FABRICATION AND CHARACTERIZATION OF RESISTIVE SWITCHING TITANIUM DIOXIDE MEMRISTOR

A thesis submitted in partial fulfillment of the requirements for the award of degree of ***MASTER OF SCIENCE*** *in* ***PHYSICS***

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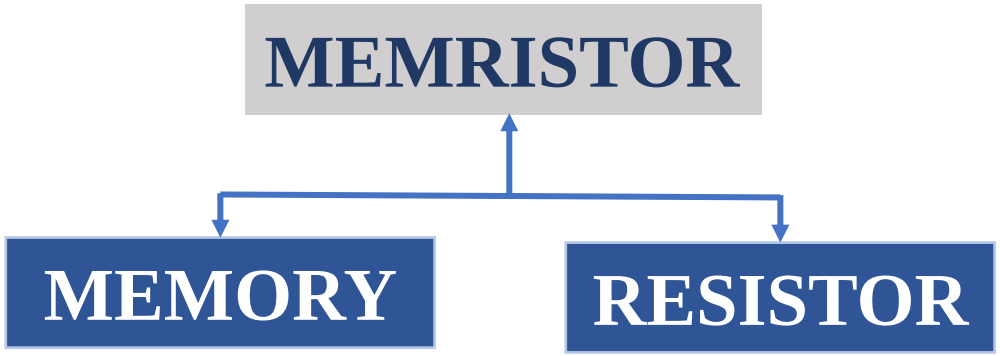
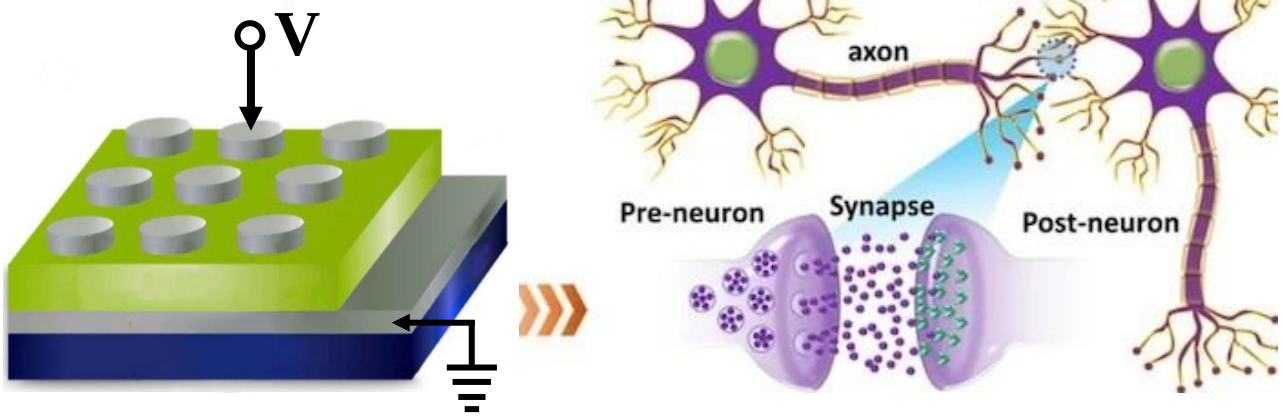
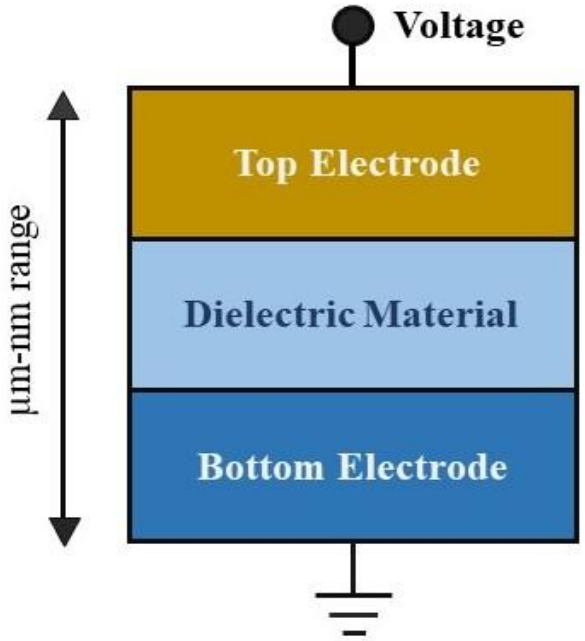
Introduction to Memristors



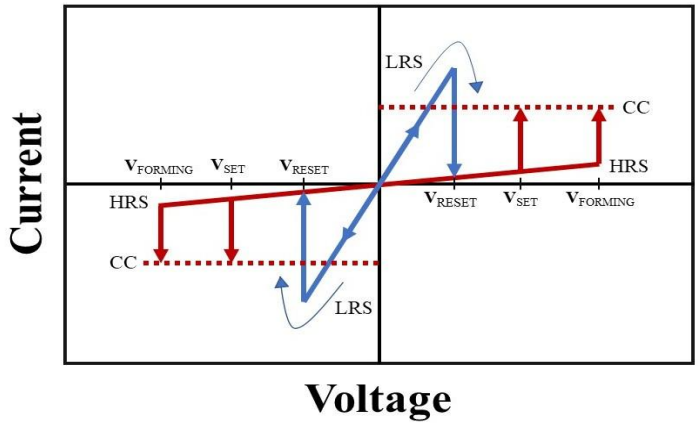


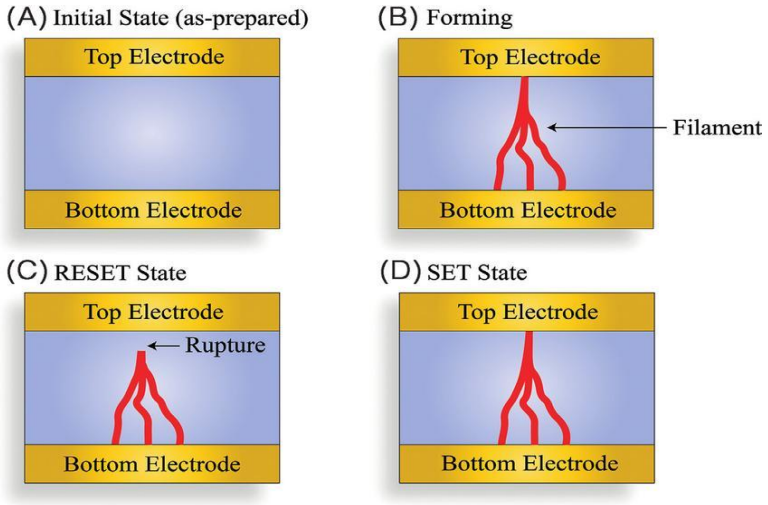


- **Non-Volatile memory device**
- **Neuromorphic computing**
- **MIM Structure**

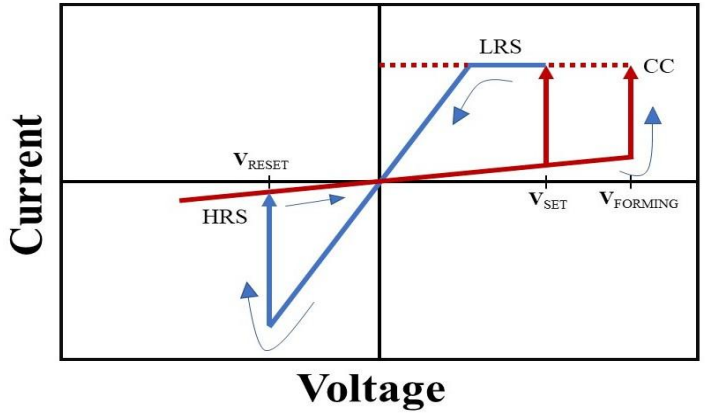
Resistive Switching

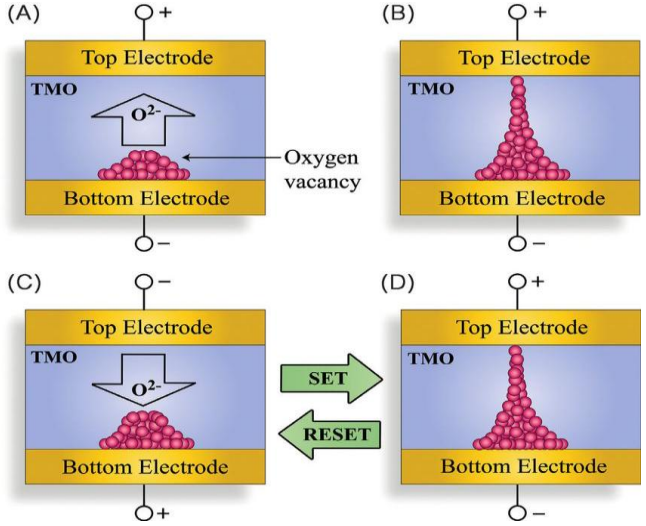
Unipolar Resistive Switching





Bipolar Resistive Switching

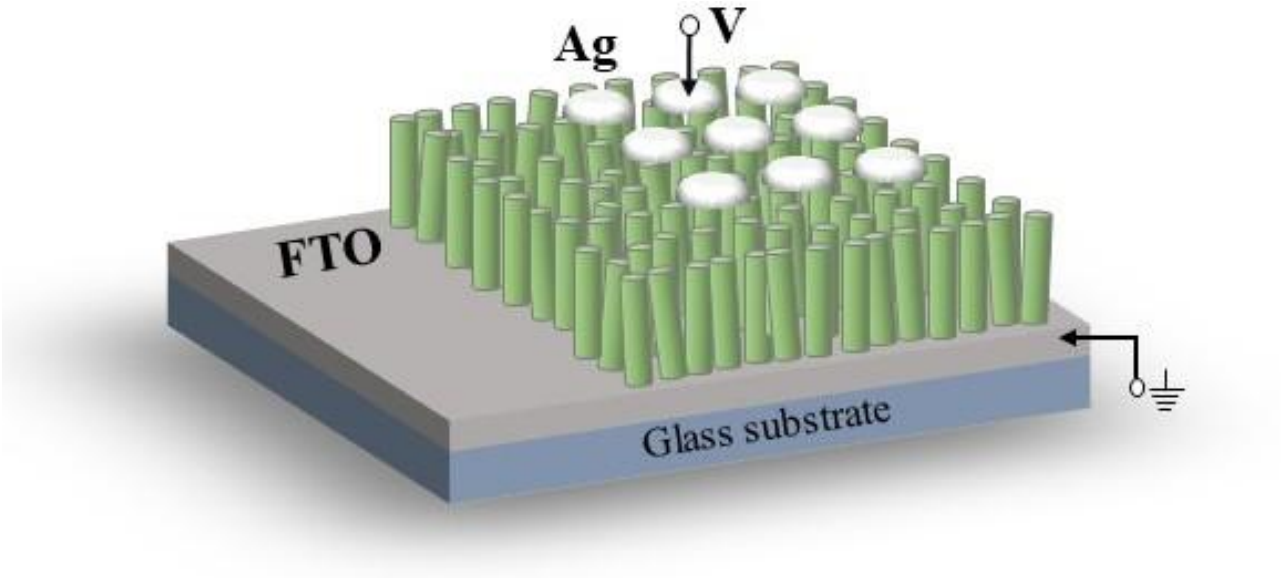




Subin, P. S., K. J. Saji, and M. K. Jayaraj. "Resistive switching in metal oxides for various applications." Nanomaterials for Sensing and Optoelectronic Applications. Elsevier, 2022. 273-299.

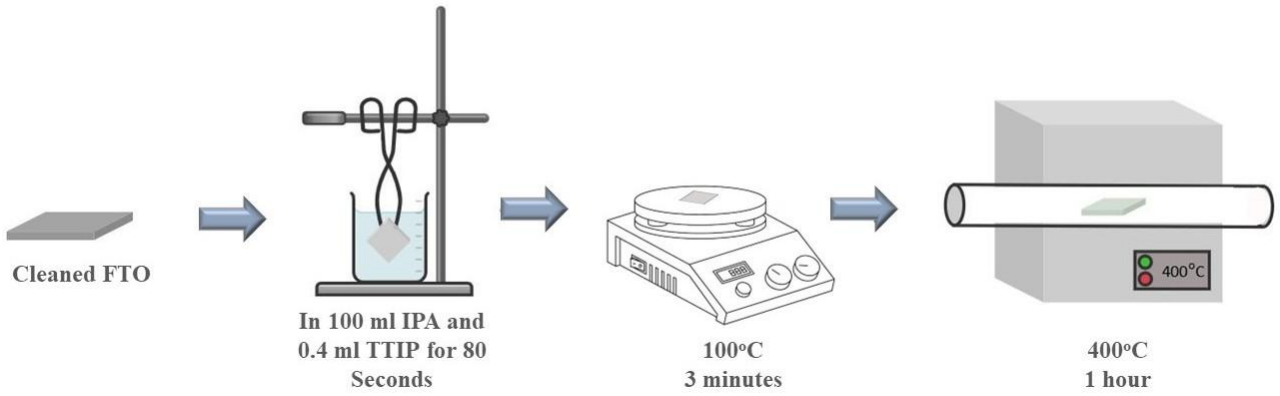
Objective of the Study

- Synthesize TiO_2 nanorods on FTO substrate using seed assisted hydrothermal method.
- Optimization of Hydrothermal growth conditions to suppress unwanted flower-like structures and achieve a clean nanorod morphology.
- Prevention of Silver electrode infiltration between the nanorod using PMMA.
- Fabricate memristor device.
- Characterize material and device properties.



Experimental details

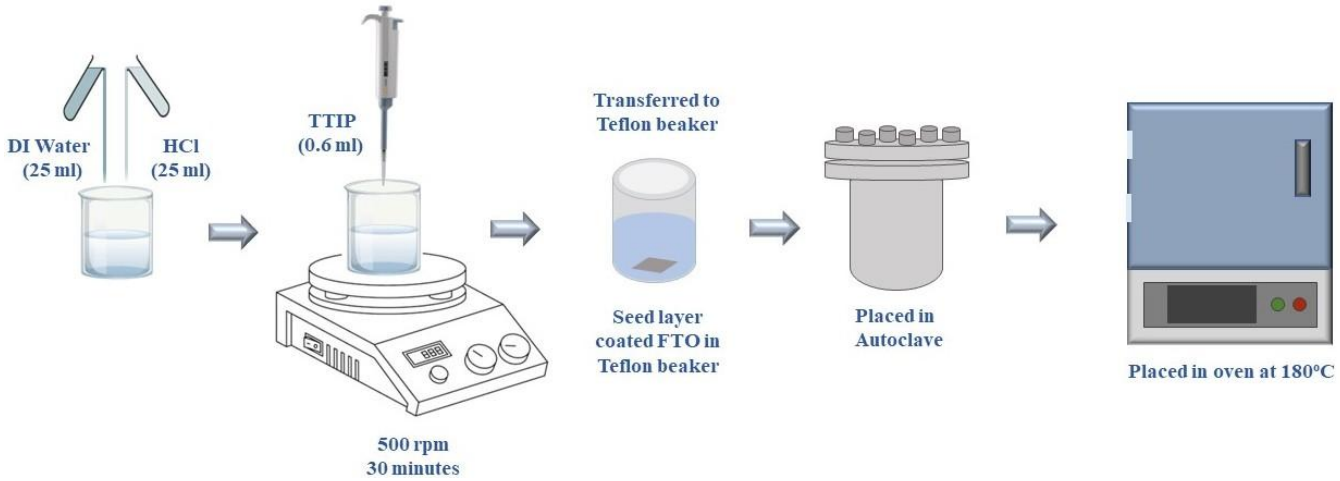
Seed layer Synthesis



- FTO ultrasonicated in Ethanol and DI water
- Dip coating for 80 seconds in 0.4ml TTIP and 100 ml IPA
- Dried in hotplate for 3 minutes at 100°C
- Annealed for 1 hour at 400°C

Hydrothermal Synthesis of TiO_2 nanorods

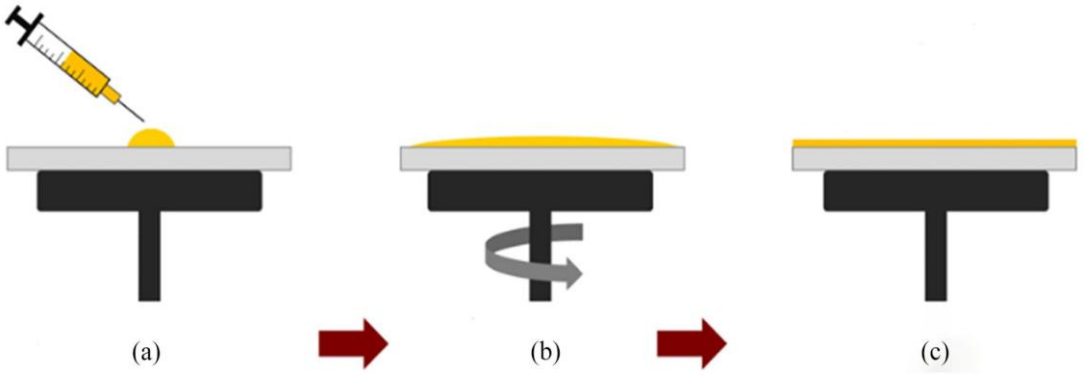
- Stirred 25 ml HCl , 25 ml DI water and 0.6 ml TTIP for 30 minutes
- Transferred to Teflon beaker where seed layer coated FTO is placed
- Placed in an Autoclave
- Placed in Oven at 180°C



Sharon, A., Subin, P. S., Arun, G., Jayaraj, M. K., & Antony, A. (2025). Surface-modified TiO2 nanorods using oxygen plasma for optical synaptic performance and neuromorphic computing applications. Surfaces and Interfaces, 64, 106357.

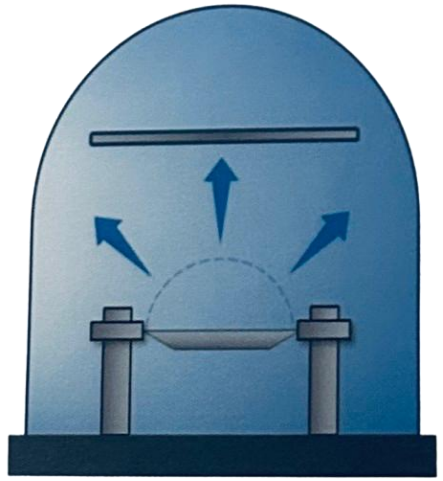
Spin coating with PMMA solution

- To fill the gap between the nanorods.
- PMMA solution of 3 wt% was prepared by dissolving 61.86 mg of PMMA (Alpha Aesar) in 2 ml of Anisole (Sigma-Aldrich, 99%).
- The mixture was stirred at 75°C at 1000 rpm for 1 hour and 20 minutes.
- Spin coated at 4000 rpm for 45 seconds
- Dried at 180°C for 3 minutes in hotplate
- Coated in one-layer and two-layer.



Top electrode deposition by thermal evaporation

- Base pressure : ~ 7 x 10^{-6}
- Source Current : 101 A
- Silver used : ~ 180 mg
- Thickness Achieved : ~ 150 nm
- Thickness measurement done using Stylus profilometer.

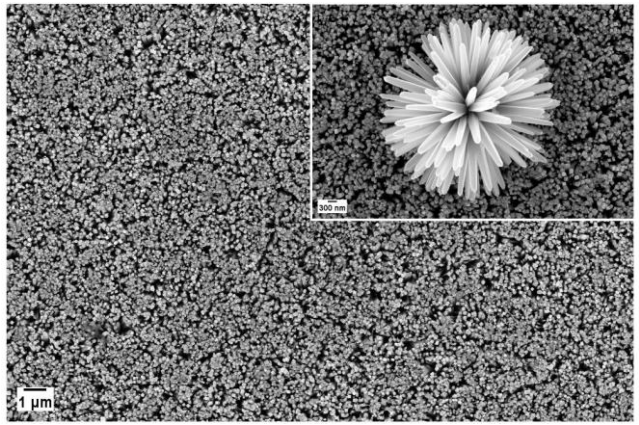


Results and Discussion

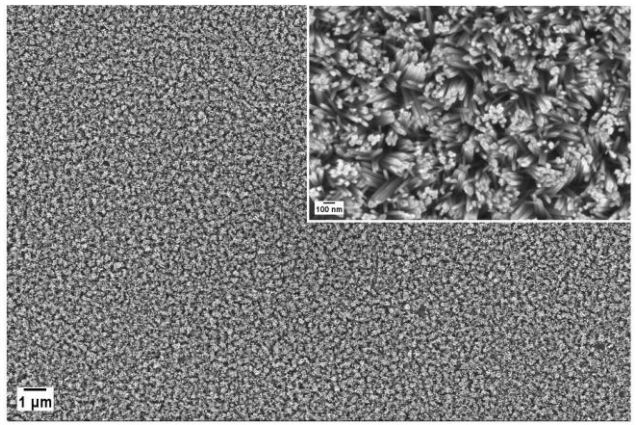
Characterization of TiO_2 nanorods

(a) Morphology

Rapid cooled samples

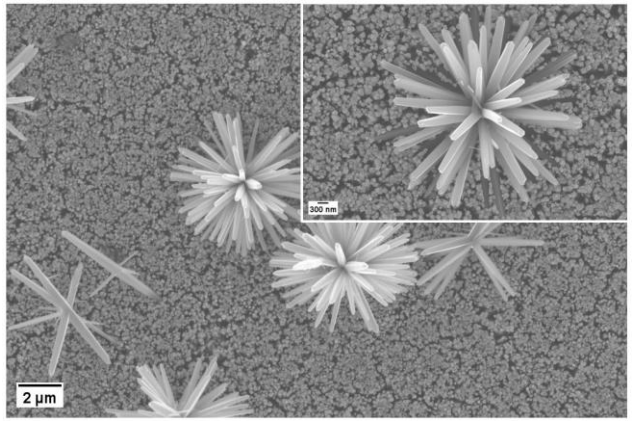


S_3* sample

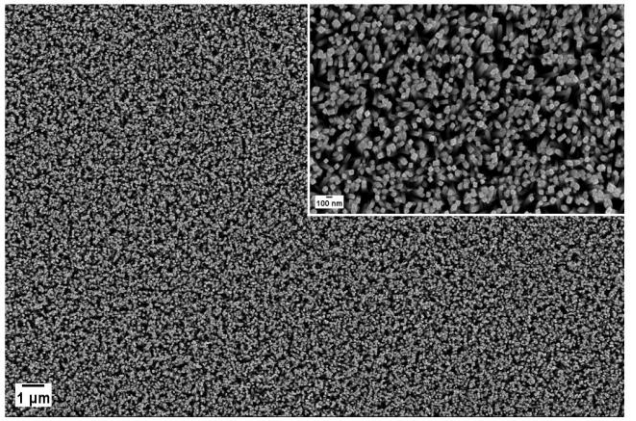


S_1* sample

Slow cooled samples



S_3 sample

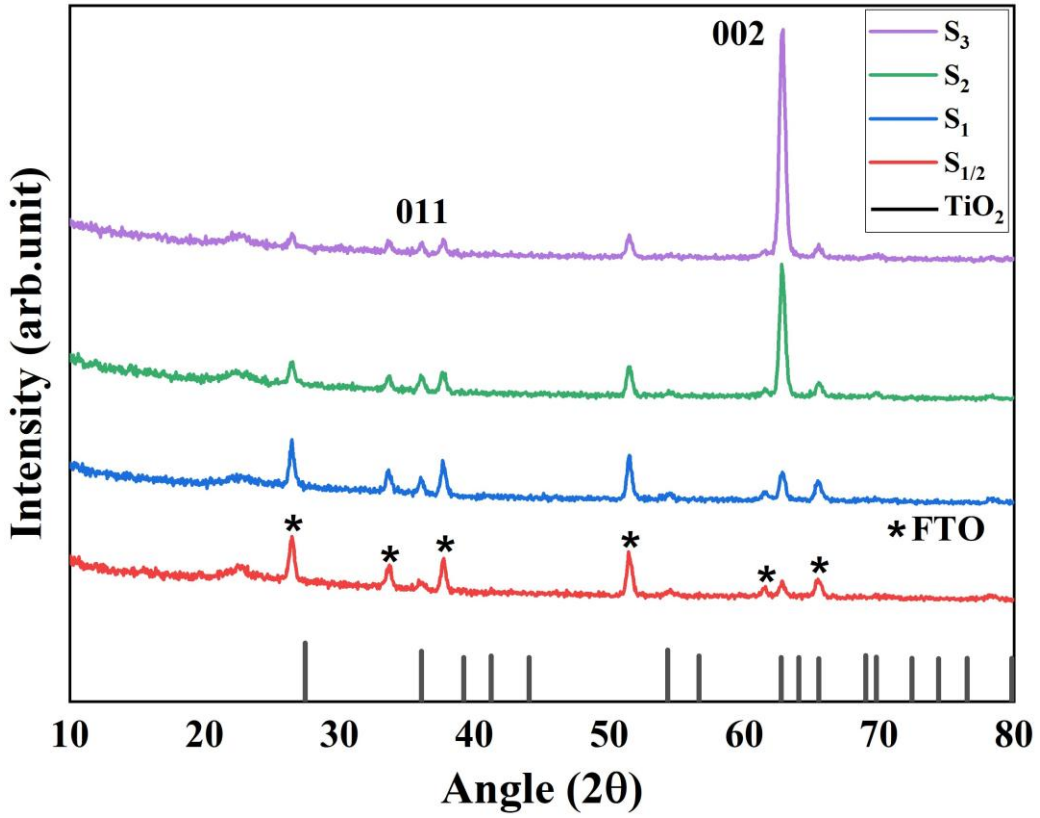


S_1 sample

S_3*	S_2*	S_1*	S_3	S_2	S_1	$S_{1/2}$
3 hours	2 hours	1 hour	3 hours	2 hours	1 hour	1/2 hour
Rapid cooled	Rapid cooled	Rapid cooled	Slow cooled	Slow cooled	Slow cooled	Slow cooled

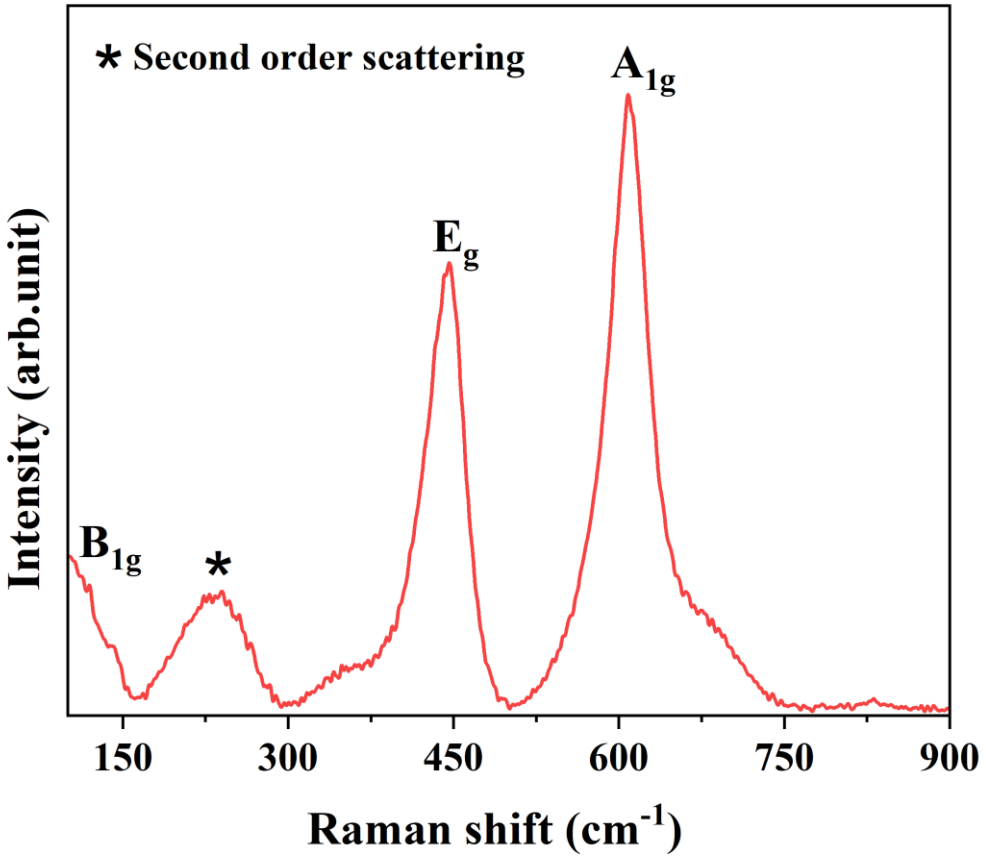
(b) X-Ray Diffraction

- Rutile TiO_2
- $2\theta = 62.7^o$ – (002) plane
- $2\theta = 36.1^o$ – (011) plane



(c) Raman Spectroscopy

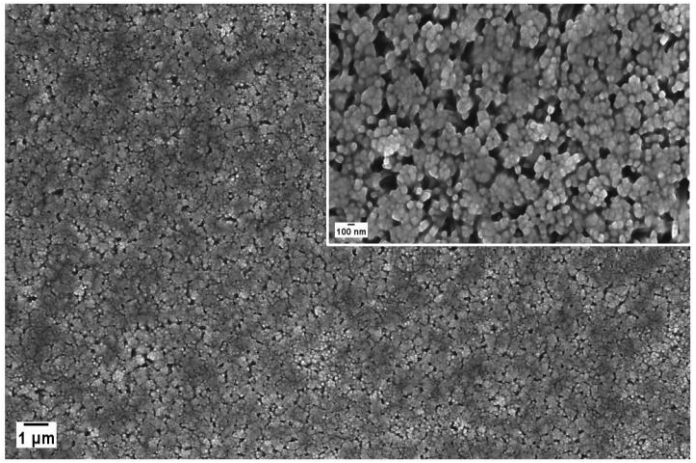
- 144 cm^{-1} B_{1g} mode,
- 446 cm^{-1} E_g mode,
- 610 cm^{-1} A_{1g} mode.



Subha, P. P., Hasna, K., & Jayaraj, M. K. (2017). Surface modification of TiO2 nanorod arrays by Ag nanoparticles and its enhanced room temperature ethanol sensing properties. Materials Research Express, 4(10), 105037.

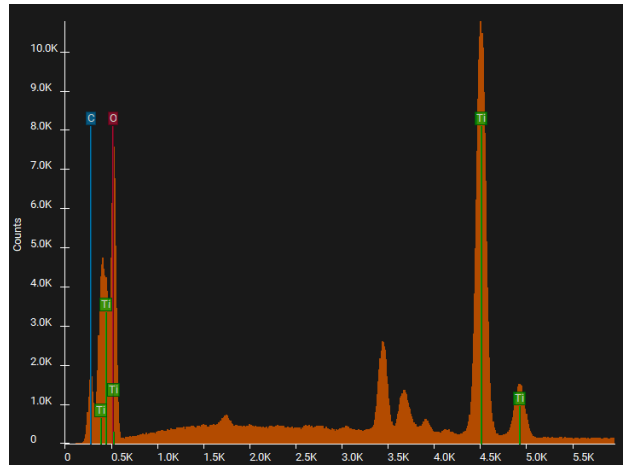
Characterization of PMMA coated TiO_2 nanorods

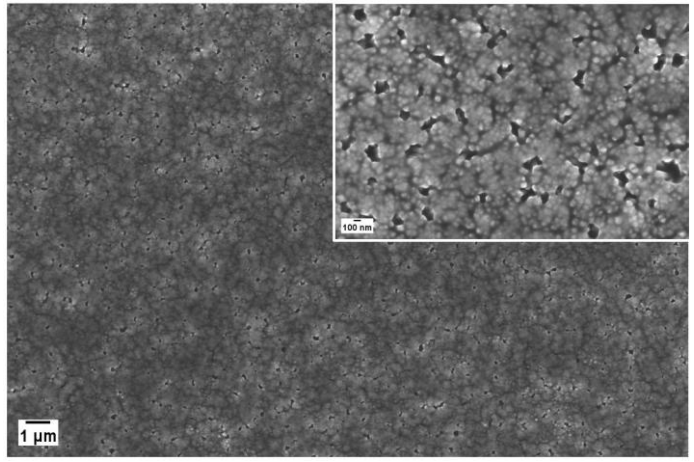
(a) Morphological and Elemental Analysis



PMMA Coated in one layer

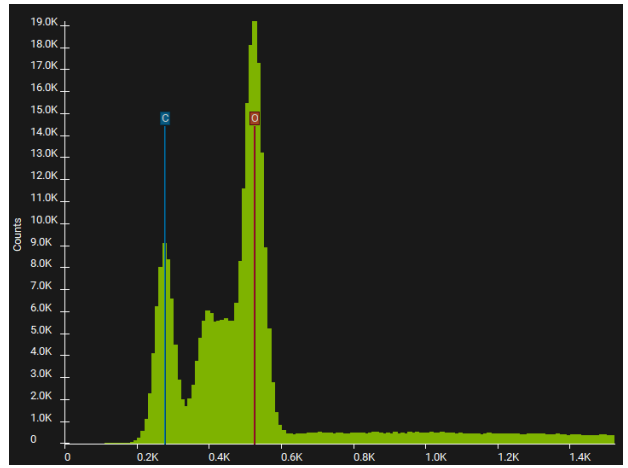
Element	Atomic %	Weight %
Titanium	26.71%	53.56%
Oxygen	57.18%	38.33%
Carbon	16.11%	8.11%



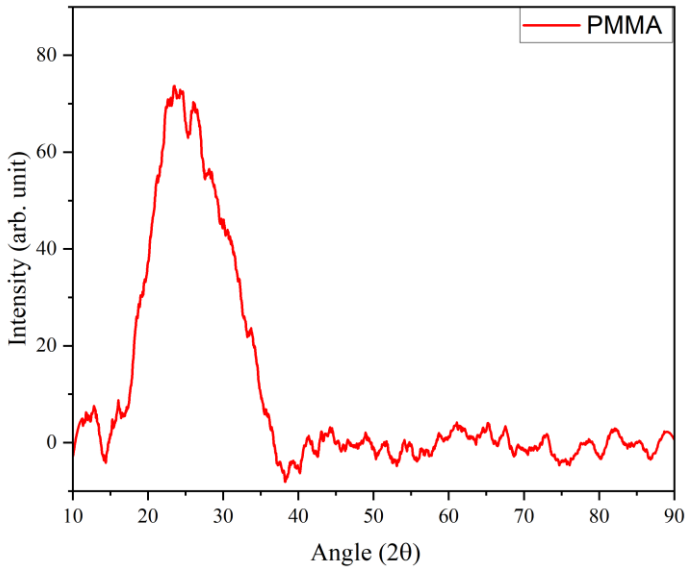


PMMA Coated in two layer

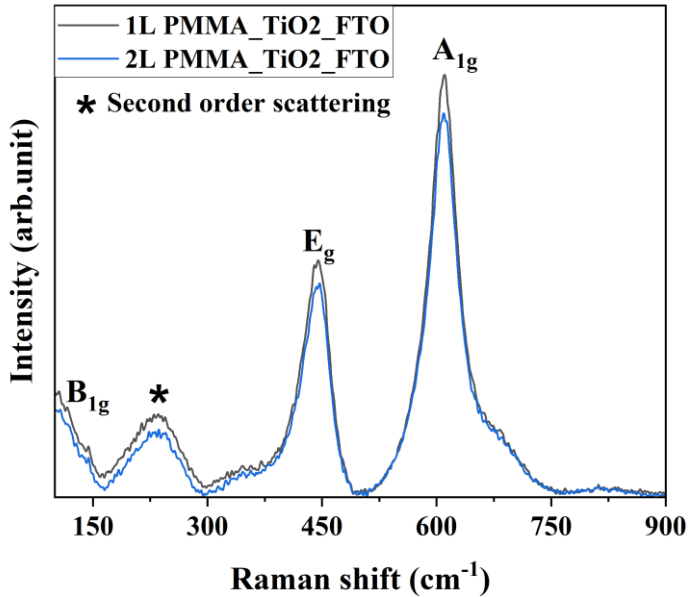
Element	Atomic %	Weight %
Carbon	57.75%	50.64%
Oxygen	42.25%	49.36%



(b) XRD

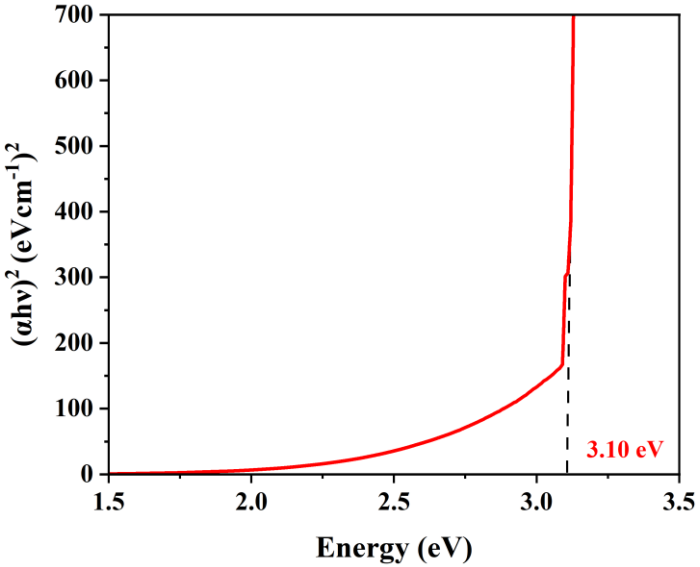


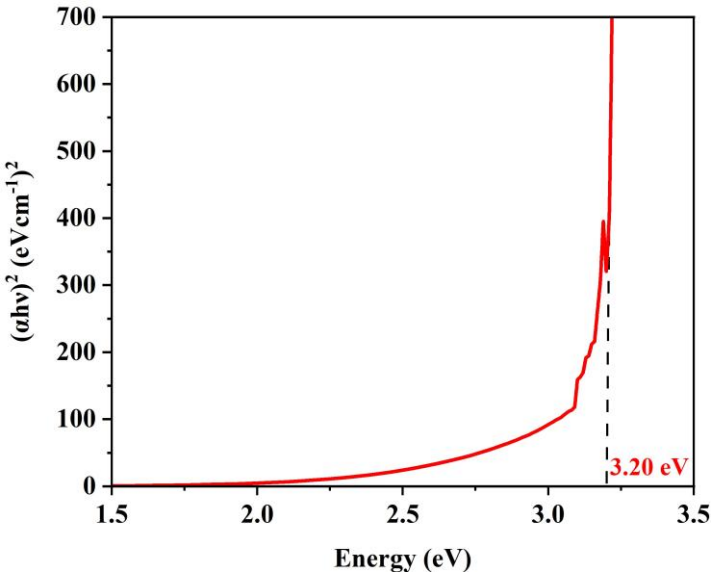
(c) Raman Spectroscopy



- Broad humps - Non-crystalline nature
- Reduction in Raman peak intensity – Increased thickness of PMMA layer
- TiO2 (rutile) – 3.0 eV
  1L PMMA_TiO2 – 3.1 eV
  2L PMMA_TiO2 – 3.2 eV
- Band gap widening – Increased thickness of PMMA layer

(b) UV-Vis Spectroscopy





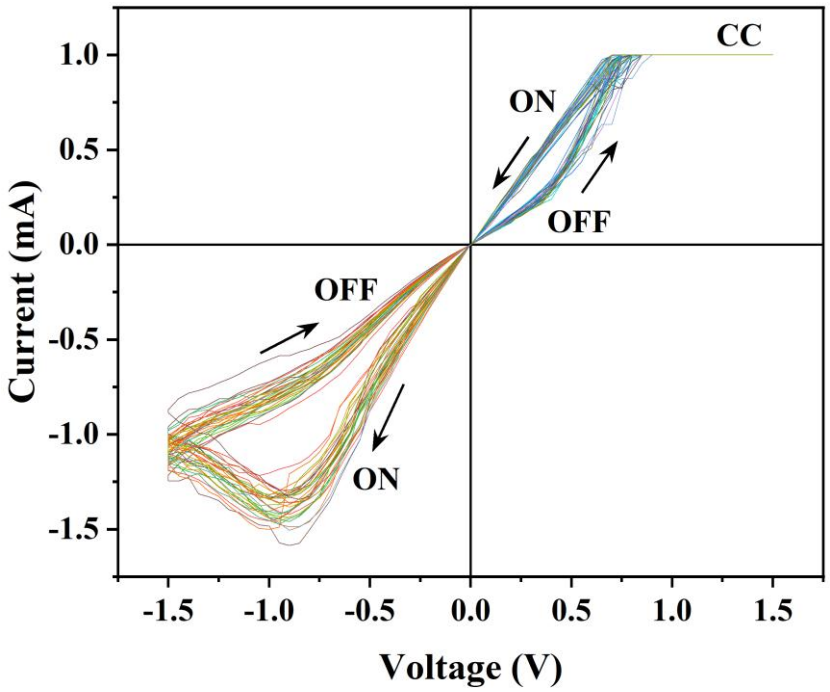
Electrical Characterization

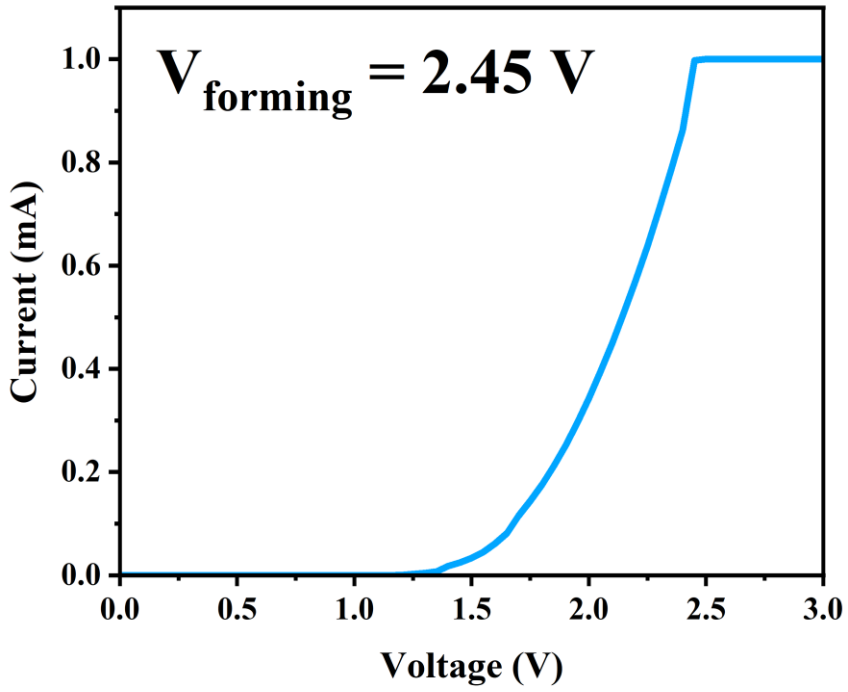
I-V Characteristics

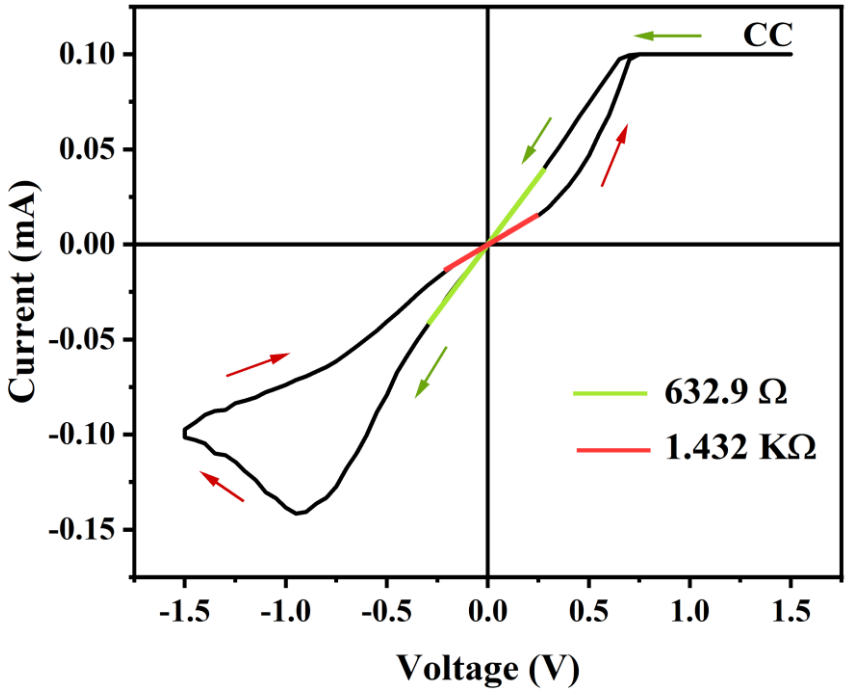
- Forming Voltage : 2.45 V
- V_{set} : 0.4 V
- V_{reset} : -0.9 V
- Endurance : 105 cycles

ON-OFF Ratio

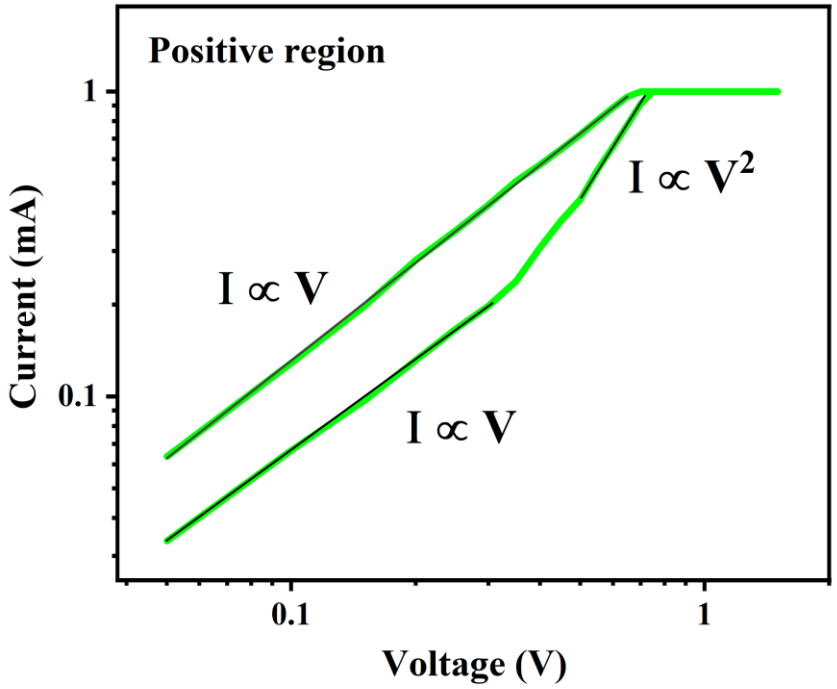
- R_{OFF} = 1.432 KΩ
- R_{ON} = 632.9 Ω
- ON/OFF Ratio = R_{OFF}/R_{ON}
  = 1.432 K Ω / 632.9 Ω
  = 2.232

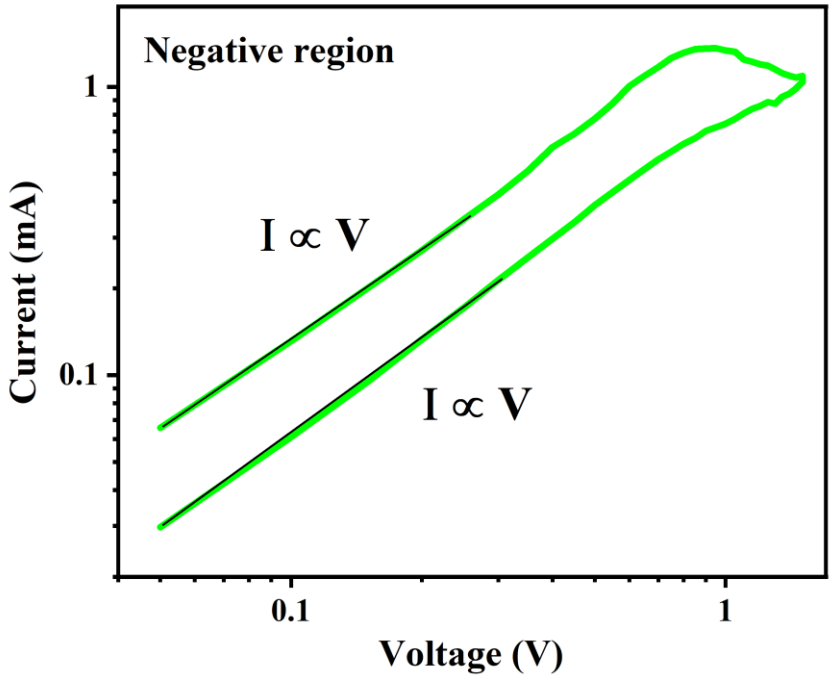




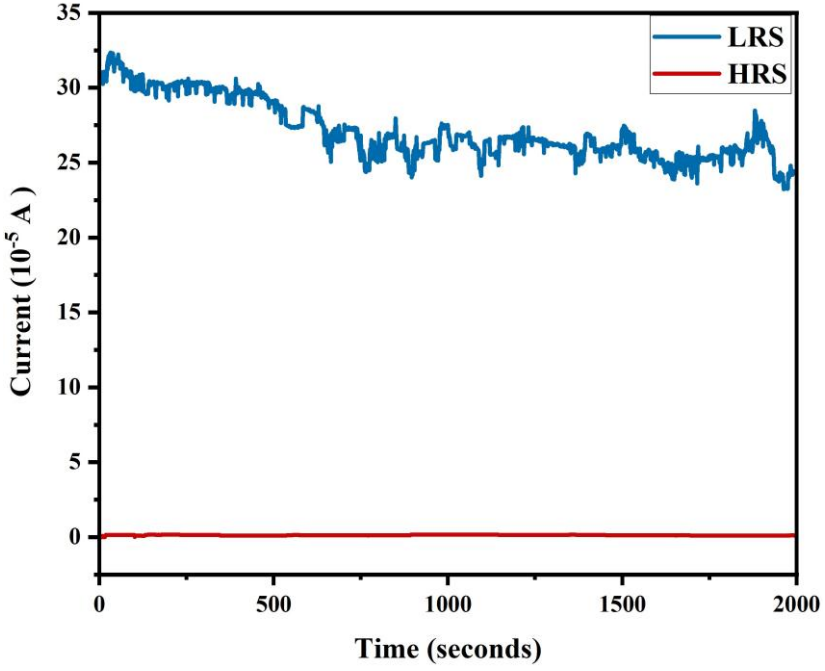


Conduction Mechanism





Retention



Conclusion

- **TiO_2-based memristor successfully fabricated using hydrothermal method.**
- **PMMA layer used to prevent Ag infiltration between nanorods.**
- **XRD and Raman spectroscopy confirmed rutile phase; FESEM showed nanorod morphology.**
- **UV-Visible was used spectroscopy to find band gap.**
- **Device showed clear bipolar resistive switching (SET ~0.4 V, RESET ~ -0.9 V).**
- **The device shows an endurance of 105 cycles, a retention time of 2000s and an ON/OFF ratio of 2.232.**

Future work

- **Explore the memristor's potential for neuromorphic computing:**
  - Mimicking synaptic functions like potentiation and depression.
- **Investigate photoresponse under UV illumination:**
  - Analyze I–V characteristics under varying light intensities.
  - Evaluate response time, photocurrent generation, and stability.

Thank you

Presented by
Fathima Shamsad C P