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Approach to Enhance Electrical Properties of Memristor utilizing Proton Irradiation Technique

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1. Introduction

Memristor is attracting attention in future high-tech fields such as artificial neural networks and quantum computing because it has the ability to memorize the resistance of applied external voltages [1]. There are various types of analog switching devices, and among them, CBRAM (conductive-bridging random access memory) that utilizes high mobility of metal ions has the advantages of fast switching speed and high on/off ratio [2]. In order to effectively control the ion transport of CBRAM, it is essential to secure an effective conductive path within the dielectric in terms of improving electrical performance.

On the other hand, protons, which is a heavy charged particle, have significant mass compared to electrons, so when they collide with atoms constituting the target material, they can induce a defective state, such as creating vacancies and interstitial locations [3].

In this study, we intend to enhance the electrical properties of the memristor device by inducing displacement within the dielectric layer by using the proton irradiation technique.

2. Methods and Results

Memristor components are stacked on a Si substrate in the order of Al electrodes, Al_2O_3 dielectrics, and Cu electrodes in the 50 x 50 um^2 region, each with a thickness of 50 nm, 10 nm and 50 nm. Al and Cu electrodes were deposited through thermal evaporation, and Al_2O_3 dielectric layer was fabricated using ALD (atomic layer deposition) technique. OM (optical microscope) images of the memristor device prepared in this way are displayed in Figure 1.

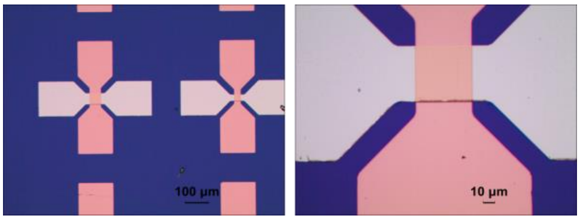

Fig. 1. Optical microscope images of memristor device (top view)

To generate a conductive path within the dielectric layer through proton beam irradiation, a cyclotron accelerator at the Advanced Radiation Technology Institute was utilized (Figure 2). 1 MeV protons were irradiated to memristors with a beam current of ~500 nA for 5 minutes to reach a 1 x 10^{15} protons/cm^2 fluence.

<cyclotron> <beam line>

Fig 2. Photos of cyclotron facility and beamline

Figure 3 shows the results of the electrical properties of the memristor device before and after proton irradiation. To observe the memristor characteristics, SET and RESET voltages were measured in the ranges of 0 – 8 V and -2.5 – 0 V, respectively, and 4 elements in the batch were measured for 10 cycles each. LRS (low resistance state) and HRS (high resistance state) were measured at reset -0.1 V. After irradiation, there was a slight decrease in the deviation of electrical properties, but no significant effect of proton irradiation was observed.

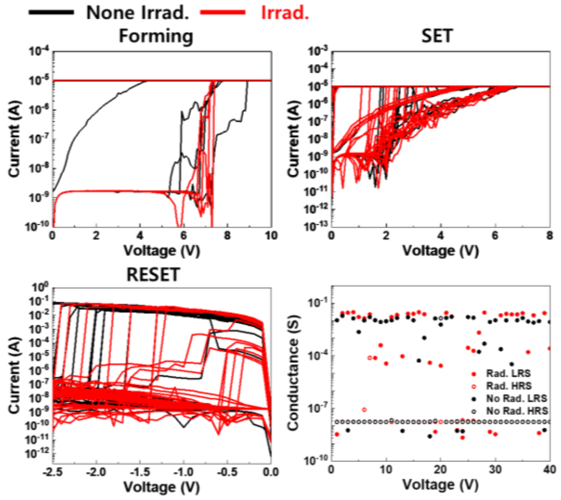

Fig. 3. Measurement of electrical properties of memristor device before and after proton irradiation

As shown in Figure 4, the result of dpa (displacement per atom) values to each layer of memristor from proton irradiation was calculated through the SRIM software. Each density of the Cu electrode, Al_2O_3 dielectric and Al electrode using calculation was set to 8.92 g/cm^3, 3.97 g/cm^3, 2.702 g/cm^3, respectively [4].

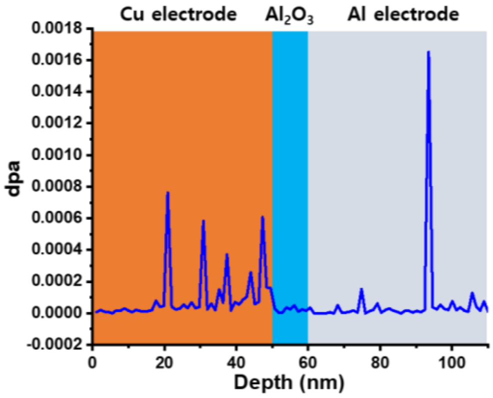

Fig. 4. Depth-dependent dpa profile calculated using SRIM software for each memristor device layer.

When calculating the dpa value induced on the memristor device using SRIM software, it was confirmed that the dpa value of the Al_2O_3 dielectric layer was significantly lower than that of the Cu and Al electrode layers.

From these results, it can be expected that in order to offer an effective conductive path for the CBRAM device, more significant dpa should be induced into the dielectric layer by lowering the accelerating proton energy or increasing the beam fluence.

3. Conclusions

A proton irradiation technique was introduced to generate an effective conductive path in the CBRAM memristor device. Al_2O_3 dielectric layer deposited by ALD technique was irradiated with 1 MeV protons at a fluence of 1×10^{15} protons/cm^2. SET/RESET voltage, LRS, and HRS were measured to observe changes in the electrical properties of the memristor device by proton beam irradiation and compared with the SRIM calculation results. After irradiation, there was a slight decrease in the deviation of electrical properties, but no significant effect of proton irradiation was observed. From these results, in order to have a more significant irradiation effect on the Al_2O_3 dielectric layer, further studies should be conducted under optimized beam conditions, such as lowering the energy of the accelerated ions or increasing the beam fluence.

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