FABRICATION OF CANTILEVER ARRAYS WITH TIPS FOR PARALLEL OPTICAL READOUT

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***Abstract* — We report on progress in the fabrication of cantilever arrays with tips. The process features only one lithographic step for the definition of both the tips and cantilevers. The tips have a uniform height distribution and are placed by self-alignment on the cantilever. The arrays are fabricated for an optical readout technique under development in which the cantilever arrays serve as diffraction gratings. This work describes our ongoing effort in array fabrication as well as preliminary results on optical readout of a previously fabricated batch of tipless cantilever arrays using Fraunhofer diffraction.**

Keywords : **Cantilever array, Tip fabrication, Optical readout**

I - Introduction

Arrays of microcantilevers are fast and highly sensitive transducers having enormous potential in a variety of applications, among which probe-based data storage [1], probe based nano-lithography and nano-manufacturing. There are many challenges related to maturing cantilever array technology for application purposes. In this work we are concerned with two major consequences of scaling up from a single cantilever to a cantilever array.

Firstly, fabrication tolerance will result in deviation in tip height across the array. This is not only caused by the actual height of the tip, but also by the cantilever that supports it. When trying to utilize such an array one has to apply a higher loading force in order to make all cantilever tips touch the sample underneath. Meaning that tolerance in tip height will directly translate into different loading forces on the tips while operating them. Variation in loading force across an array will, in turn, results in reduced overall performance.

Secondly, many applications require readback of cantilever motion and readback techniques have to be able to handle arrays. A common way of detecting cantilever motion is by integrating a sensor into the cantilever and then wiring, in a matrix fashion, each sensor [2]. The most used sensors include piezoelectric [3], thermal [4] and magnetoresistive sensors. However, such a sensor integration will not only add to the complexity of the fabrication process, it also poses extra demands on cantilever probe design and possibly puts a limit on admissible fabrication steps.

In this work we aim to reduce the complexity which arises from fabricating and reading out cantilever arrays. We show progress on the fabrication of cantilever arrays where only one mask is used to define both tip and cantilever. The fabrication process is partly based on [5]. The tip is self-aligning on the cantilever and its height is defined by a wet etching step. Therefore we expect to obtain a small deviation in tip height and position across an array. Next, we propose an optical readout method that can read out cantilevers in parallel, while not posing extra demands on the cantilever design, unlike an optical readout solution reported in [6]. The optical readout technique is non-invasive and is easily replaceable in case of breakdown. Whereas integrated sensors cannot be replaced. First experimental results on optical readout of previously fabricated tipless cantilever array are presented.

II - Fabrication Details

The cantilever arrays are fabricated using silicon on insulator wafers with a device layer thickness of 10 µm that has a <100> orientation. The process flow for the fabrication of the cantilever arrays is shown in figure 1. A layer stack of 25 nm silicon rich nitride (SiRN), 100 nm silicon oxide and 20 nm SiRN is deposited. The top layer of SiRN is patterned with a first lithograpic step. A wet etch in buffered HF is applied to locally remove the silicon oxide layer and we purposefully create about 1 µm of undercut under the top SiRN layer. This undercut sharpens the corner that will house the tip, effectively increasing the resolution of our lithography process, which is limited to 1 µm. Consequently, the final tip apex will be more precise defined and also its position is set more accurately. After removal of the top SiRN layer by a phosphoric acid etch, the cantilever is cryogenically etched out of the device layer. The cryogenic etch is a critical step in the fabrication process, because it creates two side walls of the tip. Most important is the transfer of the hard mask into the first hundreds of nanometers of silicon. Any amount of undercut will reduce the height of the tip when the KOH etch is performed. By optimisation of the cryogenic etching process a nice, straight etch profile is obtained, as shown in figure 2. The cryogenic etch is performed with an ADIXEN AMS100 SE. At a temperature of -100°C and at a pressure of $1.3 \cdot 10^{-2}$ mbar an SF_6 flow of 100 sccm and and an oxygen flow of 12 sccm is applied to etch the silicon 5 µm down.

After the cryogenic etch, the sidewalls of the cantilever are protected by local oxidation. Now a wet, anisotropic KOH etch creates the tips. This is possible

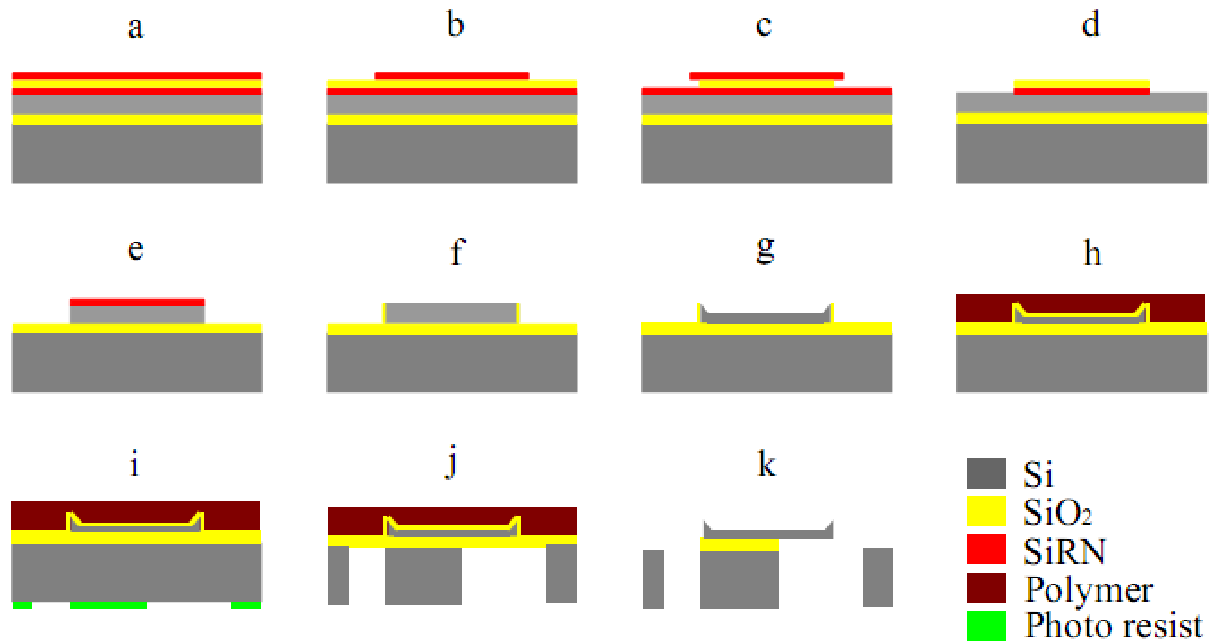

Figure 1: *Process flow of the fabrication process of the cantilever arrays with tips. (a) Deposition of 25 nm SiRN, 100 nm SiO_2 and 20 nm SIRN layers. (b) Patterning of top SiRN. (c) BHF etch of SiO_2. (d) Phosporic acid etch removes SiRN locally. (e) Cryogenic etch defining cantilever outline. (f) SiRN removal and oxidation to 100 nm. (g) KOH etch creating tips. (h) Oxidation to 100 nm and spray coating of a polymer film protection layer. (i) Backside patterning in second lithographic step. (j) Backside etch until the buried oxide layer. (k) Removal of pyralin and local removal of SiO_2.*

since the cantilever is aligned with the <110> direction and the triangular shape of the tip end yields the tip due to the slow etching of the {111} plane. Due to the uniformity of the KOH etching step, tip height is expected to show little variation within one array. The KOH etch also defines the final thickness of the cantilever. Another oxidation step grows 100 nm of silicon oxide to both protect as well as sharpen the tips. A polymer film (DuPont MX5000) is applied by lamination to add additional protection to the tips during the backside etch procedure.

A second lithographic step is now used to pattern a 3.5 µm thick layer of photo resist on the backside of the wafer. A wafer-through backside etch is performed using a deep reactive ion etch. A pulsed process is used with SF_6 (400 sccm, 4 s) and C_4F_8 (25 sccm, 0.5 s). The polymer film is then removed by oxygen plasma stripping. Finally, both the protective oxide layer, as well as the exposed parts of the buried oxide layer are etched away in 1% HF. This final step releases the cantilevers.

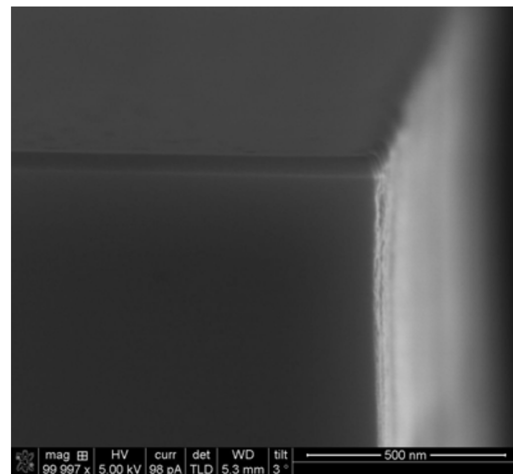

Figure 2: *SEM image of a well defined straigh etch profile obtained by cryogenic etching after the etching procedure has been optimized. Important is the lack of undercut, since undercut will influence the tip height in a later stage of the process.*

II – Current Fabrication Results

We have completed a successful test run where silicon wafers have been used instead of silicon on insulator wafers. The process flow is exactly the same, except for the final few steps, i.e. figure 1 (j) and (k). As a result cantilevers with tips are created on top of a silicon wafer and cannot be released, as shown in figure 3.

A disadvantage of the described process is the occurrence of a ridge that stands on the sides of the cantilever, see figure 2 (a). These ridges are caused by the slow etching of the {111} plane, just like the formation of the tip plane. We solve this issue by adding a small taper to the width of the cantilever. Figure 2 (b) shows that an angle of 10 degree is sufficient to remove the ridge. Note that remainders of the SiO_2 protection layer are still present.

III – Experimental Details

The cantilever arrays are fabricated for optical readout experiments where the array serves as a diffraction grating. The medium topography is transferred into bending of the cantilevers hereby modifying the diffraction grating, which results in a change in a detectable change in the diffraction pattern. We have constructed

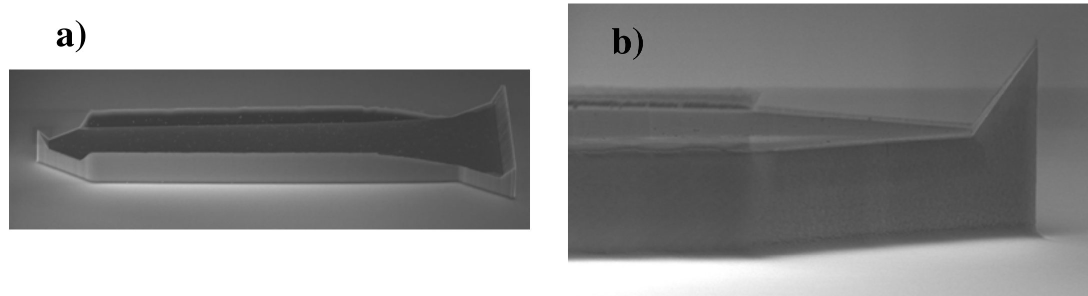

Figure 3: (*a) SEM photograph showing a fabricated cantilever with tip and standing ridge at the cantilever sides and base. The cantilever has not been released from the substrate. (b) SEM photograph showing a cantilever design where the ridge is effectively prevented at the sides of the cantilever by adding a taper of 10° to the width of the cantilever. Note that the silicon oxide protection layer is still visably present.*

an optical setup to readout a one dimensional array of cantilevers. A schematic depiction of the optical path is shown in figure 4. The spot from a diode laser with a wavelength of 635 nm and 5 mW power is expanded five times using a beam expander. The beam is send through a rectangular shaped slit and then focussed in one direction by a cylindrical lens with a focal distance of 200 mm. A prism reflects the beam on the cantilever array, which is positioned in the focal point of the cylindrical lens. The laser spot is now line shaped and illuminates each of the cantilevers in the array. The reflected light from the cantilever array creates a one dimensional Fraunhofer diffraction pattern. The pattern is reflected by a second prism into a second cylindrical lens with a focal distance of 60 mm. This lens is rotated 90 degrees with respect to the first cylindrical lens. This second lens determines the width of the diffraction pattern on the CCD camera. The CCD camera is connected to a computer equipped with software capable of reading back the data from the CCD camera.

The cantilever array is positioned inside a measurement chamber that can be sealed off using a glass window. Depending on the experiment the chamber can either be air filled, pumped to a high vacuum or filled with nitrogen gas. Current measurements are taking place with the glass cover removed.

The first optical readout experiments are performed using previously fabricated cantilever arrays. The arrays have been fabricated much along the lines of the current fabrication process, however they lack tips. The aim of these experiments is to verify whether Fraunhofer diffraction theory is applicable to an array of cantilevers and to quantify the quality of the optical patterns recorded by our newly constructed setup.

IV – Experimental Results and Discussion

Figure 5 shows the intensity profile obtained from the diffraction pattern of an array consisting of three cantilevers. The cantilevers are 30 µm wide and are spaced 10 µm apart. In the same figure a simulation of the expected profile is shown. The error of fit between the measurement and a calculated Fraunhofer diffraction profile is 0.87%. Although difficult to see at this scale, it is noted that at larger angles of diffraction (θ), the deviation between the measured and simulated pattern increases. We attribute this deviation to abberation of the second cylindrical lens.

Other authors have presented diffraction profiles from cantilevers before; however these profiles were

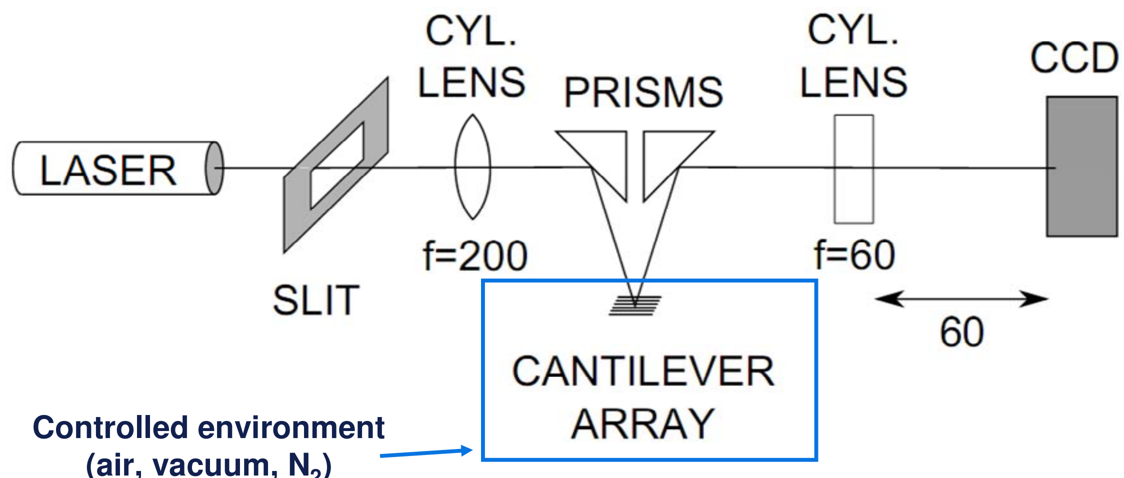

Figure 4: Schematic depiction of the optical readout setup for cantilever arrays. A rectangular laser spot is focused by a cylindrical lens into a line shaped beam, illuminating all cantilevers within the array. A second cylindrical lens (rotated 90 degree with respect to the first) shapes the diffraction pattern to fit the active CCD area.

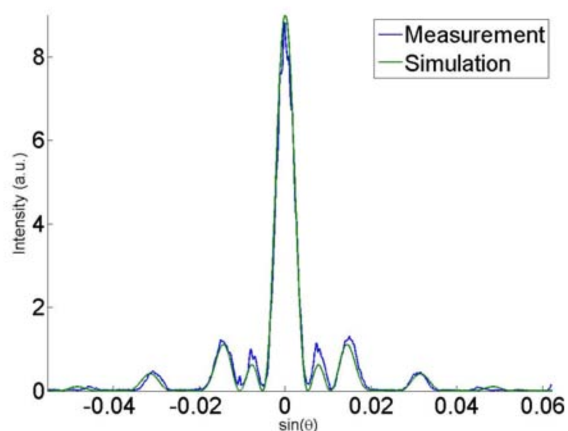

Figure 5: *Intensity profile of the diffraction pattern of a cantilever array consisting of three cantilevers. The blue line is the measurement which fits very well (0.87% fitting error) with Fraunhofer diffraction theory (green line).*

produced using a grating that is fabricated within every cantilever [6]. Here the array itself serves as a grating. This approach actively makes use of the complete array of cantilevers, in contrast to the approach of previous work to start off by reading out one cantilever and then gradually add more cantilevers.

Based on our calculations we expect that small cantilever deflections will result in only very small changes in the diffraction profile. This makes the optical readout method less suitable for applications in which nanometer sized deflections have to be measured. For applications such as indentation based probe storage the technique offers a distinct advantage. Since indentations are ideally all of the same depth, the deflection of each cantilever is either one of two possibilities: undeflected or deflected by the indentation depth. This eases the task of retrieving cantilever positions from the diffraction profile greatly.

V – Conclusions

In conclusion we have shown significant progress in the fabrication of cantiver arrays with tips using only one mask to define both tips and cantilevers. A corner sharpening step is included in the process to overcome the 1 µm resolution limit of our lithography tools. Cryogenic etching has been optimised to create straight etch profiles that will define the sidewalls of the tip. A KOH wet etch anisotropically etches the cantilever tips, self-aligned in the corner at the free end of the cantilever.

Also we have proposed an optical readout method capable of reading out cantilevers in parallel without any modification to the cantilever design. Illuminating the complete array by line shaped laser beam has been shown to result in a diffraction pattern obeying Fraunhofer diffraction theory. This opens up the way to readback of cantilever motion in a parallel fashion.

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References

[1] P. Vettiger, G. Cross, M. Despont, U. Drechsler, U. Duerig, B. Gotsmann, W. Haeberle, M. A. Lantz, H. E. Rothuizen, R. Stutz and G. K. Binnig, *IEEE Trans. Nanotechnol.*, vol 1, pp. 39-54, 2002.

[2] M. Despont, J. Brugger, U. Drechsler, U. Duerig, W. Haeberle, M. Lutwyche, H. Rothuizen, R. Stutz, R. Widmer, H. Rohrer, G. Binnig, P. Vettiger, *Sens. Actuators A*, vol. 80, pp. 100-107, 2000.

[3] C. S. Lee, H.-J. Nam, Y.-S. Kim, W.-H. Jin, S.-M. Moon Cho and J. Bu, *Appl. Phys. Lett.*, vol. 83, pp. 4839-4841, 2003.

[4] W. P. King, T. W. Kenny, K. E. Goodson, G. L. W. Cross, M. Despont, U. T. Duerig, H. Rothuizen, G. Binnig and P. Vettiger, 2002.

[5] M. Kitazawa and A. Toda, *Jpn. J. Appl. Phys.*, vol. 41, pp. 4928-4931, 2002.

[6] T. Sulchek, R. J. Grow, G. G. Yaralioglu, S. C. Minne, C. F. Quate, S. R. Manalis, A. Kiraz, A. Aydine and A. Atalar, *Appl. Phys. Lett.*, vol. 78, pp. 1787-1789, 2001.