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Characterization of ultra-thin tungsten layers

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Abstract: Atomic force microscopy and surface resistivity measurement were used for characterization of ultra-thin tungsten layers deposited on purified silicon with 200 nm thermic silicon dioxide substrate. Radio-frequency magnetron sputtering was used for tungsten deposition.

Keywords: atomic force microscopy; surface resistivity; tungsten; ultra-thin film; nanocharacterization; metrology; nanocomposite.

INTRODUCTION

Nanotechnologies are one of the most perspective science fields with possible impact in almost all part of human being and knowledge. One of their parts are ultra-thin layers.

Ultra-thin layers can be defined as material, where one of dimensions is at nanoscale. Ultra-thin layers are very interesting area of physics with properties located between microphysical structures, where classic physics takes place, and nanophysical structures, where quantum physics is used. They are interesting from application point of view, because their properties can dramatically change according to the thickness, material or substrate used.

These layers have great potential in industry, e.g. as a diffusion barrier in electrical components fabrication [1]. These layers are also used in semiconductors [2], photonics [3], optoelectronics [4], spintronics [5] or for improvement of mechanical properties and temperature stability of materials [6].

Characterization and diagnostics of ultra-thin layers can be done only by a limited number of methods which are able to follow the features of these structures approaching atomic resolution. In our case, atomic force microscopy was used. This method is one of the scanning probe microscopy methods capable of measuring both conductive and nonconductive materials, providing high resolution and three-dimensional comprehensive information about the measured sample.

Ultra-thin layers deposition can be done in many ways by physical or chemical deposition methods [7-10]. In this paper, physical deposition method – radio-frequency magnetron sputtering was used for deposition of ultra-thin tungsten layers on purified silicon with 200 nm layer of thermic silicon dioxide.

DEPOSITION OF ULTRA-THIN LAYERS

Ultra-thin tungsten layers were deposited in a sputtering unit using tungsten target with 99.95% in purity. The argon flux was regulated with high accuracy mass flow controller. The pressure was measured by Baratron membrane vacuum gauge. Argon deposition pressure was kept at 165 mPa. Layers were deposited by radio-frequencymagnetron discharge at power of 150 W and the distance between the target and the rotating substrate holder was 50 mm. The rotation speed was set on 2.73 rpm. Two depositions in order to determine the deposition rate werecarried out. We have deposited after 200 passages of the sample under the target 64.9 nm and 62.7 nm. Therefore after one passage approximately 0.3 nm tungsten layer was deposited. One up to six passages under the tungsten target were accomplished on substrates. All samples were cleaned and checked on laser confocal microscope Olympus LEXT OLS 3100.

EXPERIMENT

No special sample preparation was used. Measurement was performed with Agilent Technologies 5420 AFM/SPM atomic force microscopy in ambient air at common laboratory conditions. AFM silicon probe AAC (size 225 x 38 µm, spring constant of 48 N/m, resonant frequency of 190 kHz and with tip radius less than 10 nm) were used. Measurement area of 4 µm x 4 µm was chosen for all analysed samples. Three different random locations of sample surface were chosen for measurement of AFM topography. Results were visualized using Gwyddion software [11].

Samples were marked as $SiO_2$0W0for substrate without tungsten (Figure 1), $SiO_2$0W3 for 0.3 nm tungsten layer (Figure 2), $SiO_2$0W6 for 0.6 nm layer (Figure 3), $SiO_2$0W9 for 0.9 nm layer (Figure 4), $SiO_2$1W2 for 1.2 nm layer (Figure 5), $SiO_2$1W5 for 1.5 nm layer (Figure 6) and $SiO_2$1W8 for 1.8 nm tungsten layer on purified silicon with 200 nm thermic silicon dioxide substrate (Figure 7).

Figures 1-7 present topography maps of the measured samples. Continuous growth of ultra-thin layers can be seen in Figure 1 – 3. However; structures in Figure 3 are much bigger than expected especially when compared to Figure 4-5. It can be assumed, that growth of these ultra-thin layers is nonlinear. Surface resistivity (Figure 8) of these samples wasmeasured using digital multimeter Keysight 34461A.

As can be seen in Figure 8, surface resistivity of $SiO_2$1W8 is approximately thousand times lower than in the case of $SiO_2$1W2 sample. Electrical percolation threshold is probablylocated around a thickness of 1.8 nm. However; analysis of layers beyond 1.8 nm would be needed.

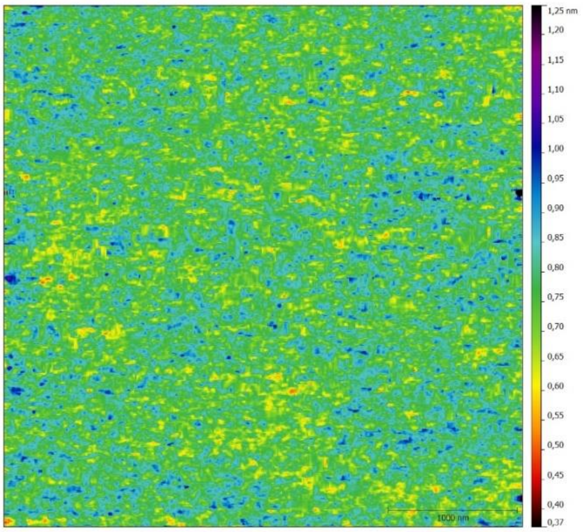

Figure 1: $SiO_2$0W0 topography

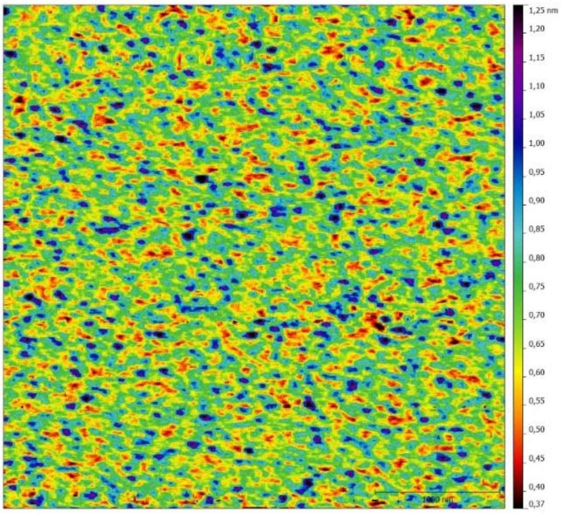

Figure 2: $SiO_2$0W3 topography

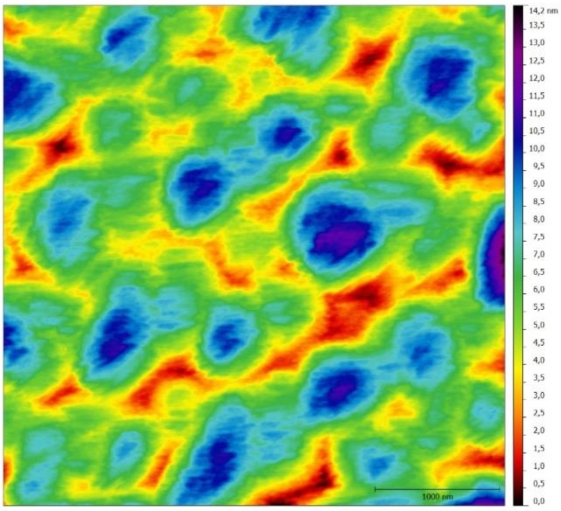

Figure 3: $SiO_2$0W6 topography

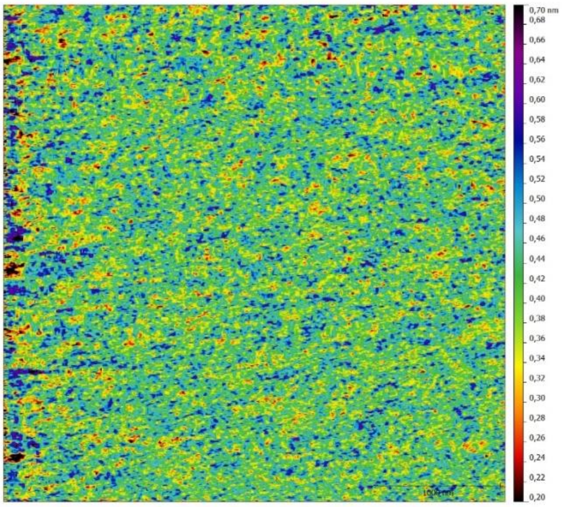

Figure 4: $SiO_2$0W9 topography

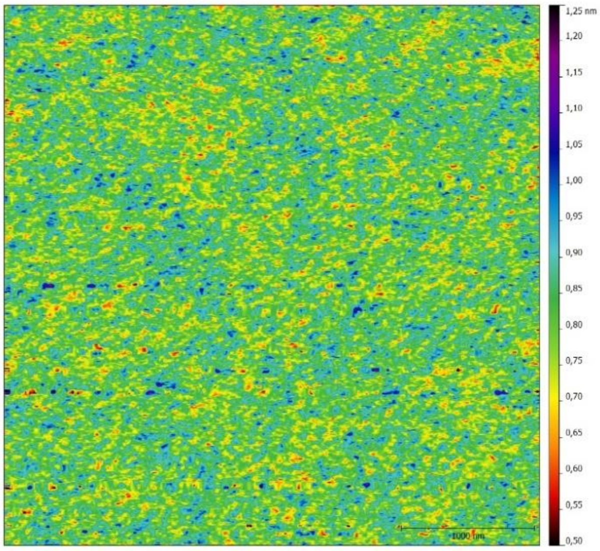

Figure 5: $SiO_2$1W2 topography

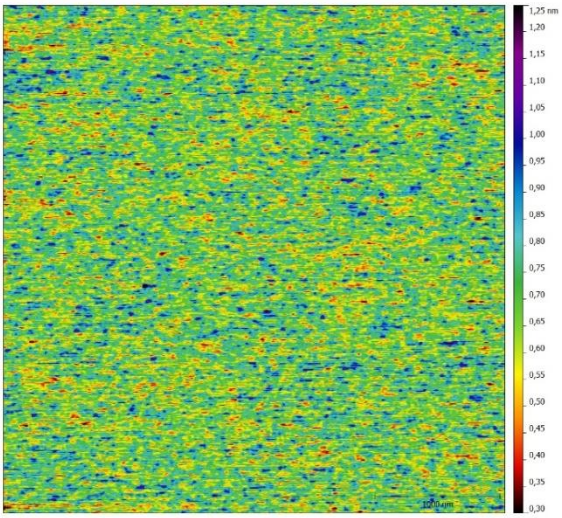

Figure 6: $SiO_2$1W5 topography

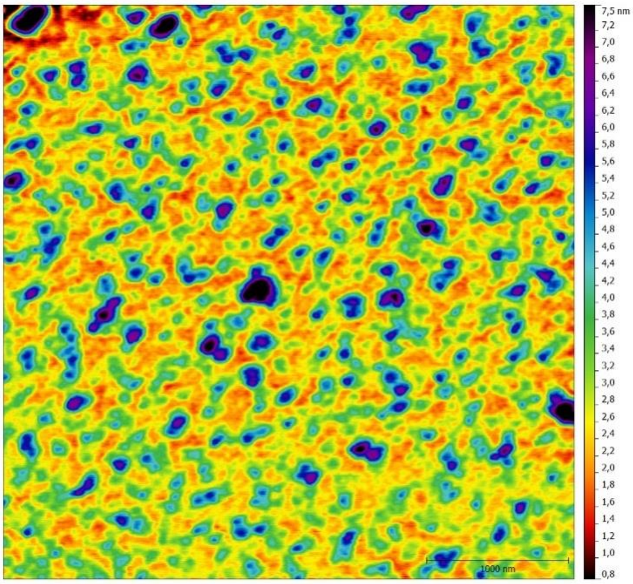

Figure 7: SiO_21W8 topography

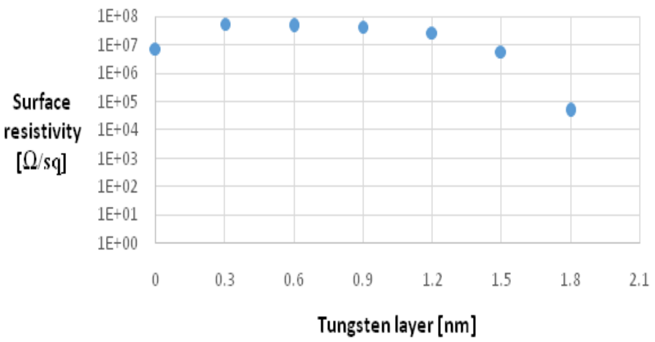

Figure 8: Surface resistivity measurement

CONCLUSION

Nanoscale characterization of ultra-thin tungsten layers deposited by radio-frequency magnetron sputtering was presented using atomic force microscopy and surface resistivity measurement. This tool showed the potential for nanoscale characterization of ultra-thin layers, their growth and for control of sputtering process.

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