A Study on the influence of thermal energy on the behaviour of TaOx-based RRAM

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Abstract

Artificial Intelligence (AI) has been a major topic of discussion in the scientific community in recent years. In particular, topics circling face and speech recognition, machine translation, classification, etc. attract the most attention. To carry out the studies about AI Deep Neural Networks (DNNs) are required to be trained on datasets of significant size. To accelerate the neural networks there have been several research directions. Improving the hardware memory has propagated in the direction of Phase Change Memory (PCM) and Resistive-switching Random Access Memory (RRAM). This study will discuss the effect of thermal energy on tantalum oxide (RRAM) film quality. The advantages of using the lower temperature TaO_x deposition will be presented.

Ⅰ. Introduction

Artificial Intelligence (AI) has been a major topic of discussion in the scientific community in recent years. In particular, topics circling face and speech recognition, machine translation, classification, etc. attract the most attention. To carry out the studies about AI Deep Neural Networks (DNNs) are required to be trained on datasets of significant size. Furthermore, to facilitate the need in increasing demand for processing speed more specially oriented equipment (i.e. tensor processing unit and graphics processing unit) is being used, which enables machines to perform significantly better at tasks related to pattern recognition. However, one of the major features of the DNN, which is also its major disadvantage, is an extensive consumption of energy and time recourses while transferring data between processing units and memory storage from the tasks of backpropagation, weight updates, forward propagation, and to storing the data. Consequently, there is a situation where it is necessary to improve the energy efficiency of networks with the help of advancements in analog memory and computations that require non-von Neumann architecture.

To accelerate the neural networks there have been several research directions. Improving the hardware memory has propagated in the direction of Phase Change Memory (PCM) and Resistive-switching Random Access Memory (RRAM). One of the major advantages of these rising technologies is the ability to work based on particular laws of physics, namely Kirchhoff's Law and Ohm's Law, thus enabling matrix-to-vector multiplication (MVM) while reducing the size and energy consumption. Furthermore, both PCM and RRAM retain the ability to facilitate multiple levels in a single cell, which is essential for energy reduction and precise measurements while updating the synaptic weights. Achieving the high accuracy and low variation for the abovementioned systems imposes significant challenges while trying to find a material that functions with a large memory window, appropriate device yield, high endurance, and low forming voltage.

There are several methods of depositing thin memory films. Among them, PVD and CVD methods using ALD, Sputter, E-Beam evaporator, etc. represent the most popular ones. In this study PVD using Sputter was performed. In general, PVD methods are done at room temperature, however, the quality of oxides material rises with the temperature, so the effect of thermal energy on the TaOx film will be discussed in this paper.

Ⅱ. Results

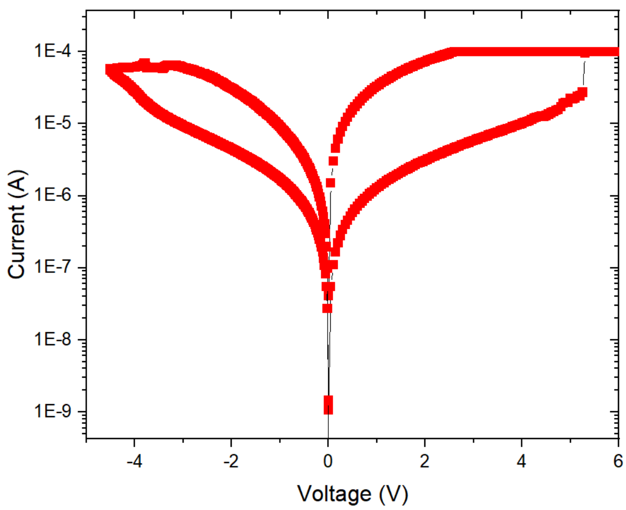

Figure 1. SET/RESET switching of the high-temperature TaO_x device

One of the more promising materials in the RRAM field is Tantalum Oxide. In combination with several other materials, tantalum oxide can exhibit low forming voltage, and low set/reset voltages and shows promising results as a potential candidate for a successful RRAM insulator. The structure analyzed in this study is the Platinum bottom electrode (12 nm), TaO_x (10 nm), and TiN top electrode (60 nm). All the materials have been deposited using the PVD method via sputtering at room temperature and TaOx was deposited at 200 Celcius. Measurements have been performed using the Keithley 4200-SCS Semiconductor Characterization System.

Figure 1 shows the results of the measurement of the high-temperature TaO_x device. The structure was able to operate at the compliance current of 10E-4 A. SET voltage was approximately 5.2 V and RESET voltage was approximately -4 V through multiple cycles. No compliance current was enabled for the RESET part. Although the general trend remained similar, there were few cycles where a higher voltage sweep was necessary to form a successful filament.

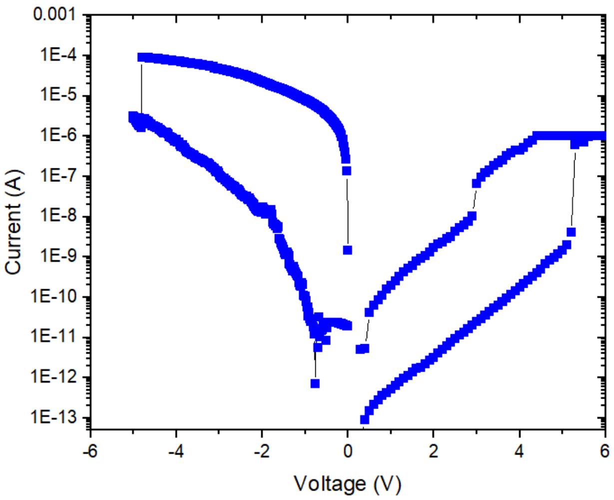

Figure 2. SET/RESET switching of the low-temperature TaO_x device

The second structure discussed in this study is a 70 Celcius Tantalum Oxide device. The following design was used: Platinum bottom electrode (15 nm), Tantalum oxide insulator (10 nm). All materials have been deposited using PVD via sputtering at room temperature and TaOx was deposited at 70 Celcius. ReS2 has been transferred at room temperature.

Figure 2 shows the results of measurements of the low-temperature Tantalum Oxide device. It was possible to lower the compliance current down to 1E-6 A. The SET variance remained unchanged around 5 V. RESET variance was from -4 to -5 V, averaging around -4.5 V. Significant improvement in the overall consumption of the energy by the structure and increased memory window has been observed with the trade-off in stability

The memory window for the low-temperature TaOx is around 1000 times in comparison to the memory window of the high-temperature TaOx which is only 10 times.

Ⅲ. Discussion

First of all, the memory window is a significant contributor to choosing a multi-level memory device. In that regard, the low-temperature structure showed 100 times bigger memory window which is a significant improvement.

The next important factor is the cycle-to-cycle variation inside the devices. In this category, high-temperature TaO_x outperforms low-temperature TaO_x. Variations on the SET and RESET sides were more noticeable for the low-temperature device. No significant changes in the number of cycles have been noticed.

Energy consumption of the structure is the final criterion used in this study. Results show that on average low-temperature TaO_x device has a SET compliance current 100 times lower than the high-temperature variant, which results in a significant reduction of energy consumption.

The overall performance of both devices had its advantages and disadvantages. However, the low-temperature TaOx device shows more promising data for future development, since it has better energy consumption and improved memory window compared to the high-temperature TaO_x device.

Acknowledgments

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