SOLID-ELECTROLYTE SWITCH FOR RECONFIGURABLE LSI

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Nanoscale electronic devices such as molecular or atomic devices have been extensively investigated, since they have potentials to complement Si-LSI or overcome its limitations. One of the intriguing device is a solid electrolyte switch which conductance changes when a nanometer-scale metallic bridge is formed [1,2]. The solid-electrolyte switch has a simple structure of potentially $4F^2$ and has a low ON resistance, which is lower than that of MOSFETs by two orders of magnitude.

The device structure is depicted in Fig.1. The top layer is a Ti electrode, which electrically makes contact with the Cu_2S/Cu film via a hole in the insulating layer. The Cu_2S film is a solid electrolyte (and a Cu-ionic conductor). Figure 2 shows the IV characteristics of a switch with a 30-nm contact hole. There are two resistance states, ON and OFF. The switching voltage from OFF to ON is -0.28 V. The switching voltage depends on the sweep rate of the voltage. The ON/OFF ratio is larger than 10^5. This conductance switching is repeatable and each state persists when the voltage is low. This switching behavior is observed up to about $3X10^3$ cycles (Fig. 3). For devices that have a hole diameter of 0.3 μm, the cycle number is in the order of 10^5. The retention time of each state is more than one month.

Conductance switching can be explained by creating and dissolving a metallic bridge inside the Cu_2S film. When a negative voltage is applied to this top electrode, Cu ions in the Cu_2S are electrochemically neutralized and precipitated (Fig. 2). Cu ions are supplied via this electrochemical reaction at the Cu_2S/Cu interface. By applying a positive voltage, the Cu bridge is dissolved into the solid electrolyte, resulting in the OFF state. In the experiments, the ON current did not depend on the hole diameter in the range from 0.3 μm to 30 nm. This result indicates that the conduction area is smaller than 30 nm. When decreasing the ambient temperature, the ON resistance decreases, which shows that the bridge is metallic. These two experimental results support the idea of the Cu bridge.

This novel switch is suitable for use as a programmable switch or memory element in LSI. One of the promising applications is in a field programmable logic (FPL) [3], which has become increasingly attractive because of such advantages as its short turnaround time and low non-recurring expense. The programmable switch in a conventional FPL consists of an SRAM and a pass transistor and occupies a large area ($\sim 120F^2$). Thus, FPL is costly and has poor cell usage efficiency. When the solid electrolyte switch is applied to a programmable switch, the chip size can be reduced to 1/10th compared with a conventional one and its performances (speed and power consumption) is improved (Fig. 4). To show the potentials for FPL application, we have demonstrated the reconfiguration of a crossbar switch and look-up-table, which are fundamental elements of FPL. Figure 5 shows the demonstration of 2-input look-up-table using 4 novel switches.

REFERENCES

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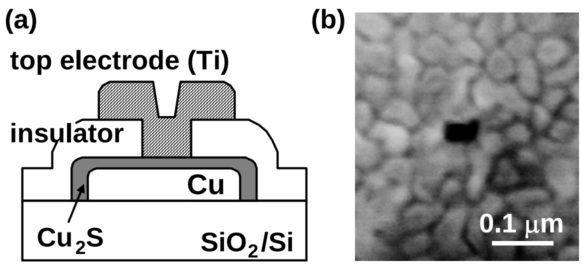

Figure 1. (a) Schematic view of the NanoBridge composed of a Cu_2S film sandwiched between a Cu film and the top electrode. (b) Scanning micrograph from top.

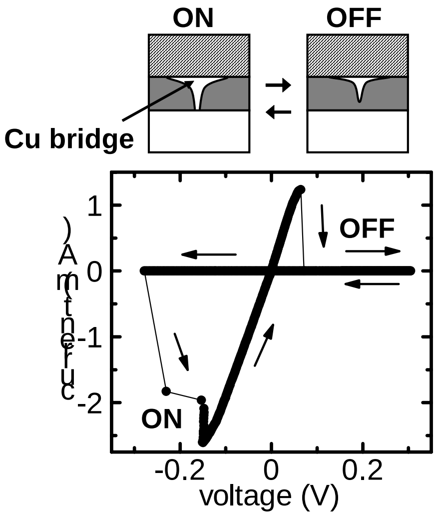

Figure 2. Current-voltage characteristics of novel switch with 0.03 μm contact hole. Top: schematic of operation principle.

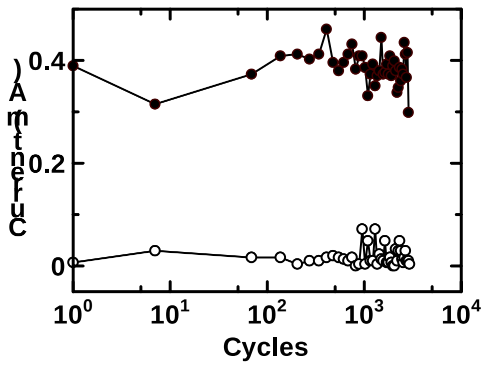

Figure 3. Cycling endurance.

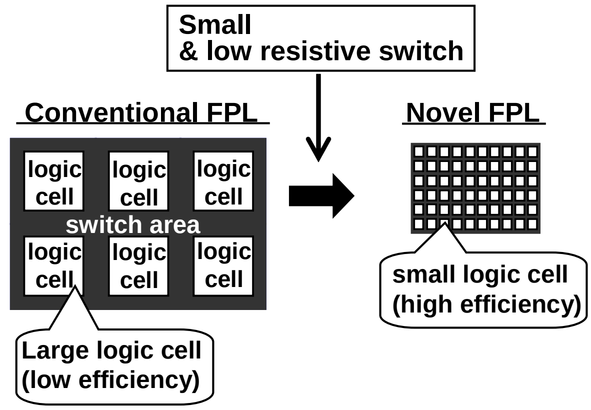

Figure 4. Conventional or novel FPL. White region represents the logic area and the gray one represents the switch area. When our technology is applied, the small logic cell can be used and the logic cell usage efficiency can increase.

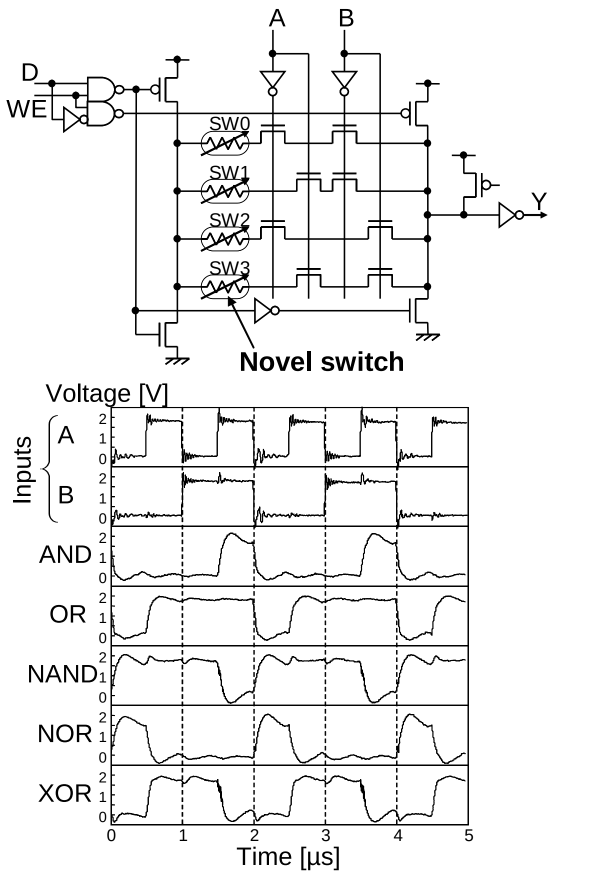

Figure 5. (a) Schematic of two-input look-up table with four novel switches. (b) Measured waveforms. Upper two waveforms are for input signals A and B, and the other waveforms are for output signal Y under AND, OR, NAND, NOR, and XOR configurations.