ADVANCING SUSTAINABLE ELECTRONICS: PRELIMINARY RESULTS ON CHITOSAN–PANI COMPOSITES FOR RESISTIVE MEMORY DEVICES

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Abstract - This study presents preliminary results on sustainably fabricated resistive random-access memory (ReRAM) devices using a bio-derived chitosan–polyaniline (PANI) composite. A 1:2 (w/w) chitosan–PANI sol–gel was prepared in deionized water and drop-cast onto ITO–PET substrates at room temperature; Ag top contacts formed the Ag/(Chitosan+PANI)/ITO–PET stack. Electrical characterization under ambient conditions reveals bipolar resistive switching with clear separation between low-resistance (LRS) and high-resistance (HRS) states. During the forward sweep the device enters LRS with ohmic ($I \propto V$) behaviour, consistent with a percolative path through PANI-rich domains. On the reverse sweep the device returns to HRS, exhibiting $I \propto V^2$ indicative of hopping-mediated transport through localized states. Endurance measurements show repeatable switching over 200 cycles at 1 V and 20 000 cycles at 3 V, while retention demonstrates stable state separation for ≥ 600 s at room temperature. These findings highlight low-energy, low-waste biopolymer–conducting-polymer composites for green memory applications.

Keywords - Chitosan–PANI, resistive switching, ReRAM, drop-casting, sustainable electronics, hopping conduction, ohmic conduction, ITO–PET.

I. INTRODUCTION

The rapid growth of modern electronic technologies has intensified the demand for energy-efficient, environmentally friendly, and scalable materials for next-generation memory devices. Conventional resistive switching (RS) materials, although widely studied, often rely on synthetic polymers, metal oxides, and fabrication routes that present challenges in terms of sustainability, biocompatibility, and environmental impact. As global emphasis increasingly shifts toward green electronics and sustainable manufacturing, bio-derived and eco-benign materials have emerged as promising alternatives for electronic device engineering[1]–[3].

Chitosan is a naturally occurring biopolymer commonly obtained from the deacetylation of chitin, offers several advantages—including biodegradability, non-toxicity, film-forming capability, and abundant availability—which position it as a compelling matrix material for sustainable electronic applications[4]–[6]. When blended with conducting polymers such as polyaniline (PANI), the resulting composite exhibits improved electrical conductivity, tunable charge transport pathways, and enhanced structural functionality suitable for resistive switching phenomena[7], [8]. The synergy between chitosan and PANI enables the development of hybrid materials that meet both performance and environmental sustainability requirements[7], [9].
Resistive switching devicescontinue to attract significant research attention due to their potential for non-volatile memory storage, neuromorphic computing, and high-density integration[10]–[12]. Developing such devices using green-processed composite materials aligns with global sustainability goals and addresses the environmental drawbacks associated with conventional microelectronic fabrication. In this context, simple and low-energy fabrication techniques are equally important. The drop-casting method, recognized for its low resource consumption and minimal waste generation, provides an accessible and environmentally sustainable approach for forming thin films suitable for electronic device architectures.
This study presents preliminary experimental results on resistive switching behavior in chitosan–PANI composite films fabricated using the sustainable drop-casting method. The investigation aims to evaluate the electrical characteristics, switching performance, and material behavior of the composite toward its potential application in eco-friendly resistive memory devices. These early findings contribute to the advancing field of sustainable electronics and highlight the promise of biopolymer–conducting polymer blends as green alternatives for future memory technologies.

II. METHODS

A. Materials
Chitosan, polyaniline (PANI), and the ITO-PET substrates were all purchased from Sigma-Aldrich. Silver conductiveink, used for forming the top electrode, was also obtained from Sigma-Aldrich.

B. Preparation of Chitosan–PANI Composite

A sol-gel approach was employed to prepare the composite solution. Chitosan and PANI powders were

weighed to obtain a 1:2(PANI into Chitosan) mass ratio. The composite was then dissolved in deionized water under continuous stirring until a homogeneous sol-gel mixture was formed. This ensured uniform dispersion of PANI within the chitosan matrix.

C. Film Fabrication via Drop-Casting

The homogeneous composite solution was drop-cast onto pre-cleaned ITO-PET substrates. The substrates were cleaned prior to deposition to remove any surface contaminants that could interfere with film formation or electrical measurements. After drop-casting, the films were left to dry at room temperature for 24 hours to allow slow evaporation of the solvent and proper formation of the composite active layer.

D. Top Electrode Deposition

Once the composite layer dried, silver conductive ink was applied onto the film surface to form the top metallic contacts. The deposited silver was again allowed to dry at room temperature for 24 hours to ensure full curing and stable electrical connectivity.

E. Device Structure

The completed device (Figure 1) followed a vertical sandwich configuration defined as:

Ag / (Chitosan-PANI) / ITO–PET,with

- Ag acted as the top electrode (TE),
- Chitosan-PANI served as the active resistive switching layer,
- ITO on PET functioned as the bottom electrode (BE).

This structure was used for all subsequent electrical characterization experiments designed to evaluate the resistive switching behavior of the composite material.

F. Device Characterization

The electrical performance of the fabricated Ag/Chitosan–PANI/ITO–PET device was evaluated to assess its resistive switching behaviour and overall suitability for memory applications. All measurements were carried out under ambient laboratory conditions. The completed device was mounted onto a probe station, with the Ag TE connected to the wordline (WL) and the ITO BE connected to the bitline (BL) of the ArOne (Arc Instrument Pty Ltd, UK) Memristor Characterizer.

A voltage sweep was applied while the resulting current was recorded simultaneously. The voltage was swept in a controlled staircase profile using 0.05 V step increments, a step width of 50 ms, and an interpulse time of 0 ms. To prevent electrical overstress and ensure safe device operation, a compliance current of 100 µA was imposed throughout the measurement process.

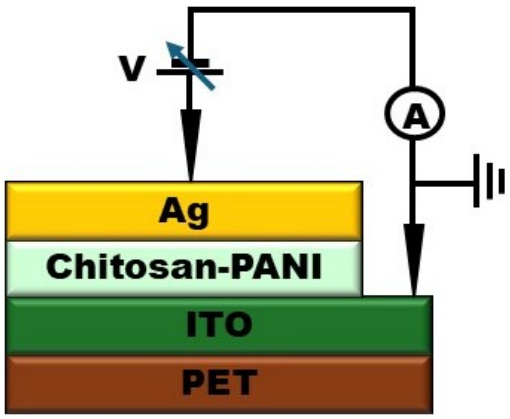


Figure 1. Schematic diagram of the ReRAM device consisting of an Ag top electrode, a chitosan–PANI composite active layer, and an ITO–PET bottom electrode.

III. RESULTS AND DISCUSSION

A. Resistive Switching Characteristics, Endurance and Retention

Figure 2a–b presents the I–V characteristics of the Ag/Chitosan–PANI/ITO–PET device in both linear and semilogarithmic scales, revealing a clear bipolar resistive-switching hysteresis as the voltage is swept through a full cycle (0 → +5 V → 0 → –5 V → 0). This hysteresis behaviour indicates the presence of two well-defined resistance states-the high-resistance state (HRS) and the low-resistance state (LRS)-thereby confirming the device's suitability for non-volatile memory applications. Importantly, the I–V curves show no abrupt or sudden current jumps during switching. Instead, the current evolves smoothly, characteristic of "O-type" resistive-switching behaviour in which filament formation and rupture occur in a controlled and gradual manner rather than through sharp, avalanche-like transitions.This "O-type" I–V hysteresis is consistent with that observed for the Ag/EBMeOH–NaCMC/W device, where EBMeOH–NaCMC refers to sodium carboxymethyl cellulose (NaCMC) blended with methanol-derived Elaeodendron buchananii plant extract (EBMeOH), and W denotes tungsten[13], and in Ag/Milk+QDs/ITO device, where QD denotes the CdTe/CdSe core-shell quantum dots[14].

Pulse endurance testing (Figure 2c–d) confirms non-volatile operation under repeated program/erase events. Using 1 V programming pulses, the device maintains separable HRS and LRS over 200 cycles with negligible degradation of the read-out windowhaving $R_{ON}/R_{OFF} = 1.56$ (Figure 2c). When stressed with 3 V pulses, robust operation persists up to 20 000 cycles and the $R_{ON}/R_{OFF} = 3.6$ (Figure 2d).

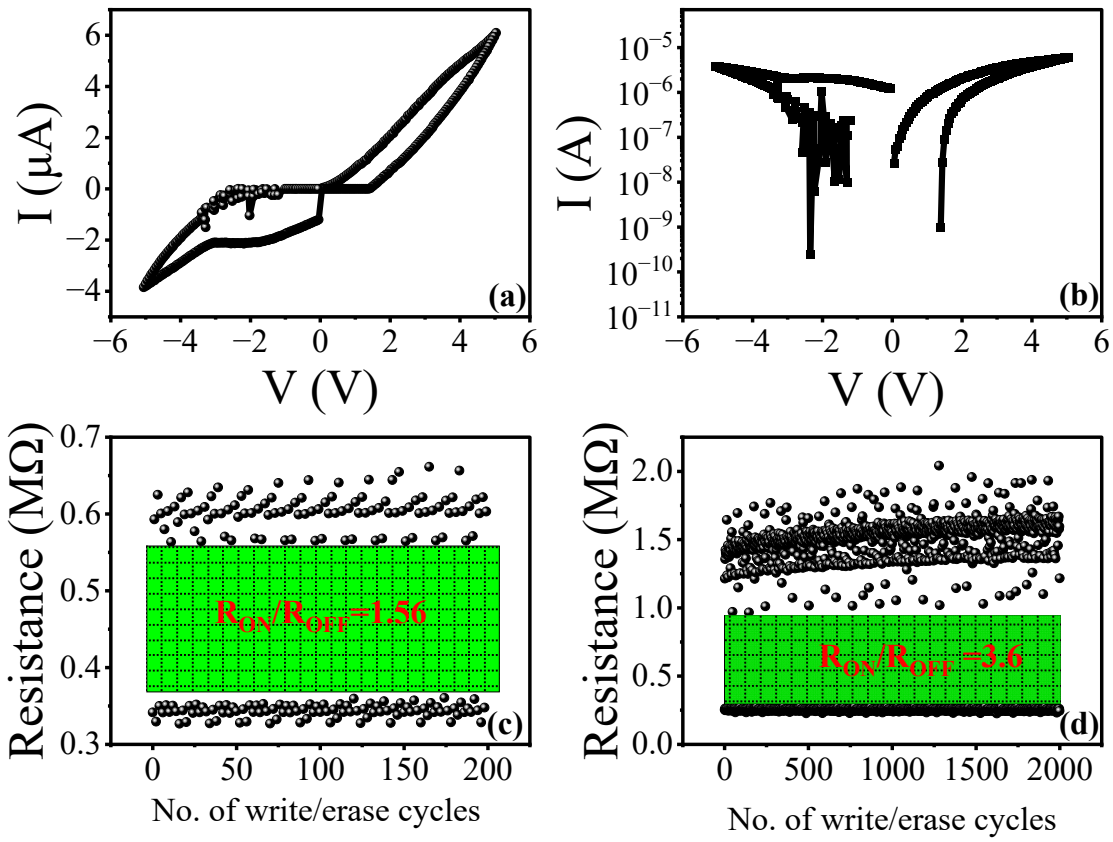


Figure 2. Memory behaviour of the Ag/Chitosan–PANI/ITO–PET ReRAM device: (a) linear-scale I–V characteristics and (b) semilogarithmic I–V characteristics illustrating the resistive switching hysteresis. The endurance performance over (c) 200 write/erase cycles using 1 V programming pulses and (d) 20 000 write/erase cycles using 3 V programming pulses.

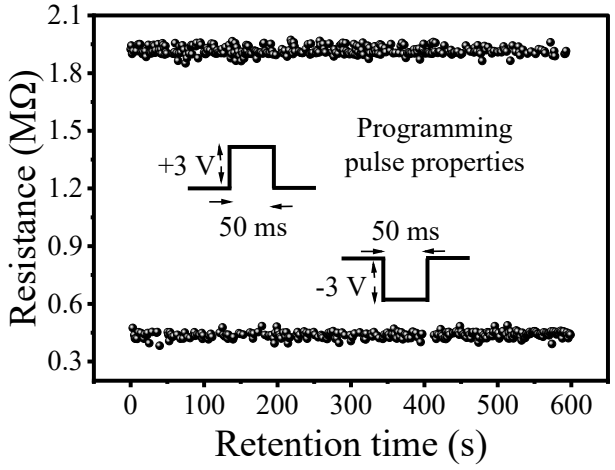


Figure 3. Data retention performance of the Ag/Chitosan–PANI/ITO–PET device, showing stable retention of both resistance states for over 600 seconds.

Figure 3 summarizes the state stability of the Ag/Chitosan–PANI/ITO–PET device under a constant read bias of 3 V. Both the LRS and HRS remain clearly separated for at least 600 s at room temperature, with no spontaneous transitions or overlap observed between the two states during the monitoring period. The stable separation of the resistance levels over time indicates that the device can maintain stored information without refresh, demonstrating the non-volatile nature of the chitosan–PANI–based active layer. These results suggest that, with further optimization of material composition and device architecture, the device holds strong potential for reliable non-volatile memory applications.

B. Transport Mechanism Analysis

The Ag/Chitosan–PANI/ITO–PET device exhibits two distinct transport regimes that correlate with the resistive state and the sweep direction.

i. Low-Resistance State (LRS): Ohmic, Percolative Transport

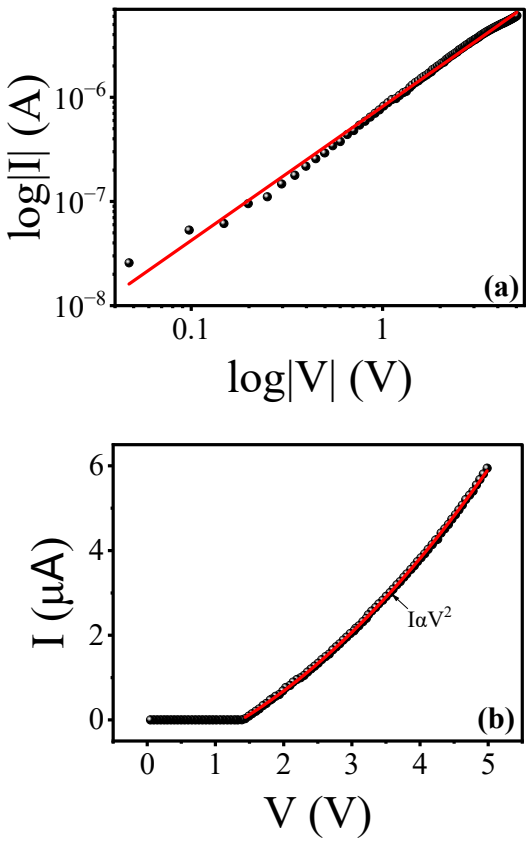


Figure 4. (a) log|I|–log|V| characteristics fitted with a linear relation, and (b) I–V characteristics fitted using a power-law dependence (I versus V²).

During the forward sweep, the device switches to the LRS and the I–V relation is linear ($I \propto V$) (Figure 4a). This behaviour indicates ohmic transport through a continuous or highly percolative network of conducting pathways. In the chitosan–PANI composite, we attribute this to field-assistedalignment/activation of PANI-rich domains creating conductive paths along the electric field direction. Once a sufficiently conductive path forms, the series resistance is dominated by the intrinsic resistance of the percolation cluster and contact resistances, yielding the observed linearity.

ii. High-Resistance State (HRS): Quadratic I–V consistent with hopping-mediated transport.
When the bias is reduced (reverse sweep), the device relaxes to HRS and the current follows $I \propto V^2$, consistent with hopping-mediated transport through localized states in a partially disrupted network[15]. Physically, the conductive path becomes discontinuous (or significantly narrowed), and charge transport proceeds via sequential hopping between localized sites (e.g., trap states within chitosan, interfacial states at PANI grains, or defects at the Ag/composite and composite/ITO interfaces). In this regime, the current scales quadratically with voltage because the effective carrier injection and occupancy of localized states increase with field, enhancing the probability of multi-step hopping across the finite thickness of the active layer[16]. Such behaviour is often captured by trap-assisted hopping models in disordered organic/biopolymer systems, where the density and energetic distribution of localized states set the nonlinearity of the I–Vcurve.

Putting these together, the switching can be interpreted as a percolation-driven LRS transitioning to an interrupted, hopping-dominated HRS. The forward sweep builds or strengthens conductive paths across PANI-rich domains (ohmic LRS). The reverse sweep weakens/breaks segments of these paths via ionic redistribution, forcing carriers to hop between isolated conductive islands, which manifests as I–V².

IV. CONCLUSION

This work presented preliminary evidence that bio-derived chitosan blended with polyaniline (PANI), processed by a sustainable drop-casting method, can function as an effective active layer for resistive random-access memory. The Ag/Chitosan–PANI/ITO–PET devices exhibited bipolar resistive switching with a clear separation between low-resistance and high-resistance states under staircase voltage sweeps. During the forward sweep, transport in the LRS is ohmic and consistent with a continuous or highly percolative path across PANI-rich domains; during the reverse sweep, the device relaxes to HRS and follows $I \propto V^2$, indicative of hopping-mediated transport through localized states in the composite. The device exhibits retention ≥ 600 s at room temperature and repeatable endurance cycling of over $\geq 10^3$support the feasibility of the composite for eco-friendly memory applications.Overall, these preliminary results show that the chitosan-PANI (biopolymer–conducting-polymer) blend combined with a low-energy, low-waste deposition method delivers meaningful memory behaviour without complex processing, aligning with the conference's emphasis on sustainability and green electronics.

Limitations andFuture Work. As this is a preliminary study, additional work is warranted to (i) quantify variability across devices and wafers, (ii) extend retention to longer horizons and elevated temperatures, (iii) map mechanism fingerprints via temperature-dependent I–V (to distinguish nearest-neighbour vs. variable-range hopping), (iv)

optimize film thickness, composition, and electrode engineering to enlarge the ON/OFF window and reduce noise, and (v) explore encapsulation and humidity control to stabilize ionic motion in the biopolymer matrix. With these optimizations, chitosan–PANI devices fabricated through scalable, resource-efficient processes could mature into reliable, sustainable ReRAM suitable for low-power and transient electronics.

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REFERENCES

[1] B. Geffroy, P. le Roy, and C. Prat, "Organic light-emitting diode (OLED) technology: materials, devices and display technologies," Polym. Int., vol. 55, no. 6, pp. 572–582, Jun. 2006, doi: 10.1002/pi.1974.

[2] Y.-J. Lee et al., "A high-extraction-efficiency nanopatterned organic light-emitting diode," Appl. Phys. Lett., vol. 82, no. 21, pp. 3779–3781, May 2003, doi: 10.1063/1.1577823.

[3] J. Xue, S. Uchida, B. P. Rand, and S. R. Forrest, "4.2% efficient organic photovoltaic cells with low series resistances," Appl. Phys. Lett., vol. 84, no. 16, pp. 3013–3015, Apr. 2004, doi: 10.1063/1.1713036.

[4] Z. W. Dlamini et al., "Conduction and Resistive Switching in Dropcast CdTe/CdSe Core-Shell Quantum Dots Embedded Chitosan Composite," Iran. J. Sci. Technol. Trans. A Sci., vol. 46, no. 2, pp. 709–716, Apr. 2022, doi: 10.1007/s40995-022-01272-y.

[5] Z. W. Dlamini, S. Vallabhapurapu, T. Bala, and A. Sahoo, "Electrode Dependent Resistive Switching Properties of CoAu Core-Shell Incorporated Chitosan," in 2023 International Conference on Electrical, Computer and Energy Technologies (ICECET), IEEE, Nov. 2023, pp. 1–5. doi: 10.1109/ICECET58911.2023.10389259.

[6] Z. W. Dlamini, S. Vallabhapurapu, and V. S. Vallabhapurapu, "Sustainable non-volatile resistive switching memory using chitosan/MEH-PPV polymer blend," Green Mater., vol. 13, no. 5, pp. 476–484, Dec. 2025, doi: 10.1680/jgrma.24.00048.

[7] B. Mohammadi, S. Pirsa, and M. Alizadeh, "Preparing chitosan–polyaniline nanocomposite film and examining its mechanical, electrical, and antimicrobial properties," Polym. Polym. Compos., vol. 27, no. 8, pp. 507–517, 2019, doi: 10.1177/0967391119851439.

[8] M. Bhaumik, A. Maity, H. G. Brink, Z. W. Dlamini, and S. Vallabhapurapu, "Resistive switching behaviour of nickel nanoparticle-embedded naphthalene sulphonic acid-doped polyaniline nanocomposites," J. Phys. D. Appl. Phys., vol. 57, no. 4, p. 045302, Jan. 2024, doi: 10.1088/1361-6463/ad039d.

[9] Y. A. Anisimov, H. Yang, J. Kwon, D. E. Cree, and L. D. Wilson, "Chitosan-Polyaniline (Bio)Polymer Hybrids by Two Pathways: A Tale of Two Biocomposites," Polymers (Basel)., vol. 16, no. 18, 2024, doi: 10.3390/polym16182663.

[10] V. de Oliveira Arnoldi Pellegrini et al., "Antimicrobial, photodegradation and BioReRAM applications of multifaceted green zinc oxide nanoparticles synthesized using coffee leaves extract," Sci. Rep., vol. 15, no. 1, p. 29054, Aug. 2025, doi: 10.1038/s41598-025-01260-3.

[11] O. A. Daramola, Z. W. Dlamini, T. Ngarivhume, W. M. Mthiyane, X. Siwe Noundou, and P. F. Tseki, "Synthesis of Garlic-Stabilised AgNPs and Their Potential Application in Memory Devices," Plasmonics, vol. 20, no. 12, pp. 11653–11669, Aug. 2025, doi: 10.1007/s11468-025-03186-y.

[12] Z. W. Dlamini et al., "Extraction, chemical, and dual-functional memory and threshold resistive switching characteristics of Elaeodendron buchananii extract," Mater. Today Commun., vol. 37, no. May, p. 107159, Dec. 2023, doi: 10.1016/j.mtcomm.2023.107159.

[13] Z. W. Dlamini et al., "Chemical and Resistive Switching Properties of Elaeodendron buchananii Extract–Carboxymethyl Cellulose Composite: A Potential Active Layer for Biodegradable Memory Devices," Polymers (Basel)., vol. 16, no. 20, p. 2949, Oct. 2024, doi: 10.3390/polym16202949.

[14] Z. W. Dlamini et al., "Resistive switching properties of CdTe/CdSe core–shell quantum dots incorporated organic cow milk for memory application," Funct. Mater. Lett., vol. 16, no. 07, Oct. 2023, doi: 10.1142/S1793604723400271.

[15] Z. W. Dlamini, S. Vallabhapurapu, and V. S. Vallabhapurapu, "Resistive Switching Property of Raw Organic Cow Milk for Memory Application," Sustainability, vol. 15, no. 10, p. 8250, May 2023, doi: 10.3390/su15108250.

[16] Z. W. Dlamini, S. Vallabhapurapu, T. S. Mahule, and V. S. Vallabhapurapu, "Electrical conduction and resistive switching in cow milk-based devices prepared using the spin-coat method," AIP Adv., vol. 12, no. 9, p. 095321, 2022, doi: 10.1063/5.0098976.

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