Institution: University of Salford

Unit of assessment: UoA13 Electrical & Electronic Engineering, Metallurgy and Materials

a. Overview

The Salford submission to UoA13 consists of researchers from the Materials and Physics Research Centre – one of eight centres in the School of Computing, Science and Engineering. Apart from researchers working in the core Materials Physics and Chemistry areas, a number of members work in cognate areas, specifically: mathematical studies of fluid flow; spray technology; liquid behaviour in porous solids; nonlinear electromagnetic theory. We are also submitting one member who works in traffic flow sensor data analysis (Electrical Engineering) We are submitting 15.55 (FTE) researchers.

b. Research strategy

The overall strategic aim of the Materials and Physics Research Centre is to link fundamental developments in the synthesis, characterisation and theoretical understanding of materials to current and future applications. Our aim is to do state-of-the-art physics/chemistry/mathematics on advanced materials but then to apply the results to important practical problems. To this end the Centre's interests are grouped into three major themes:

1- **Theory and Modelling** – interests here include: ab-initio quantum mechanical studies to predict and understand materials properties; theories and computer simulations of non-linear optical and acoustical materials including meta-materials used in "cloaking"; the macroscopic theory and simulation of solid-fluid interactions; the simulation of coherent inelastic neutron scattering from polycrystalline materials (for comparison with experiment).

2- **Materials Synthesis and Characterisation** – interests here include the synthesis of nano-materials (including thin film deposition) using a range of techniques (CVD, Magnetron Sputtering, evaporation, MBE, laser ablation, focussed ion beam shaping, diamond anvil cells (GPa pressures). Atomistic scale characterisation is performed using XRD, electron microscopies, neutron scattering, ambient and GPa optical spectroscopy. Gas-solid reaction analysis is undertaken for the development of e.g. hydrogen storage systems (gravimetric, volumetric, in situ diffraction- using neutrons and synchrotron X-rays), porosity analysis using Small Angle Neutron Scattering, contrast matching - vapour adsorption isotherms (reactor graphites, activated carbons and porous rocks).

3- **Engineering Materials** – interests here include the utilisation of new materials in engineering scale systems including energy storage (hydrogen storage), energy conversion (photo-voltaics), energy efficiency (eg thermal insulation), spray technology and analysis of liquid behaviour in porous solids.

Our research has a significant bias towards applications. One focussed area of application concerns "Energy" (photovoltaics; hydrogen storage; thermal insulation). The more fundamental research generally involves the analytic development of a theory coupled with its computational evaluation (e.g. electronic structure calculated using ab initio density functional theory, fluid flow); nonlinear electromagnetics (e.g. image processing and information coding applications include spontaneous pattern formation, fractal lasers, Fresnel diffraction and meta-materials); fluids in porous solids; molecular dynamics simulation of radiation damage; neutron (coherent and incoherent) inelastic scattering from materials.

Some research areas are more pragmatic than the above (APCVD - atmospheric pressure chemical vapour deposition; spray technology). These areas, however, already make very significant industrial impact (see 2 impact case studies in REF3).

A major part of our strategy is to develop and maintain the equipment base of the Centre – which is mainly concerned with Materials Characterisation. Thus, for instance, samples (e.g. hydrogen storage materials, nanoscale magnetic materials or porous solids) are fully characterised in our laboratories prior to being used for measurements using Central Facilities (ISIS, ILL, Diamond). A further strategic objective is to strengthen our significant presence at these central facilities which are undeniably "world class". We also operate cross-disciplinary research groups in Nanomaterials/Biosciences (**Sheel, Foster**) and in applications of meta-materials in acoustics (**Boardman, Umnova**).

A further research priority is to encourage collaborations with other institutions and the success of this can be seen in our list of collaborative projects, including e.g. : Imperial College (nonlinear optics and materials synthesis); Queen Mary University of London (optical spectroscopy of nanomaterials and supercritical fluids); Institute of High Pressure Physics, Moscow (supercritical fluids); the University of Surrey, City University London, and the University of Glamorgan (spontaneous pattern formation, fractal lasers); Institute of Physics, Chinese Academy of Sciences, Lanzhou University China (magnetic nanomaterials); University of Edinburgh (high-pressure synthesis); Universidad de Valencia (high-pressure spectroscopy); Birmingham University, Glasgow University and University of Uppsala (hydrogen storage); Curtin University, Australia and CalTech, California (simulation of solid state dynamics – radiation damage); University of Manchester(optical spectroscopy of nanomaterials and neutron damage in graphites), University of Surrey and Illinois State University (neutron damage in reactor graphites), Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland (PV, Si:H), University of Manchester (spectroscopic monitoring of APCVD), Fraunhofer, Germany (APCVD development), University of Nebraska (CVD organic precursors), University of Southampton (thermochromic materials), Sheffield Hallam (PV, CdS/CdTe). We have been particularly successful in generating strong European collaborations through various Framework programmes and otherwise e.g solitons (Universidad de Valladolid, Spain); hydrogen storage (HyTRAIN; NESSHy; HySIC etc) and APCVD(Powerfoil; N2P; PLIANT)

A further objective is to develop "outreach" activities based on our research. Numerous (over 12) public and school outreach activities have taken place since 2010 in collaboration with the (Manchester) Museum of Science and Industry. Activities are centred around demonstrations with equipment developed by **Bull** concerned with the generation, storage and utilisation of hydrogen (bicycle-powered electrolysis, metal hydride storage and fuel cell powered demonstrations). Events include hands-on workshops for schools, participation in science festival events and bespoke "meet the scientist" events at MOSI (Manchester Museum of Science and Industry). This equipment was funded through both an EPSRC outreach programme and a HE-STEM grant.

These major strategic objectives of the present submission are mainly as in RAE 2008 although some of the subject landscape has changed since then. Thus, our former ***Atomic Collisions in Solids*** group has been wound down following retirements and staff moves. However, we have been able to strengthen both our theoretical and experimental research with two important appointments. **Tomic,** (appointed as a reader) works on semi-conductor nanostructure modelling in the design of opto-electronic devices including modelling the optical properties of semi-conductor quantum dots for 3rd generation solar cell devices. **Proctor** (appointed as SL) uses in-house Raman spectroscopy at high pressures and temperatures (i.e. diamond anvils - GPa pressures) and the high pressure X-ray diffraction beam line at Diamond. Specific interests here include simulating conditions in planetary interiors, during explosions and following impacts. Materials include high pressure hydrides and both super-hard and molecular materials. Further, developments growing from existing research have

allowed us to establish new activities in theoretical photo-voltaics (**Christian**), magnetic nanomaterials (**Shen**, **Mellors**), in liquids in porous solids (**Wang**) and in neutron scattering/hydrogen storage (**Bull, Ross**). An EPSRC First Grant has facilitated the expansion of spatial-soliton modelling activities into new contexts and regimes, such as fully-oblique wave propagation in patterned photonic materials and structures (**Christian**). A notable event - involving **Chadwick** and **McDonald** and stemming from the particular interests of a research student (Hodgkinson) - has been the publication (in *Phys Rev D*) of a paper setting out a modification to General Relativity theory which provides an improved rationalisation for MOND theory, hence avoiding the need to introduce Dark Matter.

As noted above, it is a key objective of the Centre that our research should have practical applications. Therefore, much of our research informs teaching in the Physics undergraduate courses and in the postgraduate portfolio (to include a new MSc in Energy Materials).

c. People, including:

i. Staffing strategy and staff development

Building capacity and capability is an integral part of our research strategy. Our approach to staffing policy centres on the development of existing and new researchers through the mechanisms described below. Our overall recruitment strategy has been to maintain critical mass in each of the areas mentioned in **Section b** through replacement of retiring staff. Staff appointments in the "Theory and Modelling" and "Experimental Physics" groups described above contribute to teaching on Physics UG and PG courses. Staff in the Engineering Materials area come from the engineering directorates (both civil and mechanical) within the School. In recent years, two new permanent staff have joined the ***Theory and Modelling*** group (**Christian, Tomic**) strengthening activities in the areas of ab-initio modelling and non-linear materials. Three new staff members have also joined the ***materials synthesis and characterisation*** group (**Bull, Dawson and Proctor**) strengthening activities in the areas of materials synthesis and characterisation (all are users of international facilities (ISIS, Diamond, ILL). A new member of the Engineering group (**Wang**) works on the engineering properties of porous solids. These appointments include staff, appointed earlier as Academic Fellows, who have had their posts made permanent (**Christian**, **Bull** and **Wang**). In addition, a further significant appointment (**Proctor**) has been made in the area of Experimental Physics of Energy Materials, to replace a retiring staff member.

Research within our submission is part of the general research framework within the School of Computing, Science and Engineering (CSE). Within the new School structure, all staff now undergo a regular unified Performance Development Review with their line manager. This includes research activity as part of the overall academic workload. Line managers consult with Research Centre Heads beforehand to ensure that research achievements are included properly within the review. Each review includes a formal annual meeting and a mid-year progress review. Objectives for these reviews are set out within the University's Academic Career Path descriptors. These provide graduated expectations for the career progression of academic staff. Under the School's recently formalised sabbatical scheme, all staff are eligible to apply for research leave after seven semesters of normal service. To equalise opportunities for early career researchers, half of the School's eight sabbatical awards each year are reserved for non-professorial staff. All staff in the School can choose to be reviewed against the Academic Career Path criteria, either for HERA regrading to Senior Lecturer (in the case of Lecturers), or for promotion to Reader / Professor by the University Professorial Promotions Committee. **Tomic** and **Nasr** were promoted to chairs during the period 2008-2013.

Newly appointed staff have a one-year probationary period, and are allocated a formal mentor from senior staff in their disciplinary area. In discussion with their line manager, new members of staff are normally given reduced teaching loads in their first year, to enable them to get their

research activity fully established.

Research training and development is included within the staff induction programme. There are University-wide staff support schemes, such as the Vice-Chancellor's Research Scholarship Scheme for early career researchers and for members of staff new to research (see below). College strategic investment funds are available, together with a rigorous programme for staff development at Research Centre, School, College and University level to ensure that staff are able to extend their skills and competencies into a number of areas, whilst ensuring that high-quality infrastructure and technical services are available to our research students and contract researchers. As noted above, the University allocated three Academic Fellowships to our research area and these Fellows (now lecturers) are making a major contribution to our research profile. Early Career Researchers and new members of staff are encouraged from their day of appointment to present their work at presentation training programmes. Pump-priming research funds are provided for this purpose. Some research funding is also distributed depending on research income generated. The School Research Committee has additional funding available for regular bidding rounds to provide career development support to enable attendance at national workshops, courses etc.

Supervisory training is also provided to all PhD supervisors to improve their supervisory skills and to update them on revised regulations associated with PhD training. Such training also includes consideration of equality, diversity and widening participation. All members of staff are allocated to one of the Research Centres in the School but can also become associate members of other centres. This allows members to generate visibility and to fully contribute to the thematic research strategies, making explicit research synergies across centres, and ensuring research cohesion. In 2010, the University was one of only 10 institutions recognised by the European Commission for its work in supporting the professional development of its researchers and in meeting the terms of a Concordat to support career development of research staff (European Commission HR Excellence in Research Award). Further enhancement of the researcher development opportunities offered at Salford played a significant role in retaining this award in October 2012. External researchers are linked to activity within the School through the University's Visiting Research Fellow and Visiting Professor schemes. These allow Research Centres to link high-profile staff to the work, and promote the Centres' research. Examples of this are given in section **(e)** below.

ii. Research students

Our research student community is an integral part of our research programme. Postgraduate research studies and related activities are managed by the Associate Head - Research, within each School. We also have close links with the North West hub of the Vitae programme, which is committed to working with universities, supervisors and other national organisations to support doctoral researchers.

PGR student recruitment has been targeted for improvement through the REF period. External conditions (i.e. removal of EPSRC project studentships) have made this difficult and numbers have only increased slightly in the time since 2008. Over the period, the total number of pgs registered at the beginning of each session has averaged 87.8. The number of awards p.a. has averaged 9. Postgraduate research supervision is supported by a supervisory team (two supervisors and a Personal Tutor for each candidate). Postgraduate Research Representatives are elected from the student body. These students work closely with academic staff, sitting on School committees to make sure that the voice and expectations of students are heard and acted upon. We support diverse PhD modes/pathways which also enable us to maximise the number of students we recruit. These include full-time (including CASE studentships), part-time, split-site and PhD by submitted works. The University also has a successful online PhD programme, and a Professional Doctoral Programme, which began in 2008.

We strongly believe that a supportive research-focused environment is critical to research students in terms of the quality of their research, and their general satisfaction with their research experience. The University-wide Graduate Teaching Assistant (GTA) policy, which started in 2003, funds PhD studies combined with teacher-training and teaching experience. This has been very successful. To date this route has funded over 30 GTAs university wide, including 7 from the present UoA. We have also utilised external funds to provide studentship opportunities. Examples of this include two studentships in H-isotope separation funded by AWE.

All PGR students in the Research Centres complete their doctoral studies under the University regulatory framework for progression. Students are required to meet three formal points in their studies in order to proceed: a) the Learning Agreement, completed with their supervisors within three months of registration, to identify their broad research plan, training and development needs and their doctoral timeline; b) the Interim Assessment, after the first year; c) the Internal Evaluation, after the second year. These assessments are accompanied by annual progress reports from supervisors and self-evaluation documents from the students which are scrutinised by the School's PGR tutor, with any issues arising being brought to the attention of the Associate Head Research for the School.

The University, College and School all provide appropriate development in generic and subject-specific skills for PGRs. The University Research and Innovation unit (formerly Research and Graduate College) provides generic training through its Salford Postgraduate Research Training programme (SPoRT) workshops, which are aligned with the national Researcher Development Framework. These workshops cover aspects of doctoral study, such as expectations for the Progression Points, preparation of bibliographies and "Surviving the Viva", as well as introductions to core research skills, such as "getting published", making presentations and writing conference papers. The workshops also provide introductions to key methodological approaches and software. This programme has grown significantly since 2008, with the number of annual sessions offered rising from 51 in 2008-09 to 76 in 2012-13; participant numbers have increased similarly, from 441 participants in 2008-09 to 844 in 2012-13. The sessions are largely delivered internally by academic staff, R&I development staff, HR, and careers & employability staff, with a handful of specialist sessions delivered by external facilitators. Review of this provision is conducted annually, based on attendance figures, supervisors' views and student feedback - which is collected at each individual training session. Developments in national and institutional strategy relating to researcher development are also taken into consideration. For example, in response to the evaluation of the 2011-12 programme, R&I introduced additional sessions on Getting Started with the PhD as part of induction, an expanded suite of sessions on academic writing, and new sessions on impact, project management, focus groups and personal branding. The use of Blackboard Collaborate, R&I and the Library have also expanded the one-to-one on-line support available off-campus. The School provides a £500 annual contribution to the consumables and travel costs of each research student and encourages attendance at one international conference during the period of the studentship. Research students are strongly encouraged to attend the regular series of Research Seminars organised by the School. Involvement in Central Facilities enables us to take advantage of externally funded training, particularly for postgraduates, offered by, for example, ISIS and the National Computing Laboratory Summer Schools.

The University also runs the "Salford Postgraduate Annual Research Conference" (SPARC) where students and early career researchers across the disciplines can present their research and gain feedback. These conferences have run for over 12 years and attract students from many other institutions including the Universities of Reading, Bristol, Exeter and the Open University. The aim of the programme is to assist researchers in developing effective research skills as well as transferable skills to enhance employability. The programme maps fully onto the national Researcher Development Framework (RDF). The SPARC organisers publish

formal conference proceedings, complete with ISBN, and these contribute to PhD student CVs / track records.

Within the College, a specialist adviser on PGR careers is available. More generally, the Students' Union elects a dedicated postgraduate Vice-President (since 2008 two Union Presidents have themselves being postgraduates). In the last internal Postgraduate Research Satisfaction Survey, our students recorded a Satisfaction Rating which, in terms of the overall experience as students in the University was greater than 80%. Details of the variety of technical facilities available to our postgraduate research students are given in Section (**d**) below. The School also runs a series of Research Seminars which research students are expected to attend.

d. Income, infrastructure and facilities

During the REF assessment period, we have generated funding of £6.2 million. This income has been gained from a range of funders. Key highlights are:

- EPSRC grant funding (with Royal Society, British Academy and Royal Society of Edinburgh) amounting to £2,631,000). It should be noted that this portfolio includes two Case awards and two KTPs, indicating the effectiveness of our industrial links.

- We have also been effective in gaining FP6/7 European funding in CVD and hydrogen storage. These grants total £1,088,250. They each form part of large European collaborations and Salford staff have acted as both Coordinator (HyTRAIN) and Work-Package leaders (NESSHy (2); HySIC; N2P, PLIANT) in connection with these grants.

- We have been successful in gaining NWDA funding, through the Joule (Energy Research) Centre. This category of funding is included in central government bodies etc. category. The total here is £1,738,504. This includes a large direct NWDA grant to build the Energy House. This major project involved building a typical Salford terrace house within a concrete vault, previously used to house a Van de Graaf accelerator. This house has been fully equipped with temperature sensors and can be exposed to carefully-controlled external weather profiles so that it is ideal for the evaluation of retrofit thermal insulation under typical reproducible conditions. This facility is now widely recognised as providing an authoritative measure of the effectiveness of retrofitting thermal insulation and is being used by a wide range of commercial collaborators.

- The present submission is also notable for its use of Central Facilities, particularly ISIS at the Rutherford-Appleton laboratory, the ILL and Diamond. The funding in kind amounts to £824,968. As there is strong international competition for the limited number of instrument-days available at these facilities, we consider this funding to be strictly peer reviewed. In the current period, two of our ISIS experiments have been selected by the facility as scientific highlights.

We are extremely well served with respect to the provision and operation of specialised infrastructure and facilities. Our researchers benefit from the specialist facilities outlined below, which in total cost the University just over £1.5 million annually to run. In addition, we have benefited from University capital expenditure of just over £5 million through the REF assessment period which has been used to augment our state-of-the-art provision.

- **Salford Analytical Services (SAS**) is responsible for operating a range of modern characterisation equipment- XRD, SEM, MS, TEM, TGA, DSC, NMR, etc. SAS accepts commercial contracts which subsidise the maintenance costs of their equipment so that it can be made available to Research Centre members at a nominal rate. This unit is staffed by three experienced technical officers who maintain and enhance our modern equipment base.

- The Research Centre also maintains an in house HPC facility and associated workstations which, in conjunction with our access to the national computing facilities, supports the computational modelling research.
- A Video Feedback Laboratory has been developed to support theoretical modelling activities.
- A High Pressure Gas Laboratory has been set up for investigations of hydrogen absorption and for hydrogen storage applications (automated gravimetric and volumetric instrumentation).
- A Spray Technology Laboratory has been set up for developing new concepts in emulsion spray characterisation.
- Atmospheric Pressure CVD Laboratories have been established for developing new surface coating techniques.
- A Laser Laboratory is fully equipped for operating high power lasers, including a femto-second pump probe facility, in a safe environment. A new Raman scattering facility has recently been commissioned, specifically designed for use with high pressure diamond anvil cells.
- Consolidation of our laboratories, specifically the establishment of a Low Pressure Hydrogen Laboratory adjacent to our existing High Pressure Hydrogen Laboratory is planned. This followed the completion of a Wolfson award for refurbishment and forward research in the APCVD laboratories and development of organo-metallic CVD precursors.

As noted above, a significant proportion of our research is focused on the area of renewable technologies including photovoltaics and energy storage systems. Part of the outputs from our research contributes to reducing the environmental impact of the main university campus. The University has an energy team dedicated to reducing the carbon footprint of the campus and has adopted technologies developed by the Research Centre. This work is focussed on the Energy House described above.

e. Collaboration and contributions to the discipline or research base

- Commercial Collaborations

Members of the submission have made strong impacts in different technologies (further described in the Impact Case Studies), as follows:
Nasr has developed valuable IPR related to air-operated aerosol sprays. **Sheel** and **Yates** have developed significant IPR in Atmospheric Pressure CVD Technology. **Ross** and **Bull** have developed a variety of impacts in the general area of hydrogen interactions with materials. **Boardman** and **Umnova** are collaborating with the MOD and the Australian Forces research funding body on the acoustic applications of “cloaking” with metamaterials.

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- Academic Exchanges

Visiting scholars and visits by our members to other institutions as part of extensive collaborations have played an important role in our research activity and strategy. Examples of such collaborative activities are:

- **Tsiklauri** : Solar Physics (collaboration with Japan);
- **Tomic**: Photovoltaics (collaboration with the University of Tokyo);
- **Ross** and **Roach**: Neutron radiation damage in reactor graphite (Prof Nigel Marks, University of Curtin, Perth, W. Australia including 3-month research student exchange). Neutron scattering collaboration with Prof. Brent Heuser, University of Illinois;
- **Boag**: CVD precursor development (University of Nebraska);
- ORSAS students: Z. Mileeva (Russia) and S.Karthikeyan (India);
- **Ross** and **Bull**: FP6 projects: HySIC collaboration with GRINM (Beijing) and other leading Chinese laboratories. NESSHy and HyTRAIN (European collaborators) e.g. Prof

Noreus/David Moser (University of Stockholm);
- **Roach** and CALTEC, ISIS, Oak Ridge: Collaboration on the design and implementation of neutron scattering software.

Members of this submission have received many examples of external recognition of their esteem within the research community. The key examples during the REF assessment period are given below:

- *PhD External Examination appointments*: **Boag** - 1, **Nasr** - 16 (including University of Loughborough, University of Hong Kong), **Ross** - 3 (U of Birmingham 2009; U of Uppsala 2011; U of Nottingham 2009), **Shen** – 4 (U Liverpool 2008; U of York 2009; U of Manchester 2010; U of Sheffield 2013), **Tomic** – 2 (U of Manchester 2012; U of Leeds 2011);
- *MSc Examining etc*: **Boardman** (MPhys, Heriot Watt); **Nasr** (Engineering Accreditation Board (EAB) of Engineering Council for U of Newcastle, Bath; **Ross** (U of Lancaster – Safety Engineering and Decommissioning and Environmental Clean-up, 2010-present);
- *Keynote/Plenary Lectures*: **Boardman** (SPIE Edinburgh 2012; ICTON Warwick 2012;Int Workshop Novel ideas in Optics, Purdue, 2012; META'10 Cairo 2010); **Nasr** (Gas Flare Utilisation, U of Turkey; BAMA, UK; Innovation Ecosystem (UK), Gas Fire and Explosion Safety (UK);
- *Invited Lectures*: **Boardman** (SPIE Optics and Photonics San Diego 2010; Nanometa, Seefeld, Austria 2009; TaCoNa Bad Honef, Germany 2009; MetaMaterials, London, 2009; Special East-West Conference, Singapore and Taiwan 2009; PIERS Beijing, 2009; MetaMaterials, Pamplona 2008; SPIE Photonics Europe Strasbourg 2008); **Bull** – Faraday Discussion Hydrogen Storage Rutherford Laboratory 2012; **Ross** (U Uppsala 2011; CIMTEC Italy 2010; NANA Crete 2008; ICHMS Crimea 2009; ICCES Crete 2010); **Shen** (CHInano Suzhou China 2010; IUMRS-ICA Qingdao China 2010; Int Workshop Nanomaterials and Nanodevices, Beijing and Sichuan 2009); **Tomic** - 10 (including NANOSYD Denmark 2012; Semiconano Tukoshima Japan 2009; PNGP Spain 2008; CECAM EPFL Lausanne, Switzerland 2008; IOP TMCMSMN Manchester 2008); **Wang** (Int Conf Adv Mat Processing Montreal 2011); **Yates** (Invited seminar, Sheffield Hallam 2013)
- *Journal Editorships*: **Boardman** (Applied Physics B), **Nasr** (Journal in Medicinal and Disinfected Spray 2012-present; Atomisation and Sprays 2010-present)
- *Conference Organisation*: **Boardman** (Co-Chair SPIE Photonics (Metamaterials); Chair Photon10 (IoP); Committee OSA Cleo); **Nasr** (Atomisation and Sprays series 2010-present); **Ross** (Chair UNTF Salford 2009; Co-Chair ICHMS Crimea 2009; Chair MH2014 Salford Quays 2014); **Tomic** (Chair IoP TMCS Salford 2014; Chair CECAM Cork and Manchester 2010);
- *Visiting Fellowships:* **Boag** – University of Nebraska (continuing); **Tomic** - University of Manchester (continuing); **Wang** – University of Newcastle, Australia.
- *Prizes:* **Wang** - Catherine Richards Prize: Institute of Mathematics and its Application, 2013
- *Research project and journal refereeing:* Members of this UoA are frequently called upon to referee research proposals and journal submissions. We estimate that over the REF assessment period, more than four hundred of these requests have been undertaken. Of particular note is the appointment of Dr Shen to a role in reviewing research groups in the Institute of Physics, Chinese Academy of Science.