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Oxide based neuron devices employing ALD grown dielectrics and channel layer

Jung Wook Lim[1,2], Jaehee Lee[1,2] and Charin Yu[1,2]

[1]*Electronics and Telecommunications Research Institute, Republic of Korea*

[2]*University of Science and Technology, Republic of Korea*

†limjw@etri.re.kr

Artificial neural networks has demonstrated remarkable performance in learning tasks and extensively explored in recent years [1-2]. However, due to substantial power consumption and the processing of massive data, a more efficient spiking neural network approach, mimicking the human brain, has emerged as an alternative, and active research is current underway. To address these challenges, research has been conducted on CMOS-based neuron devices [1]. However, due to the intricate structure, there is still a demand for the adoption of neuron devices using 1T (a single transistor) architecture non-silicon-based semiconductor materials. Our research group implemented synaptic devices based on oxide semiconductors, demonstrating excellent linear learning characteristics [3]. In this study, we aimed to realize the firing characteristics of neuron devices in a 1T structure concerning electrical stimulation by leveraging charge trap techniques employed in this research. The neuron device with a 1T structure features a bottom gate configuration, as illustrated in Figure 1. The semiconducting channel and dielectric layers were sequentially deposited using ALD, effectively trapping charges at the interface. Under regular and repetitive electrical stimuli with a consistent voltage magnitude and pulse duration, as positive charges become trapped, the transistor's transfer curve exhibits a rapid negative shift. Furthermore, with the continued accumulation of pulse stimuli, once surpassing a critical threshold, a sudden current flow occurs, leading to firing. When applying periodic stimuli to the gate electrode of the neuron device with a voltage of 11 V and varying pulse durations of 100, 300 and 500 μs, while maintaining a pulse interval of 300 ms, the firing patterns of drain current manifested as depicted in Figures 2 (a) to (c). The on/off ratio of the firing current was approximately 10^3, and as the pulse duration increased, there was a tendency for a decrease in the frequency of firing. As firing drain current needs to be converted to the voltage signal when transmitted to the subsequent synaptic devices in the neural network circuit, requiring a conversion of current signal to voltage signal by connecting a resistor, Figure 2 (d) shows the transformation of the current signal in Figure 2 (c) into a voltage signal. Although we successfully emulated the firing characteristics of neurons with a 1T structure based on oxide semiconductors, the actual human brain exhibits more intricate firing patterns. To implement this complexity, diverse and optimized structures must be explored. It is anticipated that in the future, these structures will be effectively utilized in neural network array configurations connected through neuron-synapse 1T structures.

References

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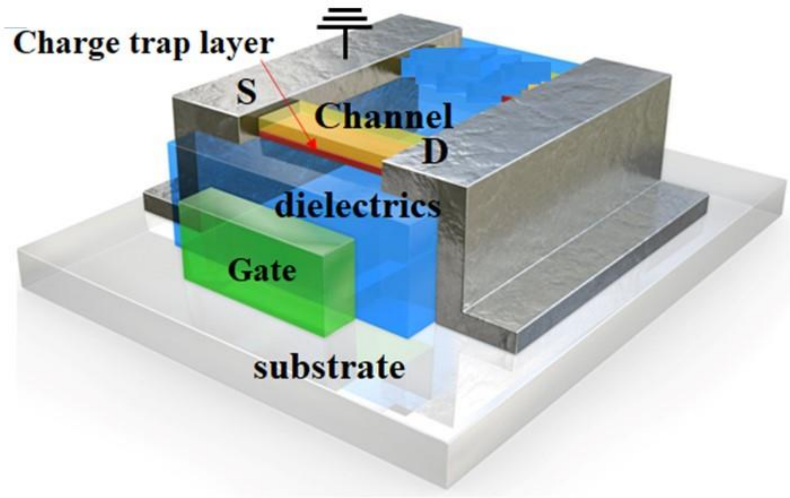

Fig. 1. The cross-sectional vertical structure of oxide-based neuron devices

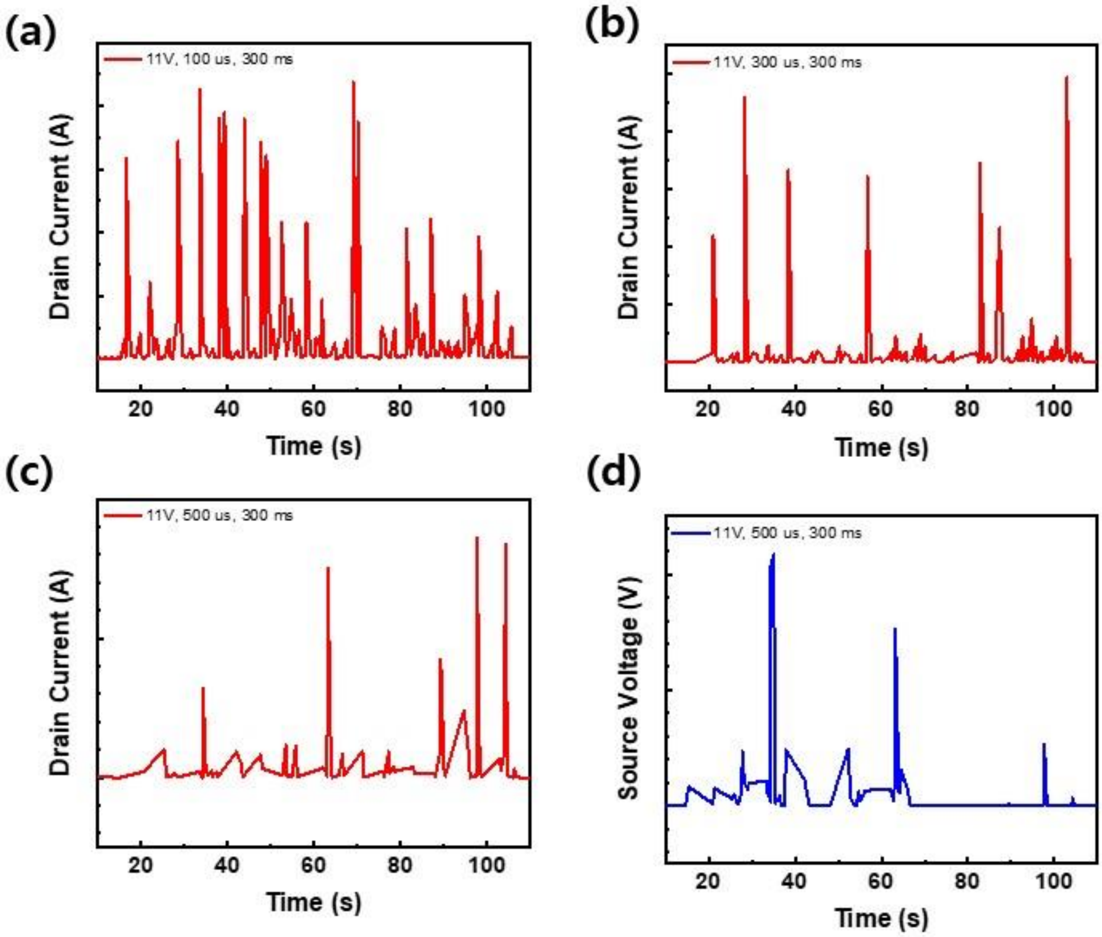

Fig. 2. The firing characteristics of drain currents and source voltage for the various supplied voltage pulses with various conditions: (a) 100 μs, (b) 300 μs and (c, d) 500 μs of pulse duration. All pulses have identical a voltage amplitude of 11 V and a pulse interval of 300 ms.