Ferroelectric Neuron for Feedforward Neural Network Application

IIS, Univ. of Tokyo (D1)Fei Mo, (M2)Yusaku Tagawa, Takuya Saraya, Toshiro Hiramoto and Masaharu Kobayashi

E-mail: mofei@nano.iis.u-tokyo.ac.jp

In this paper, we proposed a ferroelectric capacitor based activation function circuit for hardware artificial neural network. Activation function circuits receive the signal from pre-synapse and send the signal to post-synapse. The most popular activation function of feedforward neural network with backward propagation algorithm is sigmoid. Because it's derive is simple for weight updating. Many analog and digital activation functions have been proposed, however, all of them face some problems. The primary problems of analog activation function circuit are the low accuracy (which is not fitting to sigmoid function) and low program flexibility. The primary disadvantage of digital activation function is the requirement of other peripheral circuits, such as ADC, DAC and multiplier which cost large area and high power [1][2]. Our proposed ferroelectric capacitor based activation function has a good balance of area, speed, accuracy and power.

[Simulation]The Preisach model is often used to describe the P-V curve of ferroelectric capacitor which is hyperbolic tangent inherently [3][4]. Sigmoid function can be converted from hyperbolic tangent by simple calculation as shown in equation. By utilizing this property of ferroelectric capacitor, we proposed a ferroelectric activation function circuit which can generate sigmoid and hyperbolic tangent function. The structure of ferroelectric(FE) neuron is shown in Fig. 1. The FE neuron consists of three OP-AMPs, one ferroelectric capacitor, one offset capacitor and one calculation capacitor. Fig. 3 shows each controlling signal. Before receiving the voltage from pre-synapse, the FE neuron need to set the ferroelectric capacitor at positive saturation polarization and discharge the two capacitors which is happened in initial time as shown in Fig.2. After initial time, FE neuron receives the voltage from pre-synapse and output the calculated signal.

[Result and discussion] The maximum operation frequency is 500 KHz and the maximum absolute error is less than 0.02 comparing with sigmoid function which is almost the same as digital neuron and is higher than analog neuron as shown in Fig. 3. The simulation results are shown in Fig. 4 (Sigmoid function) with different threshold voltages. The benchmark with digital neuron is shown in Tab. 1. A feedforward neural network with 300 neurons in hidden layer is used to evaluate the area, speed and energy. Because digital neuron is large, therefore, only one digital neuron is used which is shared by using multiplexer. Comparing with digital neuron, the proposed FE neuron can achieve real parallel computing, occupies smaller area and has shorter time with almost same energy for per MNIST data in the hidden layer.

[Conclusion]A ferroelectric capacitor based neuron has been proposed. It not only has a high accuracy which is almost same as digital neuron, but also has a good balance between area, speed and Power which can achieve real parallel computing in hardware neural network.

Refence: [1] Boxun Li, Lixue Xia,. (2015). DAC. [2] Wu, H., Yao, P., (2017). IEDM. [3] Bo Jiangt,", Peter Zurcher (1997) VLSI. [4] Ana Maria G. guerreiro, (2011) Integrated Ferroelectrics.

Positive voltage sweep

$$P = P_r * \tanh(V - Vc) + V * C_{FE}$$

Negative voltage sweep

$$P = P_r * \tanh(V + Vc) + V * C_{FE}$$

$$sigmod(2x) = \frac{tanhx + 1}{2}$$

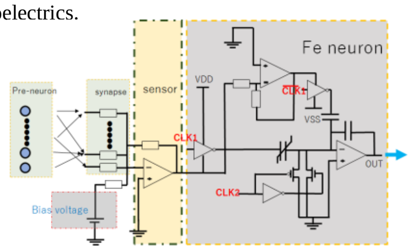

Fig. 1 Structure of FE neuron

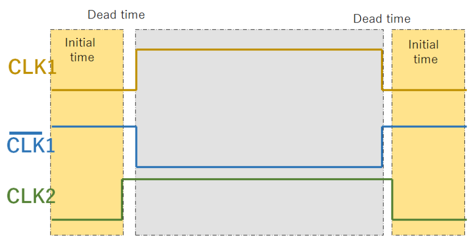

Fig. 2 Controlling signal for FE neuron

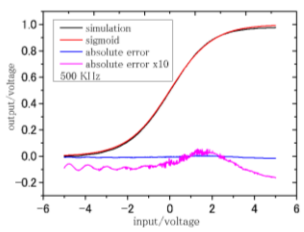

Fig. 3 The accuracy of Proposed FE neuron

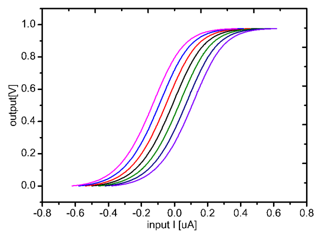

Fig.4 Sigmoid output

	Energy/Per mnist data	Time/per minst data	Area
Fe_neuron	0.39 uJ	2 us	2.76 mm^2
Digital neuron	0.375 uJ	3 us	48.5 mm^2

Tab. 1 Benchmark with digital neuron (Hidden layer)