Henry Royce Institute for Advanced Materials

The Henry Royce Institute for Advanced Materials is the UK's national institute for advanced materials research and innovation and is accessible to all Universities and industry. The £235 million Institute has been created from an initial £128 million investment via the Engineering and Physical Sciences Research Council (EPSRC) in research facilities and equipment. The Institute operates across seven partner Universities - Manchester, Cambridge, Leeds, Liverpool, Imperial College London, Oxford and Sheffield. Of this investment, £10 million funding has been awarded to the University of Cambridge.

The Institute is focused on promoting translation from materials discovery to application, and will play a major role in driving forward key elements of the Government's industrial strategy, which lays a particular emphasis on enhancing the commercialisation of the UK's world-leading basic research. The funding to the University of Cambridge has enabled the purchase of additional equipment to support its leadership of the Henry Royce Institute's *Materials for Energy Efficient Information and Communications Technology* research area. This area focuses on improving energy storage technologies, reducing power consumption and developing new materials and devices able to harness energy from the environment.

The Royce equipment is principally based in, and run from, the Maxwell Centre, enabling researchers to fabricate new energy-efficient devices such as batteries and solar cells, and to undertake the advanced characterisation of materials and machines. These characterisation techniques will, in turn, help to hasten the development of energy technologies that are safer and more efficient, including longer-life phone batteries and electric cars with extended ranges.

This booklet contains an overview of all the Royce equipment facilities based in Cambridge and their capabilities. Please contact the equipment leads for any queries and to discuss your research requirements.

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Equipment List and Contacts

EQUIPMENT	CONTACT	DEPARTMENT	EMAIL ADDRESS
Physical Vapour Deposition System	Mark Blamire	Materials Science and Metallurgy	mb52@cam.ac.uk
UHV Deposition System	David Ritchie	Physics	dar11@cam.ac.uk
Wafer Scale AFM	Rachel Oliver	Materials Science and Metallurgy	rao28@cam.ac.uk
Ambient Processing Cluster Tool	Henning Sirringhaus	Physics	hs220@cam.ac.uk
Environmental XPS	Stephan Hofmann	Engineering	sh315@cam.ac.uk
Electron-beam Lithography System	Andrea Ferrari	Engineering	acf26@cam.ac.uk
UV Lithography Tool	Michael de Volder	Engineering	mfld2@cam.ac.uk
In-situ Electron Microscopy	Paul Midgley, Caterina Ducati	Materials Science and Metallurgy	pam33@cam.ac.uk, cd251@cam.ac.uk
3D X-Ray CT	Norman Fleck, Graham McShane	Engineering	naf1@cam.ac.uk, gjm31@cam.ac.uk
Energy Harvesting Test Equipment	Henning Sirringhaus	Physics	hs220@cam.ac.uk
Energy Storage Test Equipment	Clare Grey	Chemistry	cpg27@cam.ac.uk
Electrical Characterisation Suite	Florin Udrea	Engineering	fu10000@cam.ac.uk
Magnetic Property Measurement System	Jason Robinson	Materials Science and Metallurgy	jjr33@cam.ac.uk
Nanoscale Magnetic and Thermal Imaging System	Mete Atature, Helena Knowles	Physics	ma424@cam.ac.uk, hsk35@cam.ac.uk
Wide Bore Magnet	John Durrell, Tony Dennis	Engineering	jhd25@cam.ac.uk, ad466@cam.ac.uk

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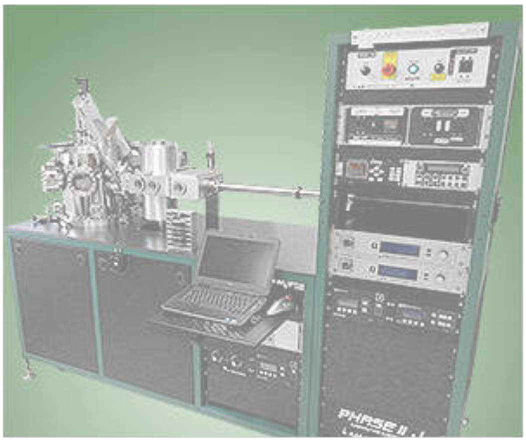
Sputter Deposition and Nanoscale Patterning Suite

The sputter deposition and nanoscale patterning suite consists of an AJA sputter deposition system for the automated growth of metallic heterostructures for devices, and a Zeiss Cross-Beam 540 focused ion beam/electron beam system for in situ patterning and device fabrication.

This will provide a unique capability for 3D heterostructure fabrication which can generate novel magnetic and optical materials systems. It will operate in association with the sputtering MBE capability of the Royce PVD suite.

If your research interests require characterisation of your materials or devices using Physical Vapour Deposition (PVD), or you would like to discuss opportunities for such characterisation please contact us.



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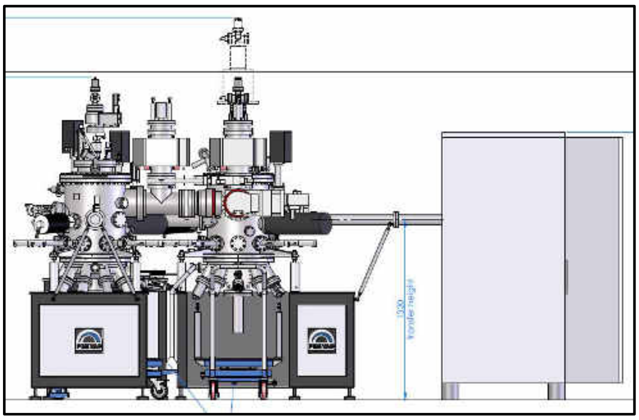
UHV Deposition System

The Ultra High Vacuum (UHV) deposition system comprises of two interconnected UHV deposition chambers. The first chamber is a molecular beam epitaxy (MBE) system for the epitaxial growth of topological insulators and related materials, and the second is a thermal and electron beam evaporator for the deposition of a range of metals.

The flexible MBE system is capable of the well-controlled growth of high-purity epitaxial layers and heterostructures covering a wide range of different compounds with unusual properties, such as topological insulators and thermoelectrics. These materials include those which have already been identified as topological insulators such as Bi_2Te_3 and Sb_2Te_3, as well as other materials of interest. After growth in this chamber, samples can be transferred under contamination free UHV conditions to the evaporator, described below, for deposition of capping layers.

The Prevac UHV evaporator chamber has several different sources using both thermal and electron beam evaporation techniques, to deposit a range of metals onto samples transferred from the MBE system. This UHV evaporator can also be used independently to provide high-purity materials suitable for spintronics and superconducting device research.

If your research interests require growth of materials using this UHV deposition system, please contact us.



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Wafer Scale AFM

This 8-inch mapping atomic force microscope (Bruker Dimension Icon Large Sample Tip) is a scanning probe microscopy system capable of accurately mapping materials topography and device electrical properties at the nanoscale across a full 8-inch (200 mm) wafer, without requiring any wafer rotation or manual position adjustment, thus allowing semi-automated morphology and performance sampling.

It will have the capability to measure a wide range of electrical properties on both unprocessed materials and processed operating devices, such as resistance, conductance, capacitance, local potential, piezoelectric response, magnetism and photoconductivity.

Key functions will include measuring the electrical conductivity of delicate samples (using PeakForce tunnelling atomic force microscopy) and the photoconductive properties of photovoltaic materials (using photoconductive atomic force microscopy).

If your research interests require characterisation of your materials or devices using wafer scale AFM, or you would like to discuss opportunities for such characterisation please contact us.

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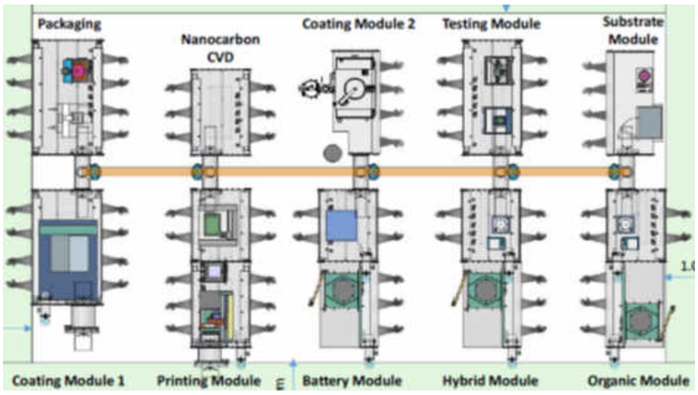
Ambient Processing Cluster Tool

The ambient processing cluster tool is a custom-built glovebox cluster tool that integrates different vacuum as well as liquid-based deposition technologies for a wide range of functional materials into a common inert glove box atmosphere.

It comprises ten glove box modules that are interconnected by a semi-automated inert atmosphere transfer system and includes tools such as thermal evaporation, sputtering, pulsed laser deposition (PLD), chemical vapour deposition (CVD) and atomic layer deposition (ALD) as well as aerosol printing, screen printing and slot-die coating. The tool also includes modules for metrology, thin film encapsulation and packaging. The tool gives access to a wide range of functional materials, including transition metal oxides for battery and other applications, organic and hybrid organic-inorganic semiconductors, two-dimensional materials, polymer composites etc.

Its unique configuration allows integration of these different classes of materials into novel hetero-architectures and but also fabrication of a wide range of devices including solar cells, batteries, mechanical or thermoelectric energy harvesters as well as integrated energy systems for energy–efficient ICT applications.

If your research interests require controlled deposition of any of the above materials or you would like to combine functional materials in novel ways and have any questions on the tool's capabilities please contact us.



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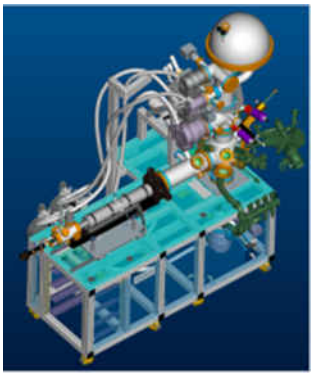
Environmental XPS

The near ambient pressure X-ray photoemission spectroscopy (XPS) system is for high-throughput chemical surface analysis under application relevant environmental conditions. The system overcomes barriers of traditional XPS systems by enabling analyses at a wide range of atmospheres, ranging from 10^{-7} mbar up to 100 mbar. Via three separate, mass-flow controlled gas inlets, the system allows the user to create a wide range of reactive environments, and hence to directly probe energy materials and devices under application relevant conditions. Via a sample holder with built-in laser heating, the tool allows direct probing of samples at temperatures up to 1000 °C in these atmospheres, enabling instant new insights into material growth and discovery, in particular for nanomaterials relevant to energy-efficient ICT.

There is a built-in plasma cleaning and a specific holder design to minimise cross-contamination and a horizontal sample loading. Sample loading is also possible without going through high vacuum, so a wide range of materials can be probed, including liquids, biological materials, ceramics, polymers, and materials with high vapour pressures.

The system uses a SPECS XR 50 MF X-ray Source, a µ-FOCUS 600 X-ray monochromator, and differentially pumped PHOIBOS 150 1D-DLD NAP analyser. The system also has a scannable focused extractor type ion source for depth profiling. The system is run as an XPS facility together with existing standard UHV-based XPS/UPS system.

If your research interests require controlled deposition of any of the above materials, or you would like to combine functional materials in novel ways, and have any questions on the tool's capabilities please contact us.



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UHV Photoemission XPS

An existing UHV photoemission instrument, an Escalab 250Xi, will be run alongside the near ambient pressure X-ray photoemission spectroscopy (XPS) system as a combined joint facility.

The current instrument has the following complementary capabilities:

- XPS for chemical analysis of surfaces under inert, UHV conditions

- Ultra-violet photoemission spectroscopy (UPS) for measurements of valence bands and work functions with a 21.2eV excitation source

- Angle resolved XPS (AR-XPS) by varying angle of the sample to vary the analysis depth down to a few nm. This is a non-destructive technique.

- Depth profiling XPS (DP-XPS) which combines a sequence of argon ion gun etch cycles with XPS analysis. This is a destructive technique.

If your research interests require access to this XPS system and you have any questions about the tool's capabilities please contact us.

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Electron Beam Lithography

The Raith EBPG 5200 electron beam tool has a thermal field emission gun for operation at 100 kV, and a high KV for high aspect ratio nanostructures, including high speed direct write with full automatisation. It has the fastest Gaussian beam system on the market, with a fast arbitrary shape pattern generator of 100 MHz. It can process 200 mm (8 inch) wafers and 7 inch masks with a minimum feature size below 8 nm. The precise overlay of features is less than 10 nm; this is currently the fastest tool for high density patterns.

The equipment can be used for flexible configuration to fit application requirements and is an essential manufacturing tool for fabrication of deep nanoscale devices. The system contributes to developing novel nanoelectronic devices, on-chip integrated optoelectronic circuits, quantum devices, layered material related devices, photonic and plasmonic systems. It allows both the cutting edge fabrication of small scale (lab level) devices, and for expanding these capabilities towards large scale production. It forms a bridge between basic research activities and wafer-scale manufacturing.

If your research interests require you to pattern silicon wafers with feature sizes ranging from hundreds of micrometers down to 8 nm, please contact us.

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UV Lithography Tool

This UV lithography tool allows the user to pattern photoresists on silicon wafers. This is a key step in any lithographic process, and this can be used to fabricate, for instance, MEMS energy harvesters or lithographically patterned electrodes for batteries or solar cells.

The fourth generation Karl Suss MA6 tool offers pattern features on Si wafers down to approximately 700 nm. The alignment accuracy is 250 nm, and this tool features a video-assisted alignment feature. It can process from millimetre-scale samples up to 6-inch wafers, and allows for proximity, soft, hard, and vacuum exposure. Further, the optics of this tool can be switched to either process thin or thick (*e.g.* SU8) photoresists and it features automatic wedge compensation. The tool is equipped with chucks to process wafer pieces, as well as 2, 3, 4, and 6-inch wafers, and a range of mask holders.

If your research interests require you to pattern silicon wafers with feature sizes ranging from hundreds of micrometres down to 700 nm, please contact us.

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In Situ Electron Microscopy

The in situ electron microscopy package comprises two dedicated TEM holders, a fast camera designed for in situ experiments, and a holder vaccum storage unit.

1. Protochips Poseidon continuous flow liquid cell in situ holder with additional electrochemical cell. The sample can be examined as part of a continuous flow experiment or by using a static cell with electrical contacts one can image structural changes during electrochemical reactions.

2. Gatan double tilt vacuum transfer holder Model 648 that enables air-sensitive samples to be transferred to the electron microscope without the sample being exposed to the atmosphere. In order to study air-sensitive samples (e.g. Li-ion battery material) in the electron microscope, in terms of their structures and morphologies, we need a simple method to transfer samples from the batteries, typically disassembled in an Ar glove box, to the TEM sample holder.

3. Gatan OneView Camera Model that enables TEM images to be acquired at high frame rates (up to 300 fps) making it ideal for in situ studies of reactions, phase transformations, domain wall movement, etc. High quality video can be recorded over a range of resolution and speed combinations, from 4096 x 4096 pixels at 25 fps, to 512 x 512 pixels at 300 fps. The camera is supplied with a dedicated PC incorporating a 'LookBack' streaming video function to post-event trigger video capture; it is possible to keep a rolling capture up to 20s in length to avoid missed reaction events.

4. Gatan turbo pumping station Model 655 designed for storing the TEM holders under vacuum.

If your research interests require in situ electron microscopy, you would like to use the vacuum transfer holder or liquid cell holder, and/or use the OneView Camera, have any questions regarding in situ TEM capabilities or would like to discuss your experimental needs, please contact us.

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3D X-Ray CT

The 3D CT microscope is used for in situ characterisation of the composition, deformation and damage development of materials for ICT at length scales on the order of 1 micron. It is useful for determining the relationship between processing and microstructure, for observing fracture mechanisms, for investigating properties at multiple length scales, and for quantifying and characterising microstructural evolution.

It can perform in situ and 4D (time dependent) studies to understand the impact of heating, cooling, oxidation, wetting, tension, tensile compression, imbibition, drainage and other simulated environmental studies.

It can perform non-destructive views into deeply buried microstructures that may be unobservable with 2D surface imaging; compositional contrast for studying low Z or “near Z” elements and other difficult-to-discern materials.

A particular emphasis will be the development of specialised loading stages that will allow for accurate monitoring of 3D deformation processes (such as the swelling of a battery) during operation.

If your research interests require specialised 3D observation of microstructure evolution and you have any questions on the tool’s capabilities or would like to discuss your experimental needs, please contact us.

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Electrochemical and Energy Storage Test Equipment

The electrochemical quartz microbalance with Low Current Potentiostat tool comprises a Q-sense Explorer system with QE 401 electronics unit, a Q-sense chamber platform a Q-sense flow module and a Q-sense electrochemistry module). This is combined with a Bio-Logic SP-200 potentiostat/galvanostat with Electrochemical Impedance Spectroscopy and Ultra Low Current mode.

This system provides the capability to characterise the changes in mechanical properties and mass of thin film materials during electrochemical cycling, chemical reactions or phase changes. Film thicknesses can be from <1 nm to several microns depending on the material. The EIS capability provides characterisation of diffusion processes within electrode materials or other electrochemical systems. Overall, it provides capability for mechanical characterisation of a wide range of material systems including battery materials, supercapacitor materials, thermoelectric materials and thin film materials for ICT applications.

If your research interests require measurement of the mechanical changes of thin film materials during electrochemical cycling, reactions, phase changes or you would like to discuss your experimental needs, please contact us.

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Electrical Characterisation Suite

The electrical characterisation suite consist of state of the art equipment for high voltage and high frequency measurements.

The suite includes a Cascade Tesla, 200 mm, high voltage, semiautomatic probe station, a Keysight B1505A Semiconductor Parametric Analyser/Curve Tracer, number of stand-alone, high precision Source Measure Units (SMUs) and a high voltage capable, Keysight 2 GHz Oscilloscope. This set of equipment allows testing and characterisation of devices and materials in wafer, die or packaged forms, very accurately from -55 °C to +300 °C. Ratings of the equipment are up to 100 A and 3 kV for wafer level measurements using the probe station and 0.01 fA to 500 A and 10 kV for packaged samples. B1505A also has C-V capability from 1 kHz to 25 MHz with a combined voltage rating of 3 kV. The oscilloscope with the high voltage probe can capture switching transients up to 4 kV.

The electrical characterization suite also includes high frequency test equipment, in particular a MGV Star Lab Antenna Measurement System (650 MHz to 18 GHz) and a Keysight N222A PNA Network Analyser (10 MHz to 26.5 GHz). The antenna testing system, in combination with the network analyser, allows accurate measurement of antenna radiation patterns. The vector analyser can also be used independently to measure scattering parameters of devices and systems.

A Keysight 65 GSa/s Arbitrary Waveform Generator and a Keysight Infiniium 20 GHz Oscilloscope are also available in the suite and can be used to investigate programming kinetics of resistive switches/phase change memories.

If you wish to use this equipment for material or device characterisation, please contact us.

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Magnetic Property Measurement System

The Quantum Design cryogen-free Magnetic Property Measurement System (MPMS) has an operational temperature range of 1.8 to 400 K, a 7 Tesla magnet, and modules for the application of multiple external fields, including: magnetic, electric, mechanical, thermal, and optical.

The system has a magnetic moment sensitivity of better than 10^{-8} emu and enables detailed, long-duration, measurements and testing of magnetic phenomena in materials and devices that exhibit a strong coupling between their magnetic and electronic/thermal/optical properties.

The MPMS consists of the following modules:

(1) Custom-designed electronic transport probe with a 5-axis sample holder with 2-point and 4-point electrical connections for magnetoelectric measurements;

(2) High pressure cell for pressure-magnetism coupled measurements of bulk crystals, thin-films and devices;

(3) Magneto-optical module with a monochromatic light source that uses a Xenon bulb and filter for illuminating samples with varying wavelengths in the 360 nm to 845 nm range for measuring photo-induced magnetisation phenomena across a wide-range of temperatures and applied magnetic fields;

(4) Oven for measuring high temperature properties up to 1000 K, which is particularly important for studying phase transitions in multicaloric materials that operate above room temperature.

If your research interests require detailed measurements of advanced functional magnetic materials, devices, and circuits, in which magnetic, electronic, optical and thermal properties are strongly coupled, and have any questions, please contact us.

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Nanoscale Magnetic and Thermal Imaging System

The Nanoscale Magnetic and Thermal Imaging System uses atomic defects in nanoscale diamond crystals to probe the local temperature and magnetic field with a spatial resolution of ~10 nm. It is a system custom-designed in collaboration with Asylum Research, which integrates a scanning probe with optical detection of the diamond defect.

The dynamic range of the system spans DC to MHz with sub mT and mK resolution for the magnetic and temperature sensing modes, respectively. The technique is non-invasive and thus enables the characterisation of surface and interface effects in highly sensitive samples with nanoscale magnetic features. The system is also ideal for probing caloric effects in thin films and devices: mK sensitivity enables the mapping of transient heat in high bandwidth devices and circuits with nm spatial resolution. In particular, this capability enables measurements and characterisation of devices for energy-efficient ICT during testing operations under ambient conditions.

The imaging system is housed in a temperature-controlled and vibrationally isolated housing which enables <0.5 K temperature stability and <5 nm drifts over the course of several hours.

If your research could benefit from this nanoscale imaging tool or if you would like more information on its capabilities, please contact us.

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Wide Bore Magnet

The wide bore magnet is a 12 T solenoid fitted with a VTI with a 100 mm usable bore supplied by Oxford Innovative Cryogenic Engineering. Temperature control is possible from 325 K to < 2 K. The system will have a field homogeneity of 0.05 % over a 1 cm DSV and 0.5 % over a 4 cm DSV. The system is entirely cryo-cooler operated with a He gas filled cooling loop. The VTI will operate in static, dynamic and one-shot modes.

The system is intended to facilitate materials characterisation and process development across the full range of Royce areas. While the system is provided with a generic fixed sample probe and a 100 A transport probe technical support will be available to exploit the large internal bore of this magnet by designing custom measurement probes. A wide range of standard laboratory equipment is available in the host laboratory to use in conjunction with the system.

This system is ideal for studying mesoscopically ordered materials, superconductors and low loss high permeability materials.

If your research interests might benefit from the use of this equipment, or if you have any questions on the system’s capabilities or would like to discuss your experimental needs, please contact us.

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The Maxwell Centre

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The Maxwell Centre was launched in April 2016 and is the centrepiece for industrial engagement with the physical scientists and engineers at the West Cambridge Science and Technology Campus. It is a gateway to cutting-edge research through external partnerships, opportunities and collaborations. The Royce equipment will be principally based in, and run from, the Maxwell Centre.

We welcome new collaborations that involve innovative and ambitious research approaches to solving real world challenges. If you are interested in working together with Cambridge researchers on fundamental problems of relevance to your business, please get in touch with the Maxwell Centre liaison team. We will be delighted to discuss and explore research areas of mutual interest. The Maxwell Centre programme fosters and supports collaborative research between academics and industry, and this includes shared access to our facilities.

To support the interactions with external partners the Maxwell Centre can offer hot-desking presence in the building to accommodate new and growing partnerships. This model can be also used to maintain a regular contact with University research, and there is also an option to establish a more permanent presence in the building. The major benefit of these offerings is a possibility to become part-time, or full-time embedded in the Maxwell community: start and build relationships, grow understanding of each other's aims, and hold face-to-face meetings with researchers. This also allows for serendipity to happen alongside the planned engagements - through encounters that occur simply by being in the right place at the right time.

We look forward to hearing from you – please feel free to get in touch to discuss your requirements.

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