Visualization of Buried Structures in Atomic Force Acoustic Microscopy

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ABSTRACT

Advanced Scanning Probe Microscopy (SPM) modes such as Atomic Force Acoustic Microscopy (AFAM) and Ultrasonic Force Microscopy (UFM) combine Atomic Force Microscopy (AFM) with an excitation of the sample or cantilever by ultrasound. These techniques become increasingly powerful tools for the determination of material properties on nanoscale.

Non-destructive evaluation of subsurface and buried structures is getting more and more important in semiconductor industries and electronics system integration technology. Existing methods that allow subsurface measurements with high local resolution are mostly based on destructive concepts as surface ablation by Focused Ion Beam (FIB) devices.

It is widely discussed in literature that AFAM and UFM techniques should have the capability to detect subsurface features. But direct proofs of this capability are hard to find. The difficulty comes from the point that in UFM and AFAM images besides elastic contrast also topological contrast is mixed in. So, for a direct proof samples are needed which (a) show subsurface contrast and (b) having definitely no surface topology correlated with the subsurface feature in question. These samples are not so easy to obtain. An appropriate sample fabrication technology was developed based on the focussed ion beam technique. Using the machined samples the buried structure visibility for the AFAM technique could be proved uniquely. The results are compared with conclusions from modelling.

Keywords: Atomic Force Acoustic Microscopy, subsurface imaging, Focused Ion Beam

1. INTRODUCTION

For Atomic Force Microscopy [1], diverse modifications exist in order to receive further information on the material in addition to topography [2]. Of special interest are mechanical elasticity and deformation, to be gathered with the high local resolution typical for AFM. Elastic properties of the surface and surface near areas can be imaged with Atomic Force Acoustic Microscopy (AFAM) [3] or Ultrasonic Force Microscopy (UFM) [4,5]. In AFAM, flexural and torsional cantilever vibrations are excited by out-of-plane and in-plane sample surface vibrations. The ultrasound is transmitted from the sample into the cantilever while forces act between sensor tip and sample. The sample surface is scanned by the sensor, and an ultrasonic image is acquired simultaneously to the topography image. The contrast comprehended in the ultrasonic image depends on surface topography and on the local elastic and adhesive properties of the sample. Voids, inclusions, or cracks, which represent regions of different elastic constants in the interior of the material, are sensed by the local elastic response of the tip at the sample surface. As a consequence, information on hidden structures can be derived from the acoustic images. Usually, this subsurface information is overlaid by additional topographic information, also contained in the ultrasonic image. Therefore a test sample having only clearly interpretable topographic information was produced, allowing a distinct proof of the sub surface capability of AFAM.

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2. EXPERIMENT

Most of the methods for generation of buried features leave a surface topology correlated with the geometry of the structure underneath. On the other hand AFAM images contain always some additional topology contrast. Thus, a proof of the capability of AFAM to gather subsurface features is always difficult and leaves room for interpretation. This can be avoided only by producing the features “from the back side” leaving the surface unmodified.

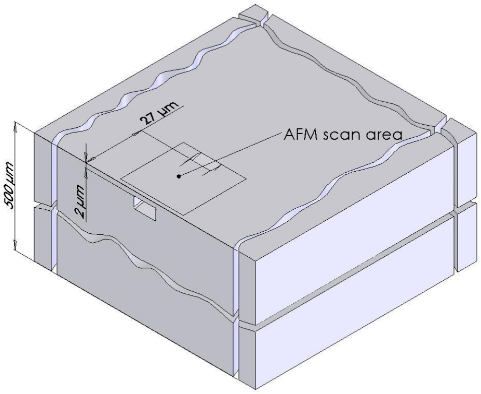

Fig. 1. Scheme of the membrane produced in a piece of a silicon wafer by FIB technique. The position of the AFM/AFAM scan area is marked.

In Figure 1, a scheme of the produced membrane sample is shown. From the side wall of a wafer piece a deep trench was milled by FIB. The incident angel of the ion beam was set to about 8 degrees off the surface. The rectangle of 5 x 5 µm was drilled with a current of about 1 nA. Its position from the edge was 2 µm. It is known for FIB milling that the side walls of trenches are always inclined by some degrees. For deep trenches and for holes this angle is approximately 3 degrees. By alternating SEM imaging the surface was observed and the drilling process was stopped as soon as the trench reached the surface. Finally a geometry has been reached with the trench being like a tunnel below the surface. The thickness of the wall between tunnel and surface decreases linearly from 2 µm to 0 over a distance of 27 µm resulting in an angle of 5.2 degrees in agreement with the beam settings.

Finally two pairs of horizontal and two vertical marker lines enclosing the area of the trench were sputtered for better orientation in imaging. Figure 2 shows the SEM-image of the membrane.

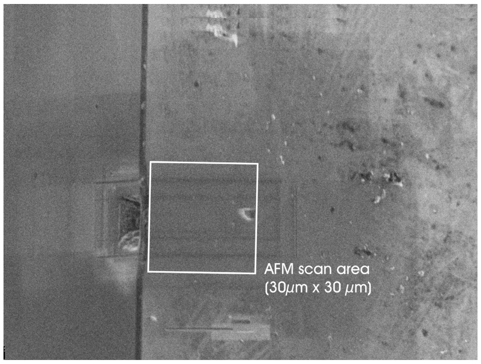

Fig. 2. SEM image of the silicon sample with the hole and the breakthrough in the white square. Markers sputtered for better orientation are visible as dark lines.

Ultrasound is applied to the sample (Figure 3) and the generated surface vibration is sensed with the tip of the AFM. As an advantage of AFAM in comparison with conventional AFM measurements, a contrast enhancement of the images can be reached in addition to information on the elasticity of the material.

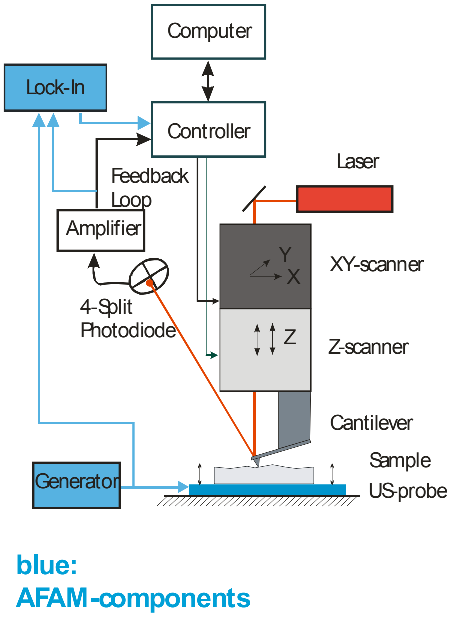

Fig. 3. Experimental set up for AFAM measurements in contact mode with ultrasonic excitation of a sample The sample surface vibrations are detected by the tip of the AFM and are evaluated by the lock-in amplifier.

3. RESULTS

The AFAM-measurements were carried out with a diamond tip on a sapphire cantilever (length 475 µm and stiffness 140 N/m). The scan area in relation to the position of the membrane is indicated in Figure 2. Figure 4 shows the result of the AFAM measurement with an ultrasonic excitation at f = 685 kHz.

Fig. 4. AFM (left) and AFAM (right) images of the membrane. The excitation frequency was f = 685 kHz, the scan size is 30 × 30 µm², the z-scales are 300 nm in the topography and 10 V in AFAM image. The edge of the wafer is located below the bottom line of the scan area.

The offset to the left side (visible also in the vertical marker line) is obviously due to AFM drift or to software effects. In the AFAM image (Figure 4 right) the response from the interaction of the membrane with the ultrasonic wave is seen in the significantly lower (darker signal) amplitude in this area. The excitation frequency was approximately the contact resonance frequency of the bulk material. From top to bottom the membrane thickness increases. Accordingly, the effective stiffness and the AFAM amplitude converge to the values in the areas without a hole. A detection depth of ~ 800 nm was reached with a tip radius of ≥ 50 nm.

Furthermore the AFAM image (Figure 4 right) has a clear contrast enhancement, structure details and surface effects are visible very fine in relation to the classic AFM image (Figure 4 left).

4. CONCLUSIONS

Possibilities of AFAM technique for characterization of buried and subsurface structures, respectively, were demonstrated at a thin silicon membrane micro-machined by the focused ion beam (FIB) technique. A thickness gradient of the membrane resulted in a corresponding gradient in the signal amplitude in full accordance with the expectation. The detection depth for the used wide membrane was significantly greater than the predictions in the literature (3 times of the contact radius of the Hertzian contact model).

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