Electronic Supplementary Information

Multilevel Non-Volatile Data Storage Utilizing Common Current Hysteresis of Networked Single Walled Carbon Nanotubes

Ihn Hwang[a,†], Wei Wang[a,†], Sun Kak Hwang[a], Sung Hwan Cho[a], Kang Lib Kim[a], Beomjin Jeong[a], June Huh[b], and Cheolmin Park[a]

a) Department of Materials Science and Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Republic of Korea.

E-mail: cmpark@yonsei.ac.kr

b) Department of Chemical and Biological Engineering, Korea University, Anam-dong, Seongbuk-gu, Seoul 136-713, Republic of Korea

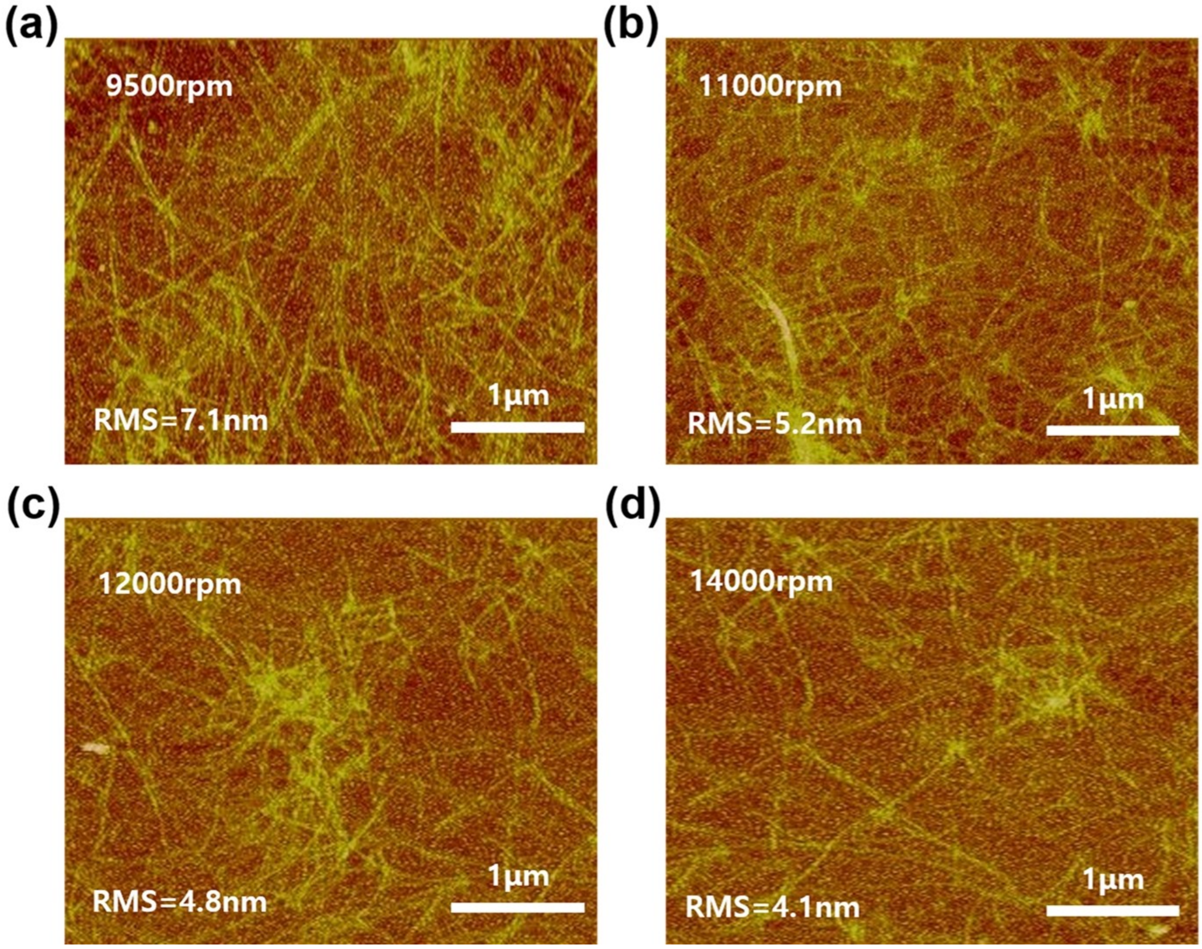

Fig.S1 TM-AFM Images in height contrast of SWNT networks as a function of centrifuge rpm on SiO_2 Substrate. Surface roughness is slightly varied with the centrifuge rpm of SWNT dispersion solution. (a). 9500rpm, RMS= 7.1nm, (b) 11000rpm, RMS= 5.2nm (c)12000rpm, RMS= 4.8nm (d) 14000rpm, RMS= 4.1nm

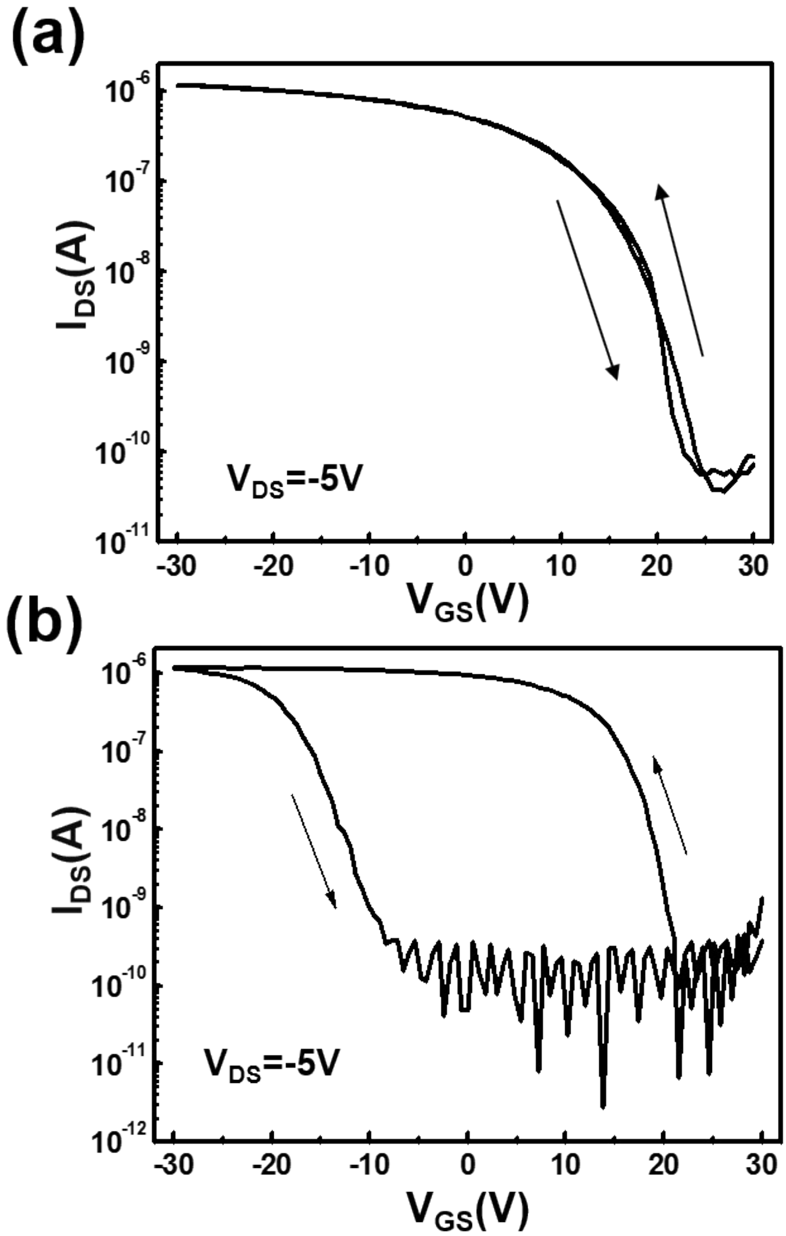

Fig.S2 The transfer characteristics of a transistor device (a) with PMMA passivation layer and (b) without a PMMA passivation layer.

Electronic Supplementary Material (ESI) for Nanoscale.
This journal is © The Royal Society of Chemistry 2015

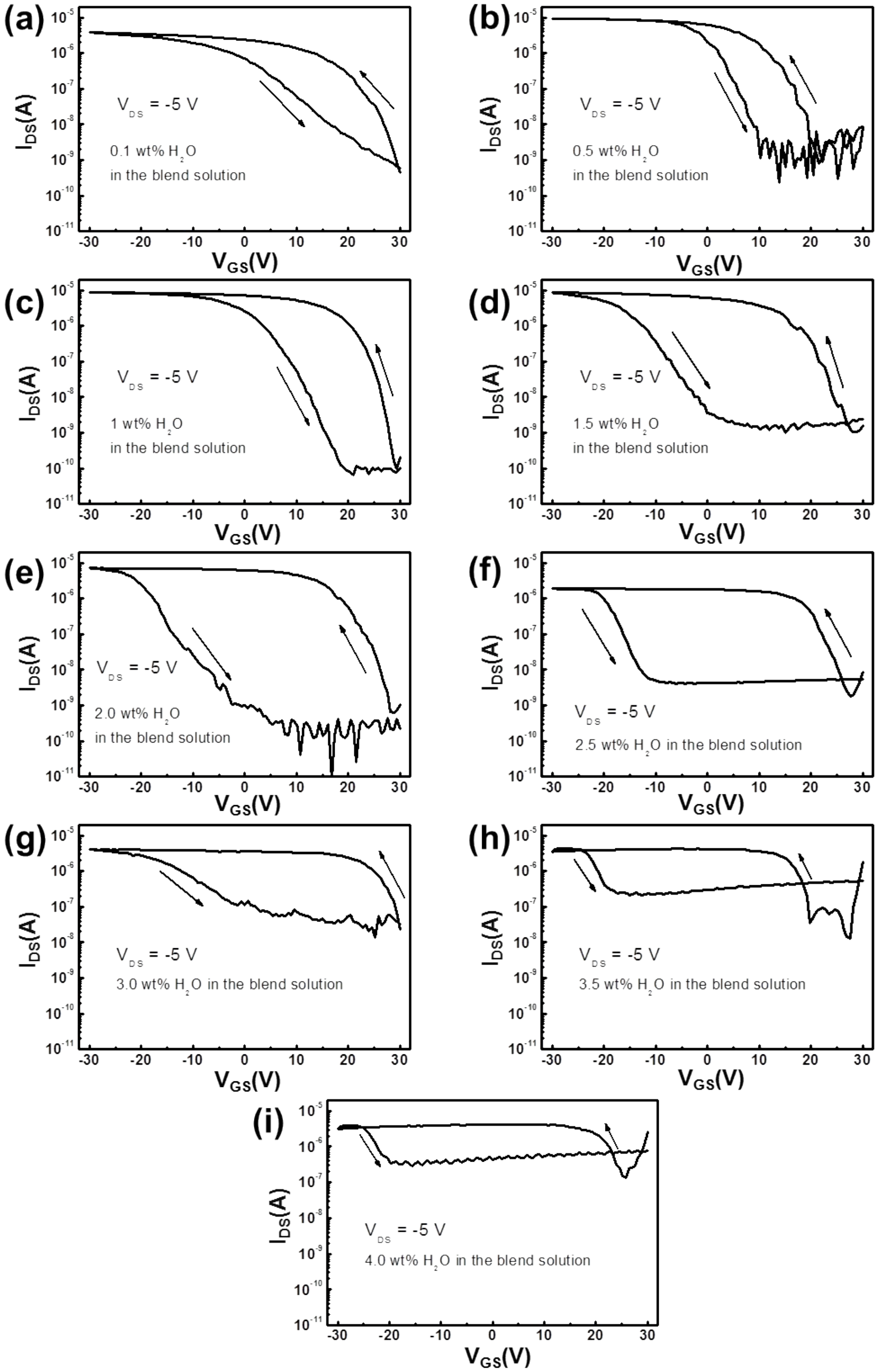

Fig.S3 The transfer characteristics of typical memory devices with the PMMA layers prepared from the blend solutions with various concentrations of H_2O.

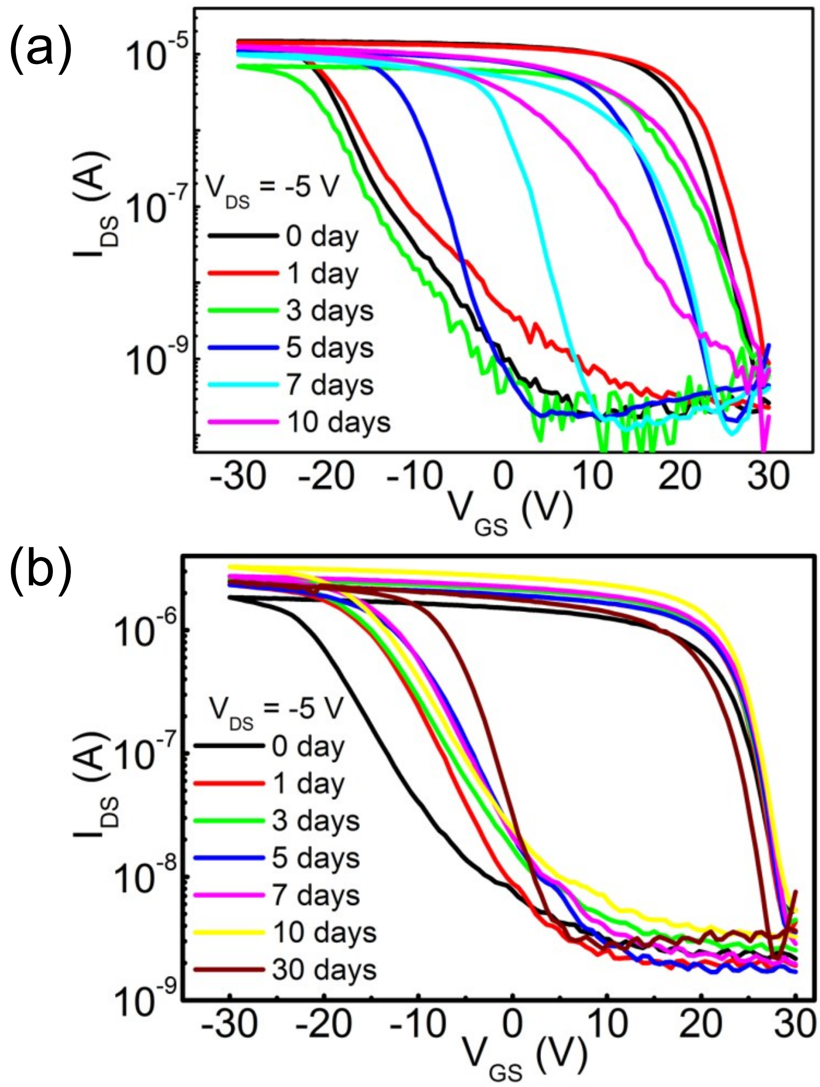

Fig.S4 The evolution of the transfer characteristics as a function of time (a) under vacuum and (b) in an ambient atmosphere

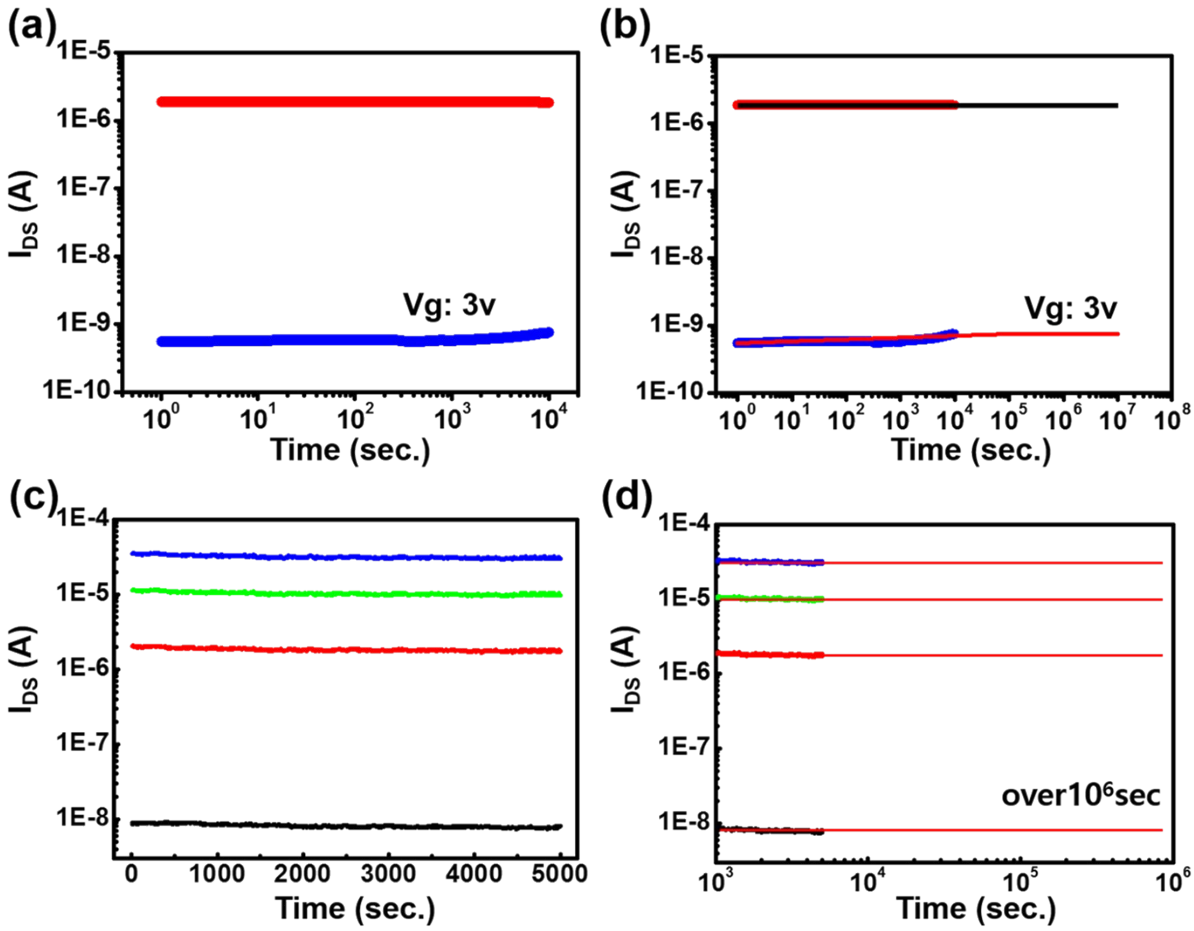

Fig.S5 Retention performance of NSWNT FET memories. (a)and (c) are the retention results shown in (Fig.2c) and (Fig.4c) respectively. (b) and (d) are extrapolation results.

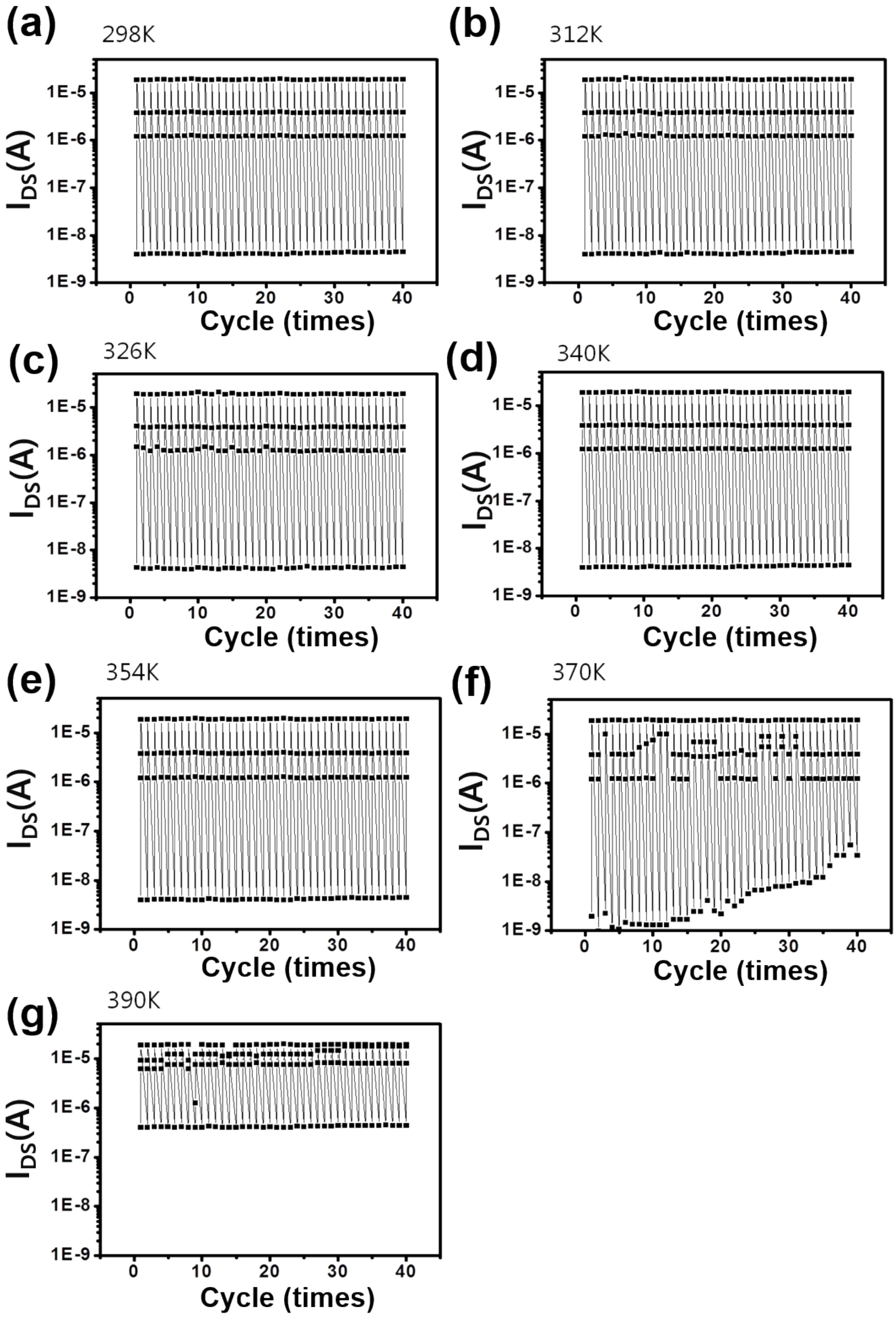

Fig.S6 The multilevel dynamic switching properties of the memory device operated at temperatures of (a) 298, (b) 312, (c) 326, (d) 340, (e) 354, (f) 370, and (g) 390 K. (h) The evolution of the four current level ratios as a function of temperature.

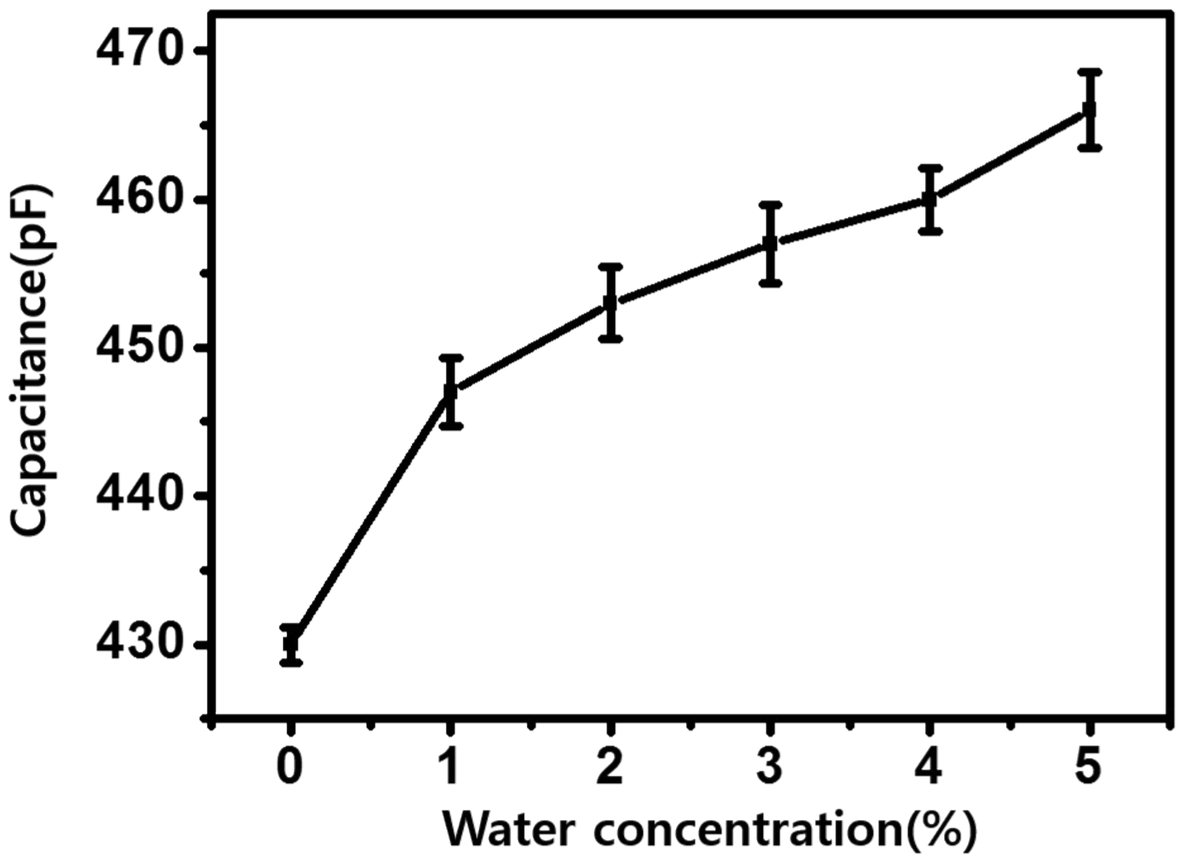

Fig.S7 Capacitance values of PMMA films containing wate. All the results were obtained with frequency and voltage bias of 100KHz and 5V, respectively. The PMMA films are approximately 1μm in thickness.

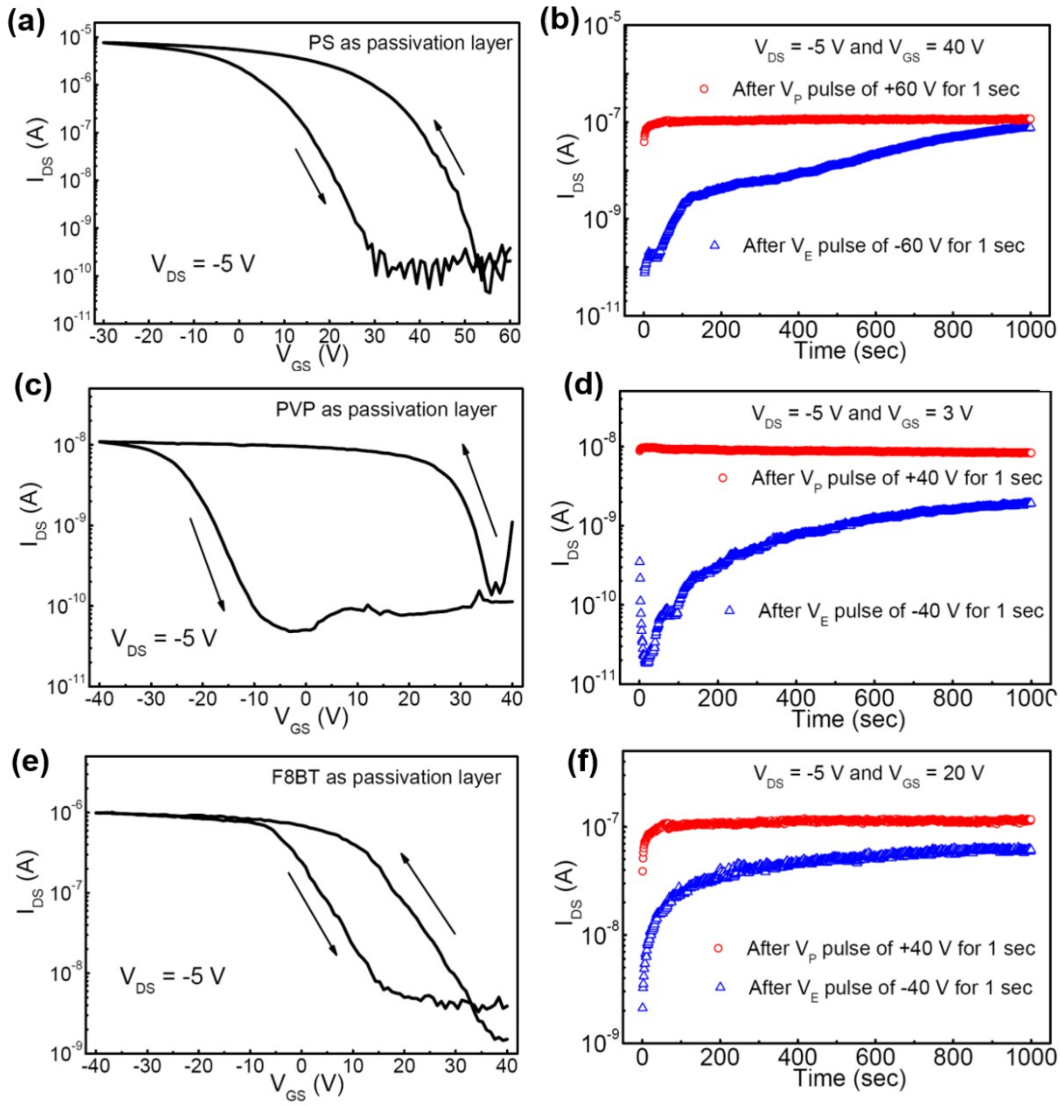

Fig.S8 (a) The transfer characteristics and (b) data retention capability of a typical memory device with an 800 nm thick water containing PS passivation layer. (c) The transfer characteristics and (d) data retention capability of a typical memory device with a 600 nm thick water containing PVP passivation layer. (e) The transfer characteristics and (f) data retention capability of a typical memory device with a 300 nm water containing thick F8BT passivation layer.

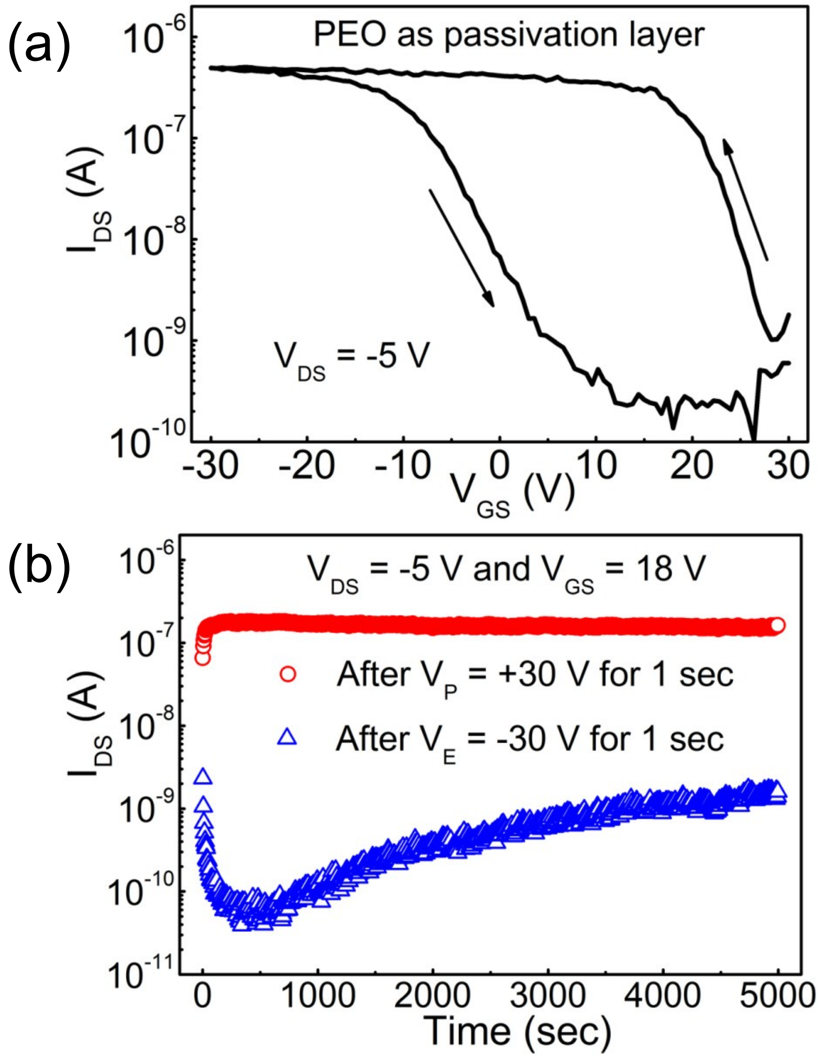

Fig.S9 (a) The transfer characteristics and (b) data retention capability of a typical memory device with a 500 nm water containing thick PEO passivation layer.

Electronic Supplementary Material (ESI) for Nanoscale.

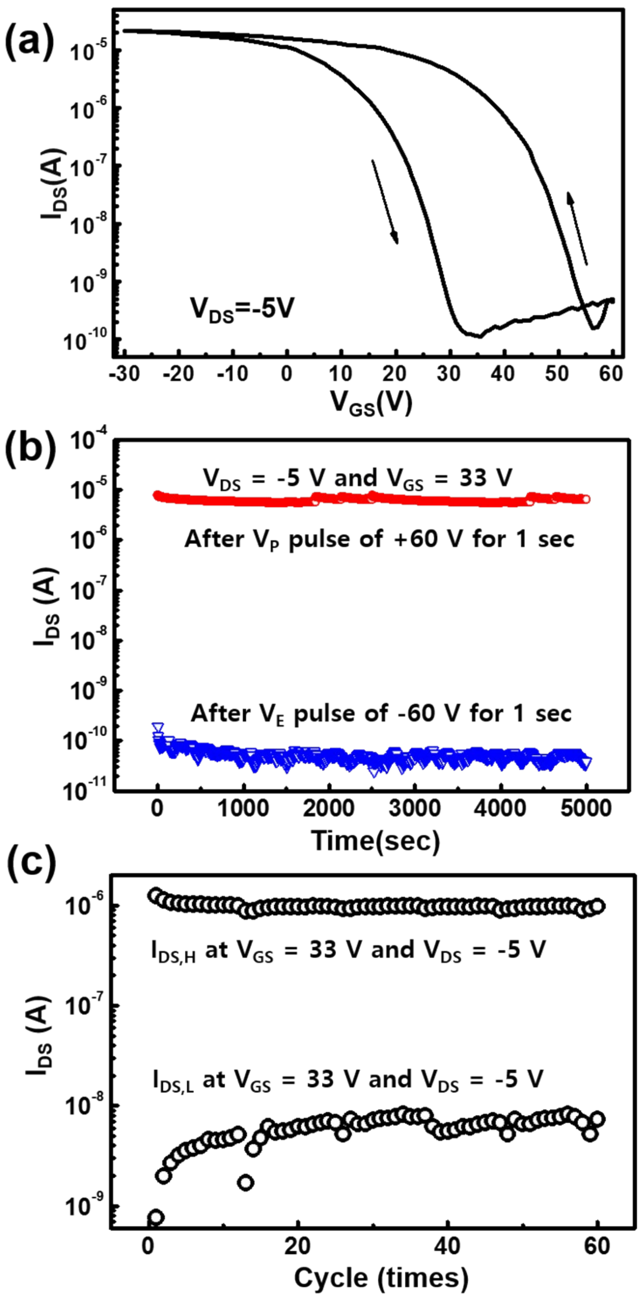

Fig.S10 (a) The transfer characteristics, (b) data retention capability, and (c) switching endurance properties of a NCNT FET memory with a water containing PVDF-TrFE layer.

Reference	CNT type	Device structure	Retention(sec)	Endurance(Times)	Multilevel
(1)	Network	FET(BGTC)[a]	1000	1000	X
(2)	Network	FET(BGTC)	$1.2*10^7$	No data	X
(3)	Network	FET(BGTC)	1800	2400	X
(4)	Network	FET(TGTC)[b]	over 10^6	500	4 state
(5)	Network	FET(TGTC)	10000	600	3 state
(6)	Network	FET(BGTC)	43200	10^4	X
(7)	Network	FET(BGTC)	$1.2*10^4$	240	X
(8)	Network	FET(TGBC)	1000	500	X
(9)	Polymer composition	Resist memory	10^4	110	X
(10)	Polymer composition	Resist memory	10^5	100	3 state
(11)	Single wire	Resist memory	500	No data	X
(12)	Single wire	FET(TGTC)	600	No data	X
(13)	Single wire	FET(BGTC)	$1.5*10^4$	18000	X
(14)	Single wire	FET(BGTC)	200	No data	X
(15)	Single wire	FET(BGTC)	20000	No data	X
(16)	Single wire	FET(BGTC)	54000	1000	X
(17)	Single wire	FET(TGTC)	over 10^6	over 10^6	X
Our Work	**Network**	**FET(BGTC)**	**over 10^6**	**over 100**	**4 state**

a) Field Effect Transistor (Bottom Gate Top Contact)
b) Field Effect Transistor (Top Gate Top Contact)

Table.S1 Comparison between previous research and this paper

Supporting Information Referance

1. M. Y. Chan, L. Wei, Y. Chen, L. Chan and P. S. Lee, *Carbon*, 2009, **47**, 3063
2. Q.g Tan, J. Wang, X. Zhong, Q. Wang, Y. Liu, J. Shi, and S. Jiang, *IEEE TRAN*. 2014, **61**, 2628
3. B. Liu , M. A. McCarthy and A. G. Rinzler, *Adv. Funct. Mater.* 2010, **20**, 3440
4. B. Cho, K. Kim, C-L. Chen, A. M. Shen, Q. Truong and Y. Chen, *Small*, 2013, ***9***, 2283
5. G. Li, Q. Li1,2, Yuanhao Jin, Q. Qian, Y. Zhao, X. Xiao, J. Wang, K. Jiang and S. Fan, *Appl. Phys. Express,* 2015, **8**, 065101
6. A. D. Bartolomeo,, M. Rinzan, A. Boyd, Y. Yang, L. Guadagno, F. Giubileo and P. Barbara, *Nanotechnology*, 2010, **21,** 115204
7. Y-C. Chiu, C-C. Shih and W-C Chen, *J. Mater. Chem. C*, 2015, **3**, 551
8. W. J. Yu , S. H. Chae , S. Y. Lee , D. L. Duong and Y. H. Lee, *Adv. Mater.* 2011, **23**, 1889
9. S. K. Hwang , J. R. Choi , I. Bae , I. Hwang , S. M.Cho , J. Huh and C. Park, *Small* 2013, **9**, 831
10. S. K. Hwang, J. M. Lee, S. Kim, J. S. Park, H. I. Park, C. W. Ahn, K. J. Lee, T. Lee, and S. O. Kim, *Nano Lett.* 2012, **12**, 2217
11. G. Sun, J. Liu, L. Zheng, W. Huang and H. Zhang, *Angew. Chem.* 2013, **52**, 13351
12. K. Seike, Y. Fujii, Y. Ohno, K. Maehashi, K. Inoue and K. Matsumoto, *Jpn. J. Appl. Phys*. 2014, **53**, 04EN07
13. M. Rinkio , A. Johansson, G. S. Paraoanu and P. Torma, *Nano Lett., 2009,* **9**, 643
14. W. Fu, Z. Xu, X. Bai, C. Gu, and E. Wang, *Nano Lett., 2009,* **9**, 921
15. M. Olmedo, C. Wang, K. Ryu, H. Zhou, J. Ren, N. Zhan, C. Zhou and J. Liu, *ACSnano*, 2011, **5**, 7972
16. J. Yao, Z. Jin, L. Zhong, D. Natelson, and J. M. Tour, *ACSnano*, 2009, **3**, 4122
17. J. Y. Son, S. Ryu, Y-C. Park, Y-T. Lim, Y-S. Shin, Y-H. Shin and H. M Jang, *ACSnano*, 2010, **4**, 7315