Natural Organic Fructose-based Nonvolatile Resistive Switching Memory for Environmental Sustainability in Computing

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Introduction

The fast growth and wide applications of Internet of Things (IoT) require enormous amounts of energy consumption and hardware devices for computation, which present significant challenges of energy efficiency and environmental sustainability. Von Neumann computing architecture is reaching its bottleneck and limited by low energy efficiency. Fabrication of conventional semiconductor devices results in depletion of nonrenewable resources, while the disposal of these devices causes electronic waste with serious ecological, health, and economic issues. One potential solution to address these challenges simultaneously is by brain-like neuromorphic computing with essential hardware components made from natural organic materials for energy efficient operation, sustainable material source, and biodegradable disposal. As the core hardware component, nonvolatile resistive switching random access memory (ReRAM) based on natural organic materials such as fructose, Aloe vera, chitosan, honey, etc. [1-4] have reported promising nonvolatile resistive switching properties. In this paper, a new fructose-based nonvolatile ReRAM is investigated with the resistive switching speed reported for the first time.

Device Fabrication

A simple solution process was applied for the fabrication of fructose-ReRAM on a pre-cleaned 2.5 cm×2.5 cm glass slide. An ITO film with sheet resistance of 10 Ω/sq was deposited by a sputter system to form bottom electrode. A 0.7 M fructose solution was prepared by dissolving D-fructose powder in D.I. water at room temperature, followed by spin-coating on the glass substrate and ITO film at 3000 rpm for 90 s. The fructose film was baked first on a hotplate at 50°C for 2 hours in air, and then dried in vacuum under 10^{-3} mTorr for 12 hours. Circular top electrodes with diameters from 100 to 500μm were formed on the dried fructose film by the deposition of Cu (100 nm-thick) through a shadow mask to complete the device fabrication. Schematic process flow and a photograph of fructose-ReRAM devices after fabrication are shown in Figure 1.

Results

The typical bipolar resistive switching characteristics of Cu/fructose/ITO ReRAM are shown in Figure 2(a). There is no "forming" process which is different from the previously reported Al/fructose/ITO and Ag/fructose/ITO ReRAM devices [1]. The device transited from high-resistance state (HRS) to low-resistance state (LRS) in the "SET" process with a current compliance (I_{CC}) applied to prevent irreversible damage by dielectric breakdown of the fructose film. The device transited back to the HRS in the "RESET" process. To examine the data endurance performance, the device was switched between HRS and LRS for 100 consecutive cycles and the cumulative probability of SET and RESET voltages are shown in Fig. 2(b). The narrow 0.3 V range shows that the device has good switching endurance capability. The data retention property was tested under a continuous voltage stress in air and at room temperature for 10^4 s at a read voltage of 0.1 V. The resulted HRS and LRS currents are shown in Figure 2(c). An ON/OFF ratio of >1000 was maintained and no significant degradation was observed in the whole 10^4 s duration and even when the stress time is extrapolated to 10 years. Figure 2(d-f) shows the transient response in RESET and SET process to demonstrate the resistive switching speed. The pulse width of the output voltage pulse determines the RESET time while the time delay between input and output voltage pulses determines the SET time. The RESET and SET times derived from the transient response were 800 ns and 100 ns, respectively.

Conclusion

The characteristics of bipolar resistive switching, good data endurance and retention, and fast resistive switching speed show that Cu/fructose/ITO ReRAM has reliable data storage capability and potential as non-volatile memory.

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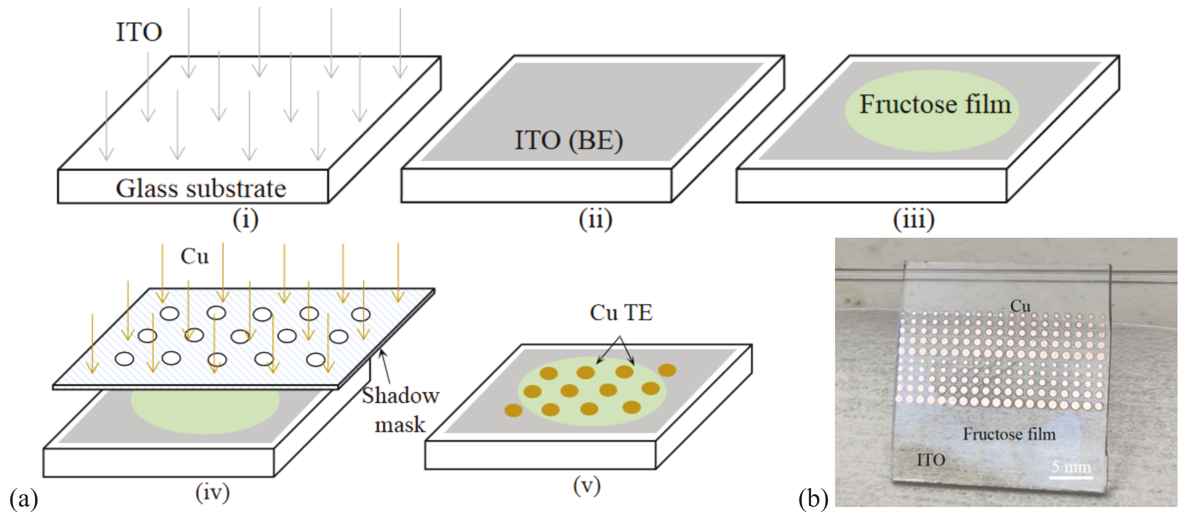

Figure 1 (a) Schematic of process flow for Cu/fructose/ITO ReRAM: (i) deposition of ITO on glass substrate, (ii) after ITO deposition, (iii) spin-coating fructose film on ITO bottom electrode (BE), (iv) deposition of Cu top electrodes (TE) through a shadow mask, (v) finished device. (b) Photograph of circular fructose-ReRAM devices.

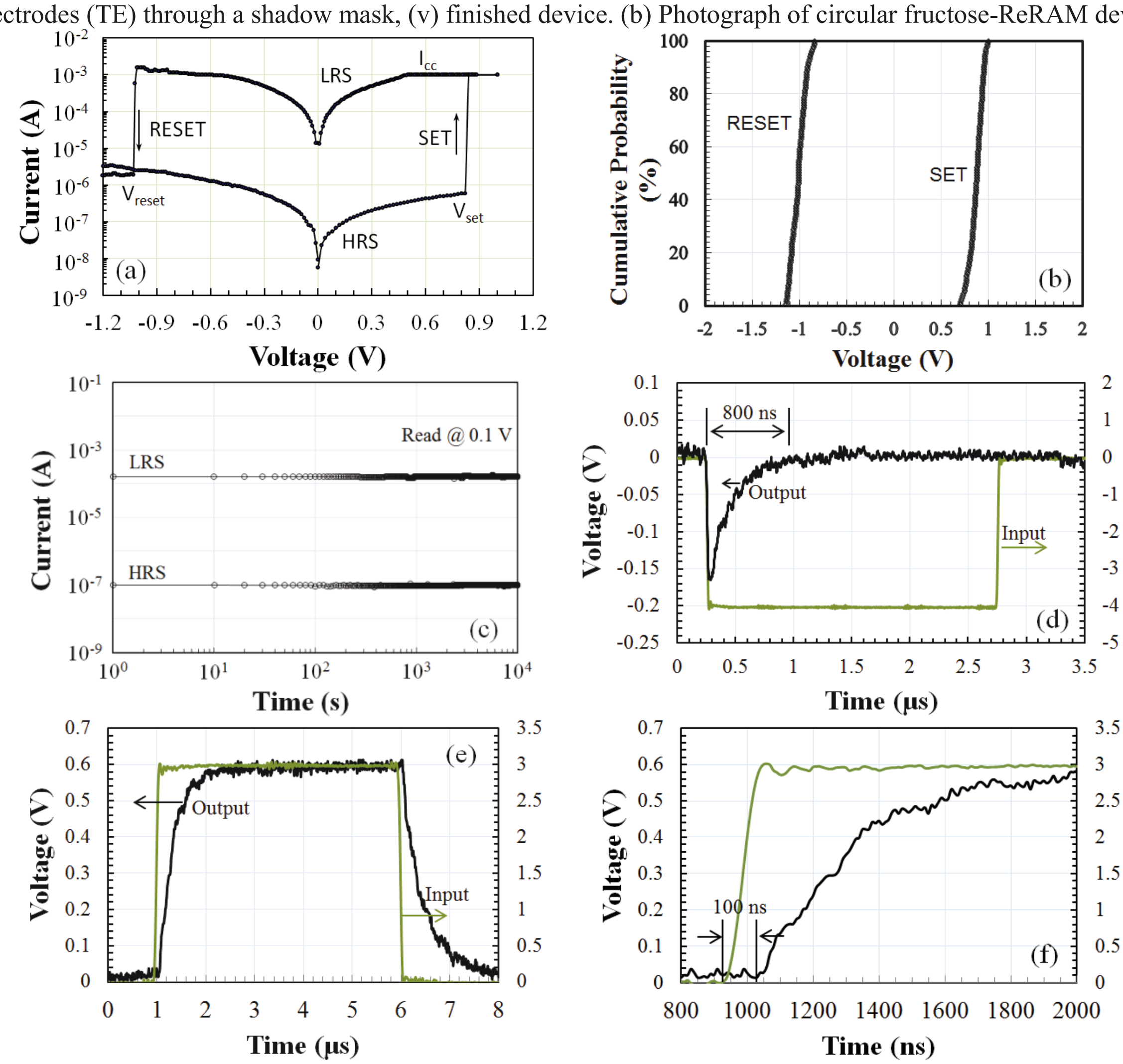

Figure 2 (a) Representative bipolar resistive switching characteristics of Cu/fructose/ITO ReRAM. (b) Endurance test in a DC switching sweep mode for 100 cycles. (c) Data retention for 10^4 s at V_{read}=0.1 V. Transient response in (d) RESET and (e, f) SET process with RESET and SET time extracted.

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