Realizing a linear synaptic weight update in ion gated graphene field effect transistors for achieving spike-timing-dependent plasticity in neuromorphic computing

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To overcome the von Neumann bottleneck and increase power efficiency in computation, neuromorphic computing has been considered, which has the capability for parallel computing, long-term potentiation, and adaptive learning for developing energy efficient neural networks.[1] Electric double layer (EDL) gated transistor uses ions within an electrolyte to induce high carrier density (10^{14} cm^{-2}) in the channel, and its short term and long term ionic responses resemble a biological synapse, making it a promising platform for synaptic applications such as artificial synapses and neurons.[2] The accuracy, computational demands, and simplicity of training neural networks depend significantly on a linear synaptic weight response (or plasticity), i.e. a proportionate conductance update in response to input signals.[3,4] However, achieving linear weight update in EDLT based synaptic devices have proven to be challenging with fixed magnitude input pulses.[5,6] In this study, we first discuss the fundamental cause for nonlinear synaptic weight update in the EDLT devices. Finite element modeling using modified Nernst-Poisson-Planck equations revealed the EDL formation and dissipation rates to be competing and dependent on the instantaneous EDL concentration.[7] A train of ten pulses with frequencies ranging from 2- 10 Hz were applied to Graphene FETs, using PEO:$LiClO_4$ as the electrolyte, which resulted in a nonlinear response. A predictive model called Linear Ionic Weight Update Solver (LIWUS) was created in Python and trained with the voltage- and concentration-dependent rate data obtained from COMSOL. Based on this data, LIWUS predicted incremental voltage pulse values that were input to the GFETs and resulted in a linear weight update. Finally, a simple spiking neural network (SNN) with three layers was built and the Modified National Institute of Standards and Technology (MNIST) handwritten digits were used for training and testing the SNN. The validation and testing accuracies for image recognition were extracted and the linear weight update model showed higher prediction accuracies and lower error rate compared to the nonlinear weight update model. The outcome underscores the critical role of linear and symmetric weight updates in SNNs, and not only provides insights into the dynamic behavior of EDLs but also paves way for the development of SNNs with improved learning capabilities through optimized STDP mechanisms.

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