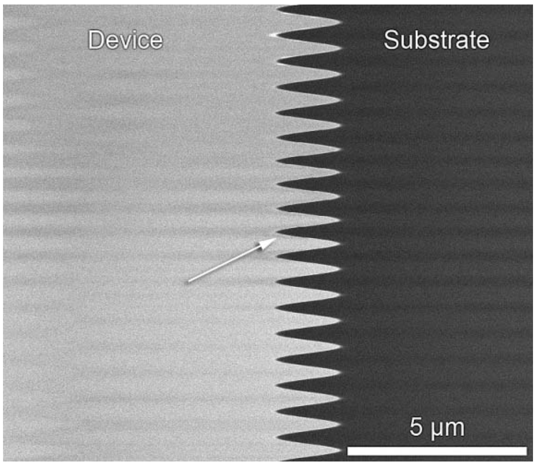

Figure 5: *Scanning electron micrograph of the unactuated side of the combdrive. On the left side the device layer is shown, while on the right side the supporting substrate is observed. The device is tilted by* 1.5° *towards the detector and the observed edge is oriented towards the detector. A clearly defined edge can be observed, see arrow. This edge has a sinusoidal appearance due to the varying electric field generated by actuation of a combdrive approximately* 1 mm *to the left of this structure.*

and unbiased cases. The results are shown in Figure 6. We observe that there is no significant difference between the unbiased and the biased cases. The measured results of the experimental situations one and three are shown in Figure 7 and Figure 8 respectively. Our observations suggest a dependence of the amplitude of deformation on the angle. However this dependence is much smaller than our models predict. The effect of the tilt is about 0.02 µm/° and only 0.5 % to 1 % of the total amplitude of deformation. The results also indicate that the influence of tilt is about the same when both the actuated and the unactuated side are compared to each other.

Note that in the results the dependence on the angle is positive in Figure 7, while it is negative in Figure 6 and Figure 8. The reason for this is that for situation one the side of the device-layer is tilted away from the electron beam for positive angles. For situations two and three the side of the device-layer is tilted towards the electron beam for positive angles. Apparently when the side is tilted away from the electron beam, the amplitude of deflection is higher. A larger amplitude of deflection occurs when the actuated combdrive is closer to the electron beam than when the device is tilted the other way.

Another phenomenon we encountered during our measurements is a difference in the amount of deflection of the electron beam for tilt angles where both edges of the device layer is shown. That is, when the device is tilted in such a way that both the edge (A) between the top of the device-layer and the side of the device layer, as well as the edge (B) between the side of the device-layer and the surface of the substrate can be observed.

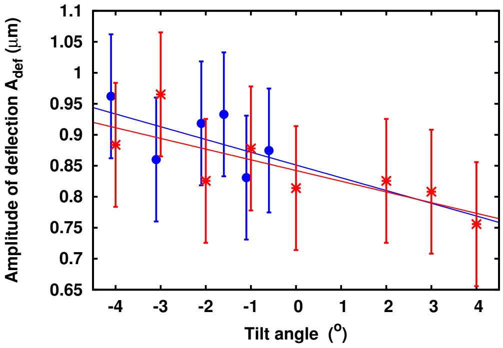

Figure 6: *Measured results for experimental situation two. The blue results show the unbiased measurements, while the red results show the biased measurements. The unbiased results (blue) were displaced in the graph by* $-0.1°$ *tilt angle to provide a clearer image. We observe that there is indeed an influence of the angle on the amplitude of deformation. The line is a linear fit that serves as a guide to the eye.*

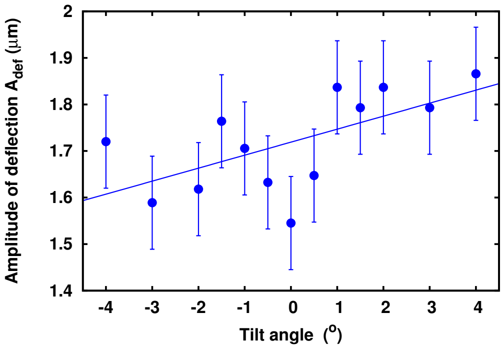

Figure 7: *Measured results for experimental situation one. The measured amplitude of deformation is shown against the tilt angle. The results suggest a small dependence on the angle. The line is a linear fit that serves as a guide to the eye.*

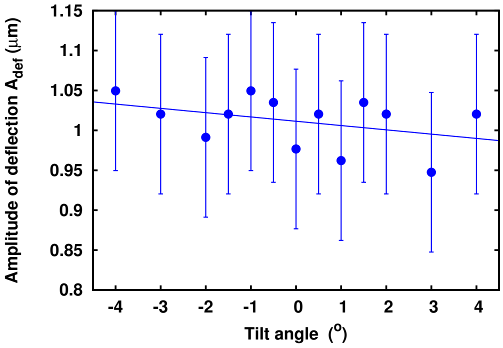

Figure 8: *Measured results for experimental situation three. The measured amplitude of deformation is shown against the tilt angle. The results suggest a small dependence on the angle. The line is a linear fit that serves as a guide to the eye.*

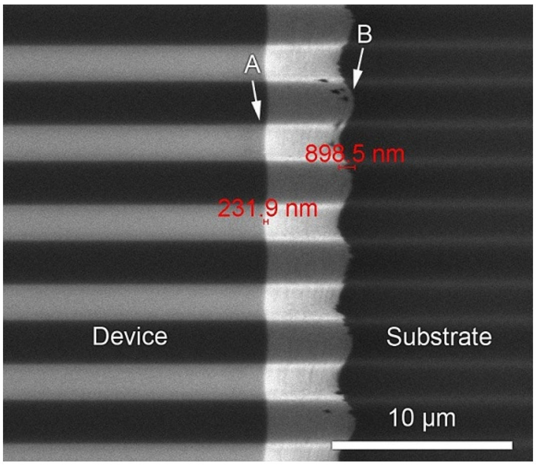

Figure 9: *A scanning electron micrograph of a tilted device. The bottom side (B) shows a much higher deflection compared to the top side (A) of the structure. The deflection for bottom side B is* 0.9 µm*, whereas for the top side the deflection is* 0.2 µm*. This structure was actuated with a* 1 Hz, 40 $V_{pp}$ *sine wave, but with other settings of the SEM than the other experiments*[1]*.*

This phenomenon is shown in Figure 9 [1]. We expect that this effect is caused by strong electric fields between the side of the device and the substrate. The fields around this area are illustrated in Figure 10 (taken from [2]).

The observed effects are in agreement with the assumption made in our model that the incident electron beam is deflected by the electric stray field. We do not understand at this point why the observed influence of the tilt angle is several orders of magnitude smaller than estimated from our calculations.

### A. Future work

Our next goal is to explore more parameters and we are hopeful to find a clearer influence of the tilt. Also, we would like to improve the method that was used to measure the amplitude of deformation by using the procedure of fitting a periodic function to the edge of the device. Since the device is actuated with a sine wave, we can use this information to acquire deflection results more accurately. Furthermore we are considering whether our simulation model needs to be improved. Other subsequent steps of our investigation are to vary the working distance in the SEM, as well as the acceleration voltage. We also would like to further investigate the influence of the postition of the detector on the amplitude of deformation. Finally we suspect that other structures on the device could be affecting our measurements and we would like to eliminate their influence from our measurements.

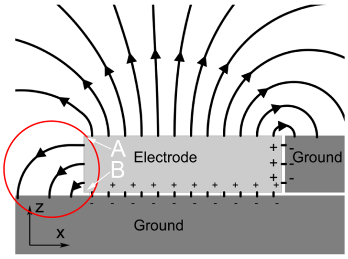

Figure 10: *Illustration of the electric field around the combdrives. The circle shows strong fields between the side of the device and the substrate. Edges A and B are also indicated in Figure 9*

## IV – Conclusion

We investigated the effect of the alternating electric stray field emerging from electrostatic actuators on the image deflection in a SEM. Simulations show a strong dependence of 1 µm/° of the amplitude of deformation on the tilt of the device in an electron microscope. However, preliminairy tests only show a 0.02 µm/° influence. At this point we do not understand why the experimental results are two orders of magnitude smaller than our simulations.

Our measurements indicate that the results for observing the actuated side of our device are comparable to the results for observing the non-actuated side, and no significant change was measured when applying a bias to the actuation voltage.

We observed that a larger amplitude of deformation occurs when the actuated combdrive is tilted closer to the electron beam than when the device is tilted the other way, which is as expected.

Finally the bottom side of structures show a much higher deflection than the top side. This indicates the presence of strong electric fields near the edge of the device layer, like our model predicts.

## References

[1] R. Vermeer, L. A. Woldering, and L. Abelmann. Effect of electric fields generated by microactuators on the imaging in electron microscopy. In *Proceedings of the 22nd Micromechanics and Microsystems Technology Europe Workshop, Tonsberg, Norway*, pages 222–225, Norway, 2011.

[2] R. Vermeer. Electrostatic actuation of mems devices in electron microscopy. Master's thesis, University of Twente, MESA+ Institute for Nanotechnology, University of Twente, PO Box 217, 7500AE Enschede, the Netherlands, October 2011.

[3] J.B.C. Engelen, H. de Boer, J.G. Beekman, L.C. Fortgens, D.B. de Graaf, S. Vocke, and L. Abelmann. The Micronium — A Musical MEMS Instrument. *Journal of Microelectromechanical Systems*, 21(2):262 –269, 2012.

[4] H. Seiler. Secondary electron emission in the scanning electron microscope. *Journal of Applied Physics*, 54(11):R1–R18, 1983.

---

[1] This image was taken using different settings than described in Experimental Details: magnification 10 000 ×, acceleration voltage 2.00 kV, beam current 57 pA, working distance 14.9 mm