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Impact of overshoot current on SET operation of Atom Switch

T. Sakamoto, M. Tada, M. Miyamura, N. Banno, K. Okamoto, N. Iguchi, and H. Hada

Low-power Electronics Association & Project (LEAP), 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan
(Phone) +81-29-879-8263, (FAX) +81-29-856-2622

Abstract: Current overshoot has significant impact on the control of resistance and reliability of resistive change device such as atom switch. We have demonstrated that the amplitude of current overshoot, caused by charging parasitic capacitance, strongly depends on transition time of resistive switching. The variation of transition time affects on ON conductance of atom switch.

Atom switch has its compactness, low resistivity and large ON/OFF conductance ratio. The atom switch is applicable to programmable switch, which realizes a three-dimensional FPGA with low power and high performance [1]. One of the issues for the resistive switch is a variation in switching characteristics. In this paper, we have clarified the impact of overshoot current on switching characteristics.

Atom switch composed of a solid electrolyte (Fig. 1)(PSE/TiO_2 [1]) shows a bipolar switching. When a positive voltage is applied to Cu electrode, Cu^+ ions migrate within solid electrolyte and a nanometer-scale metallic bridge is formed (Fig. 2(a)) [1-4]. For RESET operation, the electromigration breaks the bridge, and then, Cu residues are retrieved by the ion migration (Fig. 2(b)).

Figure 3 shows the 16kb switch array to evaluate switching characteristics. The voltages on GBL, BL, and SL are externally applied. The pulse width is precisely defined by WE with Schmitt trigger circuit. The 1T1R cell has parasitic capacitance to evaluate the effect of overshoot current on the resistive switching.

Figure 4 shows the current transient during the SET operation. When the pulse voltage is applied to SL terminal in Fig. 3, the atom switch turns on and current on BL terminal changes with a certain delay. The resistive transition is too fast to observe in our measurement setup. After the transition, the current saturates. Thus, the SET operation is composed of three steps: incubation, transition, and settling step. Figure 5(a) shows the distribution of ON conductance for different pulse width. The transition step finishes within 100nsec, and then the bridge growth saturates in settling step. The change in the conductance of the resistive switch with 1T1R configuration is well explained by thermally-activated ion-migration model [5]. During the transition, the fast increase of conductance reduces the voltage across the atom switch, resulting in an exponential decrease of the driving force for ion migration, thus suppressing growth. During settling step, the bridge slowly grows while the voltage across the switch is regulated by a negative feedback loop under current limiting scheme in 1T1R. For our case, the conductance is roughly proportional to the logarithm of pulse width (Fig. 5(a)). The conductance is also proportional to the control current of BL transistor (I_C).

Figure 5(b) shows the effect of the parasitic capacitance between the atom switch and BL transistor. The on conductance (G_{ON}) has a wider distribution and a larger value compared with the cell with small parasitic capacitance. The conductance at -2σ in Fig. 5(b) is similar to that in Fig. 5(a), but the conductance at $+1\sigma$ (shown by dotted line) becomes larger. In Fig. 6, the conductance at $+1\sigma$ for different pulse width and I_C shows that the distribution of G_{ON} approaches to that for G_{ON} under small parasitic capacitance when I_C or pulse width increases.

Large G_{ON} in Fig. 5(b) is due to the current overshoot at the resistive transition in Fig. 4 [5,6]. During the transition, the voltage at the node between the switch and BL transistor abruptly changes and the parasitic capacitor is charged, resulting in flowing a large current through the switch.

The transient voltage and current during SET operation is calculated by using SPICE, where we assume that the resistance linearly changes by 3 orders of magnitude within transition time (t_{TRAN} = 0.1, 0.3, or 1ns) (Fig. 7). As shown in Fig. 8, the current overshoot (I_{OVER}) strongly depends on t_{TRAN}. For t_{TRAN} = 0.1ns, the current overshoot is three times larger than I_C. The variation in I_{OVER} is still considerable for C_0 = 0.56fF when $t_{TRAN} < 0.1$nsec. The time to charge parasitic capacitance is estimated to be below 10ps. Thus, the capacitance is charged within transition time, resulting in large I_{OVER} for fast t_{TRAN}. Figure 8 also shows that I_{OVER} in Fig. 7 decreases with increasing also I_C, which is consistent with Fig. 6.

When we assumes that G_{ON} linearly depends on the maximum in transient current in Fig. 7(b) and that I_C of 350μA gives G_{ON} of 0.34mS in Fig. 5(a), t_{TRAN} has a range of 0.1 to 1nsec.

Summary: Atom switch is set shortly by ion migration within 100ns. The range of transition time of 0.1∼1nsec is estimated. The variation in ON conductance is originated from that in the transition time. It is essential to reduce the variation in the transition time or extend the time.

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References

[1] M. Tada, *et al.*, IEEE IEDM, pp. 403, 2010.
[2] M. Miyamura, *et al.*, ISSCC, pp. 21, 2011.
[3] T. Sakamoto *et al.*, VLSI Tech., pp. 130, 2009.
[4] N. Banno, *et al.*, IRPS, pp. 707, 2008.
[5] D. Ielmini, *et al.*, IEEE ED, Vol. 58, pp. 4309, 2011.
[6] An Chen, *et al.*, IRPS, MY.2.1, 2012.

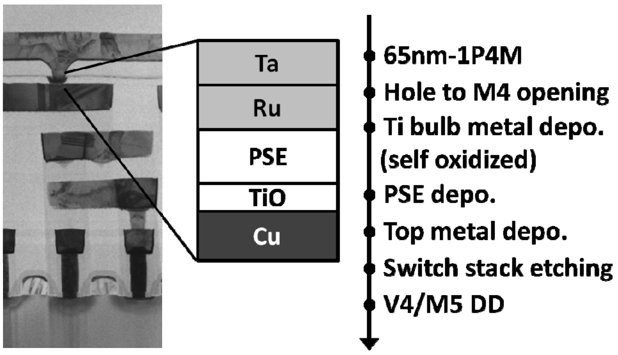

Figure 1.TEM image of atom switch embedded in 65nm 1P5M CMOS, schematic atom-switch stack using PSE/TiO_2 solid electrolyte and process flow.

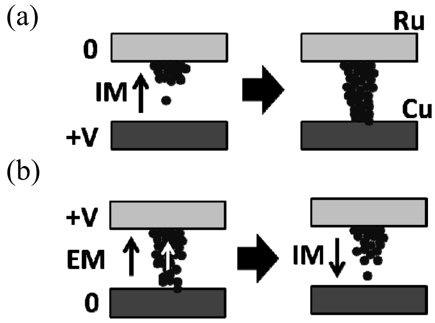

Figure 2 Schematic of (a) SET and (b) RESET operation.

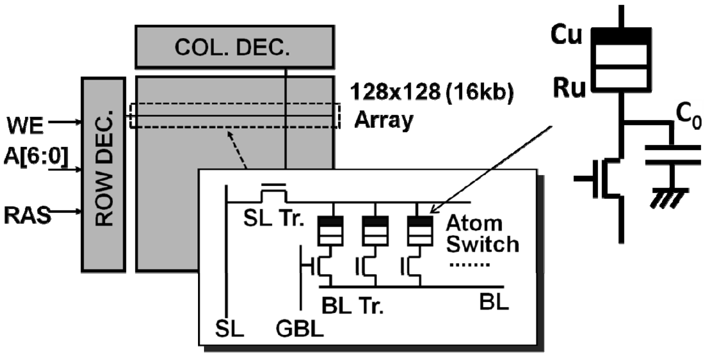

Figure 3. Measurement configuration of atom switch connected to two transistors: BL Tr. and SL Tr. in 16kb switch array. BL Tr. controls SET current. Node between atom switch and BL transistor is loaded by parasitic capacitance of 44 or 0.56fF (=C_0).

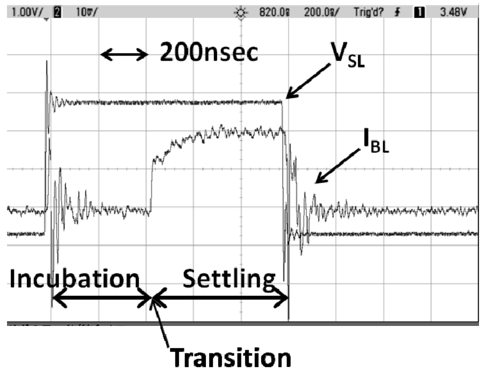

Figure 4. Current on BL (I_{BL}) during SET operation for pulse voltage on SL (V_{SL}). SET process composed of 3 steps: "Incubation", "Transition", and "Settling" steps.

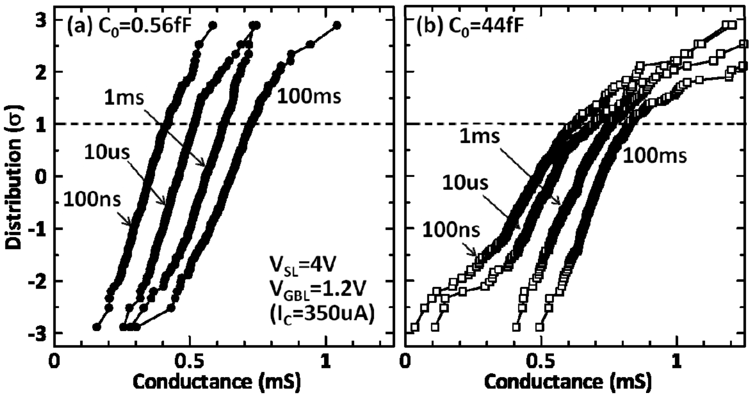

Figure 5. Distribution of ON conductance for different parasitic capacitance of (a) 0.56fF and (b) 44fF and different pulse width. Current is controlled at 350uA (=I_C) by BL transistor.

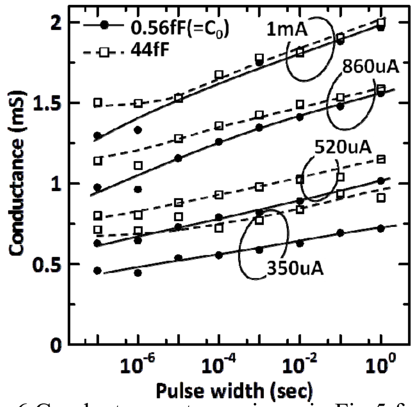

Fig. 6 Conductance at one sigma in Fig.5 for different voltage pulse-width or control current I_C.

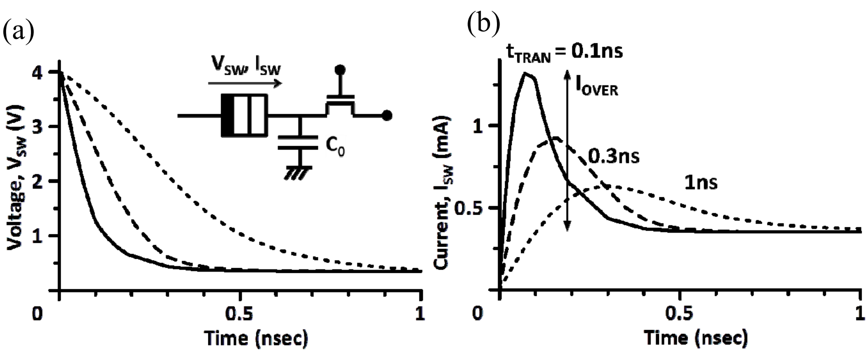

Figure 7. Calculated (a) transient voltage (V_{SW}) and (b) current (I_{SW}) of atom switch during SET operation with C_0=44fF and V_{SL}=4V. Resistance of atom switch is linearly changed within t_{TRAN}.

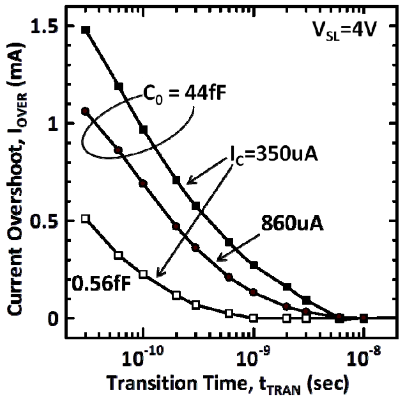

Figure 8. Current overshoot (I_{OVER}) in Fig.7. Current overshoot for different condition is also calculated.