Declaration

I hereby declare that the work presented in this thesis titled "*Flexible Resistive Memory Devices with Solution Processed Polymer:2D Material Composites as Switching Layer*" submitted to the Indian Institute of Technology Jodhpur in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Prof. Shree Prakash Tiwari and Dr. Arpit Khandelwal. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.



Shalu Saini
P19EE013

Certificate

This is to certify that the thesis titled "*Flexible Resistive Memory Devices with Solution Processed Polymer:2D Material Composites as Switching Layer"* submitted by Shalu Saini (P19EE013) to the Indian Institute of Technology Jodhpur for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work done by her under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.



Dr. Arpit Khandelwal
Thesis Supervisor



23/05/2025
Prof. Shree Prakash Tiwari
Thesis Supervisor

Abstract

Flexible electronics has emerged as an important technology due to its versatility and potential applications in various on-body wearables, electronic skin, smart prosthetics, and various devices for health monitoring. In recent years, resistive random-access memory (RRAM) has been extensively explored as a suitable non-volatile memory device for flexible electronics owing to its simple structure, ease of fabrication, and the ability to incorporate various engineered and solution processed switching layers which are suitable for low cost, low temperature and large area processing. Though there have been continuous efforts to enhance the performance of the solution processed flexible RRAMs, there have been multiple issues such as poor endurance and cycle to cycle variability which need to be addressed. This work is an effort towards applying strategies to address the performance issues of solution processed flexible RRAM devices. More specifically, it involves comprehensive exploration of composites of solution processed polymers and 2D materials aiming to improve the performance parameters as well as shelf-life stability. Moreover, multilevel resistive switching in flexible RRAM devices is also demonstrated.

To start with, resistive switching behavior of bilayer of poly(4-vinylphenol) (PVP): molybdenum disulfide (MoS_2) composite and TiO_2 in RRAM devices were explored on both rigid and flexible substrates. Flexible devices fabricated with this PVP:MoS_2/TiO_2 bilayer on polyethylene naphthalate (PEN) substrate operated on low average SET and RESET voltages (V_{SET} & V_{RESET}) of 1.5 V and −0.7 V with decent endurance of 200 cycles and high I_{ON}/I_{OFF} of more than 10^3 at reading voltage of 0.2 V. These devices maintained decent switching upon bending up to a radius of 7 mm.

The next engineered combination was poly(N-vinylcarbazole) (PVK):MoS_2/TiO_2. Flexible RRAM devices with this hybrid bilayer exhibited excellent switching with low V_{SET} and V_{RESET} of 1.2 and -1.5 V respectively, high endurance of 1000 cycles, and high stability upon bending with radii up to 7 mm for 100 cycles. A comprehensive investigation of long-term environmental stability and performance was also performed by systematically characterizing the devices for a duration of 20 months and it was found that devices were able to maintain their switching behavior with excellent retention of 10^4 s even after being in ambient environment for this long duration, indicating high shelf life. Moreover, effect of exposure to humidity and heating were studied confirming good stability against these. These investigations indicated suitability of PVK:MoS_2/TiO_2 as a switching layer candidate for environmentally stable RRAM devices for flexible electronics.

Finally, composite of a rarely explored 2D material ($MoSe_2$) with PVP (PVP:$MoSe_2$) was demonstrated as a potential resistive switching layer for flexible RRAM devices. Fabricated flexible RRAM devices exhibited forming-free and excellent resistive switching with low V_{SET} & V_{RESET} (0.7 V / ~ -1 V), high DC endurance of more than 1000 cycles, and excellent retention time of 10^4 s with decent I_{ON}/I_{OFF} of ~10^3. These devices exhibit multilevel resistive switching for 2-bit storage (four levels), by tuning the compliance current values, which can be the simplest way to achieve this functionality. This study also opens up a direction for exploration of other unique material combinations for switching layers towards application in multibit storage, as it may contribute to low cost, high density, and nonvolatile flexible RRAM devices.

Acknowledgements

This thesis represents the culmination of not only my own efforts but also the invaluable guidance and support I received from numerous individuals throughout this challenging yet rewarding journey.

First and foremost, I wish to express my deepest gratitude to my Ph.D. thesis supervisors, *Prof. Shree Prakash Tiwari* and *Dr. Arpit Khandelwal,* for granting me the opportunity to join their esteemed research group (FLAME) and for providing an exceptional team to collaborate with. Their unwavering support, encouragement, and guidance have been instrumental in shaping my academic and research journey. I am particularly grateful for their insightful feedback, enduring patience, and constant motivation, which inspired me to persevere through both successes and setbacks. Beyond their remarkable research expertise, Specially I would like to sincerely thank to *Prof. Shree Prakash Tiwari Sir* for imparting essential communication and presentation skills, which have significantly contributed to my personal and professional growth. His mentorship has been a cornerstone of my journey, and for that, I am profoundly grateful.

I also thank *Dr. Saakshi Dhanekar*, *Dr. Amandeep Kaur*, and *Dr. Satyajit Sahu,* Members of the Doctoral Committee, for providing their valuable feedback and encouragement that helped me in expanding my research from various perspectives.

I extend my heartfelt gratitude to my seniors, *Dr. Amit Shringi and Dr. Atanu Betal,* for their constant motivation and for generously sharing their insights, both technical and non-technical, throughout my research journey. Their guidance has been a source of inspiration and has significantly contributed to my personal and professional development.

I am equally grateful to my colleagues, *Mr. Anurag Dwivedi, Mr. Anil Lodhi, Miss. Gargi Konwar, Dr. Ashok, Dr. Sachin, Swati, Somnath, Nishi, Ritesh, Monika, Amit, Shaqib, Suraj, Sumit, Jai, Mubasir, Suresh, Vikash, Kishan, Arpita, and Puja*, standing by my side during challenging times. Their unwavering support, camaraderie, and encouragement made this journey not only more bearable but also memorable. I deeply cherish the stimulating discussions, shared moments of joy and sorrow, and the countless memories we created together.

I extend my sincere gratitude to *Dr. Sunita Birara* and her supervisor, *Dr. Ramesh K. Metre,* for their valuable collaboration and support during this research. Their contributions and assistance have been greatly appreciated.

I would like to extend my heartfelt gratitude to my friends who have been a pillar of strength and encouragement throughout this journey. Their unwavering support, kindness, and constant presence have been invaluable during the highs and lows of this experience. Thank you, *Dr. Amrita, Mr. Yogendra, Mr. Sarvjeet, Mr. Keyur, Mr. Srinivas, Dr. Kiran and Dr. Ram* for always being there to uplift me during tough times and for celebrating my successes with genuine joy. Your friendship has been a source of immense comfort and motivation, and I am deeply grateful for the incredible memories, laughter, and meaningful moments we have shared along the way. This journey would not have been the same without your support, and I will forever treasure the bond we share.

I would like to express my deepest gratitude to the most special people in my life, whose love, support, and presence have been my greatest strength throughout this journey.

To the love of my life**,** *Rajarshi Maity*, your unwavering encouragement, patience, and belief in me, even from miles away, have been a constant source of inspiration. Your love has kept me grounded and motivated through every challenge, and for that, I am endlessly grateful.

I heartily thankful to my parents *Mr. Satyapal Saini & Mrs. Saroj Saini*, who have been my greatest supporters and my unwavering pillars of strength, I am deeply indebted to you for your unconditional love, sacrifices, and constant encouragement. To my elder sister *Dr. Luxmi Rani* and My brother *Mr. Yogesh Kumar*, my Di and Jija ji, *Mrs. Parul Saini & Mr. Manu Jain*, thank you for your endless support and for always believing in my dreams. You all mean the world to me.

To my grandparents ***Lt. Ilam Chand Saini & Lt. Smt. Shanti Devi,*** I dedicate this work to your loving memories, which continue to guide and inspire me every day. I hope this achievement makes you proud.

Finally, to my adorable cat *Pihu,* thank you for filling my life with joy, warmth, and unconditional love. Your presence has been a source of comfort and happiness during my toughest moments.

I also bow in devotion to **Lord Krishna**, whose divine guidance, blessings, and teachings have been a beacon of light during difficult times. My faith in Him has given me strength, resilience, and peace in this journey.

To each of you, I owe a debt of gratitude that words alone cannot express.

Shalu Saini
P19EE013

Contents

		Page
Abstract		v
Acknowledgements		vii
Contents		ix
List of Figures		xi
List of Tables		xv
List of Symbols		xvii
List of Abbreviations		xix
Chapter 1: Introduction		1
1.1	Resistive Random Access Memory	2
	1.1.1 Valance change RAM (VCRAM)	3
	1.1.2 Conducting Bridge RAM (CBRAM)	4
	1.1.3 Structures of RRAM device	4
1.2	Performance Parameters of Resistive Switching Devices	5
	1.2.1 Endurance	5
	1.2.2 Retention	6
	1.2.3 Variability	6
1.3	Conduction Mechanism of Resistive Switching	8
	1.3.1 Direct Tunnelling	8
	1.3.2 Fowler-Nordheim Tunneling	8
	1.3.3 Thermionic Emission	9
	1.3.4 Poole-Frenkel Emission	9
	1.3.5 Space Charge Limited Conduction	9
1.4	Current Status of Flexible RRAM	9
1.5	Performance Requirements and Challenges of Flexible RRAM	11
	1.5.1 Flexibility and Stretchability	11
	1.5.2 Substrate Selection	12
	1.5.3 Failure Mechanism of RRAM device	13
1.6	Research Focus and Thesis Organization	13
Chapter 2: Fabrication and Characterization Techniques		
2.1	Fabrication of flexible RRAM device	17
2.2	*Spin Coating*	18
2.3	Thermal Evaporation	19
2.4	*Atomic Layer Deposition (ALD)*	20
2.5	*Ultra-Violet and Visible Diffuse Reflectance Spectroscopy (UV-Vis DRS)*	21
2.6	*Atomic Force Microscopy (AFM)*	22
2.7	*Raman Spectroscopy*	23
2.8	*Surface Profiling*	24
2.9	*Differential scanning calorimetry (DSC)*	25
2.10	*2.4.6 Thermogravimetric analysis (TGA)*	25
2.11	Electrical Characterization & Parameter Extraction	26
Chapter 3: Investigation of Resistive Switching Behavior of Selected Materials and Combinations		
3.1	*Introduction*	29
3.2	*Fabrication of RRAM Devices with Various Pristine, Composite, and Hybrid Layers*	30
3.3	*Results and Discussion*	31
3.4	Conclusion	33
Chapter 4: Investigation of Resistive Switching from PVP:MoS_2/TiO_2 Hybrid Bilayer		
4.1	*Introduction*	35
4.2	*Fabrication of Rigid and Flexible RRAMs*	36
4.3	*Results and Discussion*	36
4.4	Conclusion	42

Chapter 5: Flexible RRAM Devices with in MoS2:PVK/TiO2 Hybrid Bilayer
5.1 *Introduction* 43
5.2 *Fabrication of Ag/MoS2:PVK/TiO2/ITO Flexible RRAMs* 44
5.3 *Results and Discussion* 45
5.3.1 Film and Material Characterization 45
5.3.2 Electrical Performance of Flexible RRAMs 47
5.3.3 Conduction & Switching Mechanism 48
5.3.4 Bending Stability 50
5.3.5 Shelf- Life Stability 51
5.3.6 Humidity and Temperature Stability 52
5.4 Conclusion 55

Chapter 6: High Performance Flexible RRAM Devices for Multilevel Resistive Switching
6.1 *Introduction* 57
6.2 *Fabrication of Solution Processed Hybrid Flexible RRAMs* 58
6.3 *Results and Discussion* 59
6.3.1 Surface Morphology and Material Characterization 59
6.3.2 Electrical Performance of Flexible RRAMs 59
6.3.3 Conduction & Switching Mechanism 62
6.3.4 Charge Transport Mechanism 64
6.3.5 Reliability Test 64
6.3.6 Bending Stability 65
6.4 Conclusion 66

Chapter 7: Summary and Future Work
7.1 Summary 67
7.2 Scope for Extension and Material Selection Guidelines for Future Flexible RRAM Devices 69
7.3 Conclusion 69
7.4 Future Scope 70

References 74

List of Figures

Table	*Title*	*Page*
1.1	Schematic diagram of flexible electronics and its applications.	1
1.2	Schematic diagram of switching mechanism of bipolar RRAM device.	2
1.3	Schematic diagram of switching mechanism in VCRAM.	3
1.4	Schematic diagram of switching mechanism in CBRAM.	4
1.5	Schematic structures of the commonly used RRAM device. (a) BE is common for each cell and the switching layer and TEs were patterned. (b) Cross-point structure. (c) Cross-bar structure forms multiple cross-point cells interconnected to each other.	5
1.6	Endurance plot of RRAM device at read voltage of 0.2 V for more than 450 consecutive DC cycles with distinguishable LRS and HRS throughout the measurement. (b) Retention of RRAM device at read voltage of 0.2 V for around 10000 seconds with distinguishable LRS and HRS throughout the test.	6
1.7	Cumulative probability distribution and statistical distribution of SET and RESET voltages respectively of a particular device for cycle-to-cycle variability test. (c) I-V characteristics of a particular flexible RRAM device for testing of device-to-device variation.	7
1.8	Band Diagram of M-I-M structure (a) Direct tunneling and (b) F-N tunneling.	8
1.9	Schematic structure of bending radius (a), where Θ is bending angle, r is the bending radius and l is the length of the device and strain ratio (b) of flexible RRAM.	12
1.10	Chemical structure of common flexible substrates (a) PET, (b)PEN, (c) PI.	12
1.11	Cracks in flexible RRAM devices which is the main reason of failure of device.	13
2.1	Digital image of ultrasonic cleaner	17
2.2	(a) Schematic structure and (b) digital image of the fabricated device.	18
2.3	(a-d) Schematic illustration of thin film deposition using spin coating technique, and (e) Digital image of the HOLMARC spin coater.	19
2.4	(a) Schematic illustration and (b) Digital image of thermal evaporation system.	19
2.5	(a) Schematic illustration of one complete cycle of ALD.	20
2.6	(a) Digital image of the Savannah S200 ALD system and (b) schematic process flow of ALD system.	20
2.7	(a) Schematic and (b) digital image of the UV-Vis Spectrometer.	21
2.8	(a) Schematic and (b) digital image of the AFM.	22
2.9	(a) Schematic and (b) digital image of the RAMAN spectroscopy.	23
2.10	(a) Schematic and (b) digital image of the Profilometer.	24
2.11	(a) Schematic and (b) digital image of the DSC.	25
2.12	(a) Schematic and (b) digital image of the TGA.	26
2.13	(a) Schematic and (b) digital image of the SCS 4200.	27
2.14	(a) I-V characteristics of flexible RRAM device with VSET/VRESET of ~1 V/-1.5 V. (b) The DC endurance of 1000 switching operation at read voltage of 0.2 V.	28
3.1	Liquid phase exfoliation process of 2D materials.	30
3.2	(a) Device Structure, (b) digital image of fabricated flexible RRAM. Chemical structure of PVP (c), PVK (d), MoS_2 (e), and $MoSe_2$ (f).	31
3.3	I-V Characteristics and corresponding retention time of pristine PVK (a & f), PVP (b & g), MoS_2 (c & h), and $MoSe_2$ (d & i), and TiO_2 (e & j) respectively. In retention time plots are carried out at read voltage of 0.2 V for both LRS and HRS.	32
3.4	I-V Characteristics of composites of PVP:MoS_2 (a), PVP:$MoSe_2$ (b), PVK:MoS_2 (c), and PVP:$MoSe_2$ (d) switching layer RRAM device.	32
3.5	I-V Characteristics of bilayer of PVP:MoS_2/TiO_2 (a), PVP:$MoSe_2$/TiO_2 (b), PVK:MoS_2/TiO_2 (c) and PVP:$MoSe_2$/TiO_2 (d) switching layer RRAM device.	33
4.1	(a) Schematic structure of fabricated RRAM device, (b) AFM image of TiO_2/(PVP:MoS_2) film on rigid substrate, (c & d) digital picture of flexible sample.	36
4.2	I-V characteristics of Ag/(PVP:MoS_2)/TiO_2/ITO (a) rigid and (d) flexible substrate respectively. Retention time characteristics for rigid (b), and flexible (e) RRAM device. Multiple cycle repeatability for rigid (c) device up to 100 cycles, and (f) flexible device of I–V up to 200 cycles.	37
4.3	I–V characteristics with varying compliance current for rigid (a), flexible substrate (b) RRAM device.	38

4.4	Conduction mechanism in SET and RESET are shown for rigid in (a) & (b), and flexible in (c) & (d) respectively, demonstrated through double log I–V plots.	38
4.5	Cycle to cycle variation of operating voltage distribution for SET (a), and RESET (b). (c) Endurance of consecutive 200 DC cycles at read voltage of 0.2 V. Digital image of flexible device is shown in the inset. (d) I–V characteristics at different bending radius up to 7 mm.	39
4.6	Schematic energy band diagram for Ag/(PVP:MoS_2)/TiO_2/ITO RRAM device. (a) Before biasing, (b) during SET state, and (c) during RESET state.	40
4.7	Switching mechanism for SET (a) and RESET (b).	41
5.1	Schematic structure (a) and digital picture (b) of fabricated flexible RRAM device. AFM image of PVK/TiO_2 film (c), and PVK:MoS_2/TiO_2 film (d).	45
5.2	Figure 5.2 UV-Visible absorbance spectroscopy (a) and Tauc plot (b) of MoS_2. Plots of TGA (c) and DSC (d) for PVK, MoS_2, and PVK:MoS_2 composite. AFM image of surface of PVK/TiO_2 (e) and PVK: MoS_2/TiO_2 (f).	46
5.3	(a) I–V characteristics and (c) multiple cycles of Ag/PVK/TiO_2/ITO. (b) I–V characteristics and (d) multiple cycles of Ag/PVK:MoS_2/TiO_2/ITO.	47
5.4	Endurance characteristics at 0.2-V read voltage of devices: (a) Ag/PVK/TiO_2/ITO and (b)Ag/PVK: MoS_2/TiO_2/ITO. (c) & (d)Retention characteristics of Ag/PVK/TiO_2/ITO and Ag/PVK:MoS2/TiO2/ITO devices, respectively. Both the LRS and HRS currents are taken at 0.2 V read voltage.	48
5.5	Double log I–V characteristics of Ag/PVK:MoS_2/TiO_2/ITO (a) & (b), and Ag/PVK/TiO_2/ITO (c) & (d) for positive and negative voltage sweep.	49
5.6	Schematic of the switching mechanism for (a) LRS and (b) HRS showing the movement of Ag and oxygen ions.	49
5.7	(a) I–V characteristics for unbent, 12.5, 10-, and 7-mm bending. (b) Retention time analysis for unbent and bent conditions for 5000 s at 0.2-V read voltage for HRS and LRS current. (c) Standard deviation and average I_{ON}/I_{OFF} of device with and without bending. Inset shows the digital image of the bent device. (d) Endurance characteristics for 1000 cycles at 0.2 V read voltage, after bending studies and aging for two months.	50
5.8	Plots of switching characteristics (a) and corresponding V_{SET} and V_{RESET} and I_{ON}/I_{OFF} (b) of a particular device. (c) Plots of average values of V_{SET} and V_{RESET} and I_{ON}/I_{OFF} of five devices on a substrate investigated after 3, 6, 10, 11, 12, and 20 months. (d) I-V characteristics of five devices on a substrate after 20 months, indicating excellent shelf life. Retention characteristics of pristine, 12th month, and 20th month of characterization for (e) LRS and (f) HRS.	51
5.9	(a) Plots of I-V characteristics of a particular device upon exposure to different RH% levels (42, 84, 99, and after 24 hours at 42 %) and (b) corresponding plots of average values of V_{SET} and V_{RESET} and I_{ON}/I_{OFF} of five devices upon humidity exposure.	53
5.10	Variation of switching performance with heating temperature variation from RT to 100 ◦C. (a) I-V characteristics, Distribution of SET (b) and RESET voltage (c), and average ION/IOFF for ten cycles (d). (e) Plots of LRS and (f) HRS at various heating temperature values.	53
5.11	(a) Plots of retention after heating on 100 °C for 1 hour and (b) log (I) versus (1/kT) plot.	54
6.1	(a) Schematic structure and (b) digital picture of fabricated Ag/PVP:$MoSe_2$/ITO flexible RRAM device. Chemical structure of $MoSe_2$ (c) and PVP(d).	58
6.2	(a) Raman characteristics and (b) Tauc plot of $MoSe_2$ thin film. AFM image of (c) PVP, (d) $MoSe_2$, and (e) PVP:$MoSe_2$ thin film.	59
6.3	I–V characteristics of PVP (a), $MoSe_2$ (b), and PVP:$MoSe_2$ (c), respectively.	60
6.4	I–V characteristics of six randomly chosen devices from the same substrate of PVP (a), MoSe2 (b), and PVP:$MoSe_2$ (c), respectively, to investigate the device-to-device variation, and average I–V characteristics of those six devices for all three cases (d).	60
6.5	Exploration of multilevel switching through I–V characteristics (a) and retention time (b) of the Ag/PVP:$MoSe_2$/ITO RRAM device by variation of the compliance current. (c) Retention time plot of Ag/PVP:MoSe2/ITO RRAM device for '10', and '11' state in the current range of 100 μA to 1 mA.	61
6.6	Endurance of Ag/PVP:$MoSe_2$/ITO flexible RRAM devices for compliance currents of 1 mA (a), 500 μA (b), and 100 μA (c).	62
6.7	Double log I–V characteristics of Ag/PVP:$MoSe_2$/ITO flexible RRAM for SET (a) and RESET (b).	63

6.8 Schematic structure of the switching mechanism of Ag/ PVP:$MoSe_2$/ITO flexible RRAM for LRS (a) and HRS (b). 63
6.9 Schematic band diagram of Ag/PVP:$MoSe_2$/ITO flexible RRAM device at zero bias (a). Charge transport mechanism at LRS at positive voltage (b), and HRS at negative voltage (c). 64
6.10 Weibull plot of positive current (LRS) (a), negative current (HRS) (b), SET voltage (c), and RESET voltage (d). 65
6.11 I–V characteristics (a) and an average of SET and RESET voltages (b) for unbent and 12.5 and 7 mm bending radii. 65

List of Tables

Table	*Title*	*Page*
1.1	Comparison of flexible RRAM devices performance	9
1.2	Comparison of properties of flexible substrates	13
4.1	Comparison of Switching Parameters of Ag/PVP:MoS_2/TiO_2/ITO RRAM Devices on Rigid and Flexible Substrates	37
4.2	Summary of performance parameters of some recently reported RRAM devices with PVP as an active material component on rigid and flexible substrates.	41
5.1	Average V_{SET} And V_{RESET} of Five Flexible RRAM Devices with PVK:MOS_2/TIO_2 Hybrid Bilayer From a Substrate Characterized for 20 Months.	52
5.2	Summary of Performance Parameters of Some Recently Reported RRAM Devices with PVK and MoS_2 as an Active Material Component on Rigid and Flexible Substrates.	54
6.1	Quantitative Comparison of Device-to-Device Variability in Flexible RRAM Devices with $MoSe_2$ in Pristine, Composite, or Bilayer Form	61
6.2	Summary of Performance Parameters of Some Previously Reported RRAM Devices with $MoSe_2$ in Pristine, Composite, or Bilayer.	66
7.1	Comparison of Switching Parameters of Flexible RRAM Devices with Different Solution Processed Polymer:2D Material Composites Switching Layer	68

List of Symbols

Symbol	*Description*
β	Shape Factor
I	Current
J	Current Density
μ	Mobility of charge carrier
ε_m	Dielectric constant of the material
θ	Ratio of free to total carrier density
V	Voltage
C	Capacitance
V_o^{2+}	Positively charged oxygen vacancy
O_o^x	Oxygen ion on an oxygen site
T	Temperature

List of Abbreviations

Abbreviation	*Full form*
HRS	High Resistance State
LRS	Low Resistance State
RRAM	Resistive random-access memory
STTRAM	Spin Transfer Torque RAM
PCM	Phase-Change Memory
MRAM	Magnetic RAM
FeRAM	Ferroelectric-based memories
FeFET	Ferroelectric field-effect transistor memory
TEM	Transmission electron microscopy
MIM	Metal-insulator-metal
PVP	Poly(4-vinylphenol)
PVK	Poly (9-vinylcarbazole)
TMO	Transition metal oxides
BN	Boron nitride
WS_2	Tungsten disulfide (
GO	Graphene oxide
$MoSe_2$	Molybdenum diselenide
MoS_2	Molybdenum disulfide
AlO_x	Aluminum oxide
HfO_x	Hafnium oxide
TMD	Transition metal dichalcogenides
TiO_2	Titanium dioxide
TE	Top Electrode
BE	Bottom Electrode
VCRAM	Valance Change Random Access Memories
O_xRAM	Oxide Random Access Memories
CBRAM	Conductive Bridge Random Access Memories
ALD	Atomic Layer Deposition
AFM	Atomic Force Microscopy
V_{SET}	SET Voltage
V_{RESET}	RESET Voltage
Redox	Reduction-Oxidation
CVD	Chemical Vapor Deposition
TMA	Trimethyl Aluminum
TDMAH	Tetrakis-dimethyl-amido Hafnium
rpm	Rotation Per Minute
UV	Ultra Violet
I-t	Current-time
C-V	Capacitance-voltage
I-V	Current-Voltage
SMU	Source Measuring Unit
rms	Root Mean Square
ITO	Indium Tin Oxide
2 D	2-Dimensional
Ag	Silver
Ti	Titanium
HfO_x	Hafnium Oxide
AlO_x	Aluminium Oxide

IPA	Isopropyl Alcohol
PET	Polyethylene Terephthalate
PEN	Polyethylene naphthalate
PI	Polyimide
PU	Polyurethane
SEBS	Styrene Ethylene Butylene Styrene
EA	Activation energy
E_g	Energy gap
DSC	Differential Scanning Calorimetry
TGA	Thermogravimetric analysis
CV	Variation coefficient
WKB	Wentzel-Kramers-Brillouin
F-N	Fowler-Nordheim
PSPD	Position-sensitive photodetector
SCS	Semiconductor Characterization System
CCD	Charge-coupled device
SCLC	Space charge limited conduction
CMOS	Complementary metal-oxide-semiconductor
HOMO	Highest occupied molecule orbital
LUMO	Lowest unoccupied molecular orbital
RH	Relative humidity
RT	Room temperature
P_{SET}	SET power
P_{RESET}	RESET power