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Electrical Characteristics of Neuron Pulse Oscillation Circuits Using Complementary Unijunction Transistors and MOSFETs

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1. Introduction

Recently, neural networks with self-adaptability as human brain have attracted much attention. It is desirable for the neuro-function to be implemented by exclusive hardware system on account of huge quantity in calculation. We have proposed a novel neuro-device composed of a ferroelectric gate FET (MFSFET) and a unijunction transistor (UJT) oscillation circuit.[1] However, it is difficult to preserve ferroelectricity on Si due to existence of interfacial traps and/or interdiffusion of the constituent elements, although there are a few reports on good MFS devices.[2] In this paper, we fabricate, as an approach to the MFSFET neuron circuit, an MOSFET neuron circuit without adaptive-learning function and characterize the elementary operation properties of the pulse oscillation circuit. Finally, a novel circuit with larger output pulse amplitude is also presented and its operation is simulated using SPICE.

2. Fabrication of a neuron circuit composed of MOSFET and CUJT.

A basic circuit of pulse frequency modulation (PFM) type neuro-device is shown in Fig. 1. In this circuit, UJT which was used as a switching component in our previous proposal[1] is replaced by a complementary unijunction transistor (CUJT), so that the source of the FET can be grounded and a constant voltage is applied between the source and gate, irrespective of charging status of capacitor C. Since CUJT is a positive feedback device, it is necessary that this circuit be fabricated in an SOI (silicon-on-insulator) structure, and that each device be electrically isolated so that the circuit is not latched-up.

Every device was fabricated by using 5 μm design rule. Impurity concentration of CUJT active region was controlled so that oscillation pulse frequency is modified in high frequency region. It is important that the S-D (source-drain) resistance of MOSFET meets the negative resistance range of CUJT. Channel length and channel width of MOSFET are 5 μm and 50 μm, respectively. Capacitors were designed to be 10 pF, 30 pF and 60 pF so that 7 different values of capacitors are available. R_L was set to 200 Ω~300 Ω. The real image of the fabricated neuron circuit is shown in Fig. 2.

3. Frequency modulation properties of the neuron circuit

A clear hysteresis loop indicating negative resistance region was confirmed for the fabricated CUJT in emitter current vs. emitter voltage characteristics. It was found from drain current vs. gate voltage measurement that the range of S-D resistance of fabricated MOSFET satisfied the oscillation condition in the low gate voltage region. Figure 3 shows the dependence of output pulse frequency on gate voltage applied to MOSFET in the circuit fabricated using 10 pF capacitor. An example of oscillation pulse is shown in the inset of Fig. 3. The modulation of pulse frequency is attributed to the variation of S-D resistance in the MOSFET. The modulation range is from 560 kHz to 11.1 MHz. It is concluded from this result that the output pulse interval of the neuron circuit can be controlled by changing the magnitude of applied gate voltage.

In actual operation of the proposed neural network, the FET acts as a synapse and it accepts pulse inputs from neurons in the previous layer. This performance was simulated by applying input pulses with various duty ratios. As shown in Fig. 4, it is possible to modulate the frequency of output pulses by changing the duty ratio of input pulse signals, which is due to the control of charging time of capacitor. Under these conditions, one output pulse is generated for every 3 to 4 input pulses. The properties on output frequency shown in Figs. 3 and 4 seem to be good enough at least for feasibility check of the PFM-type neural network. It is found, however, that the amplitude of output pulses generated by the CUJT switching component is rather small. Although the pulse amplitude becomes larger as increasing capacitance used, the value is still in the range of 0.2 V to 0.9 V. In order to realize a neural network, output pulses are necessary to be large enough in amplitude as input pulses to the next layer neurons. Thus, an improved circuit is discussed in the following.

4. Oscillation circuit using CMOS Schmitt-trigger configuration

In order to solve the problem of small amplitude of output pulse in the CUJT oscillation circuit, we propose a new circuit using CMOS Schmitt-trigger configuration, which is enclosed by dashed-line as shown in Fig. 5. The basic operation is the same as CUJT oscillation circuit, having a hysteresis region in input vs. output voltage characteristics which make possible to charge and discharge a capacitor through p-ch FET connected in parallel. The input turn-on and turn-off voltage (V_p, V_v) can be changed by varying the ratio R1/R2, and the output pulse frequency can be modulated by controlling the value of R_E. In the neuron circuit, R_E is replaced by a MOSFET or an MFSFET, as discussed earlier.

Figure 6 shows the results of SPICE simulation in this oscillation circuit with 5 μm design rule. It is confirmed that stable rectangular pulses with 5 V amplitude are generated from the output node. The range of frequency modulation is from 70 kHz (R_E=4 kΩ) to 3 MHz (R_E=500 kΩ) for C= 10pF, which shows that the modulation range is larger than that in the CUJT oscillation circuit. It was also ascertained that the maximum frequency became higher when the smaller design rule was used. This result suggests that the output pulse signals generated from the CMOS Schmitt-trigger circuit can be used directly as input signals for the next neuron circuits.

5. Conclusion

We have fabricated a PFM-type neuron circuit using MOSFET and CUJT in order to investigate the basic operation of an MFSFET circuit with adaptive learning function. The pulse frequency modulation properties of the fabricated circuit were investigated, in which DC voltage and pulse duty ratio of input signals were changed. It was concluded that the PFM properties were reasonably good for the neural network application, but that the amplitude of output pulses was too small. Finally a new circuit with CMOS Schmitt-trigger configuration was proposed to solve the amplitude problem.

Reference

1) H. Ishiwara : Jpn. J. Appl. Phys. **32** (1993) 442

2) E. Tokumitsu, R. Nakamura and H. Ishiwara : IEEE Electron Devices Lett. **EDL-18** (1997) 160

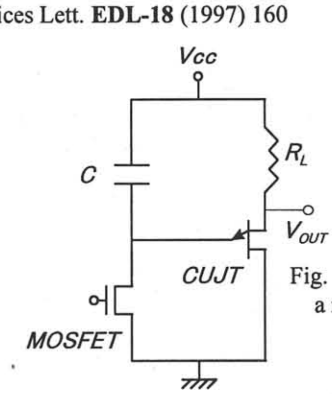

Fig. 1 A basic circuit for a neuron circuit

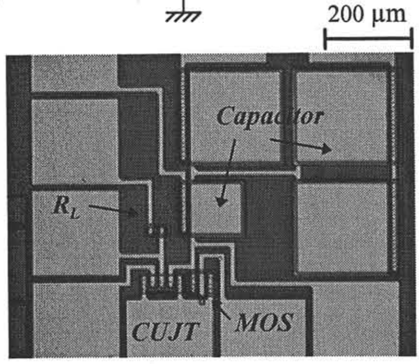

Fig. 2 The real image of fabricated circuit

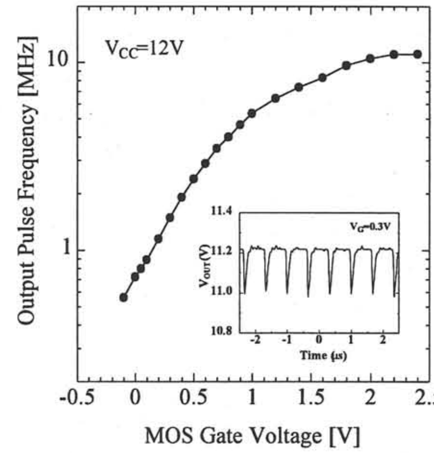

Fig. 3 Dependence of output pulse frequency on applied gate voltage. Inset is a typical output pulses when 0.3V is applied to the gate.

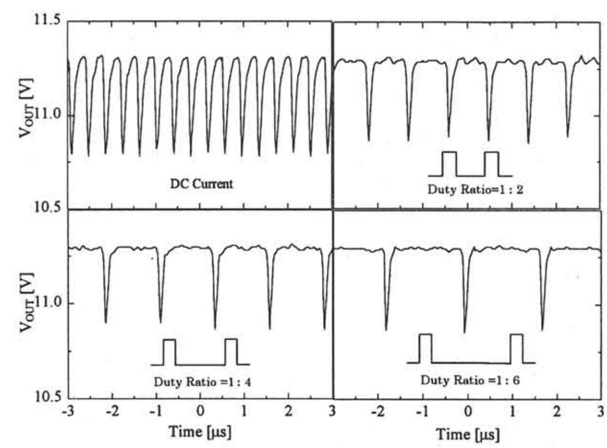

Fig. 4 Output pulse frequency is modulated by changing the duty ratio of input pulse signals

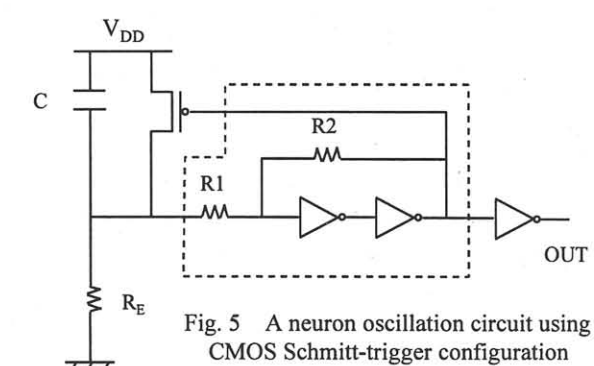

Fig. 5 A neuron oscillation circuit using CMOS Schmitt-trigger configuration

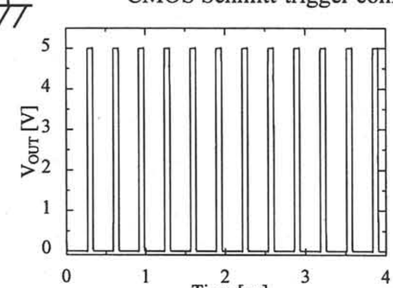

Fig. 6 The output pulses of CMOS Schmitt-trigger oscillation circuit simulated by SPICE model.