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Two Phase Change Memory (2-PCM) Neuron for Implementation of Backpropagation Algorithm

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Abstract

In this paper, we proposed a neuron circuit with two phase-change memory (PCM) devices to implement the backpropagation algorithm. One of the two PCM devices is used for forward propagation and the other one is used for backpropagation. With both forward propagation and backpropagation signals storing in neuron, it makes weight updating easier.

1. Introduction

Phase-change memory (PCM) device, which is a good candidate of next generation non-volatile memory, has been widely used in neuromorphic system with its synapse-liked characteristics [1]. In fact, the PCM devices are used not only for synapses, but also for circuits in neurons [2]. In this paper, we proposed a 2-PCM neuron to implement a variant of back-propagation algorithm [3]. Instead of evaluating the actual error, the backpropagation signal is a sign function of the error.

2. PCM device

Fig. 1 shows the experimental data and simplified model of pulse response characteristics for PCM device. The amplitude of programming pulse is divided into five regions: read, set, over set, reset and over reset. If the pulse is set within the read region (V_0~V_1), PCM device remains its resistance. If the pulse is set over the read region but below reset region, the resistance of PCM decreases proportional to the pulse amplitude until fully set state. This R-V characteristic of programming pulse amplitude dependence can be used to build an activation function in neuron circuits, and can be used for the long-term potentiation (LTP) operation on PCM synapses. The reset region (V_3~V_4) can be used for the long-term depression (LTD) operation on PCM synapses. The pulse within over set region is used as reset pulse to ensure the PCM device is programmed into fully reset state.

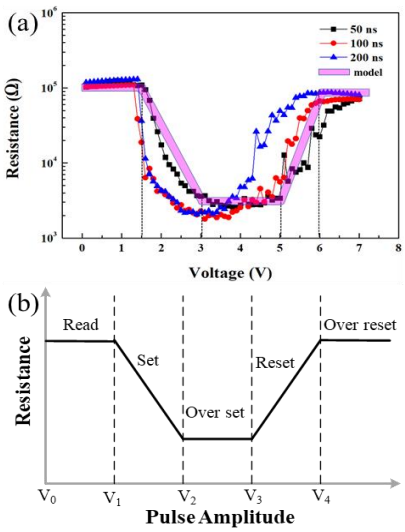

Fig. 1 (a) Experimental data and (b) simplified model of pulse response characteristics for PCM device

3. Proposed 2-PCM neuron

The proposed 2-PCM neuron consist of 5 modules, as shown in fig. 2.

(1) Basic module: It includes two PCM devices, one is used for storing forward propagation (FP) signal, and the other is for storing backward propagation (BP) signal.

(2) Voltage driver: It drives the output pulse (V_{pre}) ranging in read region.

(3) Decision module: It compares BP signal with reference signal, then judges right or wrong for testing or selects which operation (LTP, LTD or not change) for learning.

(4) Post-spike module: It provides a post-synaptic pulse to update the synaptic weight; or provides a suitable voltage during BP process.

(5) Temporary Storage Module: It is used only in output layer, for storing the V_{pre} of output layer during FP process, and subsequently is used as input of decision module during BP process.

To realize the functions in neural networks, the 2-PCM

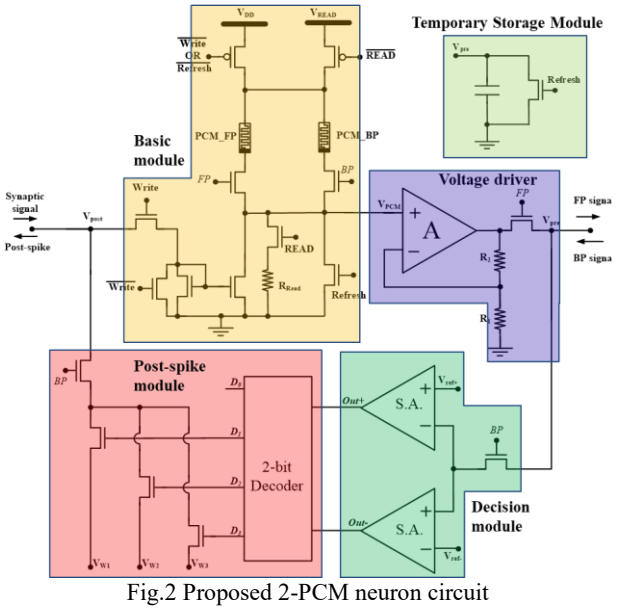

Fig.2 Proposed 2-PCM neuron circuit

neurons are set working in five different phases:
(1) FP write phase: Integrated synaptic signal is transform into neuron, and the data is write into the 1st PCM device (PCM_FP).
(2) FP read phase: Data in the 1st PCM device is read out, and a FP signal (V_{pre}) is provided based on the data.
(3) BP write phase: Integrated BP signal is transform into neuron. Compare the BP signal with a reference to generate a decision result, and a write pulse is generated based on the decision and write into the 2nd PCM device (PCM_BP).
(4) BP read phase: Data in the 2nd PCM device is read out, and compare the FP signal (V_{pre}) with a reference ($V_1/2$)to generate a decision result. Then a post-spike (V_0, $-V_1$, or $-V_3$) or a BP signal (V_{high}, V_{mid}, or V_{low}) is provided based on the decision result.
(5) Refresh phase: Both PCM devices are reset to initial state.

During the FP process, neuron provides an activation function as Eq. (1). Here, R_{PCM_FP} proportional to the input synaptic weighted signal.

$$V_{Pre} = V_{Read} \cdot \frac{R_{READ}}{R_{READ} + R_{PCM_{FP}}} \cdot \frac{R_1 + R_2}{R_1 + R_2} \quad (1)$$

4. Error Calculation and Backpropagation

At the end of FP process, an output signal is stored in the temporary storage module. To calculate the error in output layer, the neurons in output layer work in BP write phase. The stored FP signal is used as input (V_{BP}) to compare with the target (V_{ref}). The compare result is written into the PCM resistance for BP signal (PCM_BP), as shown in fig.3(a). The error is calculated by Eq.(2), and its value can be +1, 0 or -1.

$$E = sgn(V_{ref} - V_{BP}) \quad (2)$$

During the backpropagation stage, output layer works in BP read phase and hidden layer works in BP write phase. The BP signal is the dot product of error signal from output layer, as Eq.(3) and the equivalent circuit is shown as fig.3(b).

$$V_{BP} = \sum_{i \in \{E \neq 0\}} (V_i w_i) \quad (3)$$

5. Weight Updating

During the weight updating stage, the change of weight dependent both pre- and post-synaptic pulses. The pre-neurons work in FP read phase and post-neurons work in BP read phase. The post-pulse determines the weight change direction by setting pulse amplitude in set region, reset region or read region.

$$\Delta w_{ij} = \eta \cdot E_j \cdot V_{Pre,i} \quad (4)$$

Here, η is the learning rate; E_j is the error signal from post-neuron; $V_{Pre,i}$ is the FP signal from pre-neuron. Tabel I shows the configuration of each layer during BP process and weight updating process.

5. Conclusion and Discussion

In this paper, we proposed a 2-PCM neuron to implement the BP algorithm. Two PCM devices are used for storing FP signal and BP signal, respectively. With information storing in neurons, it simplifies the weight updating process without external memory blocks.

Table I. Layer configuration

Operation	Layer	Phase	V_{W1}	V_{W2}	V_{W3}
Error Calculation	Output Layer	BP, write	$V_{W,high}$	$V_{W,low}$	$V_{W,mid}$
Backpropagation	Output Layer	BP, read	V_{low}	V_{high}	Floating
	Hidden Layer	BP, write	$V_{W,high}$	$V_{W,low}$	$V_{W,mid}$
W1 updating	Input Layer	FP, read			
	Hidden Layer	BP, read	$-V_3$	$-V_1$	V_0
W2 updating	Hidden Layer	FP, read			
	Output Layer	BP, read	$-V_3$	$-V_1$	V_0
Note: W1 is the weight array between input and hidden layers, W2 is the weight array between hidden and output layer					

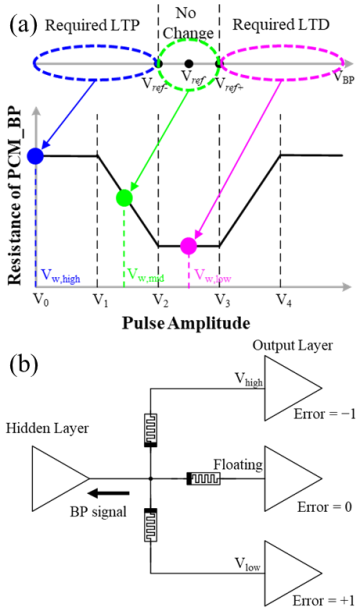

Fig.3 (a) Simplified equivalent circuit circuits of backpropagation (b) Relationship between BP signal and resistance of PCM_BP

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