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Resistive Switching Property on CdTe/CdSe Core-shell Quantum Dots Incorporated Chitosan-PVP Polymer Blend

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Abstract: -The use of biodegradable materials in memory devices has a significant impact on reducing electronic waste**.** The resistive switching capability of a sandwich-type memory device, which consists of an active layer (AL) positioned between a bottom electrode (BE) and top electrode (TE), has been investigated. The AL was made of a composite material consisting of chitosan (CS) and polyvinylpyrrolidone (PVP) polymer mix that was dispersed with CdTe/CdSe core-shell quantum dots. On the other hand, the TE was made up of silver (Ag), and the BE was provided by an indium-doped tin oxide (ITO) layer. The memory device was fabricated using a polyethylene terephthalate (PET) substrate. Interesting results were obtained by monitoring the current in the Ag/CS+PVP+CdTe/CdSE/ITO device and applying voltage between the Ag and ITO electrodes. The device showed memory hysteresis, with a reasonable I_{ON}/I_{OFF} ratio of ≥ 10 and a low working voltage of ≥ 0.2 V. These findings imply that the devicet uses minimal power and operates as a memory device. In addition, the incorporation of CdTe/CdSe in the composite material was hypothesized to optimize the Schottky barrier's height at the electrode-active layer interface, effectively blocking electron entrance into the active layer. Consequently, conductive filaments were formed due to the diffusion of Ag+ ions into the active layer. Ultimately, our results indicate that adding CdTe/CdSe QDs could potentially improve the memory device and switching capabilities of the CS/PVP blend-based resistive switching memory may be utilized

Keywords: Chitosan, PVP, CdTe/CdSe, ReRAM, green memory

I. Introduction

Current computers used Von Neumann architecture, in which memory and CPU are two separate entities. But as long as the processor and memory are independent components, memory bandwidth or interface latency will hinder computer performance [1]. Constructing memory units within computer chips is critical for the advancement of artificial intelligence (AI) and neuromorphic computing. This will address energy consumption related to data transfer bandwidth between the CPU and the memory [2]. Compared to current memory technologies, Resistive switching memories (ReRAMs) are non-volatile, highly scalable, operate quickly, and use less power and have potential for neuromorphic computing application [3, 4]. Resistive switching memories are a type of emerging memories that store data by utilizing two electrically reversible resistive states i.e. High resistive state (HRS) and low resistive state (LRS) [5, 6]. These resistive states are analogous to the binary digits "0" and "1", which makes ReRAMs useful in digital devices [7, 8].

ReRAMs possess a cell architecture, that is remarkably simple, enabling them to be miniaturized to a size that surpasses the current memory sub-nanometer size limit of memory technology. In addition, ReRAMs can be constructed using biodegradable materials, which help minimize their environmental footprint. The presence of sneak currents in a 3D crossbar array architecture [8], along with the challenge balancing biodegradability and device performance [9, 10], has been a significant obstacle in the path towards commercializing ReRAMs technology. In this study resistive switching memory was developed by combining a blend of chitosan and polyvinylpyrrolidone (PVP) blend dispersed with Cadmium telluride/Cadmium selenide (CdTe/CdSe) core-shell quantum dots (QDs).

Resistive switching has been observed in devices composed of a chitosan/PVP blend active layer with different PVP to chitosan ratios placed between silver (Ag) and indium-doped tin oxide (ITO), as well as Ag and aluminum (Al) electrode combinations [9]. When a blend of chitosan and PVP in a 1:1 ratio was utilized in conjunction with an Ag and ITO electrode combination, no switching or memory hysteresis were observed. This present study shows

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that when CdTe/CdSe core-shell QDs are integrated into this polymer blend, both switching and memory hysteresis occur.

II. Experimenta details

Chitosan (CS) and polyvinylpyrrolidone (PVP) polymers utilized in this research were purchased from Sigma Aldrich. The Cadmium telluride/cadmium selenide core-shell quantum dots (CdTe/CdSe QDs) used in this study were prepared and provided by the research group in [14]. A mixture of chitosan and PVP polymers, with a composition of 0.5 g chitosan and 0.5 g PVP was dissolved in 50 ml of ultra-purified water. Afterwards, a small amount of diluted acetic acid was added to the solution to facilitate the quick dissolution of chitosan. CS and PVP polymers served as the foundational materials. The CdTe/CdSe QDs were used to increase the conductivity of CS and PVP. Indium doped tin oxide-coated (ITO) substrates, and silver (Ag) paste was then utilized as electrode. The polymer mixture was thoroughly mixed until both polymers had been dissolved completely. Next, 1 *ml* of water-suspended CdTe/CdSe core-shell QDs with a concentration of 2.4 $mg.ml^{-1}$ was introduced into the mixture. The new solution was agitated for an additional hour. The Polyethylene terephthalate with one side coated with indium-doped tin oxide (PET-ITO) substrate purchased from Sigma Aldrich was thoroughly cleaned using sonication in isopropyl alcohol, ethanol, and finally ultra-purified water for 5 *min* each. Afterwards, the QD-polymer mixture was applied onto the ITO surface and spin-coated to form a film. The spin-coated film was room temperature cured for 24 hours. Finally, a silver (Ag) paste was carefully applied onto the film as top electrodes. The ITO layer served as the bottom electrode (BE). As shown in Fig.1, the complete device has the notation Ag/(CS+PVP+CdTe/CdSe)/ITO-PET.

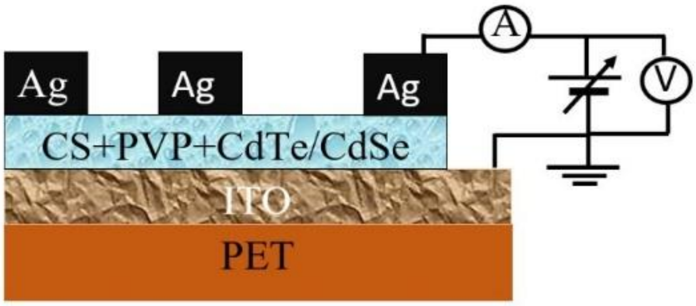

Fig.1. The schematic diagram of the Ag/CS+PVP+CdTe/CdSe/ITO-PET device connected to a simplified I-V measurement setup.

III. RESULTS AND DISCUSSION

Previous research has already covered the morphology and optical properties of the CdTe/CdSe core-shell QDs [11]. The memory behavior of the Ag/CS+PVP+CdTe/CdSe/ITO-PET device was studied by connecting the device as shown in Fig. 1. The Ag electrode was connected to a word-line (WL), while the ITO electrode was connected to the bit-line (BL). A voltage (V) was applied at the WL and steadily increased using 10 mV steps, with 25 ms steps width, while measuring the current (I) in the BL. The voltage was scanned through a complete cycle going from, 0 V to +1 V to 0 V to −1 and back to 0 V, while simultaneously measuring the current. The I-V data during the first, second and third voltage scan cycles were plotted on semi-log scale as depicted in Figs. 2(a)-(c), respectively.

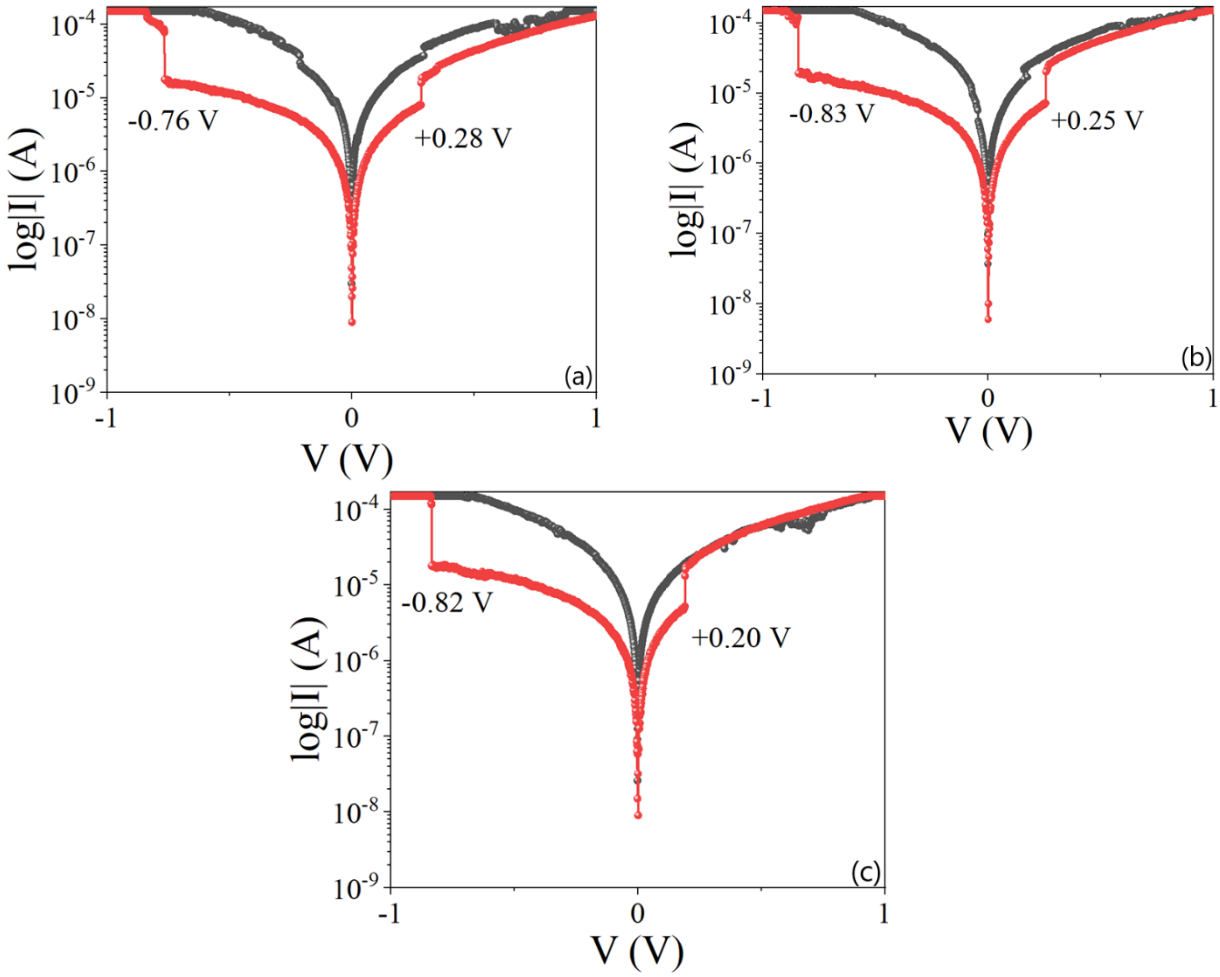

Fig. 2. The *log*|*I*| vs. *V* graphs for the Ag/(chitosan+PVP+CdTe/CdSe)/ITO-PET device taken during the first (a), second (b) and third (c) voltage scans.

Our data shows that the current does not follow the same path when the voltage is swept up (black curve) and down (red), and this creates I-V hysteresis. Based on this characteristic the device exhibits two resistive states, the low resistive state (LRS) and the high resistive state (HRS), which correspond to the ON- and OFF-states of a ReRAM device. The observed hysteresis has I_{ON}/I_{OFF} ratio of ≥ 10 which provides a distinct differentiation of these two states. Our data shows that there is switching from HRS-to-LRS, i.e., the SET process which happens at $V_{SET} = 0.76\,V$ and from the LRS-to-HRS, i.e., RESET process occurring at $V_{RESET} = 0.28\,V$ during the first cycle (a). From these observations, it is evident that the behavior of this device can be classified as somewhat symmetric bipolar switching mode. In addition, there is a noticeable increase in V_{SET} values from −0.76 V to about −0.80 V as we progress from the first cycle to the second and third cycles, (a), (b), and (c) respectively. There is a noticeable decrease in V_{RESET} going from +0.28 V to +0.20 V. For this device, the transport and switching mechanisms were carefully examined by plotting the I-V data on the log-log scale. This allows us to determine the value of the constant, n, for the generalized current density-voltage relationship, $J \propto V^n$. The value of n contains information about the actual relationship as documented in the literature [12, 13].

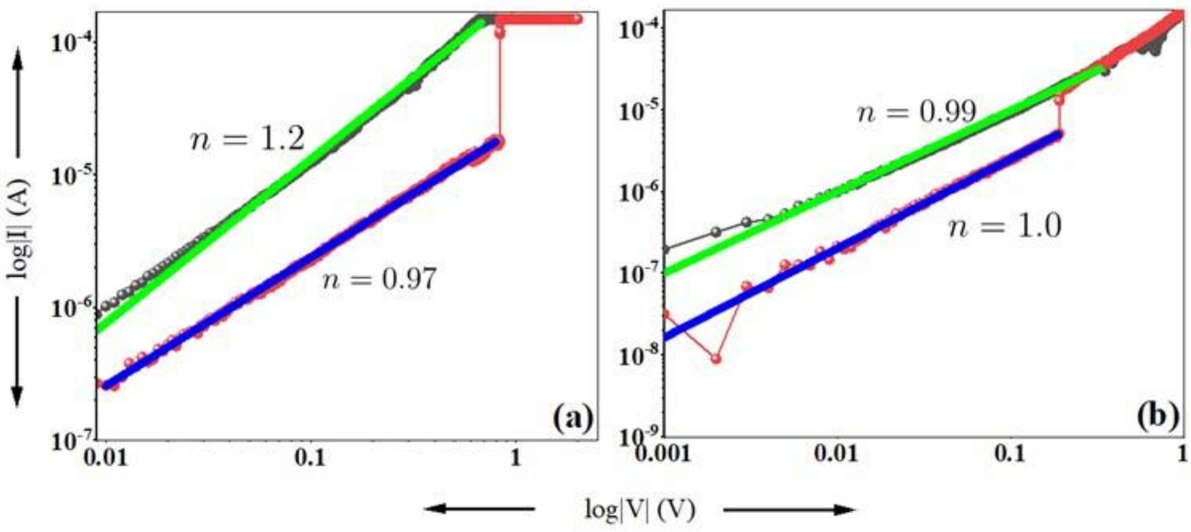

Fig. 3. The $ln|I|$ vs. $ln|V|$ graphs for the Ag/(chitosan+PVP+CdTe/CdSe)/ITO-PET device showing linear I-V dependence of the ON- and OFF- states.

Figs. 3(a and b) represent the logarithmic re-plotting of the negative and positive sides of Fig. 2(c). Based on our analysis, it is evident that there is a linear relationship ($J \propto V^n$, with n=1) between the current and voltage in the ON and OFF states. The observed linear relationship denotes that the dominant mechanism at play follows the Ohms law, where the current is directly proportional to the applied voltage. Based on the observed Ohmic behaviour in both ON- and OFF-states, it can be inferred that there are nano-scale conductive filaments (CFs) that develop from the bottom electrode towards the top electrode. The formation and rupture of these CFs lead to the SET and RESET processes observed in our findings. It is interesting to mention that previous studies have utilized the electrode combination of Ag and ITO along with chitosan and PVP blend having 1: 1 ratio as the active layer yielding varying outcomes [7]. Interestingly, the system exhibited linear I-V variation without any switching or hysteresis. Based on our current results, we can conclude that different behavior exhibited by our device can be attributed to the modification in the active layer, i.e., the introduction of the CdTe/CdSe core-shell QDs. It is possible to hypothesize that the presence of the QDs modified the electron affinity of the active layer, resulting in the formation of interfaces (Ag/ (CS+PVP+CdTe/CdSe or (CS+PVP+CdTe/CdSe)/ITO) that have Schottky barrier (SB) with significant barrier height. Therefore, when a voltage is applied at the top electrode, and the bottom electrode is grounded, there is an accumulation of electrons that are at the ITO electrode [7]. The entry of these electrons is hindered by the significant height of the SB. Thus, this could potentially hinder the linear behavior that was observed by Dlamini et al. [7]. Based on the available information, it appears that the remaining possibility is conduction caused by the diffusion of Ag^+ ions. Thus, the proposed CFs are due to reduction of these Ag+ ions into Ag atoms.

IV. Conclusion

A study has been conducted on resistive switching memory that is environmentally friendly. This memory is made using chitosan and polyvinylpyrrolidone (PVP) polymer blends, which are mixed with CdTe/CdSe core-shell quantum dots (QDs). Observations were made regarding the memory behaviour, specifically focusing on a fair I_{ON}/I_{OFF} ratio of ≥ 10 and the ability to switch at a very low operating voltage of 0.2 V. It is hypothesized that the presence of CdTe/CdSe in the composite raises the Schottky barrier height at the interface between the electrodes and the active layer. This creates an opportunity for the formation of conductive filaments because of silver electrode diffusion into the active layer.

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