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H-1-2 (Invited)

Solid-electrolyte nanometer switch implemented in Si LSI

T. Sakamoto[1,2], S. Kaeriyama[3], H. Sunamura[1,2], M. Mizuno[3],
H. Kawaura[1,2], T. Hasegawa[2,4], K. Terabe[2,4], T. Nakayama[2,4], and M. Aono[2,4]

[1]Fundamental & Environmental Research Labs., NEC Corp., Tsukuba, Ibaraki 305-8501, Japan
Phone: +81-298-50-1111 Fax: +81-298-56-6139 e-mail: sakamoto@frl.cl.nec.co.jp
[2]ICORP, Japan Science & Technology Agency (JST)
[3]System Devices Research Labs., NEC Corp., Sagamihara, Kanagawa 229-1198, Japan
[4]Nanomaterials Laboratory, NIMS, Tsukuba, Ibaraki 305-0003, Japan

1. Introduction

Cell-based integrated circuits (CBICs) are widely used for ASIC platforms because of their high performance and low die-cost. However, non-recurring expense (NRE) is huge, and the turnaround time (TAT) is long. With MOSFETs scaling down, NRE has been rising and TAT increasing. Accordingly, field programmable devices such as Field programmable gate array (FPGA) has become attractive increasingly. FPGAs have such advantages as a short TAT and low NRE. However, the die cost is high and its performance (that is, power consumption and operation frequency) is lower than that of a CBIC.

An FPGA is composed of logic cell arrays, interconnections, and switches at each cross-point. The switch consists of an SRAM and a pass transistor and has a size of $120F^2$. The switch occupies a large area in the chip. To minimize the number of switches and to maintain the logic cell occupancy, each cell has a coarse granularity ($> 10^4F^2$) with high functionality. As a result, an FPGA is costly and has poor cell usage efficiency. Moreover, the large ON resistance of the pass transistor causes routing delay in the interconnection.

We have developed a solid electrolyte switch that can achieve a field programmable device with low die cost and high performance.

2. Solid electrolyte switch

A solid-electrolyte nanometer switch comprises a Cu_2S film sandwiched between two metals (Cu and Ti). This film is a mixed Cu-ionic and electronic conductor. The switch has two conducting states (ON/OFF), which are altered by applying a positive or negative voltage to the metal and persist without a power supply (Fig. 1) [1,2]. The conductance switching can be explained by creating and annihilating a metallic bridge inside the Cu_2S film. The novel switch is characterized by two distinctive features: compactness and low ON resistance. The switch has a simple structure of potentially $4F^2$ and has low ON resistance ($< 100\Omega$), which is lower than those of FETs by two orders of magnitude.

When this switch is substituted for the SRAM-based switch in the FPGA, the switch size can be reduced to one thirtieth and the ON resistance can be reduced to one fortieth. This substitution thus provides two distinct advantages. First, the chip size of the novel field programmable device can be reduced. When our technology is applied, the chip size can be reduced to about half that of a conventional FPGA. Furthermore, when a fine grain cell such as a DFF, MUX or a primitive gate is used, the logic cell usage efficiency increases. Consequently, we can reduce the chip size further and also reduce the power consumption. If fine grain cells are used in a conventional FPGA, logic cell occupancy decreases to a few %. Second, the routing delay falls because the ON resistance of the switch is very low. We estimate the routing delay reduction ratio to be from 20 to 40% using typical parameters of the interconnections.

As a result, the novel switch would make it possible to construct a programmable CBIC. This programmable CBIC provides a new ASIC solution and offers such advantages as low cost, high usage efficiency of logic cells, and enhanced operation speed. To demonstrate the potential of our novel switch for programmable CBICs, we fabricated a 4×4 crossbar switch. The crossbar switch is a fundamental component in field programmable devices [3].

3. The 4×4 cross bar switch

The crossbar switch can be composed of a solid-electrolyte switch only. If the relationship between the program voltage (V_{PP}) and the threshold voltage (V_{TH}) of the switch is given by $V_{TH} < V_{PP} < 2V_{TH}$, the crossbar switch can be properly programmed. However, because each fabricated switch had a wide V_{TH} distribution, programming could not be properly done. Accordingly, we used a pass transistor in the cross-point switch to program each element.

We fabricated the crossbar switch using 0.18μm CMOS technology (Fig. 2). The circuit contained a pass transistor, controller and input/output buffer. The solid-electrolyte switches were stacked on the top metal layer. Fabricating the switch did not affect the CMOS and the interconnections, because the maximum process temperature was 150°C .

In fig. 3, the diagonal elements of the matrix were programmed to ON, and the off-diagonal elements were programmed to OFF. Figure 4 shows the input and the output signals. X0 through X3 were successfully transferred to Y0 through Y3. Second, when the crossbar switch was reconfigured, proper output signals were obtained. This reconfiguration was repeatedly made. The operation voltage was 1.8V, which was larger than the threshold voltage of the switch. The state of the switch therefore changed during normal operation. In the experiment, the normal operation was limited to within 2-8ms. To achieve stable operation we have to increase the V_{TH} of the switch. To program each switch without a pass transistor we should improve the distribution of V_{TH}.

We have developed a nanometer-scale switch using solid electrolyte and proposed a programmable CBIC characterized by low cost, high performance, and high cell usage efficiency. We have demonstrated the crossbar switch using the novel switch technology.

References

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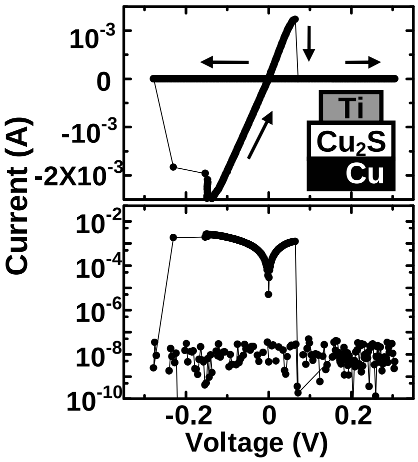

Figure 1: Current-voltage characteristics of solid electrolyte switch with 0.03 μm contact size in linear scale (upper) and log scale (bottom). Inset: Schematic view of switch composed of Cu_2S film sandwiched between Cu film and top electrode (Au/Pt/Ti).

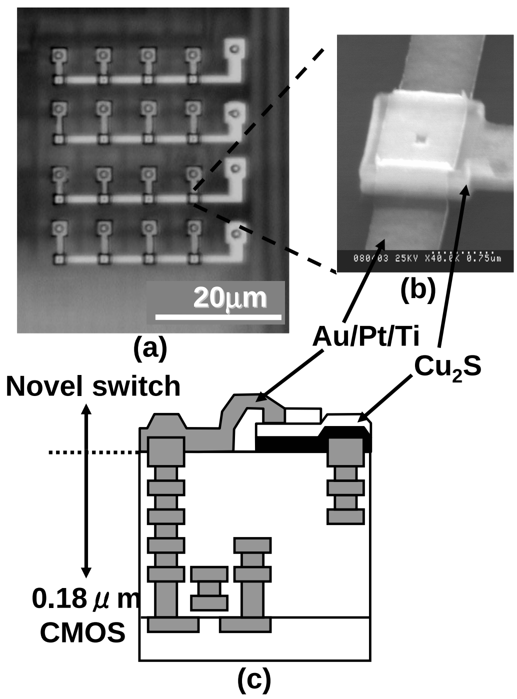

Figure 2: 4 × 4 cross bar switch. (a) Top view, (b) magnification of solid electrolyte switch, and (c) cross section.

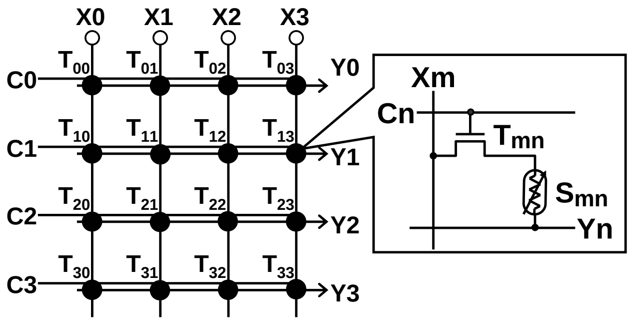

Figure 3: Schematic of 4 × 4 cross bar switch. Each element consists of pass transistor T_{mn} and solid electrolyte switch S_{mn}, each one connected to control line (C_n), input (X_m), and output (Y_n)

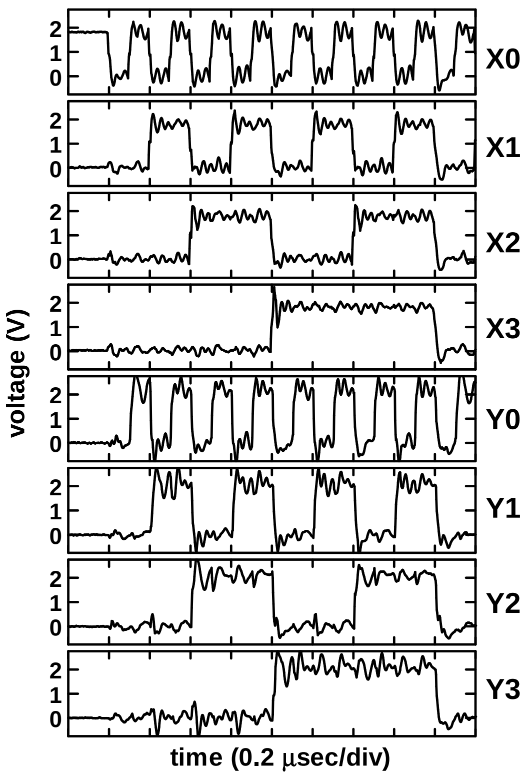

Figure 4: Waveform for crossbar switch. Inputs of X0−X3 and outputs of Y0−Y3 are shown in Fig. 3.