TWO-DIMENSIONAL MATERIALS AND THEIR DERIVATIVES FOR NEUROMORPHIC MEMORY APPLICATIONS

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by

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ABSTRACT

Brain-inspired computation and the development of synaptic devices are becoming the thrust area of research in electronic materials, to cope up with future data storage and computation demands. This Thesis unravels the possibilities of employing two-dimensional van der Waal's materials and their derivatives for neuromorphic synaptic electronics. We attempted to examine both electronic and optical characteristics of selected 2D materials, with an intention to explore their applicability in electronic and photonic neuromorphic engineering. Therefore, the first work was to study the exciton dynamics of MoS_2 quantum dots (QDs) prepared using liquid-phase exfoliation method. By closely examing the emission spectrum of these exfoliated MoS_2 QDs, we analysed the influence of the surrounding media on its photoluminescence, where the signature peaks corresponding to neutral and charged excitons were carefully analyzed. The emission intensity of the peaks corresponding to the quasiparticles strongly influences the electronegativity and dielectric permittivity of the dispersion media.

Further, ReRAM devices were fabricated using MoS_2 QDs as an active layer, which exhibits an on-off ratio of 10^4 and endurance of the On and OFF states for more than 1000 seconds. Subsequently, we analyzed the ability of FTO/MoS_2 QD/Au e-synapses to emulate the basis synaptic functions such as Paired Pulse Facilitation (PPF) and Paired Pulse Depression (PPD), etc. The defects present in the QD layer is found to be the reason for both resistive switching and synaptic characteristics.

The flexibility of electronic devices is a constant demand raised by the scientific community for future technology. In this view, we have demonstrated the flexible synapse by using Al_2O_3/MoS_2 QDs/Al_2O_3 sandwich structures, deposited on a flexible substrate. These devices emulated short-term plasticity, and especially, spike-time dependent plasticity (STDP), the most critical Hebbian learning rule in unsupervised learning in artificial intelligence. The excellent retention of the neuromorphic characteristics exhibited by these devices upon repeated bending cycles show that Al_2O_3/MoS_2 QDs/Al_2O_3 multilayer synapse can be a good candidate for flexible neuromorphic electronics.

In addition to the standard neuromorphic characteristics, for practical applications, the synaptic devices should have a linear weight update. We show that the synaptic devices composed of Al_2O_3/GO/Al_2O_3 multilayers show a near-linear weight updation. Further, the investigation on synaptic properties as a function of temperature shows a drastic reduction in memory with increasing operating temperature.

Following GO-based devices, we synthesised nanodiamonds by liquid-phase laser ablation of graphene dispersions. ReRAM devices were fabricated using spray-coated nano-diamonds, which show promising switching behaviour with an On-Off ratio of 10^4 and endurance more than 1000 s. These devices also show remarkable cycling behaviour over 400 cycles measured. Last but not least, the Random Telegraphic Noise (RTN) appearing in the current measured at constant voltage bias for single MoS_2 quantum dots were measured using Scanning tunnelling microscopy and the results suggest that RTN originates from the defects present in the QDs. This Thesis ends with suggestions for further works, mainly on the neuromorphic measurements of multiple devices in different configurations, with an emphasis on linear synaptic weight updates.