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Analysis of "hot spot" in Conducting-Bridge Random Access Memory (CBRAM) by Impedance Method

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ABSTRACT

This paper reports on the effectiveness of an impedance method to estimate memory performance of CBRAM. Electrochemical parameters were succesfully extracted from Ag/SiO_2/Pt devices utilizing the differences of characteristic time constants specific to each elemental process composing resistive switching (RS) process. V_{form} was confirmed to decrease with decreasing charge transfer resistance, indicating a close relationship between RS and electrochemical parameters which are accessible through an impedance method. By performing impedance analysis of Ag/SiO_2/Pt devices with various areas, it was suggested that RS predominantly took place at the fringe of the electrochemically active Ag-electrode.

1. INTRODUCTION

Conductive-bridge RAM (CBRAM) has a simple cell structure, in which a metal oxide (MO) film is sandwitched between electrochemically active (AE) and inactive (IE) electrodes, and, thus, is advantageous in increasing memory density. Resistive switching (RS) of CBRAM is composed by different two major processes respectively with different time constants, that is, the ionization of the AE atoms at the AE/MO interface and the diffusion of the AE atoms in the MO film.[1)] On the other hand, an impedance method has an advantage over *I-V* measurements in its capability of extracting electrochemical parameters corresponding to their characteristic time constants.[2)] Impedance method is, therefore, expected to provide critical information to know memory performance of CBRAM, if correlations between electrochemical parameters and basic memory parameters such as switching voltages are confirmed.

In this paper, we applied an impedance method to Ag/SiO_2/Pt devices and confirmed that the extracted electrochemical parameters were correlated with memory performance of CBRAM. In particular, when combined with device area dependence, it was shown that impedance method enabled us to discuss the distribution of electrochemical parameters in CBRAM devices.

2. Experiment

Figures 1(a) and (b) show a CBRAM device and measurement configuration used in this study. The SiO_2 was grown on a Pt-IE by chemical vapor deposition method, followed by an Ag-AE deposition by a sputtering method. Impedance analysis was performed on CBRAM devices with four different Ag-AE areas, *S*, of 100, 200, 300, and 500 μm in diameters. The frequency, ω, dependence of impedance, $Z(\omega)$, was measured for ω range of 20 Hz - 200 kHz, whereas forming voltages, V_{form}, were obtained by DC voltage sweep measurement. Here, $Z(\omega)$ and V_{form} were measured respectively by an impedance analyzer (HIOKI IM3590) and a semiconductor parameter analyzer (Agilent 4155C). By fitting an equivalent circuit to the $Z(\omega)$ data, charge transfer resistance, R_{ct}, electric double layer capacitance, C_{dl}, and Warburg parameter, σ_{CPE} ($\propto c^{-1}D^{-0.5}$), were extracted, where *c* and *D* are the concentration and the diffusion coefficient of Ag ions.

3. RESULTS AND DISCUSSION

3. 1 Fitting by an equivalent circuit

Figure 2 shows the area dependence of $Z(\omega)$. Semicircular and linear regions are observed for high and low ω ranges, respectively. The latter corresponds to a diffusion impedance, which is known as Warburg impedance.[2)] Considering the deviations of the capacitive semicircle from a true circle and of the slope of the line from 45°, we performed the fitting with an equivalent circuit in which two constant phase elements, CPE and CPE_W,[3)] were contained as shown in the inset of Fig. 2. Results of the fitting are shown in Fig. 2, showing the good agreement of the equivalent circuit with the $Z(\omega)$ data.

3. 2 Correlation between electrochemical and resistive switching parameters

Figure 3 shows R_{ct}-dependence of V_{form}, where the change of R_{ct} is caused by both *S* and the dispersion of R_{ct} even in Ag/SiO_2/Pt devices which have the same *S*. V_{form} weakly decreases with decreasing R_{ct} by increasing *S*. This weak R_{ct}-dependence can be attributed to the higher probability of an Ag bridge formation in Ag/SiO_2/Pt devices which have larger *S*. On the other hand, when we focuses attention on the dispersion of R_{ct} for each fixed *S*, V_{form} decreases steeply with decreasing R_{ct}.

3.3 *S*-dependence of $Z(\omega)$

Figures 4(a) and (b) respectively show $1/\phi$-dependence of R_{ct} and $1/S$-dependence of initial resistance, R_{ini}, showing the relationships of $R_{ct} \propto 1/\phi$ and $R_{ini} \propto 1/S$, respectively. The former suggests that electrochemical reaction at the Ag/SiO_2 interface predominantly proceeds at the fringe of the Ag-AE. This cannot be distinguished by normal *I-V* measurements as suggested by the latter, confirming the effectiveness of an impedance analysis.

Figures 5(a) and (b) show *S*-dependence of C_{dl} and $1/S$-dependence of σ_{CPE}, respectively. Both C_{dl} and σ_{CPE} show slopes between 0.5-1, suggesting that electric double layer (EDL) at the Ag-AE interface and the diffusion of Ag ions are not completely uniform over the whole of the AE area. σ_{CPE} linearly increases with increasing $1/C_{dl}$ and R_{ct} also increases with increasing $1/C_{dl}$ as shown in Figs. 6(a) and (b), respectively. These results suggest that Ag ions are mainly ionized at the fringe and diffuse predominantly from the fringe of the Ag-AE where the thickness of the EDL is thin and the electric field is strong, as shown in the inset of Fig. 3. Therefore, the steep R_{ct}-dependence in Fig. 3 can be attributed to the dispersion of the thickness of the EDL among Ag/SiO$_2$/Pt devices with the same S.

4. Summary

The effectiveness of impedance method in the analysis of the 'hot spot' where oxidation of Ag-AE predominantly takes place was revealed: V_{form} decreased with decreasing R_{ct}, suggesting the close relationship between electrochemical parameters extracted by impedance method and memory performance. The S-dependence of $Z(\omega)$ provides information about the location of the hot spot, in this study, the fringe of the Ag-AE in Ag/SiO$_2$/Pt devices.

References

1) K. Kinoshita, ECS Transactions **69** (2015) 11.
2) J. R. Macdonald: *Impedance Spectroscopy* (Wiley, New York, 1987).

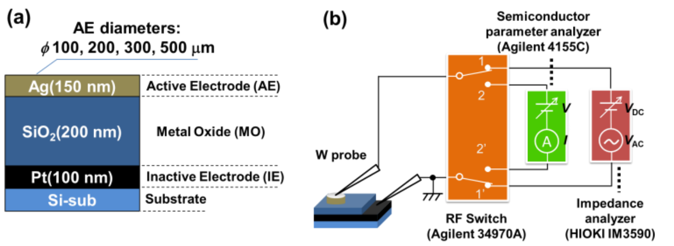

Fig. 1 (a) CBRAM device and (b) measurement configuration.

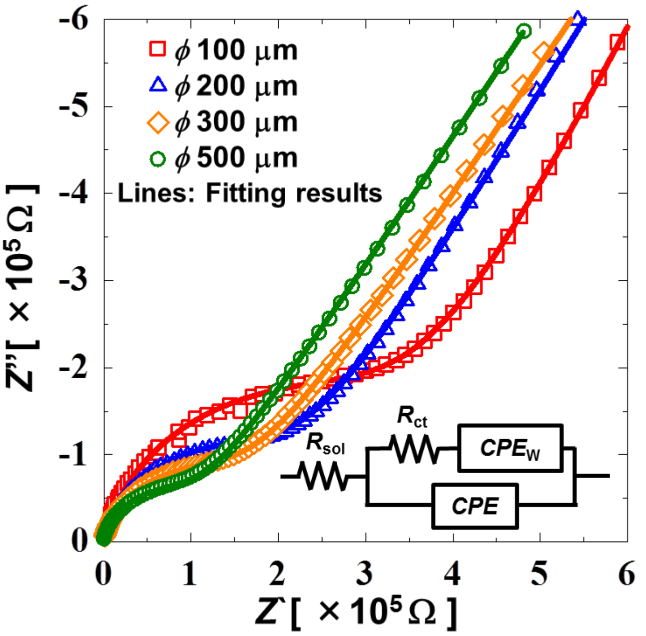

Fig. 2 The area (S) dependence of $Z(\omega)$.
Inset: An equivalent circuit for the Ag/SiO$_2$/Pt devices.

3) M. Nakayama *et al*,. The Journal of Physical Chemistry **B 107** (2003) 10603.

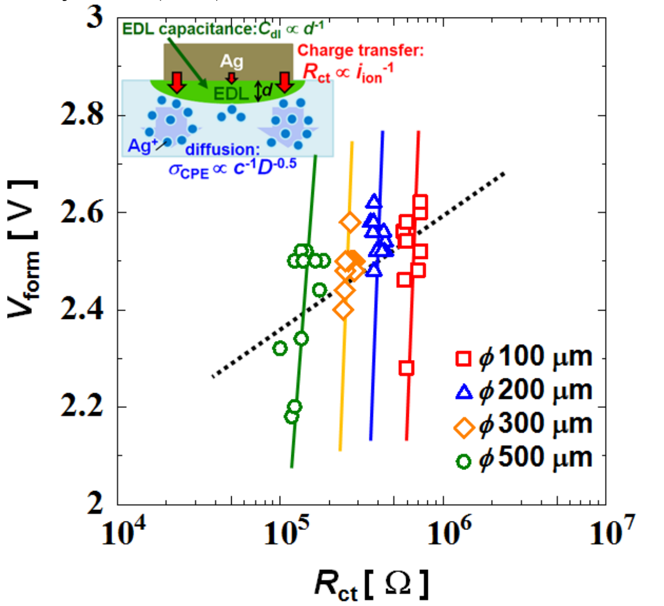

Fig. 3 R_{ct}-dependence of V_{form} for various S. Inset: Schematic view explaining the distribution of electrochemical parameters in Ag/SiO$_2$/Pt devices, where i_{ion} is ionic current density.

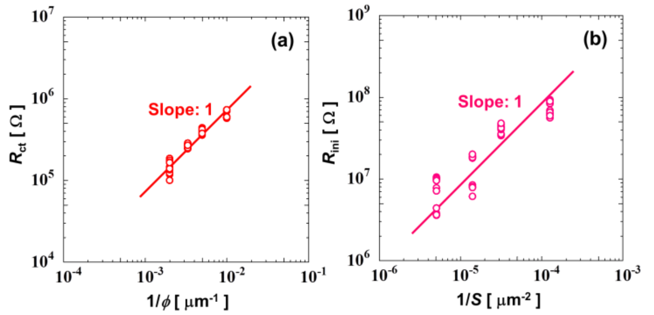

Fig. 4 (a) $1/\phi$-dependence of R_{ct}. (b) $1/S$-dependence of R_{ini}.

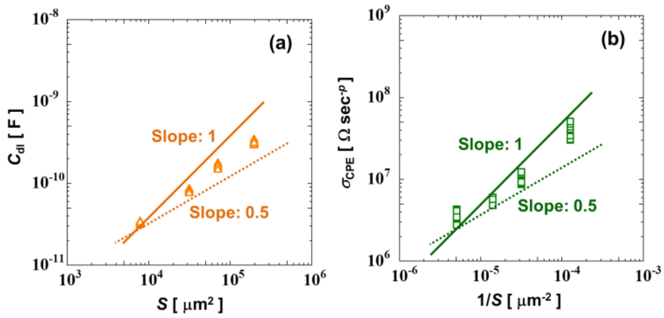

Fig. 5 (a) S-dependence of C_{dl}. (b) $1/S$-dependence of σ_{CPE}.

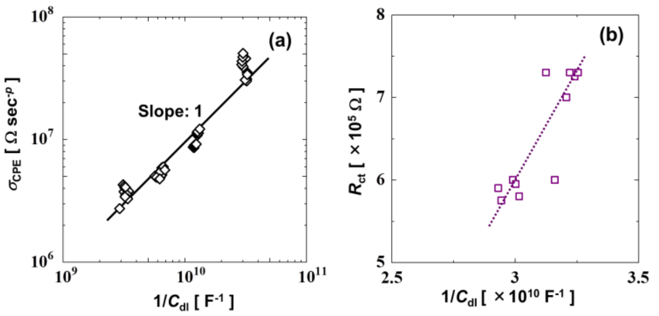

Fig. 6 $1/C_{dl}$-dependences of (a) σ_{CPE} and (b) R_{ct}(ϕ 100 μm).