

Contents

Contents	i
Introduction	v
1 Overview on the resistive switching in transition metal oxides	1
1.1 Bipolar and unipolar resistive switching	1
1.2 Resistive switching mechanism	2
1.2.1 Fuse-antifuse of conduction paths	3
1.2.2 Resistive switching induced by anion migration	4
2 Sample preparation	7
2.1 Sputtering of TiO_2 and Pt	7
2.2 Fabrication of Pt/ TiO_2 /Pt stack resistive switching cells	9
2.3 Fabrication of planar resistive switching cells	9
2.4 Fabrication of modified stack switching cells	10
3 Structural and chemical properties of pristine TiO_2	13
3.1 Microstructural characteristics	13
3.2 Chemical characteristics	16
4 Electrical properties of pristine TiO_2	19
4.1 Current-voltage-time characteristics	19
4.1.1 Electrical conduction theory	19
4.1.2 Current-voltage characteristics of Pt/ TiO_2 /Pt	21
4.1.3 Current-time characteristics of Pt/ TiO_2 /Pt	26
4.2 Impedance spectra of Pt/ TiO_2 /Pt	29
4.2.1 Dielectric behavior in time and frequency domains	30
4.2.2 Impedance behavior in the frequency domain (60 Hz - 1 MHz)	33
4.2.3 Impedance behavior in the frequency domain (0.1 Hz - 100 kHz)	35
5 Electroforming characteristics in bipolar resistive switching	39
5.1 Electroforming effect on the structural and chemical properties	39
5.1.1 Electroforming theory	41
5.1.2 Structural changes by the electroforming	42
5.1.3 Resistance degradation using conductive atomic force microscope	45
5.1.4 Chemical changes by the electroforming	45
5.1.5 Calculation of the Joule heating during the electroforming	47

CONTENTS

5.2	Electroforming effect on the electrical conduction behavior of TiO_2 . .	48
5.2.1	Electroforming with a voltage source	48
5.2.2	Electroforming with a current source	53
5.3	Modeling of the conduction behavior in the electroformed TiO_2 . . .	59
5.3.1	Calculation of the voltage distribution in $\text{Pt}/\text{TiO}_x/\text{Pt}$	61
5.3.2	Numerical calculation of the electric conduction behavior . . .	62
5.3.3	Algorithm of the calculation	64
5.3.4	Calculation results	65
6	Unipolar resistive switching behavior	71
6.1	Electroforming for unipolar resistive switching	71
6.2	Unipolar resistive switching characteristics	72
6.2.1	Unipolar resistive switching in stack switching cells	73
6.2.2	Unipolar resistive switching in modified stack switching cells .	78
6.2.3	Impedance spectroscopy	80
7	Bipolar resistive switching behavior	85
7.1	Voltage-controlled BRS measurements	85
7.1.1	Polarity dependence of the BRS	85
7.1.2	Pad-size dependence of the BRS	88
7.1.3	Abnormal BRS behavior	89
7.2	Current-controlled BRS measurements	95
7.2.1	BRS measurements in vacuum	96
7.3	Electrical conduction behavior in the HRS and the LRS	98
7.3.1	Current-voltage characteristics at various temperatures	99
7.3.2	Current-time characteristics at various constant voltages . . .	102
7.4	Transition to unipolar resistive switching characteristics	102
7.5	Modeling of the BRS behavior	103
7.5.1	Electrochemical reaction through the Helmholtz layer	103
7.5.2	Drift-diffusion of oxygen vacancies and electrons in TiO_x . . .	107
7.5.3	Finite difference method for the calculation	109
7.5.4	Calculation results	114
	Summary	123
	Bibliography	127
	Curriculum vitae	131