RESISTIVE SWITCHING TRANSFORMATION AND MULTI LEVEL STATES IN AG/CHITOSAN–PANI/CU COMPOSITE SYSTEMS FOR ENVIRONMENTALLY FRIENDLY MEMORY TECHNOLOGY

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Abstract - Sustainable memory technologies are essential to mitigate the environmental impact of conventional electronics. This work reports an eco-friendly Ag/Chitosan–PANI/Cu-PCB resistive random-access memory (ReRAM) device fabricated via low-temperature, solution-processed drop-casting on PCB substrates. The biodegradable chitosan–polyaniline composite serves as the active switching layer, while silver and copper electrodes enable low-cost and scalable fabrication. Electrical measurements reveal an evolution from volatile threshold switching to stable non-volatile N-type resistive switching with a high ON/OFF ratio ($\sim 10^4$)and well-defined multilevel low-resistance states, indicating its potential for multibit memory applications. Conduction analysis suggests hopping transport and electrochemical metallization mechanisms governing filament formation and rupture. These results highlight the feasibility of biodegradable polymer-based ReRAM devices as promising candidates for sustainable and environmentally responsible memory technologies.

Keywords - Chitosan–Pani, Resistive Switching, Reram, Drop-Casting, Sustainable Electronics, Hopping Conduction, Ohmic Conduction, Cu–PET.

I. INTRODUCTION

Environmental pollution is a major global challenge closely associated with modern industrial development. Rapid industrialization, urbanization, and technological advancement have led to substantial increases in air, water, and land pollution. In 2022, global carbon dioxide emissions exceeded 35 billion tonnes annually, making greenhouse gas emissions a dominant driver of climate change, ecosystem degradation, and public health crises[1][2]. At the same time, the world generated more than 2.1 billion tonnes of municipal solid waste, with projections indicating an increase to 3.8 billion tonnes by 2050 if current consumption patterns persist[3]. A significant fraction of this waste originates from industrial and electronic products, intensifying the burden on landfills, soil, and water systems[3][4].Notably, the global technology sector alone accounts for approximately 2–3 % of total global carbon emissions, a level comparable to that of the aviation industry[5].
The electronics industry is a major contributor to environmental pollution due to its energy-intensive manufacturing processes, reliance on non-renewable raw materials, and rapidly growing electronic waste streams[6].Among electronic components, memory devices represent a critical yet often overlooked contributor to environmental impact. Memory technologies are ubiquitous in consumer electronics, data centres, and embedded systems, leading to massive production volumes. The rapidly increasing demand for data storage, driven by cloud computing and artificial intelligence, further amplifies material consumption and energy usage[7]. Memory devices embedded in discarded electronics often contain metals and polymers that persist in the environment or release toxic substances if improperly processed. These challenges underscore the urgent need for environmentally friendly electronic components, particularly memory technologies that minimize environmental impact throughout their life cycle.

Resistive switching random-access memory (ReRAM) has emerged as a promising non-volatile memory technology owing to its simple device structure, scalability, low power consumption, and fast switching speed[8][9]. ReRAM operates by electrically toggling between a high-resistance state (HRS) and a low-resistance state (LRS), making it suitable for high-density data storage and emerging computing paradigms. Importantly, ReRAM devices can be fabricated using biodegradable and environmentally benign materials, such as plant extracts[10][11][12]), biodegradable polymers[13][14][15][16][17], milk-based matrices[18][19-22], andother natural materials, making them attractive candidates for sustainable and green electronic applications Among biodegradable polymers, chitosan has attracted considerable interest due to its abundance, biodegradability, derivation from marine waste, and compatibility with solution-based processing techniques[23].However, pristine chitosan exhibits low electronic conductivity, which limits its direct applicability in resistive memory devices. To address this limitation, chitosan is commonly blended with polyaniline (PANI), a conductive polymer with tunable electrical conductivity, good environmental stability, and low-cost synthesis. The resulting chitosan–PANI composite enhances charge transport while preserving biodegradability, providing a hybrid organic active

layer capable of supporting resistive switching behavior[24].

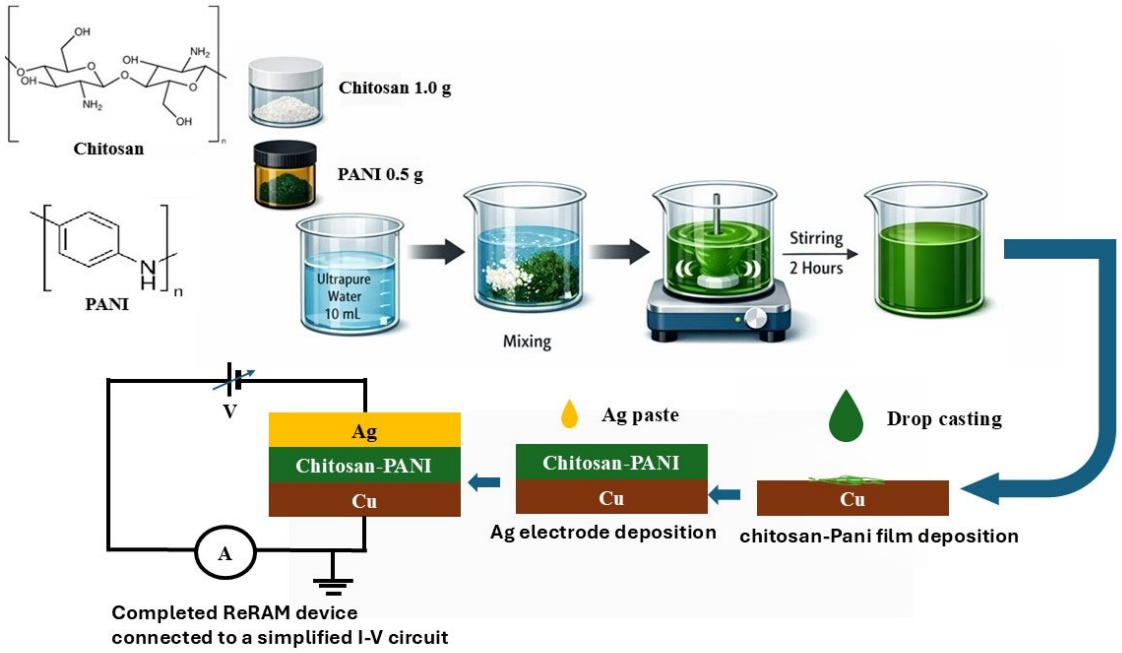


Figure 1. Flow diagram illustrating the fabrication process of the Ag/Chitosan–PANI/Cu-PCB ReRAM device using the drop-casting method. The process involves sol–gel preparation of the chitosan–PANI composite, drop-casting the solution onto a PCB substrate with Cu traces, and deposition of Ag paste to form the top electrode.

Electrode material selection further plays a critical role in device performance, switching mechanism, and environmental compatibility[25]. Silver (Ag) and copper (Cu) are highly conductive, earth-abundant metals that are less environmentally burdensome than noble metals such as gold or platinum. Copper is fully compatible with printed circuit board (PCB) manufacturing technology, while both Ag and Cu can participate in electrochemical metallization processes, enabling resistive switching without the need for vacuum-based deposition methods[26].

Despite progress in biodegradable and polymer-based ReRAM devices, significant challenges remain. Most reported devices still rely on inorganic oxides and vacuum-based fabrication, limiting sustainability and large-scale applicability. Moreover, achieving stable multilevel resistive switching and understanding the transformation from volatile threshold switching to non-volatile behavior in environmentally friendly polymer systems remain insufficiently explored. Such multilevel functionality is essential for high-density memory and neuromorphic computing applications.

In this work, Ag/Chitosan–PANI/Cu resistive memory devices fabricated using a low-temperature, solution-processed approach are investigated. The devices exhibit a transition from volatile threshold switching to stable non-volatile N-type resistive switching, accompanied by the emergence of well-defined multilevel low-resistance states, demonstrating their potential for environmentally friendly and scalable memory technologies.

II. METHODS

A. Materials

Chitosan and polyaniline (PANI)and silver (Ag) paste were purchased from Sigma-Aldrich. The PCB with copper (Cu) thin layer war purchased from a local supplier.

B. Preparation of Chitosan–PANI Composite

A sol-gel approach shown in Figure 1was 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 chitosan-PANI composite solution was drop-cast onto pre-cleaned printed circuit board (PCB) substrates having copper (Cu) traces. 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.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.The completed device (Figure 1)consisted of the following notation: Ag / (Chitosan-PANI) /Cu-PCB,with:

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

D. Device Characterization

The electrical performance of the fabricated Ag/Chitosan–PANI/Cu-PCB 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 Cu 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. Toprevent electrical overstress and ensure safe device operation, a compliance current of 100 µA was imposed throughout the measurement process.

III. RESULTS AND DISCUSSION

The electrical characteristics of the Ag/Chitosan–PANI/Cu-PCB ReRAM device were investigated using current–voltage (I–V) measurements under ambient conditions. Figure 2 shows the I–V characteristics of the Ag/Chitosan–PANI/Cu-PCB ReRAM device plotted on (a) linear and (b) semilogarithmic scales. A pronounced threshold switching behavior is observed, marked by a sudden increase in current beyond a critical threshold voltage of $V_{\text{th}} = +1.7\text{V}$,driving the device into the low-resistance state (LRS). Upon reducing the applied voltage, the device returns to the high-resistance state (HRS) at a holding voltage of $V_{\text{hold}} = +0.4\,V$. Under negative bias, the set process occurs at $V_{\text{th}} = -1.5\,\text{V}$, while the resetprocess takes place at $V_{\text{hold}} = -0.4\,\text{V}$. The large ON/OFF current ratio of approximately 10^4 , visible on the semilogarithmic scale, confirms effective resistance modulation. This volatile switching behavior is attributed to the formation and subsequent rupture of unstable conductive paths within the chitosan–PANI composite, consistent with electrochemical metallization mechanisms reported for polymer-based resistive switches [26].From a technical perspective, threshold switching devices are particularly attractive for selector applications in crossbar memory architectures, where their volatile nature can effectively suppress sneak-path currents without requiring an additional selector element.The sharp turn-on behavior, high ON/OFF ratio, and self-resetting characteristics observed in this work meet key selector requirements for high-density ReRAM integration[26][27][23].Moreover, the low-temperature, solution-processed fabrication combined with biodegradable chitosan–PANI active layers aligns with emerging trends in sustainable and low-power electronics, extending the applicability of threshold switching devices beyond conventional silicon-based systems[27].

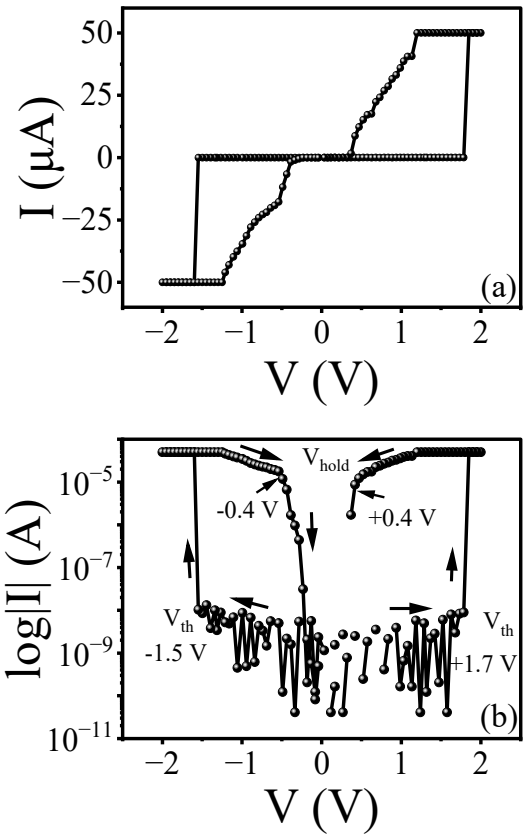


Figure 2. Current–voltage (I–V) characteristics of the Ag/Chitosan–PANI/Cu-PCB ReRAM device plotted on (a) linear and (b) semilogarithmic scales. The device exhibits pronounced threshold resistive switching behavior.

The evolution of switching behavior over repeated cycling is illustrated in Figure 3(a), which presents ten consecutive I–Vcycles. The device gradually transitions from volatile threshold switching to nonvolatile multistep N-type resistive switching by the 10th cycle. This behavior suggests progressive stabilization of conductive filaments due to repeated electrical stress, acting as a conditioning process, as commonly observed in electrochemical metallization-based resistive switching

devices[26].Figure 3(b) shows the I–V curve of the 10th cycle, where the device demonstrates stable N-type resistive switching with multiple switching events. The inset reveals well-separated HRS and LRS levels with defined upper and lower bounds, indicating good state distinguishability and the potential for multilevel memory operation.The observed switching behavior is attributed to a combination of bulk-limited charge transport and electrochemical metallization (ECM) effects. The Ag and Cu electrodes serve as active sources of metal ions, while the chitosan–PANI matrix facilitates both ionic migration and electronic conduction. At low electric fields, hopping conduction dominates, whereas higher fields promote conductive filament formation, leading to an ohmic-like low-resistance state.

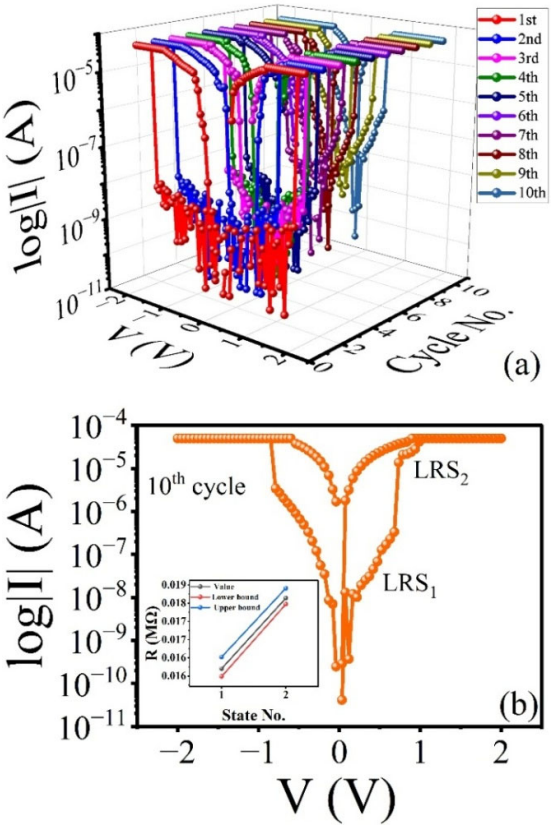


Figure 3. Semilogarithmic I–V characteristics of the Ag/Chitosan–PANI/Cu-PCB ReRAM device. (a) Ten consecutive I–V cycles and the (b) I–V behavior of the 10th cycle, showing stable N-type resistive switching with evidence of multiple switching events.

These results demonstrate that the Ag/Chitosan–PANI/Cu-PCB structure enables reliable resistive switching using solution-processed, biodegradable materials and PCB-compatible electrodes, highlighting its potential for low-cost and sustainable memory applications.

Figure 4 presents the log–log I–V characteristics of the Ag/Chitosan–PANI/Cu-PCB device in different resistive states. The fully formed LRS exhibits alinear dependence (Figure 4a) with a slope of $n \approx 1.2$, indicating ohmic conduction associated with a stable metallic filament bridging the electrodes. In contrast, during the voltage up-sweep, the device undergoes multilevel switching, where it initially transitions into an intermediate LRS1 characterized by a higher slope of $n \approx 3.3$. A subsequent transition at approximately +0.68 V leads to a second intermediate state (LRS2), which also follows a similar power-law dependence before the current is limited by the compliance current (Figure 4b). These intermediate conduction states are attributed to partially formed or multiple weak conductive filaments within the chitosan–PANI matrix, where charge transport is governed by trap-filled-limited hopping conduction.

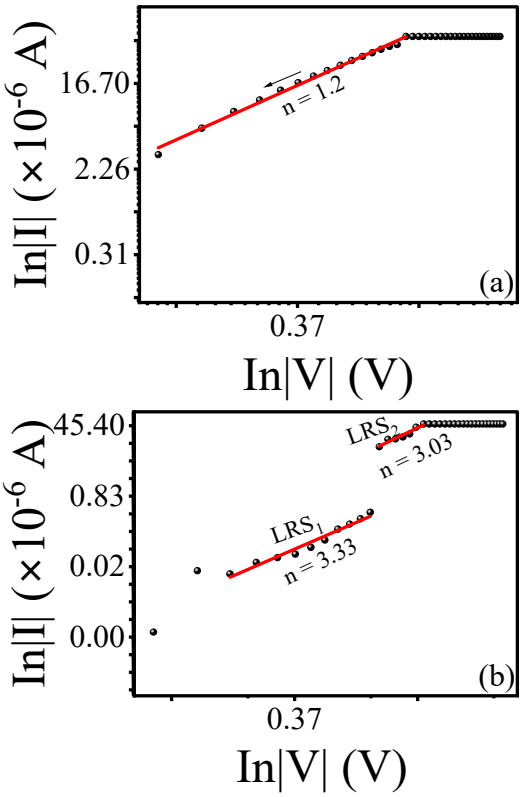


Figure 4. log-log I-V characteristics of the (a) LRS and (b) HRS of the Ag/chitosan-PANI/Cu-PCB device fitted with linear fit.

IV. CONCLUSION

A sustainable Ag/Chitosan–PANI/Cu-PCB ReRAM device was successfully fabricated using a low-temperature, solution-processed drop-casting approach. The combination of biodegradable chitosan–PANI composites with earth-abundant Ag and Cu electrodes and PCB-compatible substrates demonstrates a promising route toward low-cost and environmentally responsible memory technologies. Electrical measurements revealed a transition from volatile threshold switching to stable nonvolatile N-type resistive switching, accompanied by the

formation of multilevel low-resistance states. Conduction analysis showed that the fully formed low-resistance state is governed by ohmic transport, indicating a stable metallic filament, while intermediate resistive states follow trap-filled-limited space-charge-limited current, attributed to partially formed conductive filaments within the polymer matrix. The observed multistate switching capability, high ON/OFF ratio, and sustainable material selection highlight the potential of this device for multibit memory and green electronic applications.

FUTURE WORK

Future work will focus on improving device reliability, endurance, and data retention to further validate the suitability of the Ag/Chitosan–PANI/Cu-PCB ReRAM for practical applications. Systematic optimization of the chitosan–PANI composition, film thickness, and electrode geometry will be undertaken to achieve improved control over multilevel resistive states and reduce cycle-to-cycle variability. Long-term stability studies, including temperature- and humidity-dependent measurements, are planned to assess environmental robustness. In addition, pulse-based switching and endurance tests will be explored to evaluate the device performance under realistic operating conditions. Investigation of flexible substrates and large-area fabrication will also be pursued to extend the applicability of this sustainable memory platform to flexible and wearable electronics.

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