Fabrication of Multi-Bit Data Storage Memories Based on Multilayer MoS_2

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Molybdenum disulfide (MoS_2) recently emerged as a promising material candidate for making non-volatile memory devices with fast speed and low cost.[1] A great deal of research effort has been invested to create MoS_2-based memory devices based on existing flash-memory transistor structures, which need complicated heterostructures, hybrid organic/inorganic materials, precise deposition of multiple material layers, and multiple overlay lithography processes to define floating gates, blocking and tunneling layers.[1-5] Such MoS_2-based memory fabrication solutions indeed increase complexity and cost of memory cells and are not advantageous over state-of-the-art memory fabrication processes at all. Therefore, new device structures and fabrication processes based on MoS_2 and atomically layered 2D materials are needed for enabling low-cost and upscalable memory solutions.

We present a new fabrication solution for making MoS_2-based floating-gate-free, non-volatile, multi-bit memory field-effect transistors (FETs) with a unique combination of excellent retention/endurance property, extremely simple structure, and low cost.

The new multi-bit memory FETs are fabricated by using our recently developed plasma-assisted doping technique (Fig. 1).[6] Using such MoS_2 FETs, we have demonstrated highly reliable binary and 2 bit (*i.e.*, 4 data levels) data states with potential for year-scale data retention (Fig. 2), as well as 3 bit (*i.e.*, 8 data levels) data states at least suitable for day-scale storage (Fig. 3). Such a new multi-bit memory capability is attributed to plasma-induced mechanical separation of plasma-doped MoS_2 layers from undoped pristine layers, which forms an ambipolar charging layer interfacing a pristine MoS_2 transistor channel through a tunneling barrier, therefore resulting in multiple memory states with a broad range of energies. The full presentation will also include our in-depth electric force microscopy (EFM) characterizations of MoS_2 multi-bit memory FETs, which provides additional scientific insights about the setting (or charging/discharging) schemes in such memories.

This work greatly leverages the unique structural property of MoS_2 and other atomically layered 2D materials for applications in the fields related to data storage technologies. The presented fabrication methods and device structures hold a significant potential to be further developed into a low cost, upscalable memory solution for making future high-performance disposable electronic products such as electronic labels, digital newspapers, medical care tags, and point-of-care biosensors.

[1] Liu, Juqing, et al. "Preparation of MoS2 Polyvinylpyrrolidone Nanocomposites for Flexible Nonvolatile Rewritable Memory Devices with Reduced Graphene Oxide Electrodes." Small 8.22 (2012): 3517-3522.
[2] Xiao, Di, et al. "Coupled Spin and Valley Physics in Monolayers of MoS and Other Group-VI Dichalcogenides." Physical Review Letters 108.19 (2012): 196802.
[3] Bertolazzi, Simone, Daria Krasnozhon, and Andras Kis. "Nonvolatile Memory Cells Based on MoS2/Graphene Heterostructures." ACS nano 7.4 (2013): 3246-3252.
[4] Lee, Hee Sung, et al. "Data Storage: MoS2 Nanosheets for Top-Gate Nonvolatile Memory Transistor Channel." Small 8.20 (2012): 3220-3220.
[5] Yin, Zongyou, et al. "Memory Devices Using a Mixture of MoS2 and Graphene Oxide as the Active Layer." Small (2012):727-731.
[6] Chen, Mikai, et al. "Stable few-layer MoS2 rectifying diodes formed by plasma-assisted doping." Applied Physics Letters 103.14 (2013): 142110.

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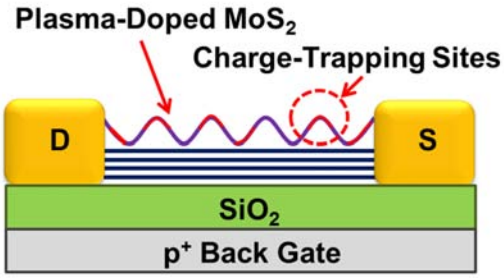

Fig. 1 Fabrication of MoS_2-based multi-bit memory FET by using plasma-assisted doping processes.

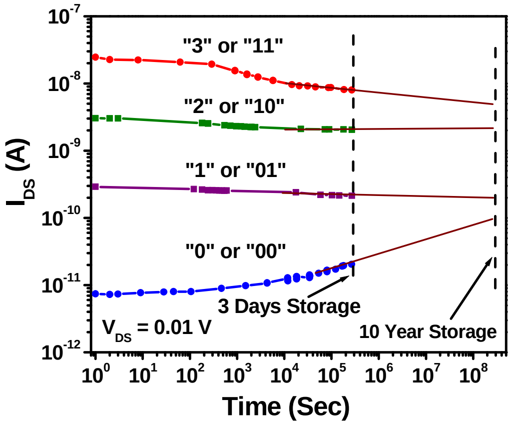

Fig. 2 Retention characteristics of 4 data states recorded for 3 days. For these 4 retention measurements, V_{DS}= 0.01 V, V_G= 0 V. It is estimated that these 4 data states can be well discernible within 10 years since the initial applications of programming V_G signals.

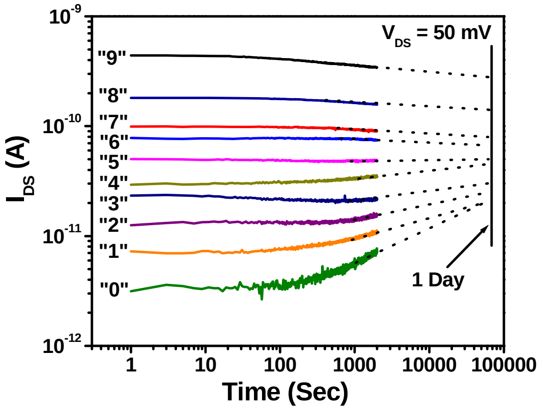

Fig. 3 Retention characteristics of 10 data states recorded for 2000 s, which are estimated to be well discernible within hour- or day-scale time durations after the initial setting.

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