NanoBridge Technology

Introduction

Nanoscale electronic devices such as molecular or atomic devices have been extensively investigated in order to overcome the limitations in silicon-based microelectronics. One of the intriguing phenomena is a conductance switching caused by the creation or annihilation of a nanoscale metallic bridge in a solid electrolyte[1,2]. The solid electrolyte switch (namely, NanoBridge) has a simple structure of potentially $4F^2$ and has a low ON resistance, which is lower than that of FETs by two orders of magnitude.

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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 1 also shows the IV characteristics of a switch with a 30nm contact size. There are two resistance states, ON and OFF. The transition voltage from OFF to ON is –0.28V. The transition 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 repeatedly observed for up to about 3×10^3 cycles. For devices that have a hole diameter of 0.3μm, the cycle number is in the order of 10^5. The retention time of each state is more than one month (**Fig. 2**).

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. 1). 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 contact size in the range from 0.3μm to 30nm. This result indicates that the conduction area is smaller than 30nm. 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.

Applications of a NanoBridge

This novel switch is suitable for use as a programmable switch or memory element in LSI. One of the promising applications is in the field programmable logic (FPL)[3], which has become increasingly attractive because of such advantages as its short turnaround time and low non-recurring expense. However, since the programmable switch in a conventional FPL, which consists of an SRAM and a pass transistor, occupies a large area (~$120F^2$), FPL is costly and has poor cell usage efficiency. When the novel 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. To show the potentials for FPL application, we demonstrated the reconfiguration of a 4×4 crossbar switch, which is a fundamental element of FPL (**Fig. 3**(a)).

The NanoBridge also has a potential for nonvolatile memory. We fabricated a 1Kb low-voltage nonvolatile memory element using NanoBridge (Fig. 3(b))[3]. The competitive potentials of this memory are scalability, a large read-margin, and low voltage operation (~0.2V). With CMOS scaling, the low voltage operation is essential for an embedded memory.

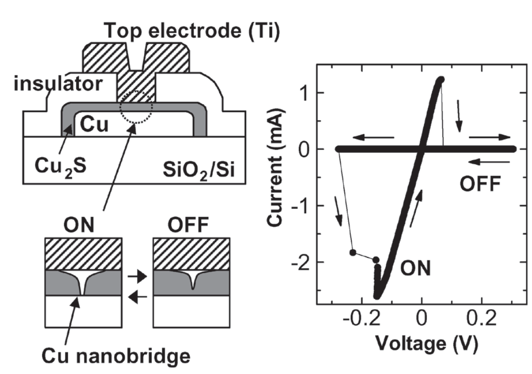

Fig. 1 Left: Schematic view of the NanoBridge composed of a Cu_2S film sandwiched between a Cu film and the top electrode. Right: Current-voltage characteristics of the NanoBridge with a 0.03μm contact size.

	Nano-Bridge	MOSFET	Phase change	MEMS switch
Feature size	0.03 μm	1 μm(=W_g)	0.1 μm	1mm
ON resistance	50Ω	1kΩ	1kΩ	<1Ω
Switching Time	~100 μs	1ns	10ns	>1 μs
Threshold Voltage	<1V	<2V	<1V	>20V
Cycling endurance	10^3-10^5	>10^{15}	10^{12}	<10^5
Non-volatility	Yes	No	Yes	No

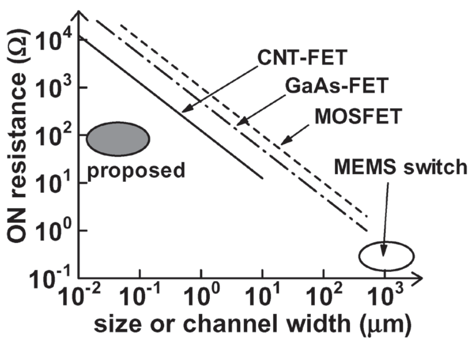

Fig. 2 Summary of the electrical characteristics of the NanoBridge (upper) and a comparison with other switches in terms of feature size and ON resistance (lower). ON resistance of NanoBridge is lower than those of FETs by two or three orders of magnitude.

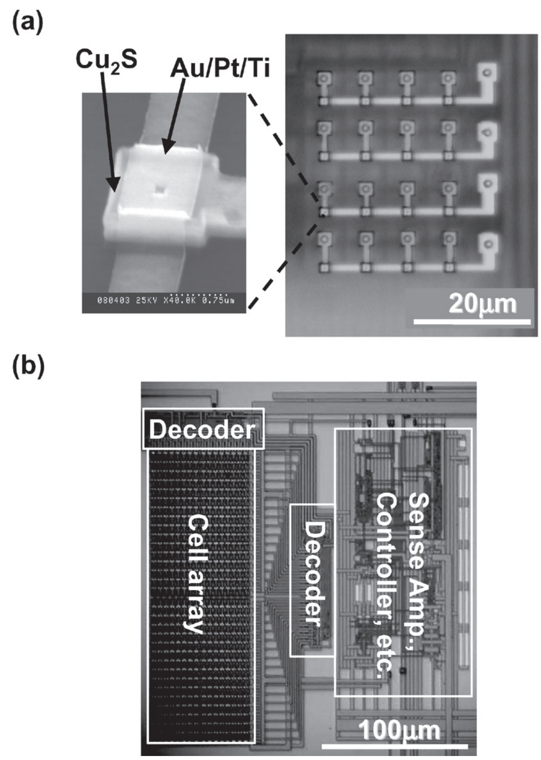

Fig. 3 (a) 4X4 crossbar switch. (b) 1Kb nonvolatile memory. NanoBridges are stacked on the top metal layer.

Conclusion

We have developed a nanometer-scale switch (NanoBridge) using a solid electrolyte. We have also demonstrated the crossbar switch and 1Kb nonvolatile memory using the novel switch technology.

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