Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 382-383

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A Discrete Time Cellular Neural Network based on Negative Differential Resistance Devices

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1. Introduction

Recently, negative differential resistance (NDR) devices attract increasing attention for Si-VLSIs as well as III-V high-speed ICs. Various types of NDR devices based on Si were proposed in the last few years [1]. Besides memory applications, functions arising from the NDR could simplify circuit complexity. One of the most important applications of the NDR devices is the MOBILE (MOnostable-BIstable transition Logic Element) [2], which works as a threshold logic device with multiple inputs. This function is useful for various types of applications.

The discrete-time cellular neural network (DTCNN) is one of the interesting applications of the MOBILE [2, 3]. The DTCNN is a relative of cellular automata. The major difference is that analog inputs are supplied to the cells and the cell's evolution obeys the threshold logic function for the weighted sum of local input signals. When an image is supplied as analog inputs, the DTCNN can be used for image processing and image recognition.

Here, we will propose a novel DTCNN circuit based on the MOBILE. This DTCNN can change its weights and function, different from the previous proposals. We will also discuss the design of the proposed circuit based on the emulation circuit of the MOBILE using CMOS. This emulation circuit is useful to study circuit behavior when the circuit size is too large to use circuit simulators.

2. DTCNN based on NDR devices

The DTCNN's are defined by the algorithm

$$x^c(k) = \sum_{d\in N_r(c)} a_d^c y^d(k) + \sum_{d\in N_r(c)} b_d^c v^d + i^c \quad (1)$$

$$y^c(k) = u\left(x^c(k-1)\right) \quad (2)$$

The output $y^c(k)$ of a cell c is binary and is determined by the sign of $x^c(k-1)$. ($u(x)$ is sign function.) The value +1 denotes a black pixel, and -1 a white pixel. The value of x^c is controlled by the inputs, v^d, and outputs of adjacent cells d within a r-neighborhood $N_r(c)$, which is defined as the set of adjacent cells within a distance r including cell c. The weight parameters a^c_d, b^c_d and the threshold control parameter i^c, called a template, are not binary but real, and are translationally invariant, which means that each cell is influenced identically by its neighbors.

Figure 1 shows the circuit configuration of the cell we propose. The circuit consists of two MOBILEs, and they switches alternately according to the clocks. First one behaves as a threshold logic device and the other behaves as a latch. The point is that the inputs from the neighboring cells are fed to the inverters and the weights are proportional to the external voltages, V_W. So, one can easily change the weights by changing the voltages. It should be noted that the weights are the same for all cells, so that only a few number of external voltages are necessary for the DTCNN.

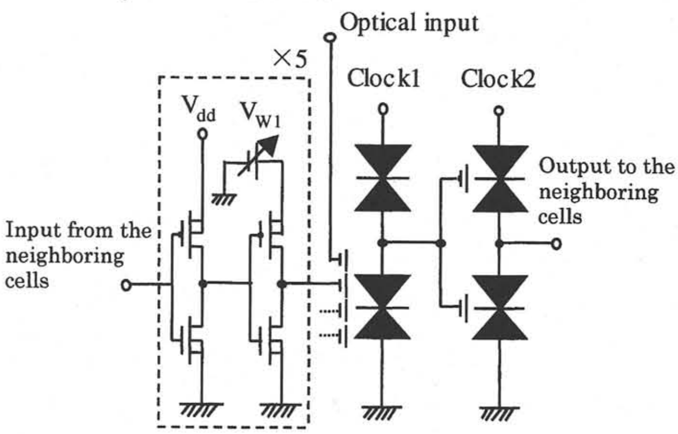

Fig. 1. The circuit configuration of the cell. A cell consists of two MOBILEs, and they switches alternately according to the clocks.

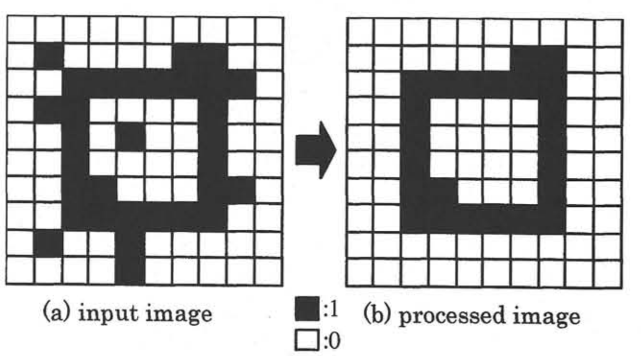

Fig. 2 An example of the circuit simulation results. (a) an input image; (b) an processed image. The black pixels indicate cell state 1,and white pixels 0.

Figure 2 shows an example of the circuit simulation results. Here, the DTCNN carries out noise reduction operation. The weight templates are

$$a=\begin{pmatrix}0&1&0\\1&1&1\\0&1&0\end{pmatrix},b=\begin{pmatrix}0&0&0\\0&0&0\\0&0&0\end{pmatrix},i_c=2.5$$

Here, the input image was set as an initial condition.

3. The Emulation circuit using CMOS

We designed the above circuit using NDR emulation circuit using enhancement-mode MOSFETs. Figure 3 shows the circuit configuration of the NDR emulator. Two types of NDR emulators were designed. One is for the lower device used in MOBILE, and the other is for the upper device. The latter is necessary because the emitter voltage of the upper device changes according to the clock and input. The control voltage for the upper device is applied with respect to the clock. It should be noted that the control voltage can be common to all upper NDR devices driven by the same clock, so only the limited number of the control voltages are necessary to emulate MOBILEs.

The emulation circuit was fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC). Figure 4 shows the basic operation of the MOBILE emulation circuit. This is the result of the inverter-type MOBILE. This figure demonstrates the proper operation of the circuit. With these emulation circuits a large scale DTCNN is fabricated.

3. Summary

We have proposed the DTCNN using NDR devices, which is capable of changing the weights and hence the function. We designed the circuit based on MOBILE emulation circuit using CMOS, and demonstrated the proper operation.

References

[1] For example, see Ext. Abs. of the 2001 Int. Conf. SSDM, Tokyo, 2001, D-10 Resonant Tunneling Devices, pp. 580-589.

[2] K. Maezawa et. al, IEEE Trans. Electron Devices, vol. 41, pp. 148-154 (1994)

[3] M. Hanggi, L.O. Chua, ISCAS 2001, Vol. 2, pp.93-96, 2001.

"The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo with the collaboration by Rohm Corporation and Toppan Printing Corporation."

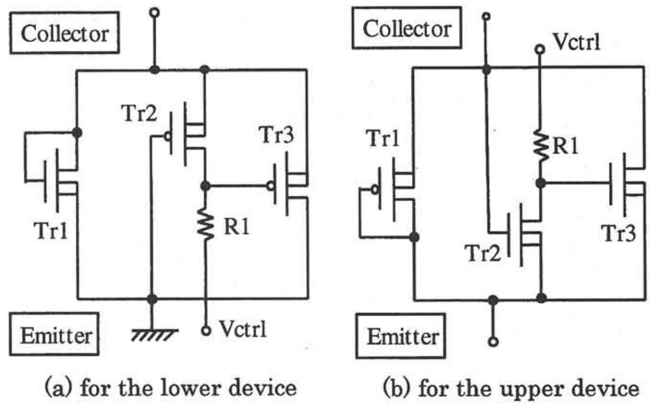

Fig. 3 The circuit configuration of the NDR emulator. (a) is for the lower device used in MOBILE, and (b) is for the upper device.

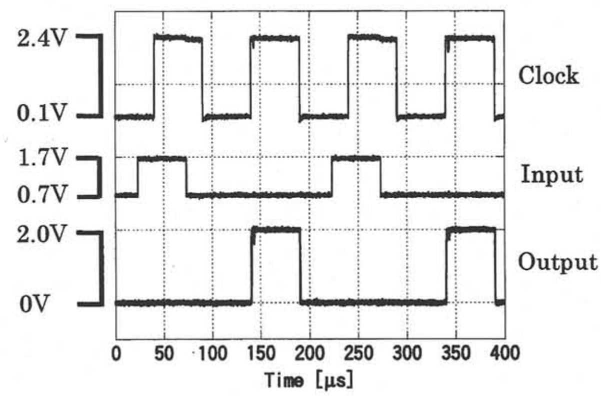

Fig. 4 The basic operation of the MOBILE inverter emulation circuit.