

Co-ordination of access sub-committee report.

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Electron microscopy is the dominant technique for spatially-resolved analysis of materials' structure, chemistry and functionality beyond the diffraction limit of visible light. As such, it underpins a substantial fraction of the EPSRC research portfolio, notably in research areas involving quantum materials, nanomaterials, microelectronics, optoelectronics, sensors and energy materials. Researchers in these areas need frequent, easy access to EM instrumentation and expertise. Low-end, 'workhorse' instruments in the £100k-£500k price range are ubiquitous and housed in most major research institutions with portfolios in the physical sciences. Mid-range tools (£500k - £2M) are located in a smaller number of specialist centres; and high-end tools (£2M - >£5M) are restricted to national centres and university institutions that tend to focus on 'unique' local research interests.

The range of EM instrumentation available to the UK scientific community is amongst the best in the world and has been supported by significant EPSRC investment. In the decade running up to the community survey, over £40M had been invested in aberration corrected (S)TEM alone, to upgrade and support the 17 aberration corrected instruments across the UK. In the past 3 years, funding has been announced for at least 3 more such instruments, and there is a commitment to fund the £120M RUEDI facility at Daresbury. For the wider UK scientific community to fully exploit the range of EM instrumentation and expertise within the UK, clear and transparent routes to external access are required. Here we summarise the current state of provision and suggest potential improvements.

Current provision

The UK EM infrastructure can be broadly segmented into three categories: National Facilities (Tier 1); National centres of excellence and large regional facilities (Tier 2); Smaller regional and institutional facilities (Tier 3). Each of these provides an important resource for UK research and should be available for access by both academic and industrial researchers from across the UK. The UK hosts two Tier 1 national EM centres for physical sciences: SuperSTEM and ePSIC.

SuperSTEM boasts nationally unique and internationally world leading instrumentation and expertise, providing access to instrumentation for high spatial resolution imaging and high energy resolution imaging and spectroscopy. It houses four primary instruments. SuperSTEM 3 is a monochromated 40-100keV instrument offering sub-Angstrom resolution imaging and 5meV spectral resolution. SuperSTEM 2 and SuperSTEM 1 operate at 100keV with sub-Angstrom resolution and 300meV spectral resolution. SuperSTEM 4 is a low voltage SEM-STEM instrument with EELS capability, operating between 1 and 30keV with spectral resolution of 300meV. SuperSTEM also offers access to FIB and other associated equipment for sample preparation.

Access to SuperSTEM is free at the point of access for UK academics, funded via an EPSRC NRF grant³. Applications are submitted through a web-based form and reviewed by an advisory board. Experiments are run by dedicated SuperSTEM staff who, each year provide

over 360 user days of instrumentation across the two main instruments (SuperSTEM2 & 3), hosting over 40 users per year and attracting approximately 25 application proposals.

ePSIC has a focus on high spatial resolution imaging to address a broad range of materials science problems. It houses two main instruments: E01, an aberration corrected STEM for sub angstrom imaging and spectroscopy with a spectral resolution of 300meV (note: E01 is owned by Johnson Matthey PLC who provide 50% of time on E01 to the ePSIC user community); and E02, an aberration corrected STEM/TEM instrument for sub-Angstrom imaging. It is also equipped with an array of direct electron detectors for 4DSTEM. Access to ePSIC is free at the point of access, funded by Diamond Light Source and the University of Oxford. Proposals are submitted through the Diamond User Administration System, a web-based portal⁴. ePSIC operates calls for proposals every three months. As at SuperSTEM, proposals are reviewed first for technical feasibility by ePSIC staff and then by an external review panel. ePSIC also operates a 'rapid access' route for quick turnaround access. Users are provided accommodation, sustenance and travel cost reimbursement within limits set out by Diamond Light Source. Experiments are run by ePSIC staff members with training offered to repeat users. ePSIC runs an average of 240 peer reviewed user days per year over the 1.5 instruments and is approximately 100% oversubscribed. Since opening in 2017, ePSIC has welcomed over 600 users from over 120 research groups representing 77 institutions, (41 UK, 16 EU, 20 RoW). Collectively, ePSIC users have published over 240 peer reviewed papers covering a wide range of the EPSRC portfolio and strategic priorities. ePSIC has delivered over 1600 days of supported microscope access to the UK scientific community with operational and staffing costs to date from Diamond Light Source and University of Oxford alongside significant hardware contributions from JEOL UK and Johnson Matthey Plc.

We distinguish Tier 2 facilities as having at least one aberration-corrected EM instrument that is available to external users. These include EM centres at Imperial College London, Cambridge, Oxford, Cardiff, Warwick, Manchester, York and Glasgow (and others). Funding and access arrangements are specific to each centre. Some are run as facilities separate from academic research groups; others maintain strong links to a specific research group with a specific research expertise; and several are involved in multi-institution collaborations to provide more than one access route. For example, the York JEOL Nanocentre is internationally leading for environmental TEM techniques whilst the Kelvin Nanocharacterisation Centre at the University of Glasgow pioneered Lorentz EM techniques for the study of magnetic materials. The survey suggests that the focus of most Tier 2 facilities is on local users, with around 20% external usage being typical.

A larger number of institutions host Tier 3 facilities that may not host aberration-corrected instruments but nonetheless provide access to substantial infrastructure and expertise, often including several instruments.

For direct access to Tiers 2 & 3, the quality of information on available capabilities, access routes and charging is variable. The Royal Microscopical Society¹ hosts a central database of available resources, but inclusion is voluntary, and the database is neither well-known nor comprehensive.

The Henry-Royce Institute hosts the largest centralised database of UK EM capability and provides funded access for both academics and SMEs to a wide range of EM equipment and expertise based at partner institutions². It describes itself as a co-operative of eleven different HEIs or RTOs, all of which advertise imaging capability via Royce. Applications are submitted to the relevant facility using a standard access form and must meet specific scientific eligibility criteria, though these are sufficiently broad to cover all aspects of materials research. Experiments are run by staff at the relevant partner institution with costs being recovered through Royce. Current partner institutions include Leeds, Cambridge, Sheffield, Imperial College London, Manchester, Oxford, the UKAEA and the National Nuclear Laboratory. Royce also has two Associate Partners, the Universities of Cranfield and Strathclyde. Through Royce, users can access three aberration corrected TEM instruments (Oxford, Manchester, NNL), six TEM instruments (Leeds, Cambridge, Sheffield, Manchester and Oxford), five SEM instruments (Leeds, Sheffield, Manchester, UKAEA, Oxford), five FIB-SEM (Leeds, Imperial, Manchester, Oxford) and three electron beam lithography instruments (Leeds, Cambridge and Oxford). We do not currently have access to detailed usage statistics for Henry Royce Institute schemes but in the period April 2023- April 2024, they report 701 requests for EM projects, a majority of which are for SEM and FIB instruments, with around 15% projects relating to TEM or STEM techniques.

EM survey results

Of 44 EM laboratory leaders who responded to the accompanying survey, 40% reported less than 10% external users and 70% reported less than 20% external users. 82% reported charging for access to instrumentation with 64% offering no reduced cost access for early career researcher. 64% of lab leaders stated that that availability of staff and trained users was limiting their instrument capacity.

Approximately a third of 129 EM users responding to the survey reported using national facilities for aberration corrected STEM (37%), 4DSTEM (36%) and EELS (27%). Despite an increasing number of Tier 2 facilities with capabilities for high resolution imaging and spectroscopy, demand for Tier 1 facilities remains above current capacity. Over 60% of respondents to the survey reported not being able to access sufficient time for EM with access to technical expertise and the cost of access being the biggest barriers to access.

Challenges

The UK has seen a high level of sustained capital investment in electron microscopy from EPSRC, resulting in an enviable suite of instrumentation. Nevertheless, the landscape of Tier 2 & 3 facilities is patchy, disconnected and hard to navigate. It is not clear where and how would be best to conduct a given experiment. Note that while Tier 1 facilities work best with well-characterised samples with clear requirements for analysis, the majority of exploratory research in Tier 2 & 3 facilities is different: the quality of samples may be variable and multiple samples may be required to iterate towards a solution to a problem. In these cases, the proximity of the facility to the research lab is essential; or a rapid service with real-time, online interaction is required. Addressing this challenge first requires improved information in the form of an accessible, well-maintained and comprehensive database. It should be

informed by better signposting to instruments funded through strategic infrastructure grants that have pledged external access time. It then needs to be coupled to a structure for limited free at the point of access to instrumentation. This will help to feed the national facilities as well as act to pump prime future grant proposals to fund EM access.

The sustainability of existing facilities is a major challenge that is poorly addressed by current funding opportunities. It could be argued that it is currently easier to win funding for new equipment than it is to run existing equipment! The main microscope manufacturers provide service contracts that, for higher-end instruments, can substantially exceed £100k per annum per instrument. Rates and the level of cover are typically negotiated locally and there is no clear oversight of the aggregated cost per annum to the EPSRC. In many cases these charges are met by recouping costs directly from research grants, producing per diem access costs of order £1k per day at facilities across the UK. This can create problems in ensuring an equity of access. Doctoral students and early career researchers in particular are less likely to have access to funds to support EM access. Service costs have also pushed higher-end instrumentation beyond the feasibility of individual research groups and is necessitating the use of multi-user facilities. There would be scope for the EPSRC to provide more opportunities for block-funding of the running costs of existing EM infrastructure.

A coupled, major challenge is the availability of sufficiently expert staff to support experiments within facilities, both research technical professionals and academic staff. Initiatives including the Technician's Commitment are a welcome addition to national strategies that maintain the pipeline of RTP training. There is scope to expand such activities, particularly towards higher employment grades, which would be essential for the retention of highly-trained personnel.

A further challenge is the availability of ancillary equipment. Tools including focused ion beam (FIB) microscopes and ion mills are essential for the production of high quality samples for TEM analysis. These tools allow users to provide a bulk sample to the facility and have it prepared for TEM analysis. FIB instruments are essentially core equipment but can cost in excess of £1M, placing them beyond the budget for most core equipment funding schemes. There is scope to provide a national service in TEM sample fabrication. The Royce model has potential to be applied to address this challenge.

Strategic priorities

Having reviewed the current state of access to UK EM, this subcommittee has identified the following priority areas to improve access to instrumentation and expertise.

Short term (1-2 years):

- Maintain national facilities, which are highly regarded by the community and continue to meet their primary function to provide access to world-class facilities in imaging and spectroscopy.
- Collate comprehensive statistics for the provision and usage of EM Tiers 2 & 3 instrumentation across the UK. This should include oversight of what has been

promised in funding awards to provide more a 'joined-up' analysis of the current status. Robust reporting mechanisms to track the range of access and outputs should be considered, perhaps through ResearchFish.

- Develop a national strategy, based on further consultation with the community, for the sustainable provision of EM instrumentation.

Medium term (3-7 years):

- Establish a model for sustained funding for Tier 2 and Tier 3 facilities through free at the point of access UK distributed model, drawing best practice from national and international distributed facilities including:
 - Microscopy Australia (<https://micro.org.au/academic/access-guide/>), a collated database of hardware and expertise across Australian microscopy with nationally subsidised access for Australian scientists.
 - the UK National Crystallography Service (<https://www.ncs.ac.uk/>), which provides an alternative model that could be adopted across a larger number of distributed sites. It enables users from across the UK to have their samples prepared and analysed by xray/electron diffraction.
 - iNEXT-discovery (<https://inext-discovery.eu/>). A pan-European access and training scheme for structural biology funded through Horizon-2020.
- Use the model to enhance the funds available for existing strategic infrastructure in EM at Tier 2 and Tier 3 facilities.
- Improve the national provision of training opportunities for facility staff in EM, perhaps with buy-in from the major microscope manufacturers, who also struggle to find trained staff. There is potential to consider a distributed Centre for Doctoral Training at the doctorate level. For RTP staff, promoting the Royal Microscopical Society's proposed Chartered Microscopist scheme may be effective.

