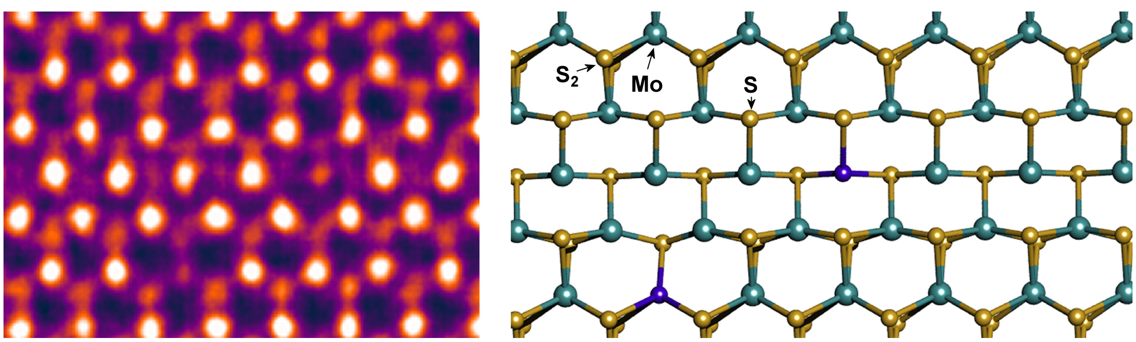
Understanding 2D material memristors by atomic resolution imaging

The relentless advance of Moore's Law, and the evermore powerful computational capabilities it has gifted us through continued device miniaturisation, will soon cease. We cannot shrink our current silicon-based electronics much further. Designing new devices beyond the traditional MOSFET, realising the potential of new materials, and even developing entirely new computational architectures, will all be necessary to ensure continued progress in computing power.

Resistive memory (ReRAM, also known as memristors) are a memory where the on and off states correspond to different resistances toggled by an applied potential. They are an emerging device of interest in 'beyond Moore' electronics, with potential applications in high-speed memory and neuromorphic 'brain-like' computing. New 2D materials, like monolayer MoS_2, can now be used to make these devices atomically thin. However, there remains significant ambiguity over the atomic mechanisms behind this resistive switching property. Understanding this process at the fundamental atomic level would allow us to engineer better devices.

This PhD project will use the state-of-the-art atomic resolution imaging facilities available at Warwick University to diagnose these underpinning mechanisms and thus inform the design of next-generation electronic devices. (See the below figure for an example experimental image). We will conduct transmission electron microscopy (TEM) imaging of 2D material ReRAM devices while they are being operated inside the microscope. These operando experiments will directly reveal the atomic mechanisms that occur inside an operational memristor. The student will benefit from training in 2D material preparation and handling, semiconductor device fabrication, and TEM imaging techniques, as well as international collaboration with partners in Korea.



LEFT: An atomic resolution TEM image of a MoS_2 monolayer, viewed from the top. The bright dots correspond to Mo, and the fainter dots to the S atoms. Running left-to-right through the centre of the image is a line defect, which are predicted to act as conducting channels. We can also see two instances of Cr dopants replacing Mo atoms. **RIGHT:** The computationally calculated (DFT) atomic model of the TEM image.

If you are interested in this project please contact me at alex.w.robertson@warwick.ac.uk. You can also have a look at some of my previous related publications in TEM of 2D materials:

- https://doi.org/10.1126/sciadv.aba4942 - TEM to understand fundamental defects in graphene
- https://doi.org/10.1039/C8CS00236C - A review on dopants and defects in 2D metal dichalcogenides
- https://doi.org/10.1021/acsnano.7b05080 - Operating a suspended 2D device *inside* the TEM
- https://doi.org/10.1021/acsnano.6b05674 - Imaging and spectroscopy of dopants in MoS_2