

Scanning probe nanolithography of resistive memory element based on titanium oxide memristor structures

V I Avilov*, N V Polupanov, R V Tominov, V A Smirnov and O A Ageev

Southern Federal University, Institute of Nanotechnologies, Electronics and Equipment Engineering, Research and Education Center “Nanotechnologies” 347922, Taganrog, Russia

*AvilovVI@sfedu.ru

Abstract. The paper presents the results of the formation of the resistive memory element prototype based on the memristor structures of titanium oxide using probe nanolithography by the local anodic oxidation. Such structures exhibit a memristor effect without carrying out an additional electroforming operation.

1. Introduction

Modern computing evolution is closely associated with the development of the newest fast and energy efficient nanoelectronics devices, such as the resistive random-access memory (RRAM) based on memristor structures [1-2]. Although the memristive behavior have been observed in many materials, the memristor structures based on titanium oxide exhibit high switching speed and the resistance ratio in high resistance state and low resistance state [3-4]. The formation of memristor structures for RRAM devices related with research and development of high-resolution nanolithography processes [5]. The analysis of the existing lithographic methods, such as electron-beam lithography, X-ray lithography, and focused ion beam lithography, has reached a limit. The actual solution of this problem consists in the new techniques of profiling substrate surface based on scanning probe nanolithography by local anodic oxidation in atomic force microscopy (AFM) mode [6-13]. Local anodic oxidation is one of the promising methods of fabricating oxide nanoscale structures on the surface of various conducting and semiconductor materials. It can be used for development of the nanoelectronics devices and micro- and nanosystems engineering. The aim of this work is to study memristive behavior of oxide nanoscale structures obtained by local anodic oxidation and the formation of the resistive memory element prototype based on the obtained structures.

2. Experimental

Experimental samples of titanium oxide nanoscale structures were produced (Fig. 1). First, 20 nm thick titanium film was deposited on the structure of Si/SiO₂ by magnetron sputtering. Then local anodic oxidation of titanium film was carried out using probe nanolaboratory Ntegra ("NT-MDT", Russia) with NSG 10/Pt cantilevers. As a result, titanium oxide nanoscale structures with different heights were formed. Electrical characteristics of the obtained structures were measured in the AFM spectroscopic mode, titanium film serving as a bottom electrode and AFM probe – as an upper one.



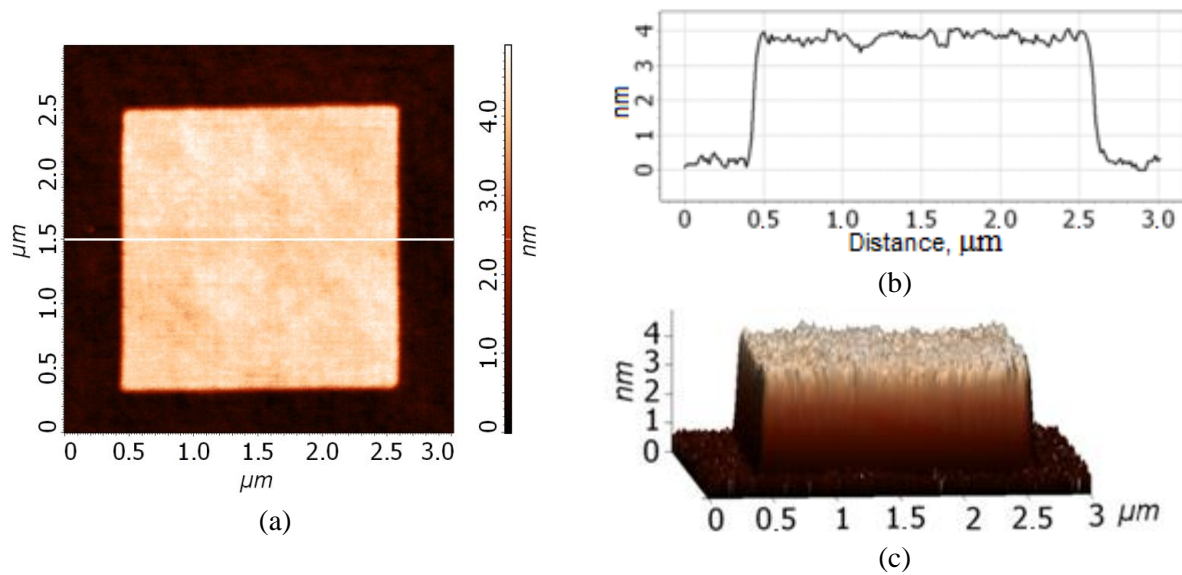


Figure 1. AFM-images of titanium oxide nanoscale structures obtained by local anodic oxidation: (a) topography, (b) profilogram, (c) three-dimensional image of the surface.

3. Results and discussion

Figure 2 presents I-V characteristics of the obtained oxide nanoscale structures. The analysis showed that the structures with height from 1.7 ± 0.1 to 3.4 ± 0.3 nm demonstrated memristive behavior under applied voltage pulses ± 2.4 V, without electroforming process; while the structure with thickness of 3.6 ± 0.3 nm in this voltage range did not demonstrate memristive behavior.

Moreover, it was revealed that increasing the height of the oxide from 1.7 ± 0.1 to 3.4 ± 0.3 nm, led to current decrease from 1.92 nA to 0.8 pA, and increase of the high resistance state value from 15 to 88 G Ω and the low resistance state value from 0.5 to 2.4 M Ω .

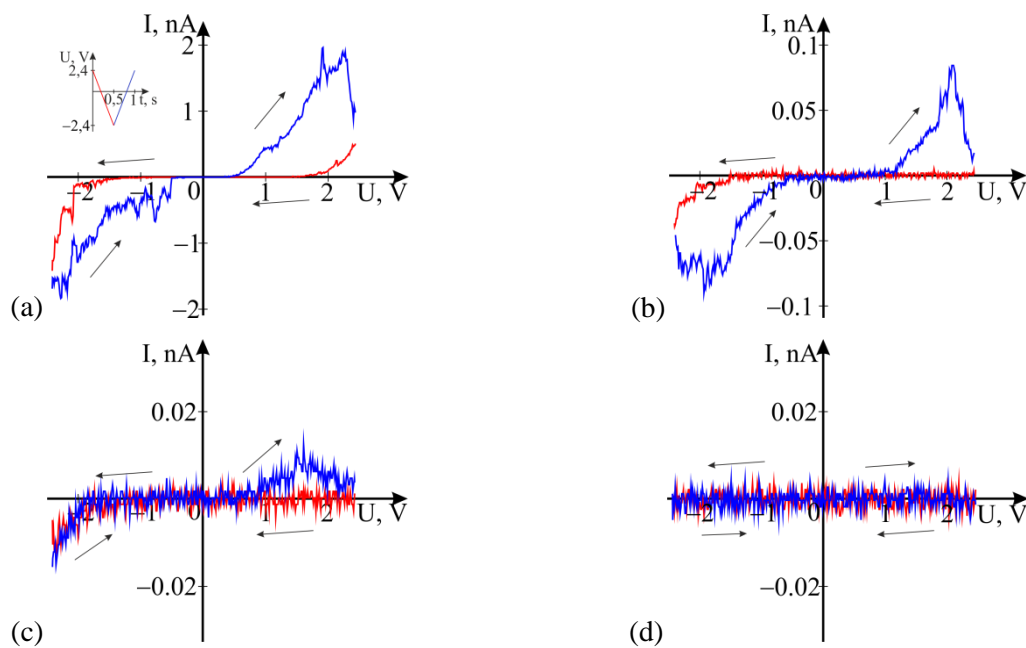


Figure 2. I-V characteristics of the oxide nanoscale structures surface with different heights: (a) 1.7 ± 0.1 nm; (b) 2.5 ± 0.2 nm; (c) 3.4 ± 0.3 nm; (d) 3.6 ± 0.3 nm.

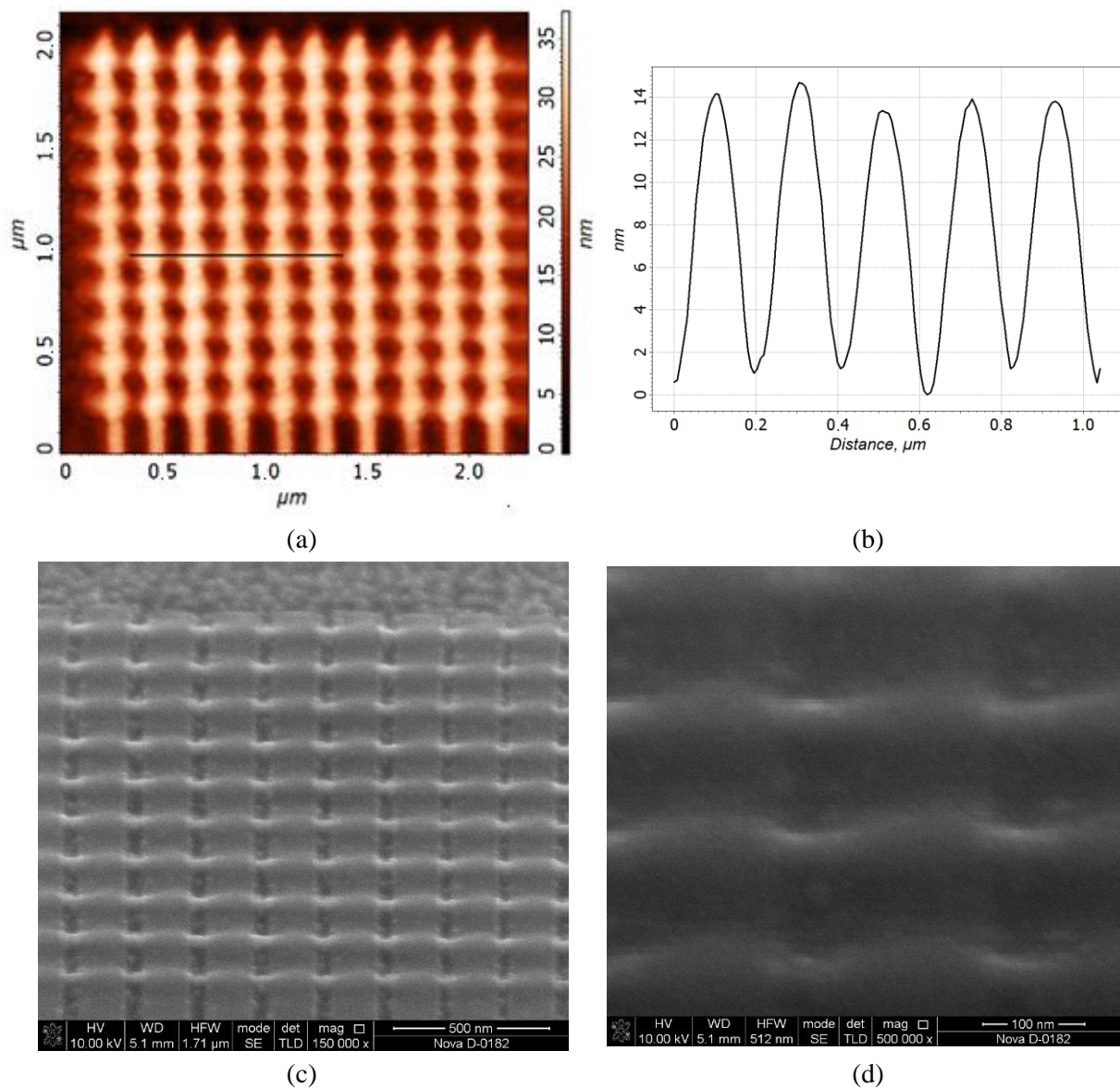


Figure 3. Resistive memory element prototype based on titanium oxide memristor structures: (a) AFM-image, (b) profilogram, (c) and (d) SEM-images.

4. RRAM element prototype fabrication

The lower contact topology of the resistive memory element prototype was formed using focused ion beam of the scanning electron microscope (SEM) Nova NanoLab 600 (FEI, Netherlands). Then titanium film was conducted by local anodic oxidation using probe nanolaboratory; as a result, 2 nm thick titanium oxide nanoscale structures were formed. In order to produce a cross-bar array of the memristor, the top carbon contact lines were deposited on the structures by nanolithography (Fig. 3).

5. Conclusion

We have revealed that titanium oxide nanoscale structures obtained by the local anodic oxidation demonstrate the memristive behavior without electroforming process. Increasing the height of the structures leads to current decrease and increase of their high and low resistance states values.

The obtained results can be used for development of the technological processes for fabrication of the components for microelectronics, nanoelectronics, and micro- and nanosystem engineering.

Acknowledgments

The study was supported by the RFBR (projects No. 16-32-00069 mol_a, 16-29-14023 ofi_m) and Southern Federal University (internal grants No. 07/2017-02, 07/2017-26). The results were obtained using the equipment of Research and Education Center and the Center for Collective Use “Nanotechnologies” of Southern Federal University.

References

- [1] Chang T-C, Chang K-C, Tsai T-M, Chu T-J and Sze S M 2016 Resistance random access memory *Materials Today* **19** 254-64
- [2] Ye C, Wu J, He G, Zhang J, Deng T, He P, Wang H 2016 Physical Mechanism and Performance Factors of Metal Oxide Based Resistive Switching Memory: A Review *Journal of Materials Science & Technology* **32** 1-11
- [3] Pan F, Gao S, Chen C, Song C and Zeng F 2014 Recent progress in resistive random access memories: Materials, switching mechanisms, and performance *Materials Science and Engineering R* **83** 1-59
- [4] Sieu D and Ramanathan S 2011 Adaptive oxide electronics: A review *J. Appl. Phys.* **110** 071101
- [5] Avilov V I, Ageev O A, Kolomiitsev A S, Konoplev B G, Smirnov V A and Tsukanova O G 2014 Formation of a memristor matrix based on titanium oxide and investigation by probe-nanotechnology methods *Semiconductors* **48** 1757-62
- [6] Ageev O A, Smirnov V A, Solodovnik M S, Rukomoikin A V and Avilov V I 2012 A Study of the formation modes of nanosized oxide structures of gallium arsenide by local anodic oxidation *Semiconductors* **46** 1616-21
- [7] Chen A 2016 A review of emerging non-volatile memory (NVM) technologies and Applications *Solid-State Electronics* **125** 25-38
- [8] Ageev O A, Avilov V I, Smirnov V A, Solodovnik M S and Tsukanova O G 2015 Studying the modes of nanodimensional surface profiling of gallium arsenide epitaxial structures by local anodic oxidation *Nanotechnologies in Russia* **10** 214-9
- [9] Linggang Z, Jian Z, Zhonglu G and Zhimei S 2015 An overview of materials issues in resistive random access memory *J Materiomics* **1** 285-95
- [10] Avilov V I, Ageev O A, Blinov Y F, Konoplev B G, Polyakov V V, Smirnov V A and Tsukanova O G 2015 Simulation of the formation of nanosize oxide structures by local anode oxidation of the metal surface *Technical Physics* **60** 717-23
- [11] Siles P F, Archanjo B S, Baptista D L, Pimentel V L and Joshua J 2011 Nanoscale lateral switchable rectifiers fabricated by local anodic oxidation *J. Appl. Phys.*, **110** 024511
- [12] Klimin V S, Solodovnik M S, Smirnov V A, Eskov A V, Tominov R V and Ageev O A 2016 *Proceedings of SPIE* **10224** 102241Z
- [13] Acharyya D, Hazra A and Bhattacharyya P 2014 A journey towards reliability improvement of TiO₂ based resistive random access memory: A review *Microelectronics Reliability* **54** 541-60