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NANOINDENTATION STUDIES OF AMORPHOUS CARBON THIN FILMS FOR MEMS APPLICATIONS

K. Wielgo, M. Ekwińska, Z. Rymuza

Warsaw University of Technology, Institute of Micromechanics and Photonics, ul. Sw. A. Boboli 8, 02-525 Warsaw, Poland. E-mail: krzysztow@gmail.com; m.ekwinska@wp.pl; z.rymuza@mchtr.pw.edu.pl

Amorphous carbon films deposited by PECVD techniques on silicon substrate have been tested by nanoindentation. The morphology of the surface of the films was identified by the use of AFM. The effect of material and surface topography was taken into consideration to estimate nanomechanical properties of the tested films.

Introduction

Soon after the micro electro-mechanical systems (MEMS) have been emerged [1–3] it was obvious that their development is not accompanied with the adequate studies of material properties in micro and nanoscale. Later investigations, which were performed on the most commonly, used material in MEMS: silicon, showed that material properties in micro and nanoscale are different from the ones in micro scale. Quite high friction and wear observed on silicon [5–8] forced material science to look for alternative materials and technologies [1, 4, 9–11]. Under those circumstances nowadays the majority of materials used in MEMS are coatings made on silicon substrate.

We report results of comparison of surface topography and mechanical properties of amorphous carbon films deposited at various conditions on silicon substrate.

Experimental details

The investigation was carried out under laboratory conditions: temperature 21 ± 1 °C, humidity 45 ± 5 %, atmospheric pressure, air atmosphere.

For the identification of surface morphology cantilever CSC37/AlBS made by MikroMasch was used. This cantilever has a silicon tip with 10–20 nm radius. Geometrical parameters of the cantilever's lever were: length 350 ± 5 μm, width 35 ± 3 μm, thickness 2 ± 0.3 μm. During the surface topography investigation the contact mode of the atomic force microscope (AFM) was used. The scanning speed was 15.69 nm/s.

The nanoindentation test was performed using Hysitron's Triboscope®. A diamond Berkovich tip with the tip curvature radius 50 nm was used during the investigations (Fig. 1). During the test triangular model of loading was used eg. 3 s loading and 3 s unloading. The instrument is load controlled but during the measurements stable depth of indentation was maintained.

The investigated samples were four samples of amorphous carbon labelled as NFC2, NFC6, NFC7 and NFC10, which were made in Argonne National Laboratory. All films were deposited on the polished surfaces of Si wafers, by plasma enhanced CVD, to the thickness of 1mm. The differences of these samples are in the percentage

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of gases that were used for the reaction of deposition (Table 1).

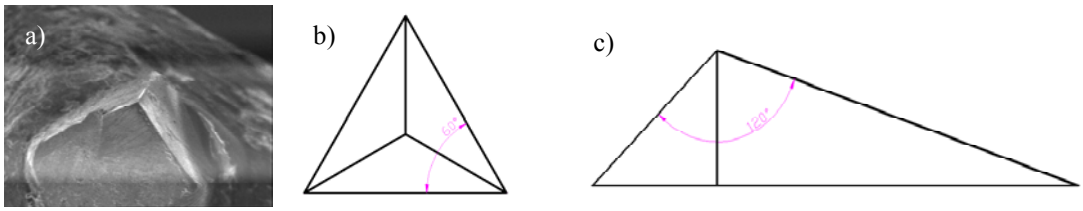

Fig. 1. The diamond tip used for the nanoindentation test, a) the electron microscopy image of the tip, b) and c) geometry of the tip

Table 1. Percentage of gasses contained in plasma during spreading the layer in CVD process

Sample denotation	Methane [%]	Hydrogen [%]	Acetylene [%]
NFC2	50	50	0
NFC6	25	75	0
NFC7	100	0	0
NFC10	0	0	100

Deposition was done in room temperature even though the samples become hot (up to 150 °C) during the deposition. The reason of that was electrical discharge in the plasma as well as dissipation of the kinetic energy of depositing atoms.

The procedure for forming these amorphous carbon films involved first sputter cleaning the substrate in the Ar plasma for 30 min by applying a 1200 – 1700 V bias. Finally, the specific gas mixtures were established in the plasma and the deposition ranged from 10 to 13 mTorr, and the rf bias was maintained between 400 and 600 V.

Results and discussions

The surface topography was measured on the atomic force microscope (AFM). The results of the measurements were: topography images, cross section profiles and values of roughness parameters. Measured roughness parameters were: R_a – average arithmetical deviation of profile of roughness, R_q – average square deviation of profile of roughness, R_{sk} – skewness, R_{ku} – kurtosis, R_m – maximum height of microasperiteies of the profile of roughness.

The results of the surface topography investigations are presented in Table 2. as well as in Figs. 2 to 6. The results of the indentation test are presented in Table 3 as well as in Fig. 7.

Table 2. The comparison of roughness parameters for investigated samples

Sample denotation	R_m, nm	R_a, nm	R_q, nm	R_{sk}, nm	R_{ku}, nm
NFC 2	110.2296	32.23536	37.55578	1.395244	2.3543
NFC 6	72.8208	9.886068	12.32999	2.70488	17.97785
NFC 7	35.946	7.325372	9.283962	2.301242	11.0224
NFC 10	145.197	33.74583	43.46542	1.730688	3.544038

Notation. R_a – average arithmetical deviation of profile of roughness, R_q – average square deviation of profile of roughness, R_{sk} – skewness, R_{ku} – kurtosis, R_m – maximum height of microasperiteies of the profile of roughness.

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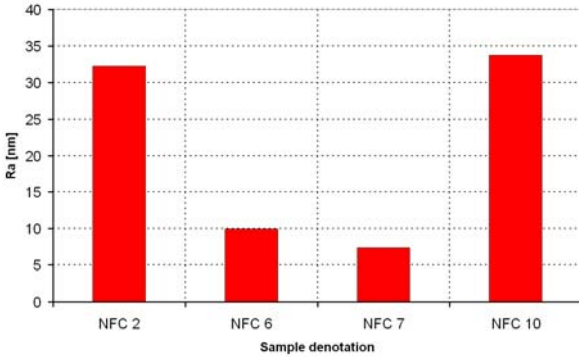

Fig. 2. Comparison of R_a parameter for investigated samples

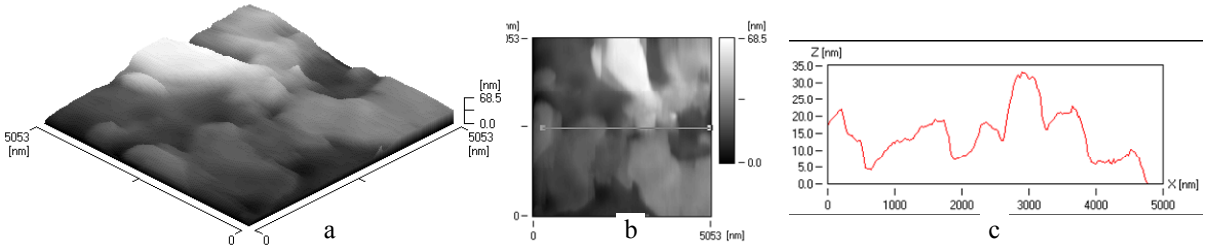

Fig. 3. Surface topography of NFC 2 sample; a) 3d picture; b) place of cross section; c) cross section

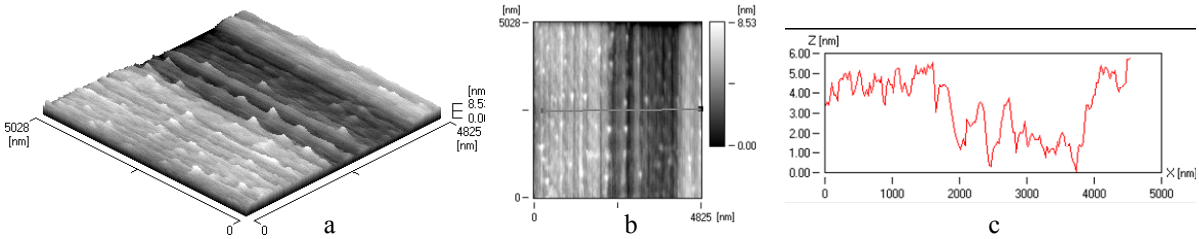

Fig. 4. Surface topography of NFC 6 sample; a) 3d picture; b) place of cross section; c) cross section

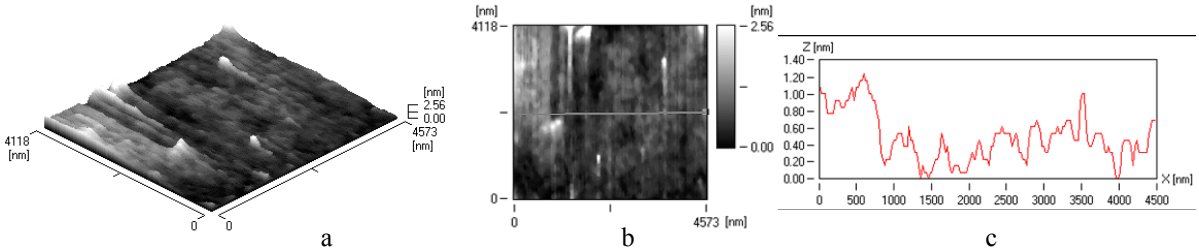

Fig. 5. Surface topography of NFC 7 sample; a) 3d picture; b) place of cross section; c) cross section

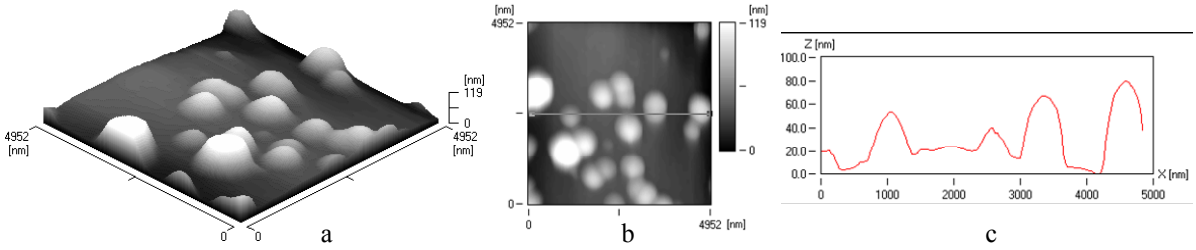

Fig. 6. Surface topography of NFC 10 sample; a) 3d picture; b) place of cross section; c) cross section

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Table 3. The comparison of mechanical parameters for investigated samples

Sample denotation	h, nm	E, GPa	H, GPa
NFC 2	49.65	66.21	10.72
NFC 6	47.82	34.48	5.18
NFC 7	47.96	58.63	9.91
NFC 10	46.36	83.79	11.50

Notation. E – reduced Young's modulus, H – hardness, h – depth of indentation

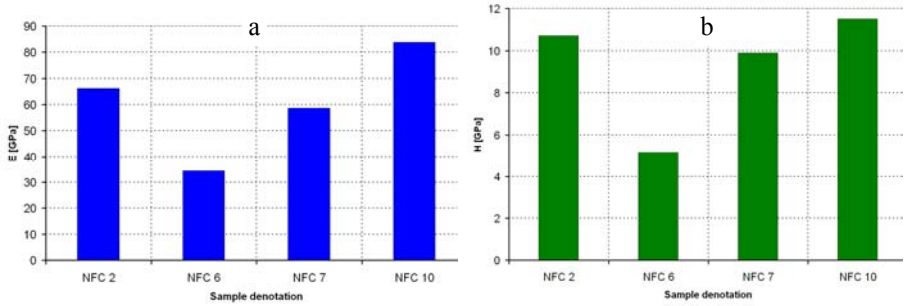

Fig. 7. Mechanical properties of investigated samples; a) reduced Young's modulus; b) hardness

Comparison between mechanical properties and roughness parameter is presented in Fig. 8.

The highest values of reduced Young's modulus (E) and hardness (H) were measured on the NFC 10 sample. These correspond with the highest values of R_a parameter, in other words with the highest variability of surface topography (Fig. 6.). Results for this sample differ much form the ones achieved on other samples because during deposition of the layer on this sample different gas was used then on other investigated samples.

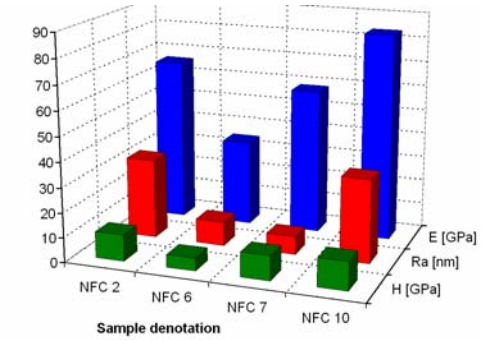

Fig. 8. Comparison between mechanical parameters and R_a parameter for investigated samples

The smallest values of reduced Young's modulus (E) and hardness (H) were measured on the NFC 6 sample. These correspond with low (below 10 nm) value of R_a parameter (Fig. 4). It means that the smallest values of mechanical parameters and small enough roughness can be achieved when there are 75% of hydrogen and 25 % of methane in the plasma used during deposition of layer.

The smallest values of roughness parameters were observed on sample NFC 7 where there was 100% of methane in the plasma used for deposition of the layer. The

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small variability of the surface topography on one side corresponds with the intermediate values of mechanical properties of the samples on the other side.

Similarly intermediate values of mechanical parameters which corresponded with intermediate values of the surface topography variability were observed for the sample with denotation NFC 2 where 50% of methane and 50% of hydrogen was used during deposition of layer.

Conclusions

Roughness parameters of the investigated samples were affected by the amount and type of gas that were used during deposition of the layer. The smallest values of roughness are observed for the layer deposited only form methane the highest for the layer deposited only from acetylene. Unfortunately for these samples values of reduced Young's modulus and hardness were either intermediate or high. In order to achieve small roughness and small values of mechanical parameters there is a need to use different amount of two gases during deposition of the layer. The smallest values of all mentioned parameters were measured for the sample NFC 6 in which 25% of methane and 75% of hydrogen was used during deposition process.

The investigation showed that not only the type but also the amount of gases used during deposition process affect morphological as well as mechanical behaviour of the coating.

The carbon films seem to be interesting coatings for MEMS structures but still the information about these layers is not complete. There is a need to investigate wear resistance of the material. Such supplementation is carried out in nearest future.

Acknowledgements

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