Mass-Fabrication of Voltage-Programmable Non-Volatile Carbon Nanotube Memory Devices

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In this contribution we report on mass-fabrication of carbon nanotube field-effect transistors (CNTFETs) with high on/off ratio to be used as non-volatile memory cells operating at room temperature. Several thousands of memory devices have been realized using a complete in-situ fabrication method.

The storage of binary data in memory units is a fundamental prerequisite in information technology. Molecular memory devices with semiconducting single-walled carbon nanotubes (s-SWNTs) are promising candidates to realize ultra-dense non-volatile memory cells [1]. However, present state-of-the-art fabrication methods of CNTFETs are very time-consuming and are not suitable for fabrication of memory chips with millions of transistors.

Our novel fabrication method allows growing of individual SWNTs directly within the desired device area (Fig. 1). No tedious manual manipulation and alignment of the SWNTs is necessary. The self-aligned fabrication process allows mass-production of SWNT memory devices with high yield (Fig. 2). Statistical analysis on hundreds of electrical measurements reveals that 71% of the devices are working (i.e. there is current between source and drain) and 67% of them show excellent semiconducting behavior (on/off ratio $\geq 10^6$, see Fig. 3). 27% of the working devices have also a s-SWNT as the channel but with a small band-gap and only 6% of the working devices show a purely metallic behavior (i.e. no field-effect notable).

The memory function is obtained by the threshold voltage shift (memory window) due to the highly reproducible hysteresis in the transfer characteristics (Fig. 3). The ratio of the current levels between a logical "1" and a logical "0" is about 10^6. The "0" and "1" current levels are seen to be temporally stable and stay within the same decade (Fig. 4). Long term data retention for more than 12 hours was also observed even at power off. More detailed measurements on data retention are in progress. Also, excellent endurance properties have been obtained after performing multiple read/write cycles. The reading current remains at the same level and depends only on the programming gate voltage applied before. Since the current levels do not depend on the previous history of read/write cycles and due to the long retention time, voltage-programmable CNTFETs have the characteristics of non-volatile memory cells.

Since the process is silicon CMOS compatible, it opens the possibility to fabricate circuits, either by structuring a top gate on the in-situ grown SWNTs or by using buried isolated bottom-gate on SOI wafers to realize high density embedded or stand-alone memory units.

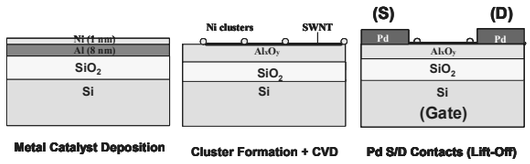

Fig. 1: Process flow of CNTFET memory device fabrication based on CVD with sacrificial catalyst [2].

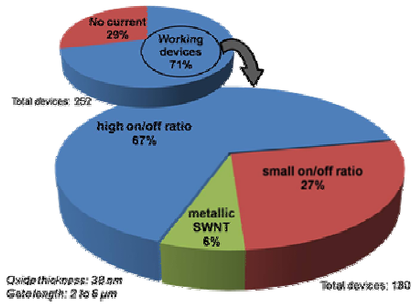

Fig. 2: Nearly 15.000 CNTFET structures have been fabricated. Statistics on hundreds of electrical measurements revealed a total yield of almost 50% (71% × 67%) for fully functional semiconducting devices, suitable for use as CNTFET memory devices.

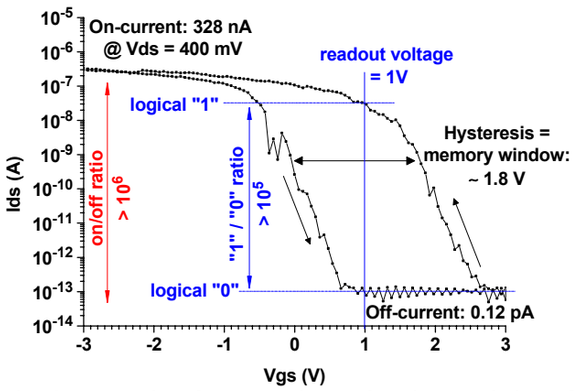

Fig. 3: Example of measured transfer characteristics of fabricated CNTFET device structures with only one s-SWNT as the channel.

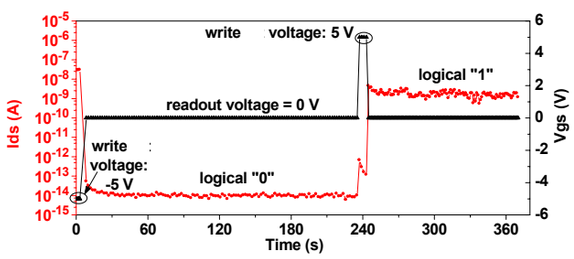

Fig. 4. Cycling of CNTFET memory cell. Black triangles: *applied* gate voltage versus time. Red dots: *measured* drain current versus time.

References

[1] S. Wang, P. Sellin, Appl.Phys.Lett. **87**, 133117 (2005)
[2] L. Rispal et al., Jap. J. Appl. Phys. **47**, 3287 (2008)