Supporting Information

Direct Observation of Indium Conductive Filaments in Transparent, Flexible, and Transferable Resistive Switching Memory

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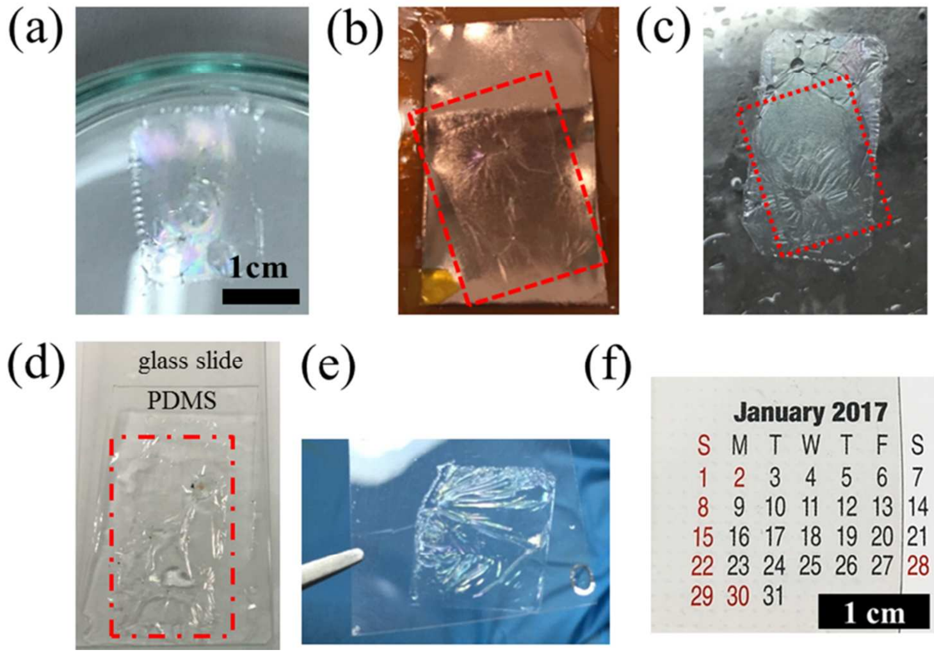

Figure S1. (a) hBN film with PMMA in DI water after removal of Cu foil substrate. (b) The transferred hBN film with PMMA onto graphene/Cu foil. The hBN/PMMA film was highlighted by the red rectangle frame. (c) The transferred hBN/graphene film with PMMA in DI water after removal of Cu foil substrate. The hBN/PMMA film was highlighted by the red rectangle frame. (d) The hBN/graphene film with PMMA was transferred onto PDMS substrate. The hBN/graphene film was indicated by the red rectangle frame. (e) The transferred hBN film with PMMA onto ITO/PET substrate. After removal of PMMA using acetone, ITO top electrode was deposited on the hBN/ITO/PET to construct transparent and flexible ITO/hBN/ITO/PET memory device (f).

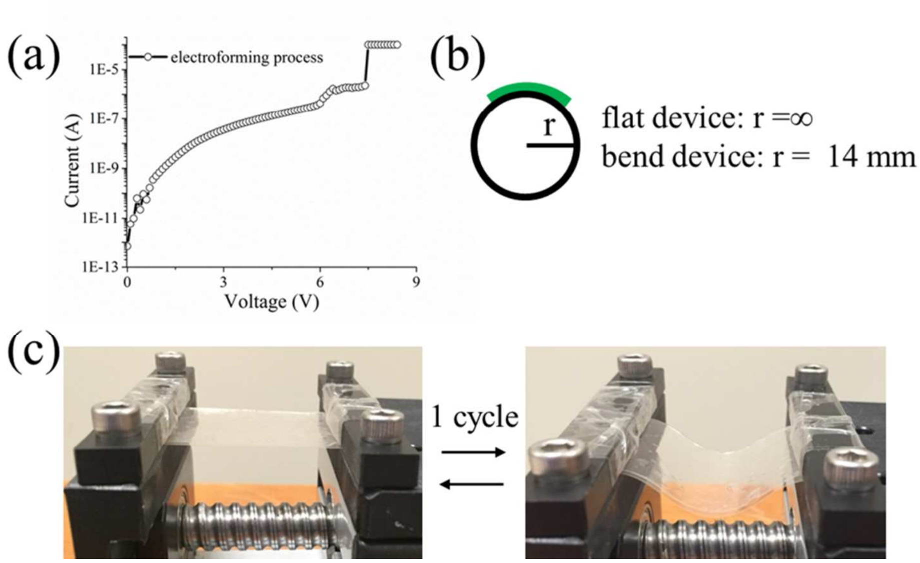

Figure S2. (a) A typical electroforming process with a relatively high voltage of ~7.4 V in an ITO TE/HBN/graphene/PDMS memory device. (b, c) Illustration of 1 cycle bending test with bending radius of 14 mm. The measured memory cells were near the middle of the sample.

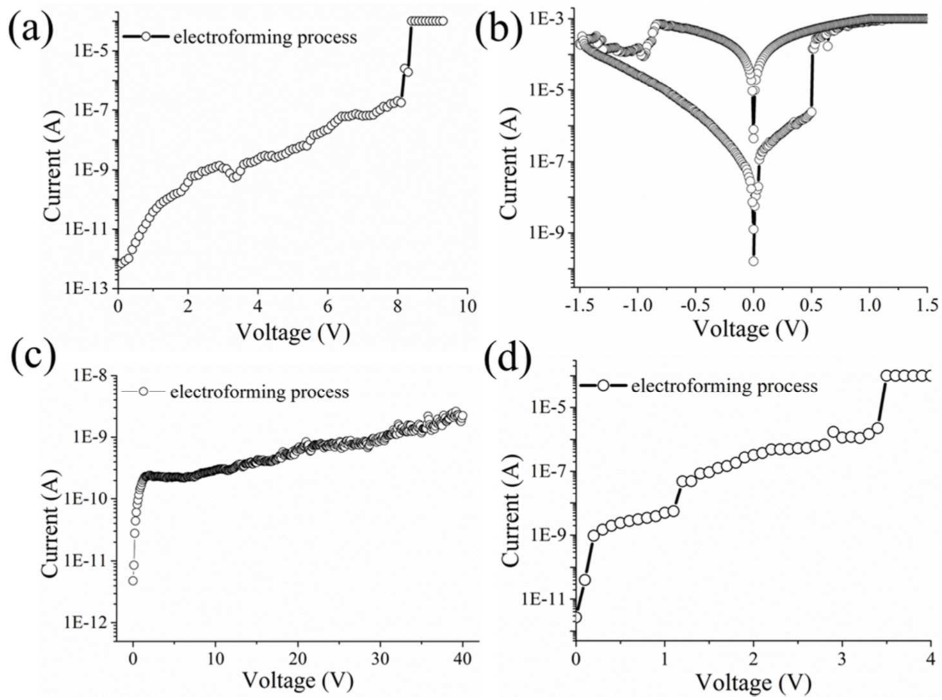

Figure S3. (a) Initial electroforming process for ITO TE/hBN/ITO/PET memory device with voltage of ~8.3V. (b) Switching characteristics of ITO TE/hBN/ITO/PET memory device after electroforming process. (c) Initial electroforming process for ITO/hBN/FLG/Cu foil memory device. During the electroforming process, the positive voltage was applied on the graphene/Cu foil electrode, while the ITO electrode was grounded. It is clear that there was no resistive switching even with a high voltage, indicating the Cu foil which was isolated by few-layer graphene cannot contribute the resistive switching. (d) Initial electroforming process for Ag TE/hBN/FLG/Cu foil memory device with voltage of ~3.5V.

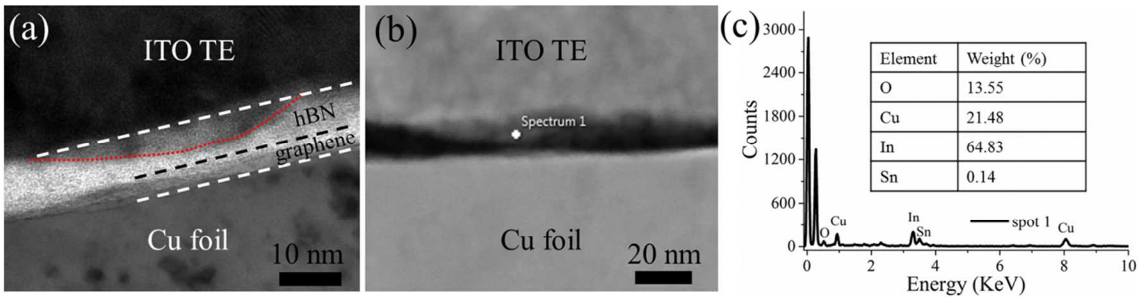

Figure S4. Observation of conductive filaments in ITO TE /hBN/FLG/Cu foil memory cell at OFF state. (a) TEM image of a non-complete filament in the memory cell (highlighted by the closed regions), indicating the filament ruptured at the thinnest part of the filament at the hBN/graphene interface, leading to the OFF state. (b) STEM image of the ITO TE /hBN/FLG device, corresponding to (a). (c) EDS spectrum of the filament in region "1" of (b).

The memory cell was reset to the OFF-state through more than 20 repetitive switching cycles for the *ex-situ* TEM measurements. **Figure S4**a showed a cross-sectional TEM image of the OFF-state sample after RESET process. The OFF-state filament (**Figure S4**a) with a wider base at the ITO/hBN interface and thinner part at the hBN/graphene interface is similar to the one at ON-state (**Figure 4**b). It is clear that the dissolution of the filament occurred at the hBN/graphene interface where the thinnest part of filament was, leading to the OFF state. To determine the nature of the ruptured filament, the filament composition was studied *via* EDS point analysis (region 1 in **Figure S4**b). As shown in **Figure S4**c, the detailed studies verified that the ruptured filament is mainly composed of In element

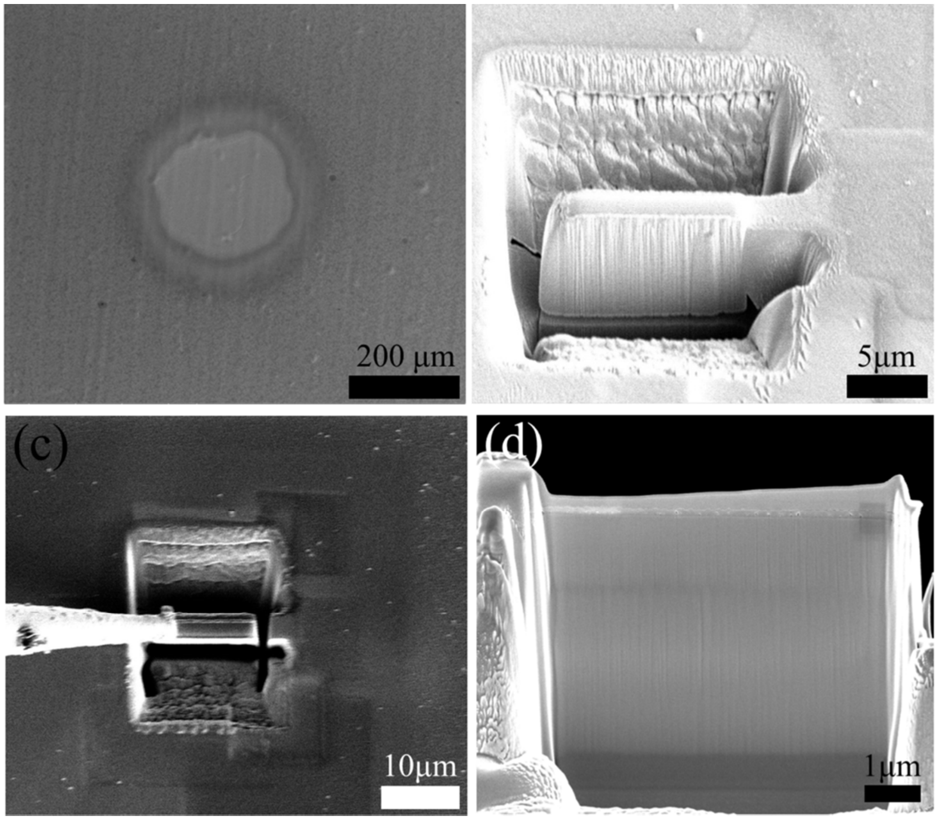

Figure S5. SEM images showing the *ex-situ* TEM specimen preparation *via* FIB. (a) ITO/hBN/graphene/Cu foil memory cell. (b) The memory cell was cut using a focused ion beam with a Ga ion beam at 30 kV beam energy. (c) FIB lift-out process (d) The memory cell was thinned down to ~ 100 nm and cleaned at 8 kV beam energy.

The cross sectional TEM specimen was prepared out of the ITO/hBN/graphene memory cell by successive cutting, lift-out and thinning processes. As shown in **Figure S5**, the ITO/hBN/graphene memory cell (**Figure S5**a) was cut using a FIB with a Ga ion beam at 30 kV beam energy (**Figure S5**b), followed by lift out (**Figure S5**c), thinning (down to ∼100 nm) and cleaning at 8 kV beam energy (**Figure S5**d).