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AlN on nanocrystalline diamond piezoelectric cantilevers for sensors/actuators

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Abstract

Micro-cantilevers can be used as both sensors and actuators. In this work, the design, fabrication and characterization of piezoelectrically driven nano-crystalline diamond (NCD) cantilevers are reported Diamond films were grown on silicon (100) substrates by microwave plasma enhanced chemical vapor deposition (MW-PECVD). Cantilevers are coated by DC pulsed piezoelectric with AlN films that is sandwiched between two metallic electrodes. The thicknesses of AlN and diamond layers are 1µm and 700nm, respectively. The influence on the electromechanical response of cantilevers length was studied. The motion of the electrically driven cantilevers is performed by measuring the evolution of the electrical impedance at the resonant frequencies that varies between 10 kHz and 130 kHz for the resonant mode.

Keywords: Nanocrystalline diamand NCD, Piezoelectric AlN, MEMS resonators

1. Introduction

Nanocrystalline diamond (NCD) is expected to be an excellent material for microelectromechanical applications (MEMS). This interest is driven by diamond's unique material properties. It is a wide band gap semiconductor presenting extreme mechanical properties such as a highest acoustic wave velocity, low acoustic loss, high chemical stability and thermal conductivity.

Micromechanical resonators based on cantilevers are excellent tools to measure tiny forces as shown by the development of atomic force microscopy (AFM) techniques [1]. Micro-cantilevers are among the most sensitive acoustic sensors as their resonant frequencies are modified when cantilevers are mass loaded. Different structures based on piezoelectric driven silicon or polysilicon cantilevers are reported in the literature [2]. Diamond thin film based resonant structures offer several advantages over silicon and other thin-film materials used in micro- and nanofabrication [3]. As resonant structure, nano-crystalline diamond cantilevers are expected to access to higher quality factor values. The MEMS structures based on diamond thin films can be used for a lot of applications including RF micro and nano-resonators, high speed actuator and sensing applications. The goal of this work is to

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develop a reliable and reproducible piezoelectrically driven NCD cantilevers for MEMS applications as resonant sensors and actuators.

2. Device fabrication

The micromechanical resonators, developed in this study (Fig. 1) are based on silicon support, NCD diamond as a cantilever and a thin aluminium nitride film for the piezoelectric actuation. Fig 1 shows the schematic of piezoelectrically driven NCD cantilevers.
Nano-crystalline diamond films were deposited on (100) silicon substrate by microwave plasma enhanced chemical vapor deposition [4]. The NCD films were studied by atomic force microscopy (AFM) (Fig. 2): one can observe a polycrystalline structure with grain size of 15–20 nm. The root mean square (RMS) surface is 25 nm for 700nm of NCD film thickness.
The AlN thin films have been deposited by DC pulsed reactive magnetron sputtering [5]. The X-rays diffraction diagram (Fig. 3) shows the AlN films are (002) oriented, i.e with the c-axis perpendicular to the surface.

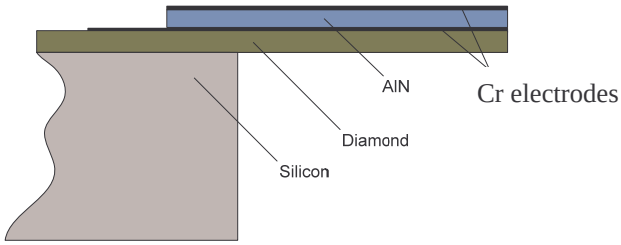

Figure 1: Schematic of a nano-crystalline diamond cantilever with piezoelectric AlN thin film..

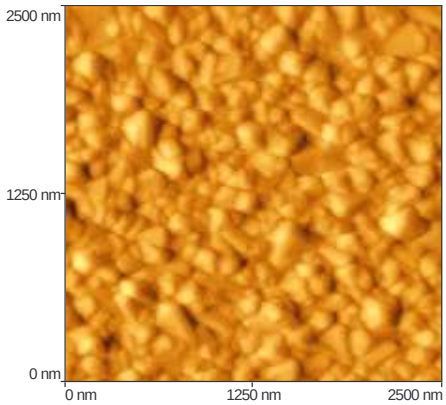

Figure 2: AFM picture of a nanocrystalline diamond film on silicon..

The cantilevers are processed using standard MEMS micro-fabrication techniques. The pattern of the cantilevers into the diamond film was made by plasma etching in oxygen. An Al layer of 1 µm deposited by sputtering and patterned by photolithography and wet etching was used as an etching mask. Thus, the diamond layer was etched by reactive etching in pure oxygen (step 1). The first level metallic (Cr) electrode is then patterned using magnetron sputtering, photolithography and wet etching (step 2). Then, the AlN layer is deposited (step 3) by sputtering and patterned using lithography and chemical etching in hot orthophosphoric acid. The second level metallic electrode (Cr) is then deposited and patterned using sputtering and lift-off techniques. The final fabrication step consist of the backside etching of silicon using the deep ion reactive etching BOSCH process to release the cantilever. Then, the AlN layer is deposited (step 3) by sputtering and patterned using lithography and chemical etching in hot

orthophosphoric acid. The second level metallic electrode (Cr) is then deposited and patterned using sputtering and lift-off techniques. The final fabrication step consist of the backside etching of silicon using the deep ion reactive etching BOSCH process to release the cantilever.

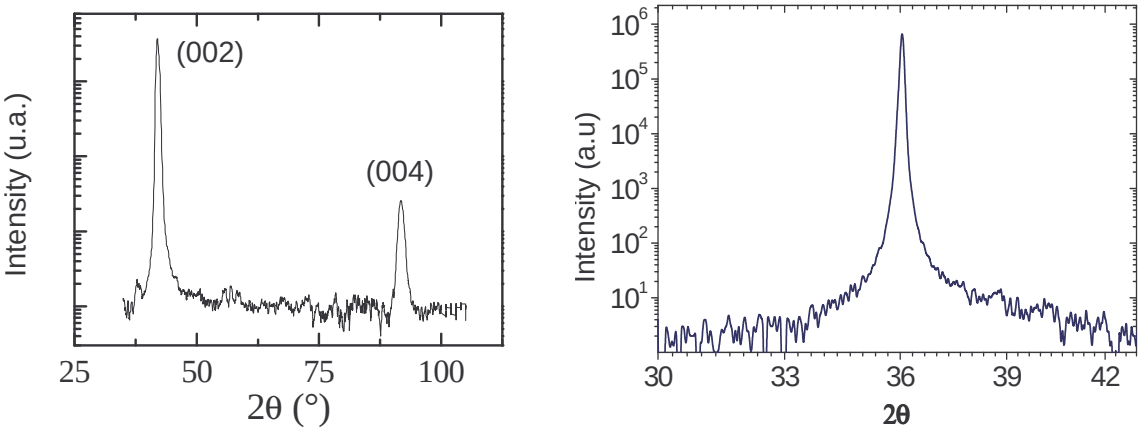

Figure 3: X-Ray diffraction diagram of an AlN thin film.

Cantilevers with different lengths (from 200 to 600µm) and a width (70µm) were successfully elaborated on the same support.. Fig. 4a presents a picture of a cantilevers array final, diced and wire connected to its package. Fig 4b shows a SEM picture of NCD/AlN cantilever resonator where we can observe an out of plane curvature over the length of the beam that is mainly due to the intrinsic stress of the AlN layer.

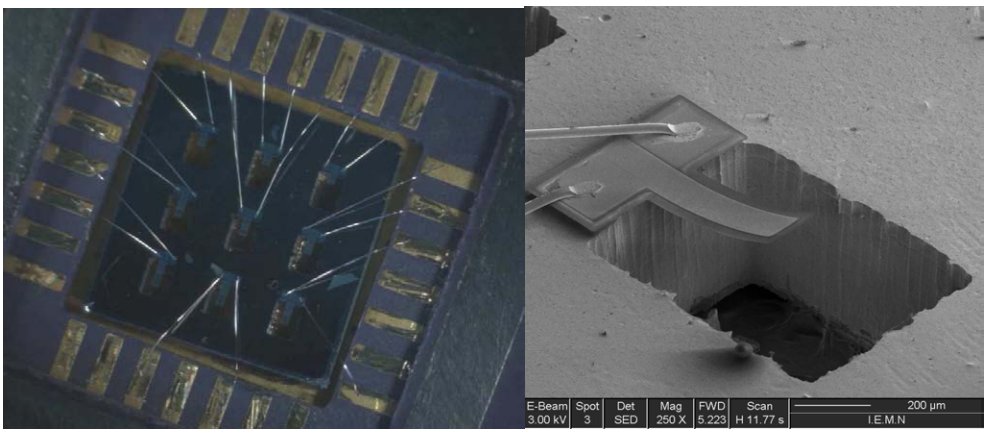

Figure 4: a) NCD/AlN cantilevers array .b) SEM pictures of NCD/AlN cantilever.

3. Resonant frequencies measurements and discussion

These NCD/AlN cantilever structures have been experimentally characterized using impedance measurements at the first resonant mode. The cantilevers can operate different pressure [6]. However, only the measurement performed in vacuum are presented in this contribution. Fig 5a shows the impedance modulus and phase shift of the first and second resonant modes of a 320 µm long cantilever at a pressure of 200mTorr. Fig 5b shows the measured first mode resonant frequency as a function of the inverse of the square cantilevers' length. The linear behaviour of the

frequency is in agreement with the expected theoretical predictions. For these cantilever resonators, the measured Q values were in the range of 1000–3000 depending on the beam length and the resonant mode.

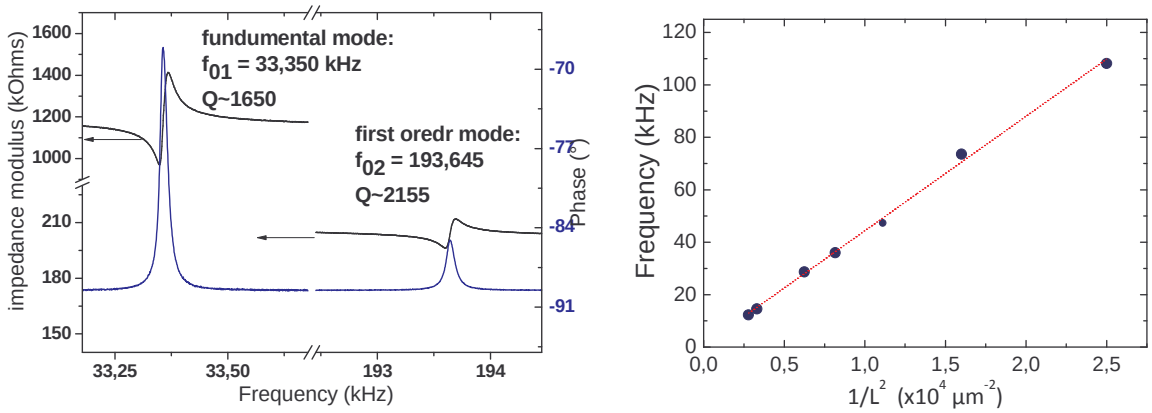

Figure 5: a) Impedance spectra of a 320µm long and 70µm wide AlN/NCD cantilever at the first and second resonant modes. b) First mode resonant frequencies plotted as a function of the inverse of the square beam's length.

4. Conclusions

In this paper, array of nano-crystalline diamond cantilever with piezoelectric AlN layer sandwiched between two electrodes is presented. Good response has been achieved by piezoelectric actuation method. Quality factor in the range of 1000-3000 is obtained. These results show the availability of such micro-resonators for MEMS resonant sensors and high speed actuators.

References

1. UETSUKA H ; YAMADA T; SHIKATA S "ICP etching of polycrystalline diamond: Fabrication of diamond nano-tips for AFM cantilevers", Diamond and Related Materials 17 (4-5) 728-731 (2008).
2. Andrei A, Krupa K, Jozwik M, Nieradko L, Gorecki C, Hirsinger L, Delobelle P, "Fabrication, characterization and reliability study of AlN driven Cantilevers », Proc. SPIE 6188 (April 2006) (2006), Strasbourg.
3. Auciello O., Sumant A.V., Hiller J., Kabius B, Srinivasan S "Science and technology of piezoelectric/diamond hybrid heterostructures for high performance MEMS/NEMS devices", Materials Research Society Symposium Proceedings 1052 259-264 (2008).
4. Mortet V, D'Haen J, Potmesil J, Kravets R, Drbohlav I, Vorlicek V, Rosa J, Vanecek M, Diamond & Related Materials 14 (2005) 393–397
5. Mortet V, Nesladek M, Haenen K, Morel A, D'Olieslaeger M, Vanecek M, Diamond and Related Materials 13 (2004) 1120–1124
6. Mortet V, Petersen R, Haenen K, and D'Olieslaeger M, "Wide range pressure sensor based on a piezoelectric bimorph microcantilever '' Appl. Phys. Lett. 88, 133511 (2006)