Single-Electron Synaptic Depression

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Background: Synaptic depression, network dynamics, and their applications have recently attracted the attention of many modelers who mainly focused on the dynamic implications of neural systems. Abbott *et al.*, for example, reported a striking feature of synaptic transmission between neurons [1] where postsynaptic firing rates for input spike trains are limited at some value because of short-term synaptic depression. Furthermore, interesting applications of various neural networks with depressing synapses have also been proposed [2, 3, 4], and various hardware synapses on neuromorphic CMOS devices have been fabricated [5, 6]. Such neuromorphic devices can be expected to be high-functioning information processing devices in the future. This paper reports on our design of a single-electron depressing synapse (SEDS) on a single-layer nanodot array, showing that device implementation of the SEDSs on such a nanodot array is much easier than the implementation of depressing synapses on CMOS VLSIs.

Single-electron depressing synapse circuit: In designing a SEDS, we use a pair of single-electron oscillators (Fig. 1) that we proposed for use in designing an excitable media [7] and a spiking neuron circuit on a single-layer nanodot array [8]. The oscillator has excitatory, refractory, and resting periods. Here we propose the use of refractory properties of spiking neurons, where the neuron cannot fire continuously for high-frequency input spike trains, as depressing characteristics of the SEDS; i.e., we regard an array of spiking neurons as a depressing synapse because input spike trains are depressed by each neuron operating in its refractory period. Therefore, we can use an array of single-electron oscillators to construct the SEDS. It should be noted that the term of the refractory period increases as values of g_{Na} and g_{K} increase [7].

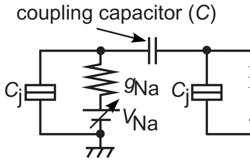
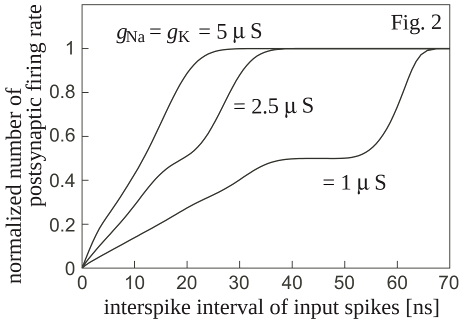


Fig. 1

There is a neuromorphic relationship between the proposed SEDS and electronic Hodgkin-Huxley (H-H) models: i) a tunneling junction (C_j) corresponds to a membrane capacitance and voltage-controlled gates in H-H models, ii) nonlinear chemical reactions between Na^+ and K^+ can be mediated by a coupling capacitance (C) because of the neuron’s dielectric inside the soma.

Results: We examined the depressing properties of a single SEDS by numerical simulations. We used typical parameter values for the single-electron circuit [7], except for g_{Na} (= g_{K}) = 5 μS, 2.5 μS and 1 μS. Figure 2 shows synaptic conductivities (~ the number of postsynaptic spikes) for interspike intervals (ISI) of input spike trains. As the ISI increases, the conductivity increases because each SEDS can easily be recovered from its depressed (refractory) period as the ISI increases. Because the depressed period increases as g_{Na} and g_{K} increase, the SEDS’s conductivity for increasing ISIs decreases significantly.



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