Two dimensional hexagonal boron nitride thin film for flexible resistive switching memory

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Abstract

With the significant impact of flexible electronics and the recent advances in nanotechnology, the development of flexible circuits has attracted tremendous attention. Here we present a route to fabricate highly flexible resistive switching memory (ReRAM) device by using two- dimensional (2D) hexagonal boron nitride (hBN) as the switching layer. The hBN-based resistive memory exhibits reproducible switching endurance, long retention time, and the capability to operate under extreme bending conditions.

1. Introduction

The continuing demand for improved computing performance requires new computing technologies which should be scalable and multifunctional. Among the many competitors for nonvolatile memory, resistive switching memories offer high write/erase speed, high endurance, and low power consumption, making them the promising candidate to replace charge-based memory devices[1-2].

Future electronic modules are expected to deliver functionalities such as flexibility and wearability.[3] Resistive memories have emerged as excellent candidates with their ease of fabrication and adaptable to the ever-growing demand for potential applications in the next-generation flexible electronics.[4] However, typical switching materials based on ceramic dielectric thin films often suffer from detachment from substrates and cracking under repetitive bending, deterring their use in flexible devices. As a two dimensional (2D) nanomaterial, the 2D hBN exhibits exceptional mechanical properties due to the strong covalent B-N bonds, the high elastic constant and breaking strength, indicates excellent integrability in flexible electronics applications [5, 6].

Herein, we report a novel flexible resistive memory device using the chemical vapor deposition (CVD)-grown 2D hBN dielectric film as switching layer. The as-fabricated hBN-based memory device featured long retention time, stable memory characteristics on different substrates, and reliable flexibility under bending conditions.

2. Experimental

Few-layer hBN fims were grown on Cu foils by atmospheric pressure CVD similar to previous report.[7] The as-grown hBN film on Cu foil was transferred onto other substrates using conventional wet transfer approach.[7] The top electrode with a diameter of 200 μm was deposited by electron beam evaporation. The current-voltage (I-V) characteristics of these resistive memory devices were conducted in an ambient atmosphere and dark room on Keithley 4200 semiconductor analyzer in DC voltage sweeping mode.

3. Results and Discussion

Figure 1a and b shows the schematic of the hBN-based resistive memory device structure with Ag top electrode (TE) and Cu foil bottom electrode (BE) on the PET substrate. After electroforming process (Figure 1c), the hBN-based memory device exhibited a typical bipolar switching behavior. Furthermore, we monitored the other electrical switching properties of the Ag TE/hBN/Cu foil memory device (Figure 2), which demonstrated steady write operation with 550 cycles (Figure 2a) and long retention time of ~3 $\times 10^3$ s (Figure 2b). In order to confirm the feasibility of our hBN-based device for flexible memory application, bending tests were carried out under repeated cycles (750 times) as shown in Figure 2c and d. It is observed that the ON/OFF ratios did not change much when a bending radius of 7 mm was applied to the devices, indicating excellent bending stability and suggesting that this Ag TE/hBN/Cu foil memory device is mechanically robust and suitable for flexible nonvolatile memory application. The underlying mechanism for the resistive switching behavior of Ag TE/hBN/Cu is the formation/rupture of Ag filament [7].

The hBN film can also be transferred onto polydimethylsiloxane (PDMS) substrate to construct a flexible transparent indium tin oxide (ITO) TE/hBN/graphene memory device.[8]

4. Conclusion

We have introduced a layered 2D material for creating flexible ReRAM devices with the configuration of Ag TE/hBN/Cu foil and ITO TE/hBN/graphene on different substrates, which features excellent performances in terms of retention time, write cycles and bending endurance. These studies broaden the applications of 2D materials for use as flexible ReRAM which would be useful in integrated wearable electronics in future.

References

[1] J. J. Yang et al., Nat. Nanotechnol. 8.1 (2013), 13-24.
[2] R. Waser et al., Adv. Mater. 21(2009), 2632-2663.
[3] T. Sekitani et al., Science 326.5959 (2009), 1516-1519.
[4] A. A. Bessonov et al., Nat. Mater. 14.2 (2015), 199.
[5] G. Shi et al., Nano Lett. 14.4 (2014), 1739-1744.
[6] R. Y. Tay et al., Nano Lett. 14.2 (2014), 839-846.
[7] K. Qian et al., Adv. Funct. Mater. 26.13 (2016), 2176-2184.
[8] K. Qian et al., ACS Nano 11.2 (2017), 1712-1718.

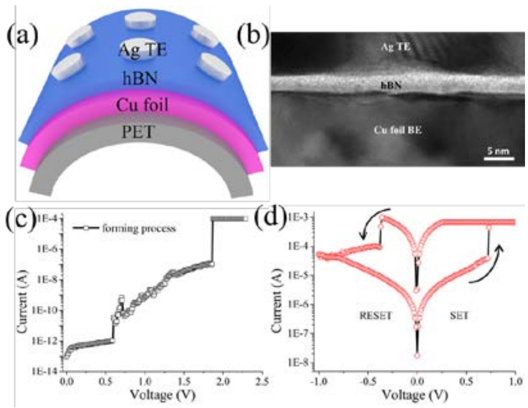

Fig.1: (a) Schematic of the Ag/hBN/Cu foil on PET substrate memory device arrays. (b) Cross-section TEM image of the Ag/hBN/Cu foil memory cell, and the thickness of hBN is about ~5 nm. (c) The electroforming process for hBN memory device with $V_{forming}$ ≈ 1.87 V. (d) The switching characteristics for the hBN memory device after electroforming process. (reference 7)

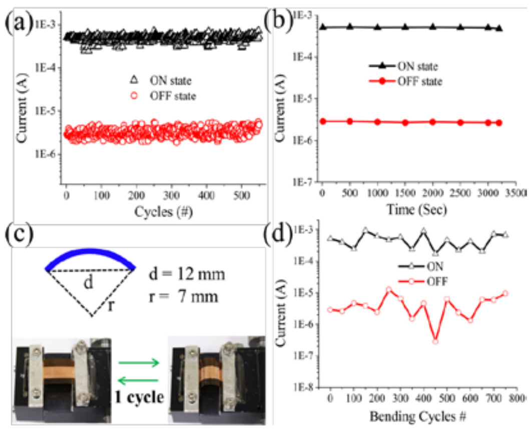

Fig.2: Characteristics of the flexible Ag TE/hBN/Cu foil memory device. (a) Write cycles and (b) retention time of the flexible device. (c) Illustration of 1 cycle during the bending test with bending radius r=7mm, and the measured devices were near the middle of the sample. (d) Continuous bending experiment of the hBN-based devices. The reading voltage is 0.1 V. (reference 7)