2016 International Symposium on Nonlinear Theory and Its Applications,
NOLTA2016, Yugawara, Japan, November 27th-30th, 2016

Letter Reprodution Simulator for Hardware Design of Cellular Neural Network consisting of Neurons using Large-Scale Integration Chip and Synapses using on-Deposited Amorphous In-Ga-Zn-O Films

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Abstract– Recently, neural networks have been developed for variable purposes including image recognition and voice recognition. However, such neural networks based on software require many times of calculation and large quantity of consuming energy. Therefore, we are developing hardware of a cellular neural network (CNN) that features low power consumption, high-density integration of electron devices, and high functionality. In our hardware system, amorphous In-Ga-Zn-O (a-IGZO) films work as synapses because they have a potential to integrated astronomical number of devices and their characteristic is available for our leaning rule. Particular in this presentation, we assume to form the neuron circuits using a large-scale integration chip and synapse devices using a-IGZO films deposited directly on the neuron chip. We modeled a-IGZO film for CNN and implemented it into the simulator to determine the network architecture and device parameters. In this time, we succeeded in confirming that this CNN can learn two letters of Arabic numerals. Moreover, we estimated the time necessary for the learning.

1. Introduction

Neural networks are types of information systems that imitate biological neural circuits in living cells of human brains [1]. Therefore, they are promising for image processing, pattern recognition, etc., that human brains can do well. Neural networks can process many and complicated data by using unbelievable figures of neurons and synapses. For example, in a human brain, there are more than 10^{10} neurons and 10^{13} synapses that connects the neurons generally [2]. Neural networks also need astronomical number of neurons and corresponding number of synapses to calculate required operations fast and efficiently.

There exist several kinds of neural networks. Among the neural networks, cellular neural networks (CNN) are suitable for actual integration of electron devices, because each neuron is connected to only neighboring neurons and there are no connections between the neurons far away [3]. Further technologies on CNN preferable for higher-density integration have been also developed from the viewpoint of device hardware [4].

In order to design a CNN at the circuit level, we are evaluating the CNN by using a simulator. Particular in this presentation, we assume to form the neuron circuits using a large-scale integration (LSI) chip and synapse devices using a-IGZO films deposited directly on the neuron chip. We will introduce the CNN that we are studying, explain a letter reproduction simulator that we developed for the CNN, and show the simulation results.

2. Cellular Neural Network

2.1. Network Architecture

Figure 1 shows the network architecture of the CNN that we are studying and used for our simulator. In this architecture, we arrayed multiple neurons and connected each neuron to eight adjacent neurons through synapses. The neurons are in a state of either firing or non-firing according to the states of the adjacent neurons and the connection strength of the synapses placed between the

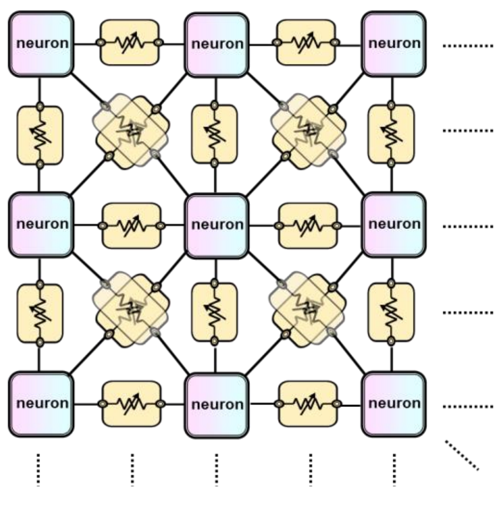


Fig.1. Network Architecture of our Cellular Neural Network

neurons. The synapses tend to make the states of the neurons connected through the synapses the same. When both neurons connected to the synapse are in firing states, the synaptic connection strength doesn't change. On the contrary, when the neurons connected to the synapse are in different states, the synaptic connection strength decreases. Such deterioration of the synapses corresponds to the learning of the CNN. We call this method of the learning "Modified Hebb's learning" [5].

2.2. Neuron Circuit

Figure 2 shows the neuron circuit. Figure 2 (a) shows the circuit architecture. We limited the necessary functions of the neuron to that a binary state is maintained by itself and altered by the input signals. We can make a neuron consist of only four transistors, therefore it is suitable for integration. Moreover, this simple architecture can be easily formed using an LSI chip. Figure 2 (b) shows the computer-aided design (CAD) layout, which we will develop in near future. Here, in addition to a circuit to connect adjacent neurons, I/O circuit is designed. The size of a neuron is only 100μm × 100μm. The light blue patterns are electrodes for the synapses. We can connect neurons through these electrodes.

(a) (b)

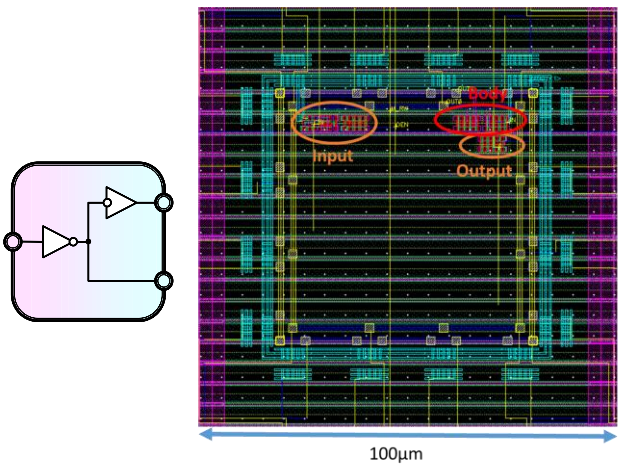


Fig.2. Neuron Circuit
(a) Circuit Architecture (b) CAD Layout

2.3. Synapse Modeling

We assumed to use a-IGZO films as synapses. The conductance of the a-IGZO films changes when an electric current flows [6], if they are made using some fabrication process. We will deposit the a-IGZO films on the all neurons as shown in Figure 3. The light blue patterns are electrodes, and the light yellow patterns are a-IGZO films. The parts of the a-IGZO films indicated by the deep yellow patern work as synapses. The adjacent neurons are connected by the synapses. In consideration of the a-IGZO film size (2μm × 10μm) and thickness (70nm) and electrical characteristics, we can guess the resistance and deterioration speed of a-IGZO from the experimental results. The initial resistance is 3.75MΩ and the resistance increases about 1% in 4 seconds when the electric current flows.

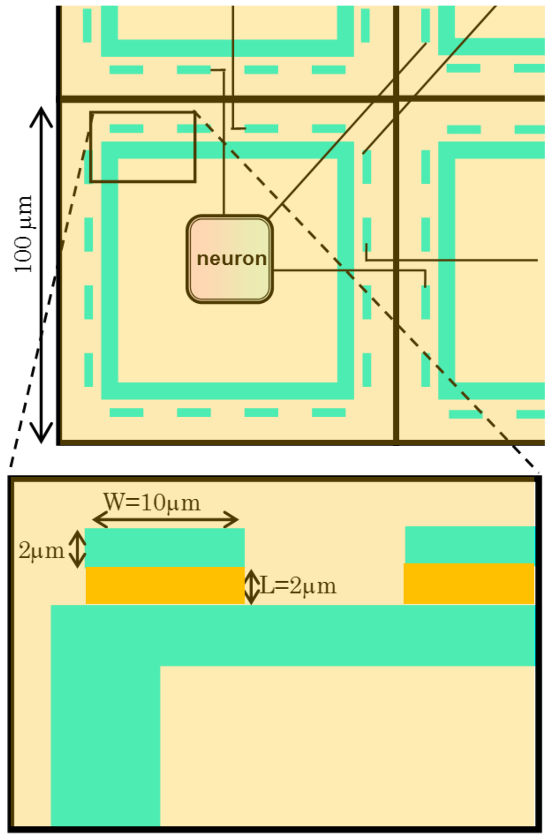


Fig.3 a-IGZO films as the Synapses depsoited on the Neurons

3. Letter Reproduction Simulator

3.1. Neuron Arrangement

In this time, we use a CNN for letter reproduction. First, we set 25 × 25 neurons. Next, we put hidden neurons between all pairs of the adjacent I/O neurons. Figure 4 shows the arrangement of the I/O neurons and hidden neurons. Here, all neurons are indicated by 625 squares, the 12 ×12 matrix of the neurons surrounded by bold lines are I/O neurons, and other neurons are hidden neurons. As a result, we can input letter images converted to the binary format of 12 ×12 pixels. In the learning stage, a pixel pattern corresponding to an input letter is inputted to the I/O neurons as firing states. For example, when a letter of "0" is inputted, firing states are inputted to the I/O neurons indicated by the red square, whereas non-firing states are inputted to the other I/O neurons.

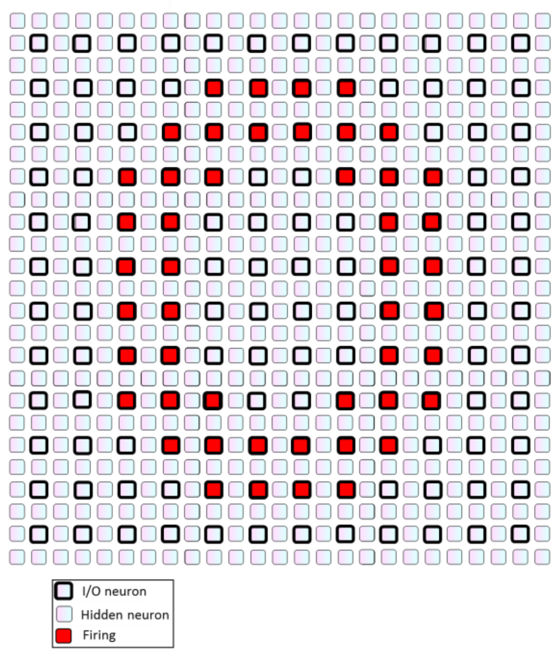


Fig.4. Arrangement of the I/O and Hidden Neurons

3.2. Simulation Algorithm

The letter reproduction simulator simulates the CNN based on the network architecture and synapse model mentioned above, which has also already reported in a previous conference [7]. Figure 5 shows the simulation algorithm of the letter reproduction simulator. First, a pixel pattern corresponding to an input letter is inputted to I/O neurons as firing states. Afterwards, the states in the hidden neurons are calculated using the majority rule of the neighboring neurons with consideration of the synaptic connection strengths corresponding to the conductance of the a-IGZO films. Next, after the all the states in the neurons are settled, the modified Hebb's learning are done, namely, when the neurons connected to the synapse are in different states, the synaptic connection strength decreases based on the deterioration model of the a-IGZO films. After that, a pixel pattern slightly distorted from the input pattern is inputted to I/O neurons as firing states and immediately removed. Afterwards, the states in all neurons including the I/O and hidden neurons are calculated. Next, it is checked whether the output pattern from the I/O neurons becomes the original inputted pattern. Finally, these procedures are repeated for multiple input patterns.

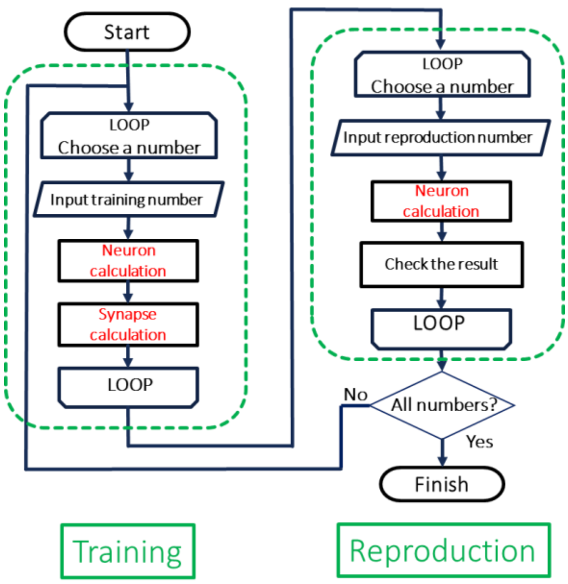


Fig.5. Simulation Algorithm

4. Simulation Result

4.1. Letter Reproduction

Figure 6 shows the input pattern for the learning and that for the reproduction slightly distorted from the former. Figure 7 shows the simulation results of the letter reproduction. Figure 7 (a) show the states of neurons and syanapses after learning, whereas figure 7 (b) show the state of neurons and synapses after reproduction, when this CNN was able to reproduce two letters. It was confirmed that this CNN can reproduce two letters. The color deepness of the red small squares corresponds to the synaptic connectin strength. It was confirmed that the firing patterns after the reproduction are completely the same as the input pattern for the learning. These results mean that this CNN can reproduce two letters.

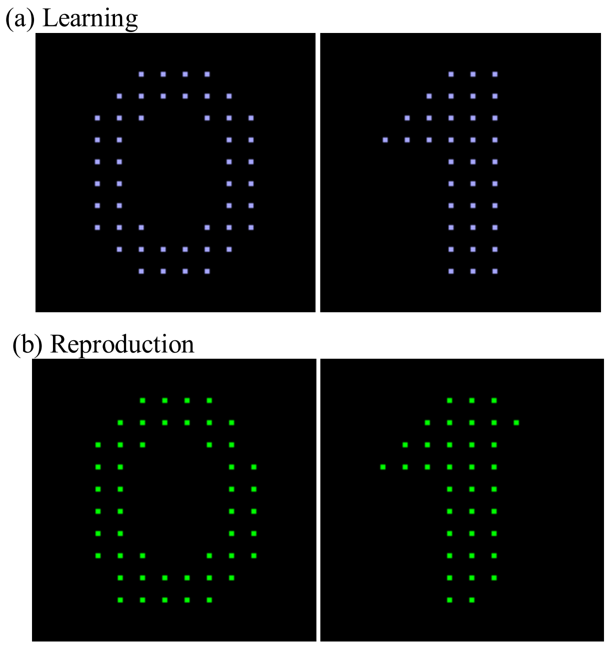
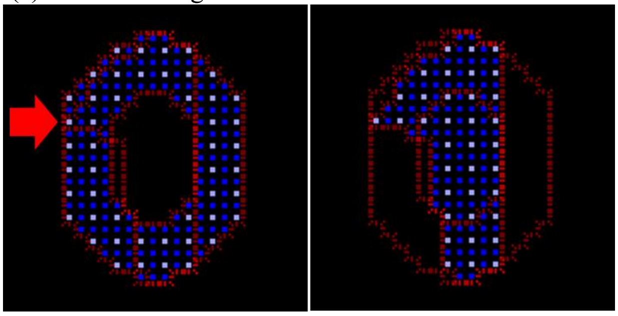


Fig.6. Input Pattern for the Learning and Reproduction

(a) After Learning



(b) After Reproduction

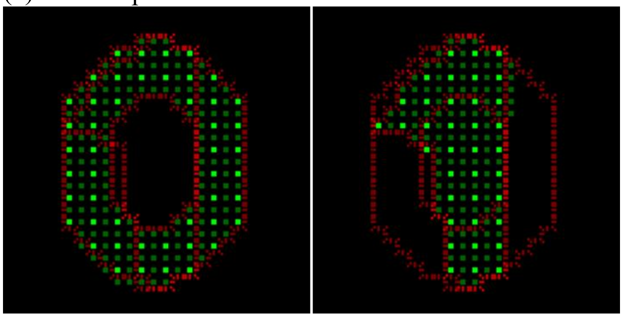


Fig.7. Simulation Results of the Letter Reproduction

4.2. a-IGZO film Deterioration

In this simulation, we recorded the resistance of the synapses that increases most, which pointed by the arrow in Fig. 7. Figure 8 shows the resistance of the synapses that increases most. When this resistance increased from 3.75MΩ to 11.25MΩ, this CNN was able to reproduce two letters. This result indicates that it takes about 446 seconds, when we use this a-IGZO film. Although we succeeded in confirming that this CNN can learn two letters as mentioned above, it takes long time and it should be shortened by finding novel structures or fabrication process of a-IGZO films to enhance the deterioration of the conductance.

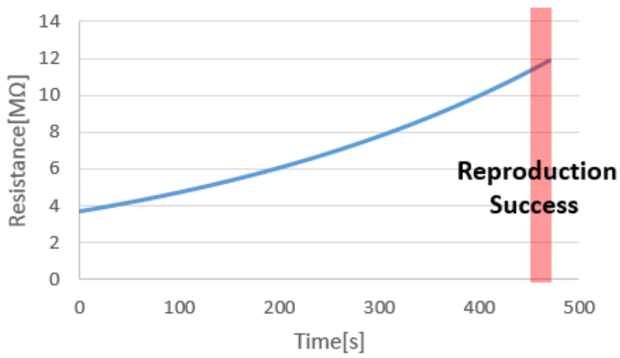


Fig.8. Resistance of the Synapses
that increases most during the Simulation

5. Conclusion

We are developing the CNN system using an LSI chip as neuron circuits and a-IGZO films as synapses, and we developed the letter reproduction simulator for the CNN. We modeled the detrioration phenomenon of the a-IGZO films and implemented it into the simulator. It is confirmed using the simulator that this CNN can reproduce two letters of Arabic numerals. Moreover, we evaluated the time necessary for the learning two characters. We believe that these results indicate the future possibility of the CNN using a-IGZO films as the synapses to realize astronomical large-scale brain-like integrated systems, and we will continue to develop them, which will be reported in the near future.

In this CNN, the neuron, synapse, and network architecture are quite different from those in the conventional one. Therefore, we might have to make some unique repersentations. Moreover, we would like to formularize the behaviors of these porcessing elements and present the dynamics and local interaction rules in the near future.

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