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MEMS based low cost piezoresistive microcantilever force sensor and sensor module

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ABSTRACT

In the present work, we report fabrication and characterization of a low-cost MEMS based piezoresistive micro-force sensor with SU-8 tip using laboratory made silicon-on-insulator (SOI) substrate. To prepare SOI wafer, silicon film (0.8 μm thick) was deposited on an oxidized silicon wafer using RF magnetron sputtering technique. The films were deposited in argon (Ar) ambient without external substrate heating. The material characteristics of the sputtered deposited silicon film and silicon film annealed at different temperatures (400–1050 °C) were studied using atomic force microscopy (AFM) and X-ray diffraction (XRD) techniques. The residual stress of the films was measured as a function of annealing temperature. The stress of the as-deposited films was observed to be compressive and annealing the film above 1050 °C resulted in a tensile stress. The stress of the film decreased gradually with increase in annealing temperature. The fabricated cantilevers were 130 μm in length, 40 μm wide and 1.0 μm thick. A series of force–displacement curves were obtained using fabricated microcantilever with commercial AFM setup and the data were analyzed to get the spring constant and the sensitivity of the fabricated microcantilever. The measured spring constant and sensitivity of the sensor was 0.1488 N/m and 2.7 mV/N. The microcantilever force sensor was integrated with an electronic module that detects the change in resistance of the sensor with respect to the applied force and displays it on the computer screen.

1. Introduction

There has been significant interest in the mechanical characterization of biological materials such as cells and tissues. Mechanical properties such as Young's modulus may be used as a useful label-free biomarker for the diagnosis and treatment of diseases [1–4]. The mechanical properties of the biological materials can be measured by nanoindentation technique which requires the ability to measure forces in the micro-to-nano Newton range. Thus, a highly sensitive micro-force sensor can be used for bio-mechanical characterization. The bending of the cantilever is related to the applied force. Thus, the applied force can be detected by measuring the displacement of the reference cantilever sensor. The sensing methods for detection of micro-forces are: piezoresistive, capacitive and optical/laser detection. The optical method, which is mostly used in AFM, is based on focusing a laser spot on the cantilever and then monitoring the motion of the reflected light using a photodiode. A highly accurate optical system is required for measuring the displacement and the tip of the cantilever depends on the laser spot size. This method therefore becomes difficult when the size of the cantilever is smaller [5]. The capacitive method is based on the change in capacitance based on the deformation of the structure. The application of this method of

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detection is in micro accelerometers and sensors for harsh environments. The capacitive structures, however, need to be completely isolated between two electrodes [6]. The difficulty in fabricating the capacitive micro-force sensor is primarily in controlling the etching area to obtain a completely isolated structure and the measurement requires complex electronic circuits. The piezoresistive transducers translate a force into a change in the value of a resistor. This type of transducer is used as nano-mechanical sensor [7], binding force sensor [8] and bio-chemical mass sensor [9]. A resolution of pN [10] and even fN [11] is possible in case of piezoresistive microcantilevers.

It is known that the single crystal silicon exhibits a strong piezoresistive effect [12]. The piezoresistive cantilever sensor is generally fabricated using silicon-on-insulator (SOI) substrate due to the established fabrication technology and excellent material properties [13–31]. However, the cost of the sensor is an issue. The polysilicon material has been explored for fabricating piezoresistive cantilevers by several groups [32–34]. In our previous work [35], we have presented our preliminary work on the fabrication of the piezoresistive sensor and performed some preliminary experiments. The present work is an attempt to address the problem of high fabrication cost of piezoresistive microcantilever using SOI substrate and fabrication of cylindrical tips by: (a) reducing the cost of the device by using laboratory made SOI rather than conventional SOI substrate—batch fabrication of SOI from standard silicon is possible and thus the cost of piezoresistive microcantilever fabricated using homemade SOI is comparatively lower than commercially available SOI substrate and (b) using SU-8 polymer as the cylindrical tip material. To understand the material properties of the sputtered silicon used in the microcantilever fabrication, material characterization techniques such as XRD, AFM, SEM and stress measurement are studied in detail. The sensor spring constant and sensitivity of the fabricated microcantilever is measured using AFM [36,37]. A sensor module is developed to integrate the sensor to measure and display the output of the sensor when a nano-to-micro Newton force is applied.

Table 1
Sputtering parameters used for depositing Si films.

Deposition parameters	Conditions
Si target size	6-mm thick, 3-mm diameter
RF power	200 W
Sputtering gas	Argon
Sputtering pressure	5 mTorr
Target-to-substrate distance	100 mm
Substrate	Oxidized silicon (4-in. diameter)
Substrate temperature	Room temperature (~30 °C)
Rate of deposition	25 nm/min

2. Experimental details

To prepare silicon-on-insulator substrate, the silicon (Si) wafers [n-type, (1 0 0), 4-in. diameter] were cleaned by using a standard wafer cleaning process and a thermal oxide (SiO_2) of 1 μm thickness was grown using the Tystar oxidation system. Si films (0.8 μm) were sputtered on oxidized Si wafer by RF magnetron sputtering (ATC 1800, AJA International) without any external substrate heating. The summary of the deposition process is given in Table 1. The residual stresses of the thin film depends on the microstructure of the film and mechanisms such as crystallographic orientation of the film, grain size, and surface roughness have been identified as possible causes for the residual stress evolution [38–41].

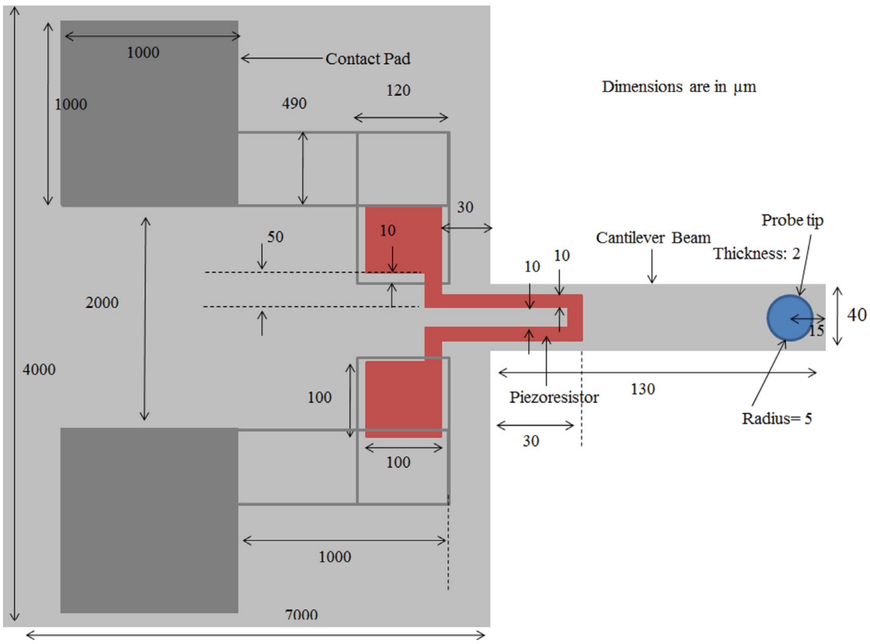

Fig. 1. Schematic of piezoresistive micro-force sensor.