Engineering and Innovation Research Studentship 2022/2023

Project title:	**Ferroelectric Material for Brain Inspired Computing**
Discipline	Electronics, Material Science, Computing
Key words:	Neuromorphic Computing, Ferroelectric material, Neural Network
Supervisory team:	Vikram Goolaup, James Bowen and Satheesh Krishnamurthy
URL for lead supervisor's OU profile	https://www.open.ac.uk/people/sg25373

Project Highlights:

- Bio-inspired hardware architecture for artificial intelligence implementation.
- Proof of concept device for voice/image recognition
- Ferroelectric materials for enabling multi-level memory.

Overview:

The human brain solves complex problems like vision processing, speech and tactile sensing quickly and efficiently. Neuromorphic engineering is an interdisciplinary area that combines biology, physics, mathematics, and engineering to emulate the design principles of the brain. Neuromorphic engineers are developing power-efficient devices whose physical architecture are based on those of biological nervous systems. Brain-inspired computing provides a promising platform for the development of artificial intelligence. The energy consumption of artificial intelligence (AI) implemented in today's computers is significantly higher compared to that of a human brain. The energy inefficiency of such hardware is largely attributed to the von-Neumann memory bottleneck due to the separation of memory and compute units and the limited on-chip memory density in computing hardware.

The brain comprises billions of cells called neurons, which are interconnected via dendrites and communicate via electric signals through synapses. External information/stimuli are received by the dendrites of the neuron, processed in the neuron cell body, and converted to an output which is passed through the axon to the next neuron, as depicted in Figure 1. The next neuron can choose to either accept or reject the signal, depending on the signal strength.

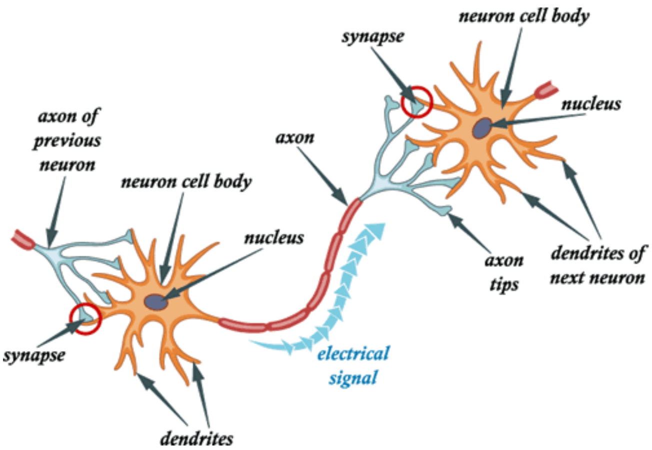

Figure 1. Typical structure of a neuron depicting electrical signal flow [1]

A key aspect of neuromorphic engineering is emulating how biological neurons pass messages between themselves via electrical signals from axon to dendrites. So-called neuromorphic chips must be built from devices that behave like neurons—in other words they transmit and respond to information sent in spikes rather than in a continuously varying voltage. Recently, remarkable implementations of neuromorphic hardware such as TrueNorth (IBM) and Loihi (Intel) have been demonstrated using complementary metal-oxide-semiconductor (CMOS) technologies. But CMOS-based technologies require large number of transistors to implement neuronal and synaptic functions, leading to increased cost of energy and area.

To overcome these problems, work has started in earnest to develop neuromorphic computing platforms based on emerging devices that can efficiently mimic neurons and synapses in an artificial neural network (ANN) [2]. Several promising materials have been suggested to mimic the electrochemical functionality of the biological synapse. Multiferroic perovskites are one such material that have recently drawn much attention due to their superior properties in exhibiting both a ferroelectric and magnetic phase simultaneously. The analog-like resistive states in ferroelectric devices enable representation of multiple states, making such devices suitable for implementing neuromorphic functionalities.

Methodology:

The aim of this project is to develop a ferroelectric hardware architecture for an artificial neural network which is capable of simple image/voice recognition. The ferroelectric properties of the material will be characterised and innovative schemes for mimicking the neural network will be developed with the aim of producing a proof-of-concept device.

The work will combine experimental investigation, and modelling. Material characterisation will be carried out using surface spectroscopy techniques, e.g X-ray Diffraction, Tunnelling/Scanning Electron Microscope. Electrical measurement techniques for characterising the ferroelectric properties will be developed as part of the project, while open-source software will be used to design proof-of-concept image/voice recognition.

An indicative project timeline:

Year 1: Literature survey coupled with synthesis and optimisation of ferroelectric material

Year 2: Design and modelling of hardware architectures using ferroelectric material for bio-plausible hardware implementation.

Year 3: proof-of-concept prototype hardware architecture for AI application and thesis write-up.

As part of the project the student will collaborate with research partners from the US and Singapore.

References & Further reading:

1. Conduction of nerve impulse [online]. Available at: https://simplebiologyy.blogspot.com/2014/08/conduction-of-nerve-impulse.html [Accessed: 10th December 2021]
2. Jacob Torrejon et al, *Neuromorphic computing with nanoscale spintronic oscillators*, Nature, 547, 208 (2017)
3. Cheng Wang, Amogh Agrawal, Eunseon Yu, and Kaushik Roy, *Multi-Level Neuromorphic Devices Built on Emerging Ferroic Materials: A Review*, Frontiers Neuroscience, 15, 661667 (2021)
4. Christian Engel, Vikram Goolaup, Luo Feilong and Lew Wen Siang, *Quantitative characterization of spin-orbit torques in Pt/Co/Pt/Co/Ta/BTO heterostructures due to the magnetization azimuthal angle dependence*, Physical Review B, 96, 54407(5) (2017)

Further details:

Student should have a strong background in electronics/electrical engineering, physics or material science, with a strong enthusiasm for experimental work. A knowledge of programming in Python will be a plus. The student will join a well-established multidisciplinary team at the Open University.

Please contact Dr Vikram Goolaup (vikram.goolaup@open.ac.uk) for further information.

Applications should include:

- A 1000 word cover letter outlining why the project is of interest to you and how your skills match those required
- an academic CV containing contact details of three academic references
- an Open University application form, downloadable from: http://www.open.ac.uk/postgraduate/research-degrees/how-to-apply/mphil-and-phd-application-process
- IELTS test scores where English is an additional language

Applications should be sent to **STEM-EI-PhD@open.ac.uk by 15.02.23**