NanoBridge Technology for Reconfigurable LSI

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Abstract

We have investigated a NanoBridge technology for a high performance LSI that is reconfigurable. The NanoBridge comprises a solid electrolyte sandwiched between two metals. The switch has two conducting states (ON/OFF) that persist in the absence of a power supply. The distinctive advantages of this switch are its small size (<30nm) and low ON resistance (<100Ω). This paper proposes a three-terminal NanoBridge, for which the control gate is separate from the current path. This innovative switch resolves the issues arising from large current during switching that occurs in a two-terminal NanoBridge.

Keywords

FPGA, reconfigurable, solid electrolyte

1. Introduction

System LSI has been selected among the ASIC (Application Specific Integrated Circuit) platforms according to customer production volumes, a product's required performance features and the time to market. One of the leading platforms is the CBIC (Cell-Based Integrated Circuit). CBIC consists of standard cells. The circuits are fixed in the factory and cannot be reconfigured. Another leading platform is the programmable LSI such as FPGA (Field Programmable Gate Array). FPGA is composed of logic cells, interconnections, and programmable switches. Customers program these switches to reconfigure circuits and create their own system LSIs.

Fig. 1 shows a comparison between these two ASIC platforms. The CBIC can be selected for large production volumes because of its small chip cost. CBIC also features performance advantages (operation speed and power consumption). On the other hand, for small production volumes, FPGA is a preferable choice because of its low initial development cost. FPGA has the advantage of short TAT (Turn-Around Time) characterized by its field programmability. However, it suffers from the drawbacks of large chip size and high chip cost. This is due to its large programmable switch composed of an SRAM and a pass transistor. The SRAM switch occupies a large area of the chip. In order to minimize the number of SRAM switches, each logic cell has a high functionality and consequently a large size. Large switches and logic cells result in a large chip size (high chip cost) and poor cell usage efficiency.

As discussed in this paper, we can provide a small and low resistivity switch. This innovative switch realizes programmable LSI with low chip cost, and high performance. The switch size may be reduced by a factor of 10 and it can be stacked on the logic cell as shown in **Fig. 2**, the size is therefore negligible. Furthermore, when a small logic cell is used, the cell usage efficiency can be increased. We estimate that the chip size is reduced by a factor of 10 compared to the conventional FPGA. Thus, the performance is improved without scaling down the feature size[1, 2).

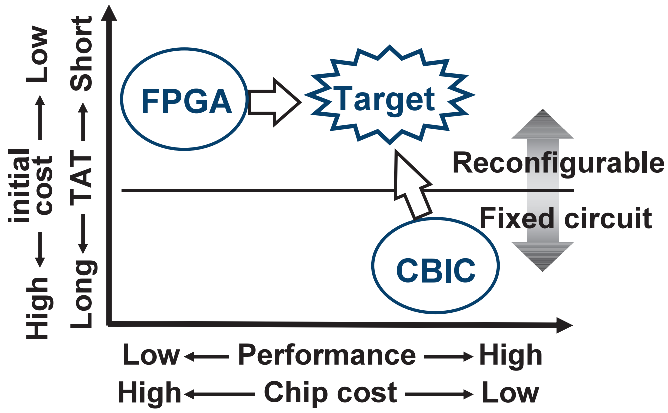


Fig. 1 Comparison between CBIC (Cell-based IC) and FPGA (Field programmable gate array).

2. NanoBridge Technology

We have proposed a two-terminal solid electrolyte switch (referred to below as a two-terminal NanoBridge), which is composed of copper sulfide (Cu_2S) sandwiched between two

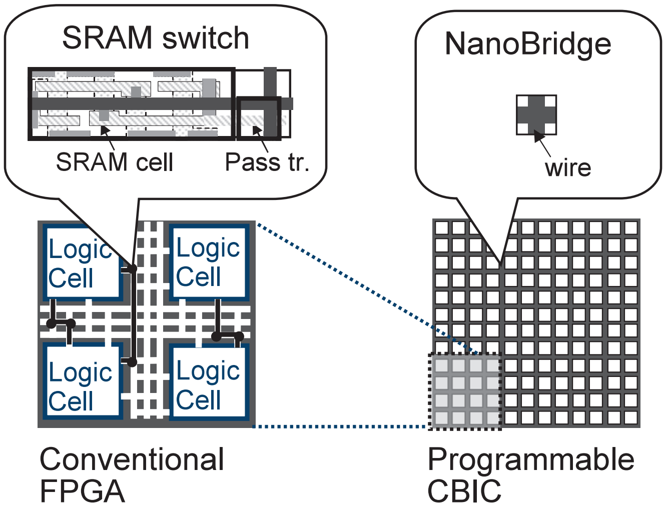


Fig. 2 Conventional FPGA and the proposed programmable device. The white region represents the logic area and the gray one represents the switch area. When NanoBridge technology is applied, a small logic cell can be used and the logic cell usage efficiency can increase.

metals (Cu and Pt) (**Fig. 3(a)**)[1,3]. Cu_2S is a Cu-ionic conductor. The switch turns on or off when a nanometer-scale metallic bridge either appears or disappears inside a Cu_2S film by biasing voltages. When a negative voltage is applied to a Pt electrode described in Fig. 3(a), Cu^+ ions in Cu_2S are neutralized and precipitated at the Pt electrode. The Cu^+ ions are supplied from the Cu electrode. Subsequently, the precipitated Cu forms conducting bridges between the two electrodes, thus changing the conductance to an ON state. Conversely, by applying a positive voltage the Cu bridge is ionized and disappears, resulting in an OFF state. Each state is nonvolatile and the switching between the two states is repeatable.

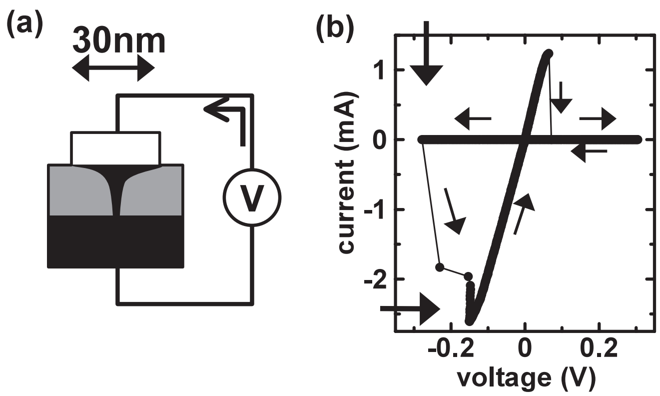


Fig. 3 Left: Schematic view of NanoBridge composed of a Cu_2S film sandwiched between Cu film and top electrode. Right: Current-voltage characteristics of NanoBridge with a 0.03μm contact size.

Fig. 3(b) shows the IV characteristics of the 2 terminal NanoBridge with a 30nm contact size. There are two resistance states, ON and OFF. The switching voltage from OFF to ON is about -0.2V. The ON resistance is 50Ω. The OFF current is below 10nA. The switching is repeatable up to 10^3 and each state is nonvolatile.

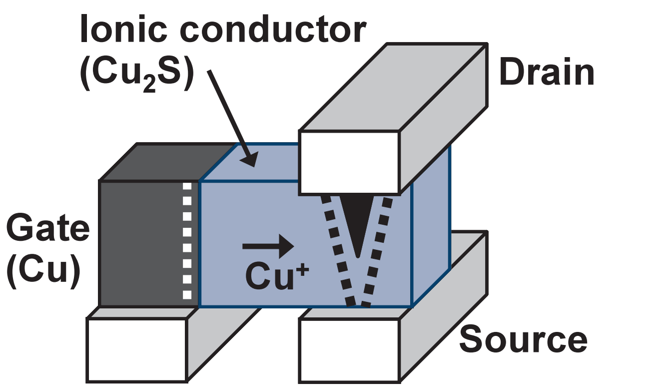
When we apply this switch to programmable logic, there are still several difficulties. Firstly, the switching voltage (V_{sw}) between the two states should be larger than the operating voltage of the logic circuit, which is about 1V for the technology node of hp65. This prevents flipping the switch on or off by applying logic signals. However, V_{sw} is below 0.3V. Secondly, during programming the current should be suppressed (>1mA) in order to avoid large power dissipation and thermal breakdown issues. When the switching voltage is raised for the first issue, the switching current is increased further.

Regarding the first issue, we have demonstrated that V_{sw} can be increased by using an ionic conductor with a small diffusion rate[4]. For the second issue, we have demonstrated that a three-terminal NanoBridge can reduce the programming current as discussed in the following[5].

3. Three-Terminal Solid Electrolyte Switch

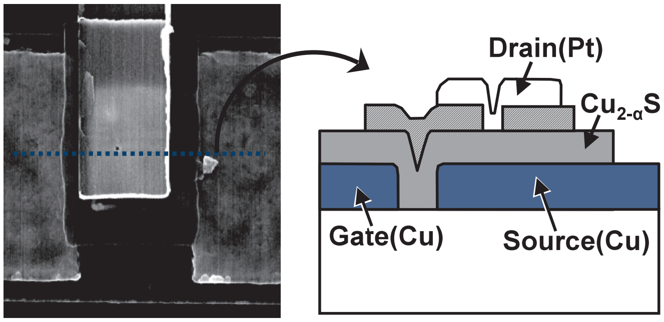
Fig. 4 shows the concept of the three-terminal NanoBridge, where the control line is separated from the conduction route[5]. Connection or disconnection between the two metal wires is altered by biasing the voltages on the control line. The current on the control line is small.

Fig. 5 is a schematic cross section of the fabricated three-



When positive voltage is applied to the control line, metal is precipitated between two metal wires via electrochemical reactions. Negative voltage results in precipitated metal dissolving in the solid electrolyte.

Fig. 4 Concept of three-terminal NanoBridge.



Drain electrode connects to $Cu_{2-\alpha}S$ via 0.2µm-diameter hole in calixarene (negative electron beam resist).

Fig. 5 SEM image and schematic cross-section of three-terminal NanoBridge.

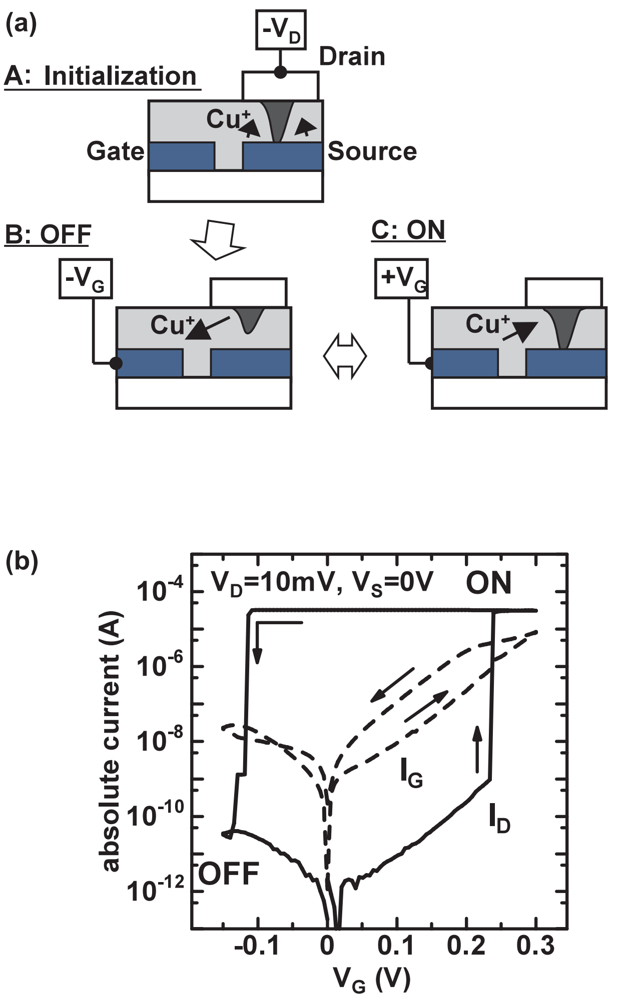


Fig. 6 (a) Operation of three-terminal NanoBridge. (b) Drain current (I_D) and gate current (I_G) with changing gate voltage (V_G).

terminal NanoBridge. The source and gate electrodes are made of Cu and supply Cu^+ into Cu_2S via an electrochemical reaction. When a positive voltage is applied to the gate relative to the source and drain, the Cu grows toward the gate from the source and drain and may cause a short circuit between the gate and the other electrodes.

In order to avoid short-circuiting, the source and drain were electrically connected prior to gate operation by applying a negative drain voltage (V_D) (**Fig. 6**A). This operation is the same as that for a two terminal NanoBridge. Subsequently, when a negative or a positive gate voltage (V_G was applied, the drain current (I_D) was reversibly turned to an OFF or ON state (Fig. 6B, C). Thus, the drain current (I_D) is modulated with changing V_G. The ON/OFF current ratio of I_D was up to 10^5. As indicated by the gate current (I_G) in Fig. 6, the current for switching the states was reduced by more than two orders of magnitudes compared with that of the two terminal NanoBridge. It was confirmed that the retention time for the ON state was more than 40 days without power supply. The number of cycles was in the order of tens. Cycling endurance becomes poor when Cu is deposited excessively or is dissolved by biasing the V_G after switching. To avoid over-writing, the biasing time was controlled using a PC. Consequently, there was a slight improvement in the number of cycles. The switching time was in the order of sub mili-seconds, which may be reduced by biasing a larger V_G.

4. Conclusion

In order to reduce the current during switching in a two-terminal NanoBridge we proposed a three-terminal NanoBridge, in which the gate electrode is separate from the conduction route.

We then successfully demonstrated that the drain current was reversibly switched when a positive or negative gate voltage was applied. The current during switching was reduced by two orders of magnitude compared with that in the two-terminal NanoBridge.

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