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Letter Reproduction using a Cellular Neural Network consisting of Simplified Neurons and Synapses fabricated by Thin-Film Transistors

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Abstract– Simplified neurons and synapses fabricated by thin-film transistors (TFTs) are proposed for cellular neural networks. A two-inverter two-switch circuit is used as a neuron, whereas only a transistor is used as a synapse. The neurons and synapses are fabricated by TFTs, which are promising for giant microelectronics. A cellular neural network consists of such neurons and synapses. Particularly in this presentation, it is observed that an alphabet letter is reproduced from a similar pattern by the cellular neural network. This function is available for letter recognition of hand-written letters.

1. Introduction

Cellular neural networks are neural networks where a neuron is connected to only neighboring neurons [1], hence exceedingly suited to integration of semiconductor circuits, and fundamental theory, operation principle, and potential applications, such as image processing [2] and pattern recognition [3], have been actively investigated using formal models and numerical simulation until now. However, actual hardware of cellular neural networks has been rarely reported [4], and we think this is because the conventional circuits of the neurons and synapses are rather complicated, even if the network architecture is extremely simplified. Therefore, an objective of this study is to simplify the neurons and synapse.

Thin-film technologies are promising for giant microelectronics having potential possibility for astronomical ultra-large-area integrated circuits [5]. Although TFTs have been widely utilized for flatpanel displays [6],[7], novel applications are ardently desired [8]. Therefore, the other objective of this study is to fabricate neurons and synapses by TFTs.

We are continuing to investigate artificial neural networks fabricated by TFTs [9]-[12]. In this study, simplified neurons and synapses fabricated by TFTs are proposed for cellular neural networks. A 2-inverter 2-switch circuit is used as a neuron, only a TFT is used as a synapse, and a cellular neural network consists of such neurons and synapses. Particularly in this presentation, it is observed that an alphabet letter “T” is reproduced from a similar pattern by the cellular neural network. This function is available for letter recognition of hand-written letters. It should be noted that the neurons, synapses, and cellular neural network were actually fabricated, and the experiment results were really obtained.

2. Neuron

Figure 1 shows the circuit diagram of the neuron. A 2-inverter 2-switch circuit is used as a neuron, where the two inverters and two switches are circularly connected. A inverter consists of a pair of n-type and p-type transistors, and a switch also consists of a pair of the transistors. The 2-inverter 2-switch circuit has the necessary functions we considered: generating a binary state and alternating the binary state by the input signal. The inverters generate a binary state, and the binary state is maintained when the switches are on, whereas the binary state is alternated when

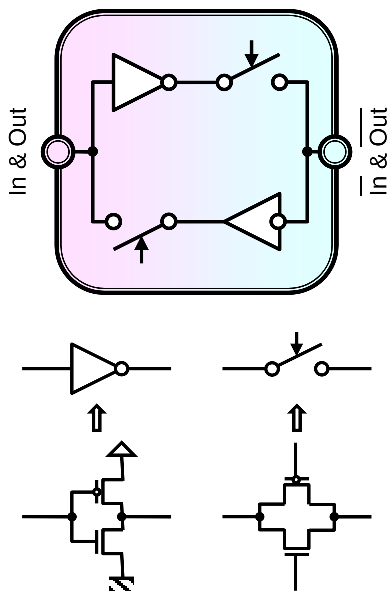

Fig. 1. Circuit diagram of the neuron.

the switches are off and some input signal is received. The switches are periodically on and off in the entire cellular neural network. The two terminals are bi-directional, that is, work as both input and output terminals. One terminal is for positive logic, whereas the other terminal is for negative logic. This neuron circuit is fabricated by eight transistors, and the number of the synapse per connected neighboring neuron is two. The n-type transistors have the gate oxide thickness (tox) = 75 nm, gate width (W) = 100 μm, gate length (L) = 7.5 μm, lightly-doped drain length (LDD) = 0.75 μm, field-effect mobility (μ) = 93 $cm^2 \cdot V^{-1} \cdot s^{-1}$, and threshold voltage (Vth) = 3.6 V, whereas the p-type transistors have the same tox, same W, L = 5 μm, single drain structure, μ = 47 $cm^2 \cdot V^{-1} \cdot s^{-1}$, and Vth = -2.9 V. The detailed explanations for the neuron are elsewhere [9],[10].

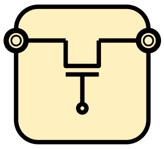

Fig. 2. Circuit diagram of the synapse.

3. Synapse

Figure 2 shows the circuit diagram of the synapse. Only a TFT is used as a synapse, where the gate voltage is used as a control voltage to induce the characteristic shift or not, and the source and drain terminals are connected to the neurons. The control voltage is constantly applied in the entire cellular neural network. The transistor has the necessary functions we considered: sending the signal from a neuron to the neighboring neuron, merging the signals from the multiple neurons for the neuron, and controlling the synaptic connection strength on demand. The transistor sends the signal as an electric current. The conductance corresponds to the synaptic connection strength. The electric currents are easily added by bundling the variable resistors in parallel, which corresponds to merging the signals. The characteristic shift occurs owing to the characteristic degradation by the electric current, which

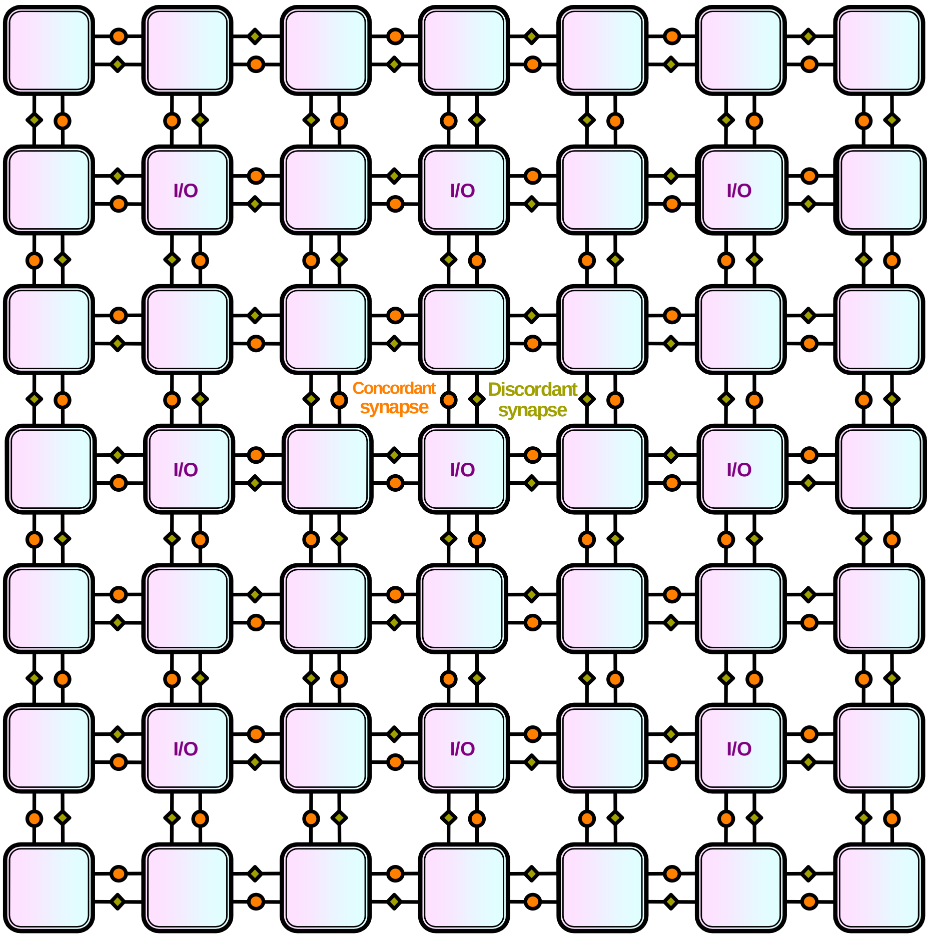

Fig. 3. Network architecture of the neural network.

corresponds to controlling the synaptic connection strength. The n-type transistor has the same parameters as those in the neurons except for W = 5 μm and single drain structure to induce the characteristic shift.

4. Neural Network

Figure 3 shows the network architecture of the neural network. The cellular neural networks have 7×7 neurons including 3×3 input/output (I/O) neurons, to which the letter pattern is inputted and from which that is reversely outputted, and hidden neurons between them. A neuron is connected to the four neighboring neurons through two-type synapses, concordant and discordant synapses. The concordant synapse connects the same logics of the two neurons, that is, positive and positive logics or negative and negative logics, and tends to make the states of the two neurons the same, whereas the discordant synapse connects the different logics of the two neurons, that is, positive and negative logics, and tends to make the states of the two neurons different. Although the size of the cellular neural network is 5×5 mm^2, because most area are used for experimental evaluation, it can be reduced to a several thousandth.

5. Experiment method

In the learning stage, first, a control voltage of 15 V to induce the characteristic shift is uniformly applied to the TFTs for the synapses. A letter pattern of “T” is inputted to the terminals for the positive logic in the I/O neurons as an input pattern of the high (H) and low (L) voltages for several minutes. (Some cellular neural networks correctly worked after the letter pattern was inputted for one minutes, whereas some other ones worked after more than one minutes such as ten minutes.) A steady pattern of the neuron states is generated in the hidden neurons based on a normal theory of dynamics of neural networks. After a while, the synaptic connection strengths are changed. The conductance of the transistors of the concordant connections are kept the same when both neurons connected to the synapses are in the same states, and are impaired otherwise, whereas the conductance of the discordant connections are kept the same when both neurons are in the different states, and are impaired otherwise. This is because electric currents flow between the source and drain terminals owing to the voltage differences in the transistor for the concordant connections when both neurons are in the different states and discordant connections when both neurons are in the same states, and characteristic degradations are induced owing to the Joule-heating and hot-carrier degradations by the electric currents [13]-[15]. We call this a modified Hebbian learning rule [16]. In the recalling stage, finally, a control voltage of 10 V to avoid the characteristic shift is applied. A letter pattern with a slightly different part from “T” is initially inputted to the I/O neurons and immediately, namely less than 1 s, released, and an output pattern is automatically outputted from the I/O neurons. It is confirmed whether it is the same as the letter pattern of “T” inputted first.

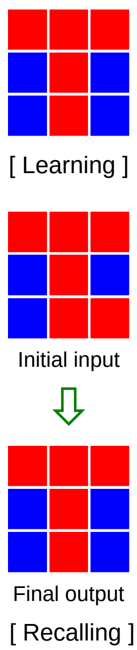

Fig. 4. Experiment result of the letter reproduction.

6. Experiment result

Figure 4 shows the experiment result of the letter reproduction. Only the states in I/O neurons are shown. In the learning state, a letter pattern of "T" is inputted to the I/O neurons for several minutes. In the recalling stage, a letter pattern with a slightly different part from "T" is initially inputted to the I/O neurons and immediately released, and an output patterns is automatically outputted from the I/O neurons. The response time is less than 0.1 s. It is observed that an alphabet letter “T” is exactly reproduced by the cellular neural network.

Incidentally, some power are consumed especially in the synapses because direct current flows, which we will evaluate soon. Moreover, we are now trying other alphabet letters and would like to report in the near future. At that time, other architectures such as 7×11 neurons including 3×5 I/O neurons or 11×17 neurons including 5×8 I/O neurons may be suitable for English alphabet letters. Simultaneous recognition of two or more letters are the next step of this research. We are also now trying it and would like to report in the near future.

7. Conclusion

We are continuing to investigate artificial neural networks fabricated by TFTs. In this study, simplified neurons and synapses fabricated by TFTs were proposed for cellular neural networks. A 2-inverter 2-switch circuit was used as a neuron, whereas only a transistor was used as a synapse, and a cellular neural network consisted of such neurons and synapses. The neurons and synapses are fabricated by TFTs, which are promising for giant microelectronics. Particularly in this presentation, it was observed that an alphabet letter “T” is reproduced from a similar pattern by the cellular neural network. This function is available for letter recognition of hand-written letters.

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