Neuromorphic Engineering: Towards printable artificial synaptic neurons with MXene 2D-materials

Principal supervisor :Dr Nicholas Power (Life, Health & Chemical Sciences)

Co-supervisory Team Dr Vikram Goolaup and Dr Zahra Golrokhi (Engineering & Innovation), and Prof Satheesh Krishnamurthy (IBC, University of Surrey)

Location The Open University, Milton Keynes, United Kingdom

Full-time only.

Duration & Funding A 3 year 3 month studentship as part of EPSRC Doctoral Training Partnership; Stipend £18,622 per annum; Training grant £4,500

Application due date: Feb 26, 2024

Notification of shortlisting and online Interviews will be arranged promptly after the closing date

Final Funding Decision: Late April/early May 2024**.** This is part of a pooled EPSRC-DTP process, so the selected applicant will be put forward to a reviewing panel in April for final decisions. Applicants will be notified if they are selected, and will be informed of the panel decision afterwards.

Start date: October, 2024

Project-related enquiries: nicholas.power@open.ac.uk

Process-related enquiries: STEM-LHCS-phd@open.ac.uk

Research area/keywords: 2D-materials, MXene, Neuromorphic, computing architecture.

Project background and description

Artificial intelligence (AI), with the aims of creating intelligent machines and systems capable of performing tasks typically requiring human intelligence is becoming ubiquitous. AI systems implemented on conventional computing architecture consume vast amount of computing resources and energy [1]. This energy inefficiency stems from the von Neumann memory bottleneck, a consequence of the separation of memory and compute units. Inspired by the neuro-biological signal

processing within the brain, Carver Mead coined the term "neuromorphic", envisioning a computing architecture modelled on the physics of real neurons and synapses [2]. This novel paradigm in information processing and storage holds the promise of significantly reduced power consumption. Neuromorphic computing systems, can directly process sensory data without converting it into digital signals, are particularly well-suited for smart front-end Internet of Things devices. Printed electronics (PE) offers an efficient, low-cost, and fast manufacturing process for implementing neuromorphic architectures in sensory applications. However, a major challenge in PE-based neuromorphic computing lies in the need for solution-processed materials as the building blocks of neuromorphic circuits, in this respect MXenes, a class of 2D materials, can meet this.

MXenes, are derived from MAX phase compounds (metal carbides or nitrides) [3]. They are known for their unique morphology, chemical makeup, and electrical conductivity, properties which allow MXenes to be prime candidates for neuromorphic applications. Their solution-processability further enhances their versatility, enabling their integration into various devices and applications. To date, there are over 74 types of MAX phases reported, and a far greater number of theoretical models are yet to be experimentally explored. This vast array of possibilities suggests that MXenes hold immense promise for the development of neuromorphic devices.

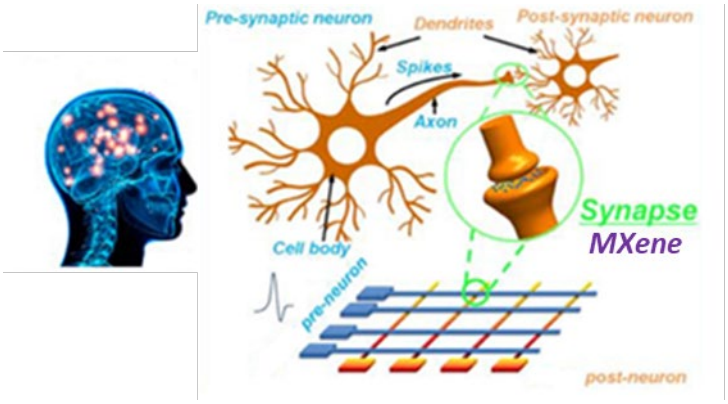

Figure 1. Typical structure of a neuron depicting electrical signal flow and corresponding neuromorphic circuit.

Aims: The overarching objective of this project is to develop MXene materials with precisely tailored electrical properties that can emulate the analog-like resistive states essential for neuromorphic computing applications. Computational modelling will be employed to design optimized MXene structures, followed by the synthesis of

solution processed MXene materials. The suitability of these synthesised MXene samples for neuromorphic systems will be rigorously assessed using circuit simulation tools before fabricating proof-of-concept neuromorphic systems on flexible substrates.

Facilities for materials characterisation at the OU include Probe Station, XPS, XRD spectroscopy, Raman, HRTEM, SEM, UV-Vis DRS, and FTIR spectroscopy (https://emsuite.stem.open.ac.uk) as well as collaborative access to the Surrey Ion Beam Centre for high end characterisation, such as Rutherford back scattering, TOF ERD etc. (https://uknibc.co.uk/SIBC/facilities.php) to understand the fundamental mechanism of surface and interface properties of the 2D systems**.**

References

1. Vries, A. The growing energy footprint of artificial intelligence., *Joule* (2023). https://doi.org/10.1016/j.joule.2023.09.004
2. Mead, C. Neuromorphic electronic systems., *Proc. IEEE* 78, 1629–1636 (1990). https://doi.org/10.1109/5.58356
3. Dey *et al*., Doped MXenes—A new paradigm in 2D systems: Synthesis, properties and applications, *Progress in Materials Science*, Volume 139, 2023, 6, https://doi.org/10.1016/j.pmatsci.2023.101166

Eligibility

1. Applicants will ideally have a First Class or Upper Second undergraduate degree or Masters degree (or equivalent experience) in chemistry, materials science, solid-state physics/chemistry or other relevant scientific/engineering disciplines. Previous laboratory experience and knowledge of synthesis and characterisation techniques for inorganic materials and a broad interest in sustainable materials would be an advantage. Good programming (python), numeracy, ICT, communication, and organisation skills are also desirable.

2. The student would be required to live in the UK and within commuting distance to The Open University campus in Milton Keynes.

We are committed to widening participation and awarding PhD studentships to a diverse community of applicants. We particularly welcome applications from under-represented groups. Equal Opportunity is University policy.

How to apply

Please check this page for application entry requirements: https://www.open.ac.uk/postgraduate/research-degrees/degrees-we-offer/doctor-of-philosophy-phd

Please submit to STEM-LHCS-PHD@open.ac.uk an:

- application form, and
- 2-page (A4) personal statement outlining your suitability for the studentship, what you hope to achieve from the PhD and your research experience to date

You do not need to submit a research proposal.

Information and the application form is found here: https://www.open.ac.uk/postgraduate/research-degrees/how-to-apply/mphil-and-phd-application-process. Note that as part of the application form, you will be asked to submit further documents (CV, degree transcripts, IELTS test scores where English is an additional language, etc.)