Working Group on a Distributed Facility Model for Advanced Electron Microscopy in the Physical Sciences

A. Current Ecosystem *(Rik Brydson and Paul D Brown, with input from BioimagingUK)*

The following represents a summary of two surveys administered by the RMS and EMAG in late 2013: one to laboratory leaders (40 responses) and one to general electron microscopy (EM) users (140 responses). Whilst admittedly being a snapshot and somewhat incomplete, these surveys did highlight the following points:

1. The current situation in terms of equipment and staffing has been arrived at in a rather ad-hoc way, via a variety of relatively uncoordinated funding streams. The UK is well provided for in many EM areas, but there are clear capability gaps. The age profile of equipment varies considerably, and it is recognised that much will need renewing in the next ~ 5-10 years;

2. The overall levels of (running) cost recovery for current EM facilities vary considerably. Significant capacity is available on these instruments, arising from insufficient staff support or a lack of trained users capable of independent working;

3. In terms of the current requirements and needs of the user community, there is a demand for more "high-throughput" analytical TEM, cryoTEM, cryoSEM, aberration-corrected TEM and FIB/SEM, plus the occasional use of more specialised *in situ* SEM/TEM techniques (*e.g.* heating, environmental, tomography etc.) and EBSD. Where it was an issue, the availability of technical expertise and access costs appear to be the main problems restricting access, particularly for high end techniques;

4. A wide range of specialised capabilities were suggested as being missing from the UK portfolio, including serial block face SEM (3view), dynamic TEM (D-TEM), sub-Å resolution variable energy TEM (SÅRVE-TEM), electron holography, electron tomography, low voltage SEM and TEM, He ion microscopy, LEEM, advanced FIB/SEM (including cryoFIB/SEM) and analytical cryoTEM, plus specialised holders for *in situ* microscopies, along with appropriate sample preparation capabilities. Some (but not all) of these do appear to be accessible already within the UK, and perhaps the responses reflected problems with access costs, capacity, expertise or coordination;

5. Notably, with an increasing drive in the physical sciences to image and analyse soft materials, there are significant overlaps with the BioimagingUK EM Roadmap,[1] particularly in terms of analytical Electron Microscopy; cryo-FEGSEM, cryo-preparation and FIB/SEM, along with correlative Light and Electron Microscopy and Electron Tomography.

An embryonic EM network had arisen as part of the creation of the SuperSTEM Facility and the subsequently awarded EPSRC mid-range AC-STEM facility. Furthermore, the initiation of both Materials and Nanoscience Equipment Access Facilities, funded since 2006/7 (some of which were still going, *e.g.* LENNF), has provided a test-bed for EM user access schemes. The development of a Laboratory Leaders network could potentially address some of the problems of the present ad-hoc development of EM capability, and would assist in coordinating efforts to facilitate wider access to facilities, thereby making greater use of spare capacity on current infrastructure. In the physical sciences, there is clear demand for equipment access in terms of overall user-numbers, but obstacles include the requirements for dedicated staff / expertise for user support and training, access to funds for small instrument upgrades to maximise throughput, along with VAT issues in regard to the provision of research services.

Increasing demand in the physical (and geo-) sciences to work with biomaterials and biological samples suggests some degree of overlap and integration of facilities across the communities would be desirable. For the physical sciences, this will be beneficial in terms of sample preparation and low dose techniques, whilst for the biological sciences, increased use of chemical analysis techniques would improve biochemical understanding of processes, to complement the study of biological ultrastructure. This represents a clear opportunity for the UK microscopy community as a whole.

[1] http://www.bioimaginguk.org/images/4/4b/EM_Roadmap_011012.pdf

B. Access and Networking Models *(Pete Nellist and Ian MacLaren)*

The review of the current ecosystem has highlighted that significant capacity is available on the UK portfolio of EM instruments, but that also that there is unfulfilled demand for high-end techniques, with the main restrictions on access being the availability of technical expertise and access costs. The aim of this document is to identify mechanisms by which investments in infrastructure can be fully exploited to deliver science.

1. *A handbook of microscopy facilities*

Prior to the formation of the EPSRC working group, the BioImagingUK community had started the process of forming a handbook of UK microscopy facilities and capabilities that are interested in hosting external users. It would seem sensible to extend that to the physical sciences. Broadly, the aim is to have a web-based system that can be searched and updated easily. The Royal Microscopical Society have expressed an interest in hosting such a system, and a small working group are developing a more detailed plan of a web-based searchable handbook of UK microscopy facilities.

2. *Centres of Excellence*

Envisaged here is a funding scheme to which an institution or consortium of institutions can make bids. The applicants would make available an agreed amount of access to instrumentation and supporting expertise in a specific leading-edge capability or technique. In the bid, they would be permitted to apply for running costs associated with the instrumentation and the associated support staff. In addition, they could bid for a limited amount of funds to upgrade instrumentation. The function of the Centre would be to provide training, access to instrumentation and expertise in performing the experiment and interpreting the data, for a particular technique or capability.

The aim is that this funding supports the sustainability of advanced capabilities. In order to allow for staff retention and longer term planning, the work would be pre-financed. Access would be peer-reviewed by the host institution or consortium, but the performance and equitability of access of a Centre would be audited by an overall Steering Panel.

The aim is to make this a free at point of access Centre. There are difficulties associated with charging access fees associated with the charging of VAT, which are thereby avoided.

It is envisaged that the costs per year of such a centre (assuming around 20-30 days access per year) would be in the range £200-£300k over 3 years.

3. *National Centres*

The Centres of Excellence described above would not preclude the formation of National Centres. Similar to the existing SuperSTEM facility (EPSRC National Facility for Aberration-Corrected STEM), such National Centres could provide a vehicle for providing capabilities to the UK that would be hard to establish in a university setting. Clearly, one role of the Technology Watch activity described in Section D is to identify capabilities that would require such an approach.

4. *Lab Leaders Network*

The BioImagingUK initiative has already identified the need for community-led development of strategy to identify funding priorities in the life sciences, and we propose the extension of this to include the physical sciences. The aim is to provide continuity to the process started by the EPSRC Working Group, through the formation of a network of those who lead electron microscopy-focused research facilities or research groups. Such a network would provide a mechanism for the sharing of best practice and the report generated by network meetings will provide a strategic coherent statement for funders and applicants to align their future calls and applications to defined priorities for the UK scientific community. This would require funding to cover travel and meeting expenses.

C. Electron Microscopy Training and Studentships: Summary (*Richard Baker and Sarah Haigh*)

A training and PhD studentship structure is proposed in order to ensure that the UK's advanced electron microscopy (EM) equipment and expertise is effectively exploited for the benefit of UK research and business. A model of a virtual, distributed EM Training Partnership (EMTP) with funding from RCUK is proposed. The main aims being to:

1. Improve awareness of the capabilities and accessibility of EM to the UK research and business communities.
2. Expand the number of PhD level EM experts in the UK and to improve high-level EM training more generally, especially through Continuous Professional Development (CPD).
3. Provide a high-quality, comprehensive and widely-recognised learning resource in EM.
4. Create a network to include, involve and connect the whole UK EM community.
5. Pool educational and research resources to ensure academic excellence in combination with cost and time savings.
6. Ensure effective representation of EM to external organisations, with the aim of attracting continued UK and international funding.
7. Be flexible enough to accommodate a wide range of PhD and CPD subjects and projects.

As a starting point, the focus of this proposed training is directed towards materials systems. However, in the future partial overlap or complete merging of this training structure with that described by BioimagingUK may be beneficial.

Funding

To make the desired impact, attain critical mass, realise economies of scale and to be inclusive of the whole UK EM community, the EMTP would aim to train 20-30 students per year for the first five years. Support at 50% would be sought from RCUK (£1-1.5m per cohort). Student funding from other mechanisms will be attracted in by the benefits of association. Universities would be invited to join the EMTP and get the benefit of the network (studentships, access to the VLE, CPD opportunities for staff etc.) in return for committing to host projects, for providing instrument access, courses or teaching material and perhaps contributing matched studentships (this *could* be made a condition of membership).

Elements of the EMTP Structure:

As students will be distributed nationwide, teaching will require the following:

A comprehensive course in a VLE on a free subscription model for EMTP members, to contain:

(a) Core lecture courses (slides/video) on the main aspects of EM, including supporting theory, with online submission and assessment of student work. Material contributed by EMTP partners.
(b) A reference section including student literature reviews, technical notes, instrument details, sample preparation techniques, analysis methods, 'tricks of the trade' etc. Multimedia and student submissions encouraged.
(c) Links to useful EM tools such as relevant software, and external sites to augment training.
(d) A programme of webinars.
(e) Online Forum to facilitate enquiry-based learning group assignments and for exchange of ideas, results, Q&A sessions, etc.

Residential courses, workshops and conferences. Two, week-long residential courses during the first year (modelled on highly successful RMS and SuperSTEM courses) and an annual student conference event with workshops on emerging topics, specific techniques, specialisms. Long-standing EMAG and RMS events will be incorporated into the programme.

Regional Training Centres (RTCs). About ten RTCs will provide hands-on EM training, concentrating on the fundamentals, within reasonable travelling distance for the students.

National Training Centres will provide high-level, specialist short courses, offered nationally.

Research Visits and Miniprojects. Funding will be available to support ~10 week PhD and CPD visits at other EMTP members.

D. Future Techwatch for EM in the Physical Sciences ***(Ed Boyes, Angus Kirkland and Quentin Ramasse)***

Techwatch Overview and Remit

1. To provide a technical structure for the field, both scientifically and organisationally
2. To introduce mechanisms for Techwatch initiation, continuation and review; ensuring that all community members have the opportunity to contribute (at MMC?)
3. To propose first generation target areas of interest, a mechanism for adding to them and continuing review of initiatives at every stage
4. To identify necessary enabling support actions; including staffing development needs

The challenge is to select those application capability developments for which a clear scientific value with economic and other societal impacts can be established and a route to capability development identified.

A pyramid of capabilities, similar to the Bioimaging model, is envisaged:

A. Major user facilities with multiple instruments, supporting infrastructure, operator and scientific staffing, and expectation of long term support
B. Centres of excellence with application specific capabilities, support for external users, staffing and maintenance contributed to centrally
C. Widely distributed local facilities

The Techwatch should support each 'level' but mainly A + B; defined on the basis of uniqueness, nationally and especially internationally, cost effectiveness, accessibility and above all scientific and wider impact.

Possible First Generation Targets for A and B Levels (in no particular order)

a. 2^{nd} and 3^{rd} generation in-situ microscopy, with reactive environments, hot stages and as a platform for custom stage developments; possibly to include a UHV system (see also c)
b. Pulsed Sources both in the fs regime for diffraction and possibly spectroscopy, and in the μs-ms regime for imaging and diffraction
c. Surface Microscopy, LEEM, PEEM, SPLEEM and ultrahigh resolution SEM (see also a)
d. Anaerobic specimen preparation and transfer systems, and possibly the development of standards with X-ray beam lines
e. Wet cells for living systems; organic, inorganic and combinations
f. Vortex and spin polarised microscopy
g. Magnetic analyses
h. New fast electron detectors enabling sub-ms to μs recording
i. Low voltage instrumentation with high performance (STEM at ≤30kV, SEM at ≤1kV) (see also j)
j. Improved vacuum systems generally (see also d)
k. Quantitative diffraction based analysis
l. Application specific stage and control developments

The process should support required core capabilities without unnecessarily restricting individual scientific initiatives.