

AFM cantilever with integrated piezoelectric thin film for micro-actuation

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Abstract— This work presents micro-actuation of atomic force microscopy (AFM) cantilevers using piezoelectric Zinc Oxide (ZnO) thin film. In tapping mode AFM, the cantilever is driven near its resonant frequency by an external oscillator such as piezotube or stack of piezoelectric material. Use of integrated piezoelectric thin film for AFM cantilever eliminates the problems like inaccurate tuning and unwanted vibration modes. In this work, silicon AFM cantilevers were sputter deposited with ZnO piezoelectric film along with top and bottom metallic electrodes. The self-excitation of the ZnO coated AFM cantilever was studied using Laser Doppler Vibrometer (LDV). At its resonant frequency (227.11 kHz), the cantilever displacement varies linearly with applied excitation voltage. We observed an increase in the actuation response (131nm/V) due to improved quality of ZnO films deposited at 200 °C.

I. INTRODUCTION

Atomic force microscopy (AFM) is a high-resolution scanning probe technique used to image, measure and manipulate matter in nanoscale regime. In AFM imaging, an atomically sharp tip is raster scanned over the sample surface and the cantilever deflections arising due to probe-sample interactions are measured using an optical lever arrangement. Tapping mode is an important AFM tool for imaging biological and liquid media samples. In the liquid environment the cantilever is subject to large capillary forces effectively reducing its scan rate and performance [1]. In order to overcome these issues it is desirable to use the tapping mode for imaging liquid media samples. In the tapping mode AFM, the cantilever is driven near its first resonant frequency using a piezotube or piezo stack which is fixed with the AFM head. The oscillating probe tip is intermittently made to contact the surface, while the tip is simultaneously scanned across the sample [2]. While exciting the cantilever to its resonant frequency the entire AFM head along with deflection measurement system and the liquid cell is forced into vibration. This gives rise to spurious resonance peaks in the liquid media and makes it difficult in the

selection of resonance peak for actuation. Therefore, a self-excited AFM probe with an integrated piezoelectric thin film actuator eliminates the need for external oscillator (such as piezotube and piezostack) and enhances accurate tuning of resonance frequency [1]. A feedback controller tracks the probing force between the tip and the sample in order to maintain small contact forces for imaging soft biological specimens [6]. An integrated piezoelectric thin film AFM cantilever precisely controls the cantilever tip force using a suitable feedback loop [7]. Also the scanning speed of current AFM systems is limited by tip deflection velocity [7]. It is found that the tip velocities increase by an order of magnitude by using integrated piezoelectric actuator rather than using standard piezotubes. Also, large tip deflections enable high aspect ratio imaging of surface features. In order to achieve large area sample imaging, AFM tips are arranged in multiple arrays and their tip deflections have to be simultaneously monitored using a conventional optical lever set-up. But this is a tedious process as it will require multiple laser-detector arrangement making the deflection measurement system bulky. Also, it will be difficult to focus the laser spot onto individual cantilever tips. However, the use of integrated piezoelectric actuator allows multiprobe scanning for large area imaging [2].

ZnO is a widely used piezoelectric material for MEMS technology due to its properties like ease of deposition, low deposition temperature, compatibility with micro fabrication technology [3], good piezoelectric performance and excellent bonding with a variety of substrates [4]. The present work illustrates a simple technique to modify an AFM cantilever by integrating a highly sensitive piezoelectric ZnO thin film for tapping mode applications. ZnO thin film was deposited using DC reactive magnetron sputtering technique by maintaining the substrate at 200°C. In order to achieve better piezoelectric performance for the ZnO thin films, the deposition parameters were optimized to obtain uniform,

dense and highly c-axis oriented crystallites. The films were characterized using XRD and SEM techniques. The micro-actuation response of the ZnO coated cantilever is studied using a Laser Doppler Vibrometer (LDV). This paper attempts to explain the reason for the improvement in the actuator response.

II. FABRICATION AND CHARACTERIZATION

A. Fabrication of piezoelectric thin film cantilever

Commercially available silicon AFM cantilever probes procured from Mikromasch, USA are used in this study. The cantilever is 125 μm long, 2 μm thick, 35 μm wide and its spring constant is specified as 5N/m. The actuator consists of a piezoelectric thin film material sandwiched between two metal electrodes. Fig. 1 shows the schematic cross-sectional view of a piezoelectric thin film deposited on AFM cantilever. The bottom metal electrode Cr/Al (5nm/50nm) was deposited using RF magnetron sputtering. Subsequently, ZnO thin film of thickness 280-300 nm was deposited over the bottom electrode by DC reactive magnetron sputtering technique. Prior to deposition of ZnO thin film, the sputtering parameters and film properties were optimized for the confirmation of its piezoelectric behavior. Table I shows the optimized sputtering parameters used. The top electrode is a Platinum thin film of 500nm thickness deposited using Focused Ion Beam (FIB) lithography technique. For this purpose UHR Dual Beam FIB System: Helios NanoLAB 600i (FEI) was used. The SEM image in Fig. 2 shows the top electrode pattern (25 μm X 25 μm) near the fixed end of the cantilever with a contact pad (100 μm X 100 μm).

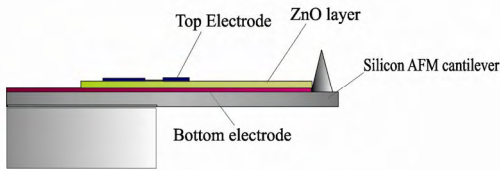


Figure 1. Schematic diagram showing cross-sectional view of ZnO coated AFM cantilever probe

TABLE I. OPTIMIZED PARAMETERS FOR ZnO SPUTTERING

Parameter	Value
Ultimate Pressure	2x10 ⁻⁶ mbar
Working Pressure	0.035 mbar
Ratio (Ar:O ₂)	91%-9%
Applied DC voltage	275 V
Current density	3.737 mA/cm ²
Substrate Temperature	200 °C
Target to substrate distance	55 mm

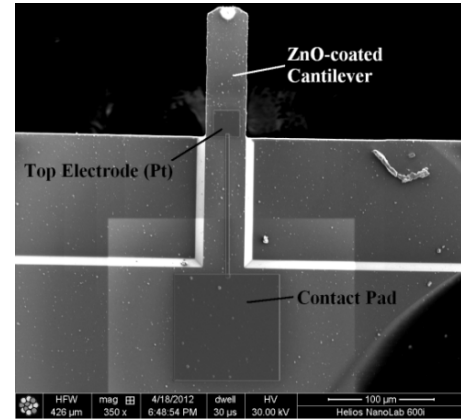


Figure 2. SEM image of ZnO coated AFM cantilever showing the top electrode pattern with contact pad

B. Characterization of ZnO thin film deposited onto AFM cantilever

Using the optimized sputtering parameters as shown in Table I, a ZnO film was deposited onto a silicon substrate. Scanning electron Microscope (SEM) and X-ray Diffraction (XRD) techniques were used in order to evaluate the quality of the film. The crystallinity of the ZnO thin films was studied using Bruker D8 Advance X-ray diffractometer. In Fig. 3 the XRD pattern of the ZnO film shows a diffraction peak at about 34.4° corresponding to (002) plane. The (002) peak has a small full width at half maximum (FWHM) value of 0.47° indicating a highly preferred c-axis orientation perpendicular to the substrate. This high degree of (002) orientation and the preferred polycrystalline structure confirms the piezoelectric behavior of ZnO film [4]. The surface morphology of the ZnO film was examined using FE-SEM (ULTRA 55, Karl Zeiss). The SEM image in Fig.4 shows the top view of the as-deposited ZnO film surface which is dense, uniform and free of defects. Also, the presence of hexagonal crystallites of large grain size 70-72nm can be seen in the Fig. 4.

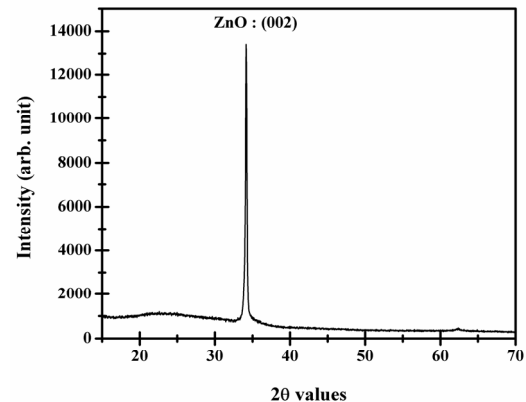


Figure 3. XRD pattern of the ZnO thin film showing c-axis orientation

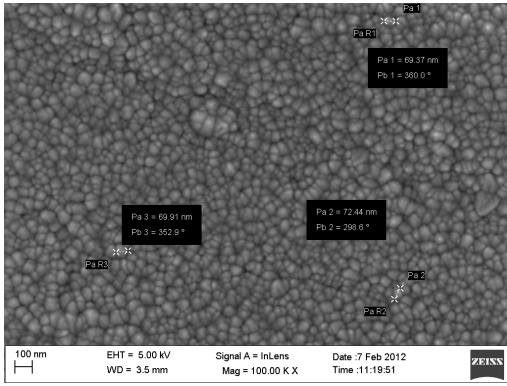


Figure 4. SEM image showing the surface morphology of the sputtered ZnO film

III. EXPERIMENT AND RESULT

Fig. 5 shows the schematic of the experimental set-up used to study the dynamic response of the ZnO deposited AFM cantilever. It consists of a function generator used to excite the actuator and the corresponding cantilever tip deflection was measured using a Laser Doppler Vibrometer (Polytech, MSA 500). In order to study the frequency response of the this actuator, a sweep frequency (0-1MHz) was applied and its tip displacement was measured.

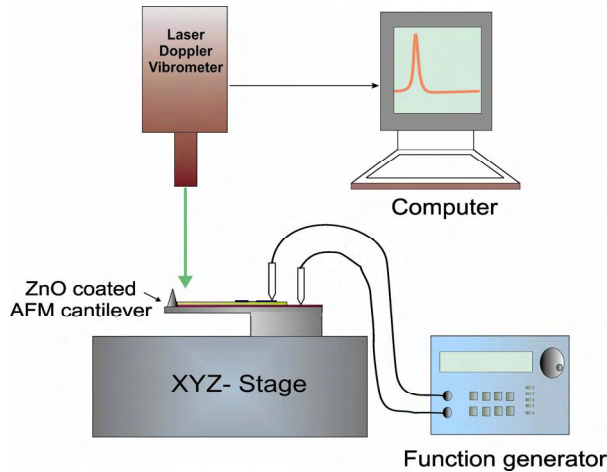


Figure 5. Schematic of the experimental set-up for measuring the dynamic response of ZnO deposited AFM cantilever.

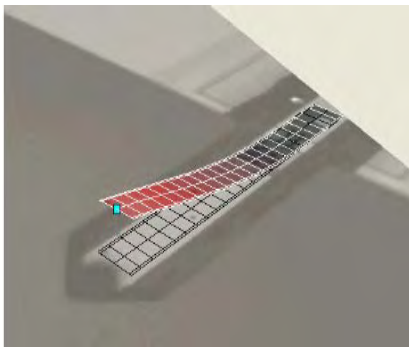


Figure 6. Typical cantilever displacement monitored using Laser Doppler Vibrometer

At its resonant frequency (227.11 kHz), the voltage in the range of 0.04 to 0.5V is applied across the electrodes. The corresponding tip displacement as measured using LDV is shown in Fig. 6. It is evident from Fig. 7, that the displacement of the cantilever with respect to applied excitation voltage is linear in the range of 0-0.5V. High actuation force requires thin film material with higher piezoelectric performance [5]. From Fig. 7, the sensitivity of our integrated piezoelectric thin film AFM cantilever is calculated to be $\sim 131 \text{ nm/V}$ which is quite high as compared to the piezoelectric cantilevers used in tapping mode reported elsewhere (typically $\sim 35 \text{ nm/V}$) [8]. This improvement in the measured actuator response of ZnO coated cantilever can be attributed to the presence of hexagonal crystallites and large grain size (70-72nm) of the deposited ZnO thin film as seen in Fig. 4.

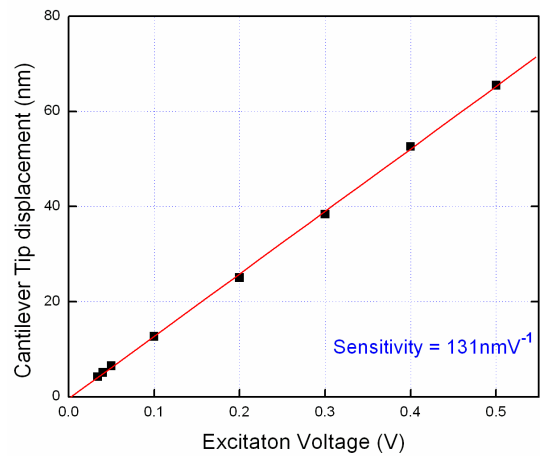


Figure 7. Cantilever tip displacement for different input excitation voltages at a resonant frequency of 227.11 kHz

IV. CONCLUSION

In this work, we have integrated a ZnO thin film onto a silicon AFM cantilever to be used as a microactuator for tapping mode AFM. A 280-300nm thick ZnO film was deposited by DC reactive magnetron sputtering technique. The XRD and SEM analysis reveals that the as-deposited ZnO films possess high c-axis orientation and yields good piezoelectric behavior. The dynamic response of the ZnO cantilever was measured using LDV. At its resonant frequency (227.11 kHz), the cantilever tip displacement with input excitation voltage varies linearly in the range of 0-0.5V. The displacement sensitivity of our microactuator was found to be 131 nm/V which is suitable for tapping mode AFM [8]. The improvement in the sensitivity is attributed to the improved quality of piezoelectric thin film. Apart from micro-actuation, integrated piezoelectric materials onto AFM cantilevers can also be used to replace the conventional optical lever arrangement in the AFM system for measuring small force gradients while scanning the sample surface laterally.

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