Formation of memristor nanostructures for RRAM memory by local anodic oxidation

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Abstract. A layout of resistive random access memory was developed and manufactured based on TiO$_2$ nanostructures obtained by the local anodic oxidation. It is shown that TiO$_2$ nanostructures exhibit a stable memristor effect without carrying out an additional electroforming operation at 20 measurement cycles. The resistance ratio of the memristor nanostructure in the high-resistance state and low-resistance state was 16.

1. Introduction

The development of modern electronics is associated with the use of new methods of nanotechnology, allowing to produce high-speed components with low energy consumption [1-4]. These components include memristors, which can find its application in the resistive random access memory (RRAM) and synaptronic elements [5-12]. Using memristors in RRAM is due to the fact that these elements have a high operation speed that exceeds the operation speed of modern dynamic random access memory (DRAM) and are nonvolatile; therefore, application of RRAM based on memristors in portable devices will reduce their power consumption and increase the operating time without additional recharging.

The analysis of publications has shown that most part of methods of forming memristor structures for RRAM contains a complex stage of electroforming oxide nanostructures (ONS) to give them memristor properties. However, the application of the local anodic oxidation (LAO) method using atomic force microscopy (AFM) techniques makes it possible to form the titanium ONS exhibiting a memristor effect without additional electroforming of structures, which will simplify the technology of manufacturing RRAM modules [12-16]. Therefore, the goal of the work is the development of manufacturing technology and the formation of RRAM elements based on memristor structures by LAO method.

![Figure 1. The layout of RRAM elements based on memristor structures.](image)
2. Experiment

In this work, a structure of RRAM elements was proposed, representing a cross-bar array of memristor structures containing an insulating SiO$_2$ substrate, structures of the lower titanium electrodes, titanium ONS obtained by the LAO method, and the structure of the upper electrodes (Fig. 1).

A technological process for manufacturing RRAM elements was developed. For this purpose, a semi-insulating silicon substrate was used, on which a thin titanium film with a thickness of about 20 nm was formed by pulsed laser deposition using an Auto 500 (BOC Edwards, UK) multipurpose installation. Then, by the method of focused ion beams, titanium film lithography by scanning electron microscope Nova NanoLab 600 (FEI, Netherlands) was carried out; as a result, the lower titanium contacts structures were formed. After this, LAO of the lower electrodes was carried out using a scanning probe microscope Solver P47 Pro (JSC “NT-MDT” Zelenograd) and NSG11 silicon cantilevers with a conducting coating, resulting to formation of memristive ONS covering the lower electrodes. At the final stage, the platinum upper contacts structure was formed by ion-stimulated deposition by scanning electron microscope Nova NanoLab 600, resulting to a cross-bar array of 16 memristors (Fig. 2).

Figure 2. Topography (a) and 3D-image (b) of the RRAM element layout.

Figure 3. Current-voltage characteristic (a) and resistance values (b) of memristor nanostructures.
Figure 4. Resistance of titanium oxide nanostructures.

3. Results and discussion
Investigation of the electric characteristics of the array showed that the obtained titanium ONS exhibited a memristor effect and switched between a high \((1.39\pm0.27) \times 10^{10} \Omega\) and low \((1.17\pm0.30) \times 10^{9} \Omega\) resistance states (Fig. 3a). In this case, 20 measurement cycles of a single memristor showed that the produced structures had stable memristive properties (Fig. 3b).

There was an insignificant increase in the resistance for both states, related to the further LAO process of the titanium film, when current-voltage characteristics were measured in air.

Then, the memristive effect reproducibility of the resulting 16 memristors array was investigated (Fig. 4). It is shown that the obtained structures have a uniform memristive effect. The obtained resistance ratio of the structure in the high-resistance state and low-resistance state is \(R_{HRS}/R_{LRS} \approx 16\).

4. Conclusion
A layout of RRAM elements was developed and manufactured, consisting of 16 memristor structures based on titanium oxide nanostructures obtained by the local anodic oxidation method. It is shown that titanium oxide nanostructures exhibit a stable memristor effect without carrying out an additional electroforming operation. The obtained resistance ratio of the structure in the high-resistance state and low-resistance state is \(R_{HRS}/R_{LRS} \approx 16\).

The obtained results can be used in the development of technological processes for manufacturing the elemental base RRAM on the basis of titanium oxide nanostructures using probe nanotechnology.

Acknowledgements
This work was supported by RFBR according to the research project № 18-37-00299, by Grant of the President of the Russian Federation No. MK-2721.2018.8, and the Southern Federal University (grant No. VnGr-07/2017-26).

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