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Find Filament in ReRAM using Thermal Analysis

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Abstract

Position of conductive filament (CF), the number of CFs and temperature of CF in ReRAM were found out using thermal analysis. The position of CF was clearly observed from Joule heat in the device. The number of CFs were depend on the size of electrode. The CF was randomly formed in the memory cell. However, the position of CF was not changed during switching cycle. Temperature of CF was also calculated.

1. Introduction

The CF plays main role in resistive switching, therefore, observation of the CF is very important from the standpoint of finding out switching mechanisms. Several attempts have been carried out to observe the CF using C-AFM, SEM, cross-sectional TEM, EBAC and EELS mapping. However, most of all reports about observation of CFs are not in situ observation of resistive switching. The filament position, number of filaments and filament temperature are difficult to find out. In this study, we report observation of CF using thermal analysis. To visualize the CF, we detects joule heating in ReRAM device using infrared detector. During a resistive switching process, current flows a narrow conductive path in filament type of ReRAM and generates Joule heat. Therefore, by detecting this Joule heating, we can find the position and the number of CF. We can also estimate the temperature of filament at switching process using heat transfer simulation.

2. Results of thermal analysis

We use two type of ReRAM devices for thermal analysis. One is Pt/a-IGZO/Pt ReRAM devices. The other is TiN/SiO2/nanoparticle (NP)/Ta ReRAM devices. Amorphous IGZO (2:2:1:7) layer with 30 nm thickness was formed on Pt bottom electrode. Pt top electrodes with a thickness of 40 nm were formed on a-IGZO. On the other hand, NPs embedded ReRAMs [1] were fabricated using biological nano-fabrication process [2]. The Joule heat was observed by an InSb detector. Resolution of this microscope is around 3 um because the system detects the infrared wavelength (3 ~ 5 μm).

Amorphous IGZO-ReRAM shows typical bipolar type hysteresis behavior (Fig. 1). At a switching process, surface temperature was observed as shown in Fig. 2. Fig. 2 (a)-(c) shows optical image of the device and temperature mapping of the device surface. In each devices, hot spots were confirmed. This hot spot indicates the existence of CF. In the device with the electrode size of 300 and 600 μm diameter, single hot spot was observed. This means that the device works with single filament. However, the device with 1000 μm diameter top electrode, three hot spots were observed. Therefore, three CFs exist in this large device. Therefore, there are main-CF and some sub-CFs in multi-CFs model.

On the other hand, NPs embedded ReRAM (Fig. 3) shows bipolar type switching behavior after electro forming process (Fig. 4). Fig. 5 shows device optical image and thermal image at the set process. In this thermal analysis, sample stage was heated at 50 ^{o}C in order to adjust a high sensitive range of infrared detector. As shown in Fig. 5 (b), clear hot spot was observed. This device works with single filament and the filament was placed near the edge of top electrode. The temperature increment follows the electrical power in the memory device (Fig. 5 (c)). At the set process, surface temperature increased around 58 ^{o}C (increment: $\Delta T = +8$ ^{o}C). Filament position was also detected during three *I-V* cycles. During the three set and reset cycle, the filament appeared the same position (Fig. 6). Therefore, the position of conductive filament did not change during switching cycle. Fig. 7 shows the result of heat transfer simulation. In this simulation, the filament diameter was set at 5 nm and cylindrical shaped conductive filament was assumed as a heat source. Then, the filament is heated until a surface temperature becomes 58 ^{o}C. As the result, filament temperature was calculated at 187 ^{o}C. Fig. 7 (b) shows the calculated filament temperature with different filament diameter. If the filament diameter is < 2 nm, the filament temperature becomes more than 500 ^{o}C.

3. Conclusions

The position of the filament and the number of the filament were analyzed using thermal analysis. We found that there are main-CF and some sub-CFs in multi-CF model. The filament position was randomly formed in the device at the forming process. But the position was not changed during the switching cycle. Therefore, thermal analysis is good method for evaluation of CF.

References

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[2] I. Yamashita, Thin Solid Films, 2001, **393**, 12–18

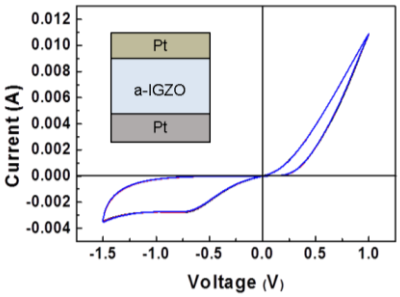

Fig. 1 Typical resistive switching behavior of Pt/a-IGZO/Pt device with electrode diameter of 300 μm.

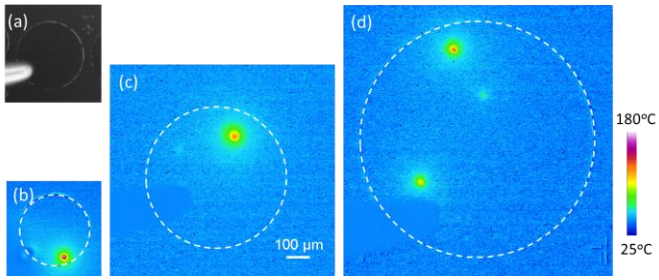

Fig. 2 Results of thermal analysis. (a) Optical image of the 300 μm electrode on IGZO film with probe. (b)-(d) Temperature mapping images of the electrode (diameter of (b)300,(c) 600, (d)1000 μm).

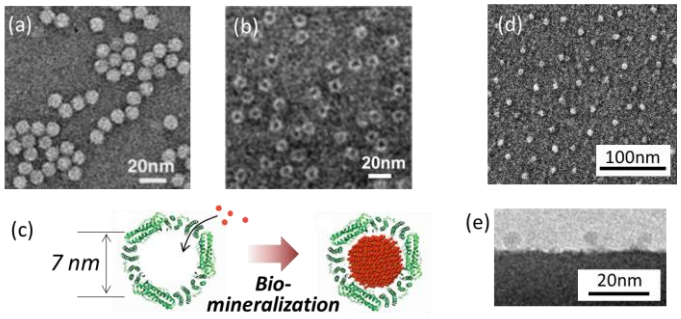

Fig. 3 (a) TEM image of apo-ferritin (w/o NP). (b) TEM image of ferritin with NP. (c) Schematic image of biomineralization of ferritin. (d) SEM image of Fe_2O_3 nanoparticles on Ta surface after. (e) Cross-sectional TEM image of nanoparticles in SiO_2.

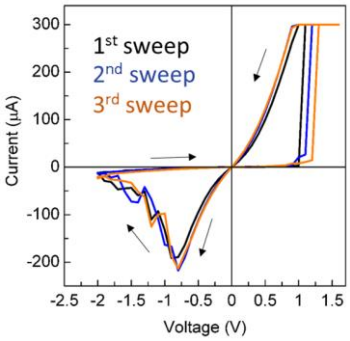

Fig. 4 Typical switching behavior NP embedded device. After the forming process, the devices show bipolar type switching behavior. Three set and reset cycles.

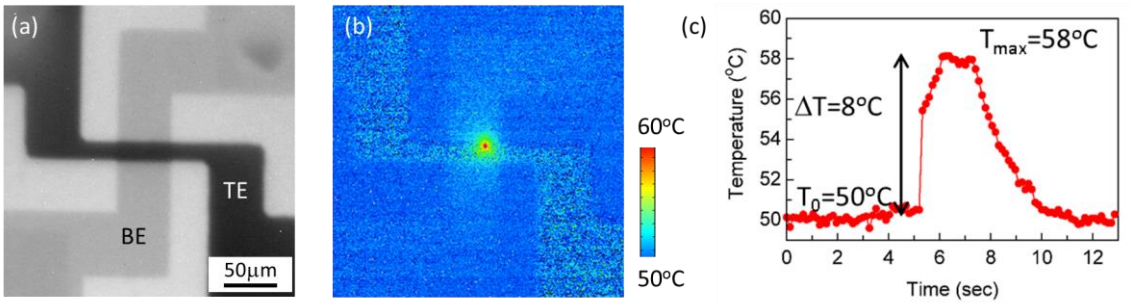

Fig. 5 Results of thermal analysis. Hot spot is observed in nanoparticle embedded device. (a) Optical image of the cross point electrode device. (b) Temperature mapping images of the device .Hot spot was observed around the center of cross point. The hot spot indicates the conductive filament. (c) Temperature of hot spot during set process. Maximum temperature of the hot spot during resistive switching was 58 °C.

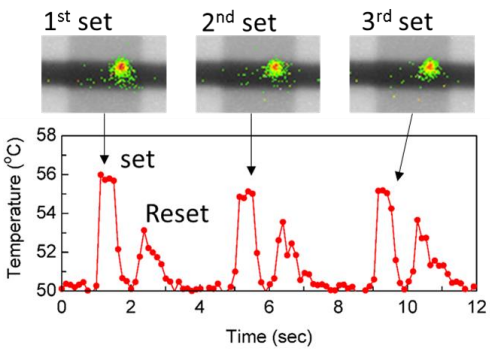

Fig. 6 Time vs temperature. This first peak comes from set process and the second small peak comes from reset process.

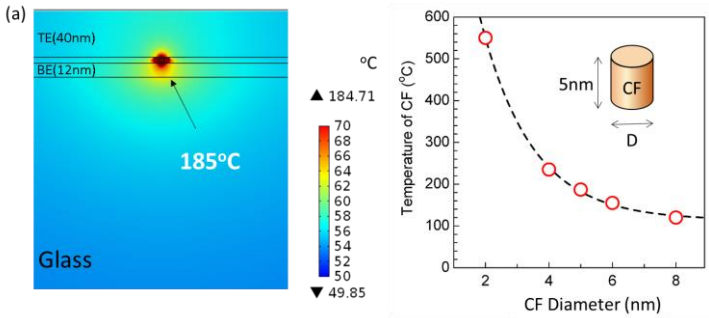

Fig. 7 (a) Calculated temperature of the CF using heat transfer simulation. In this simulation, filament diameter is assumed 5 nm and CF is set as a heat source. (b) Dependence of CF temperature and CF diameter.