Institution: University of the West of Scotland

Unit of Assessment: 13

a. Overview

Research in this UoA covers a very broad range of interests in thin films and sensors. The submission includes 100% of the staff who have worked under the banners of the Thin Film Centre (TFC), comprising 6 full-time staff; 2 Professors (Placido, Ogwu), 1 Reader (Fu), 2 Lecturers (Morozov, Reid) and 1 Senior Research Scientist (Song), plus the Microscale Sensors Group (MSS) with a Professor (0.5 FTE) (Kirk) and a Lecturer (Hutson).

The group is based in the School of Engineering and contributes teaching to the Physics Subject Development Group (along with colleagues in the Nuclear Physics Group) and also supports some teaching in Engineering. The group has grown from three members in 2007 to eight members in 2013.

As part of University strategy to strengthen and support research excellence, from Feb 2013 all 8 staff are now grouped into the Institute of Advanced Technologies, with guaranteed university funding to promote and develop research.

The group currently has 12 PhD students, predominantly funded from external sources, and 2 PDRAs. 10 PhD students have graduated since 2008. Students from this grouping are much sought after and currently our post-graduates are employed in research (Technical University of Denmark and Sheffield University) and others are with the European Space Agency, Apple Inc, E2V Ltd , Qioptiq Ltd, Doosan-Babcock Ltd and Gas Sensing Solutions Ltd.

This grouping possesses first-class facilities for thin film deposition, characterisation and device testing. These include commercial-scale PVD and CVD systems that are unique in university laboratories. Access to microelectronic fabrication facilities is also available through the Scottish Microfabrication Centre (SMC).

Since 2008, external funding of £2.2M (HESA) has been obtained from a wide variety of sources including EPSRC, STFC, DTI, Scottish Enterprise, Scottish Government, Scottish Funding Council, Royal Society, Royal Society of Edinburgh and the Carnegie Trust and this is growing rapidly as new staff win grants.

UWS was a founder member of the Scottish Universities Physics Alliance (SUPA) research pool, launched in 2005 with funding from the Scottish Funding Council (SFC). SUPA is now in Phase 2 (2009-2017) and has received total SFC funding of £48 million. Morozov and Reid were appointed in early 2012 as SUPA funded lecturers and Placido is the current UWS representative on the executive committee of SUPA. Membership of SUPA has led to inter-university collaborations and joint publications with Glasgow, Strathclyde, Heriot-Watt, Edinburgh, Aberdeen and Dundee. Because of the diversity of application areas in which we work, this grouping has contributed to 6 of the 7 themes within SUPA.

International interest in our work is very high and visitors have come from universities in China, USA, Canada, France, Spain, Germany, The Netherlands, Israel, Turkey, Poland, Pakistan, Iran, Australia, Nigeria and Bangladesh, leading to joint publications and ongoing research collaborations with academics from all of those countries.

The group has published 210 papers in the period, with 107 papers from 2011 to 2013, reflecting the inputs from new staff. The group has also been responsible for 74 conference presentations, 5 books/book chapters and 6 patents.

A large proportion of staff time is spent on knowledge exchange activities with industry at home and abroad. Highlights are two major SEEKIT awards (£1 million in total) from the Scottish Government (SEEKIT in Thin Films and SEEKIT: Inspired) allowing the employment of 7 RAs/TBMs during this assessment period and assistance to over 120 SMEs in Scotland.

b. Research strategy

Research Position in 2008

In 2007, there were two staff in TFC and one in MSS. Those three were submitted in RAE2008 to UoA29 (Metallurgy and Materials), the only submission from Scotland, and they achieved the

results shown below.

		Percentage of research activity in the submission judged to meet the standard for:				
		4*	3*	2*	1*	U/C
Overall quality profile		0.0	50.0	40.0	10.0	0.0
Sub-profiles:	Research outputs	0.0	79.2	20.8	0.0	0.0
	Research environment	3.5	22.5	44.5	28.0	1.5
	Esteem indicators	1.7	13.0	75.0	10.0	0.3

Achievement of strategic aims/ Current Position compared to RAE2008.

Following submission to RAE2008, a report was commissioned by the university and Scottish Enterprise from PA Consultants Ltd to give an external view of the case for expansion of the TFC, with very favourable results. The key objectives set in 2008 were to increase staff numbers with excellent research records, to enhance the international standing through grants, collaborations and publications and to work closely with industry in knowledge exchange. However, it was recognised that extra academic staff were contingent on increases in external funding and undergraduate numbers in physics. Through a combination of an increased involvement in SUPA and a doubling of undergraduate physics students over the last three years, we were fortunate to be able to add 4 staff members to TFC (Fu in 2011, Morozov, Reid and Song in 2012) and one to MSS (Hutson in 2009).

Publications have increased by a factor of 10 since the last submission, with 210 papers from current staff since 2008. 107 of those papers are from 2011 to 2013, a measure of work from new staff only after they joined UWS. The group has also been responsible for 74 conference presentations, 5 books/book chapters and 6 patents from 2008 to present. Research funding of £2.2M (HESA) has been won for the group since 2008, counting only income administered through UWS.

Forward vision: overview

An exciting new involvement in gravitational research, based on improved understanding of the performance of thin film mirror coatings, is set to commence in Oct 2013 with funding from STFC (**Reid** and **Placido**). This work is in partnership with the prestigious Institute of Gravitational Research in Glasgow and other UK and international academic partners and looks forward to the start of Advanced LIGO (first science run in 2015).
Other new initiatives will provide further opportunities, such as the £10M CENSIS (Centre for Imaging Systems and Sensors) programme for future Technology translation, which starts mid 2013 with UWS participation led by **Placido** and **Kirk.** Collaborations with Chinese universities are expected to continue to grow rapidly, particularly since the appointments of **Fu** and **Song.**
In the longer term, plans for sustainability of SUPA beyond 2017 are being drawn up by the executive council (EC representative **Placido**) for continuation of joint research, plus the highly successful joint graduate School and KE activities.

Recent achievements and forward plans:

Within the period, plasma sources developed through funding by Thin Film Innovations Ltd (**Placido**) are now being successfully used to produce large area mirrors for use in Inertial

Confinement Fusion experiments in the USA. The first ever A4 size flexible display was developed through EPSRC funding to Plastic Logic Ltd, Dupont Teijin Films Ltd and **Placido** and **Song**. **Kirk** and **Hutson** have seen their work on adaptive optics using piezo-mirrors, funded by STFC, also taken up by researchers at Heriot-Watt University for shaping of laser beams used in high power cutting applications. **Reid** has recently successfully transferred aspects of precision measurement science into the field of cell biology, by applying nanoscale vibrations to manipulate cell behaviour and modify human mesenchymal stem cell differentiation. This work has recently won support from the STFC Futures program. **Morozov**, in collaboration with McMaster and Barcelona universities has recently published a paper in New Journal of Physics on a new, exactly solvable, model of photonic crystals. His work in this area will continue with a newly appointed SUPA Prize student. **Fu** produced the first thin film based SAW devices for lab-on-a-chip applications.

Examples of planned future activities with great potential for impact include novel coatings for marine energy components, arising directly from industry requests to solve corrosion and bio-fouling issues (**Fu, Song** and **Placido** in collaboration with the Scottish Association for Marine Science, Oban), advanced solar cells (**Song, Placido** in collaboration with the Institute of Microelectronics, Chinese Academy of Sciences, Beijing), and a variety of new sensors based on piezoelectrics (**Kirk, Hutson**, **Fu, Song, Ogwu**). The theoretical work of **Morozov** will inform the design and production of advanced, high performance optical filters and novel methods of production will be pursued by **Song** and **Placido**.

c. People, including:

i. Staffing strategy and staff development

Our staffing strategy is closely-aligned with our research strategy: to strengthen research and knowledge exchange, without compromising our student learning experience.
Undergraduate numbers in physics have more than doubled since 2008 with an increased entry tariff. Since RAE2008, targeted appointments at lecturer level have been possible through both SUPA (Reid and Morozov) and internal funding (Hutson). In addition Song has been appointed as Senior Research Scientist. Research staff are supported by two dedicated research technicians looking after the extensive range of equipment and a full-time PhD-level electron microscopist. In addition we have assistance with electronics from an MSc-level senior technician and have access to a well-equipped mechanical workshop.

Career Development Support

Research Assistants. Recognition of the important role of RAs has increased significantly since 2008. They are expected to take an active part in planning their career progression and setting objectives for the year ahead. Promotion criteria are made clear at appointment. RAs may undertake limited teaching duties (no more than 6 hours per week) with bespoke training provided to develop skills in this area. Two former RAs now have permanent academic positions within the group (Morozov and Song), however, our RAs are also highly attractive to industry and seven of the RAs employed since 2008 have left for careers in industry.

Early Career Researchers. New staff are assigned an experienced mentor and normally undergo a two-year probationary period with annual targets in research, teaching and administration agreed with their Line Manger. A cap on teaching duties is in place for those on personal fellowships but all new staff are assigned lighter teaching loads in the probationary period. All new staff are required to undertake the University's PGCert in Teaching, Learning and Higher Education unless they already have three years teaching experience.

Established Staff. The annual PDR process involves appraisal by the line manager or, for professors, the Head of School, with assessment against published performance criteria (research outputs, funding, RS supervision, admin) and individual objectives agreed the previous year. New SMART objectives are drawn up for the year ahead. Individuals are encouraged to plan their career progression and identify training and development needs. The university has clear and advertised criteria for promotion, informed by output from the review

process above and requiring external references for reader and professorial grades.

Concordat to Support the Career Development of Researchers
The principles of the Concordat are strongly embedded in School and university practice, through the Code of Practice for the Management of Research Staff. We have an open recruitment process around an advertised job description with standard elements for each grade level. Good practice on authorship and IP ownership is implemented.

Internationalisation. The university's policy is to recruit staff from the widest possible international pool, and three of this group are originally non-natives of the UK (although now all are UK citizens). Visiting scholars to this group since 2008 have come from China, USA, Canada, France, Spain, Germany, The Netherlands, Israel, Turkey, Poland, Pakistan, Iran, Australia, Nigeria and Bangladesh, funded by their universities, various scholarships and Royal Society of Edinburgh grants. Staff from the group have themselves been to these countries on reciprocal visits.

Equality and Diversity. The university is currently applying for Athena Swan status. Within the group there are two female staff including one at professorial level. The university policy is to accommodate individual staff circumstances by offering extended leave of absence and return to work on a reduced contract when requested.

Fellowships. Reid was awarded a Royal Society of Edinburgh/Scottish Government 5 year fellowship in 2008, which continued for two years after joining UWS, and has just won a Royal Society Industry Fellowship in 2013-2017 (£159k).

(ii) Research students

Students apply through the IRO website or to annual SUPA prize studentship calls.
Our students are typically funded through EPSRC iCASE studentships, foreign government scholarships, SUPA, STFC and internal studentships. Roughly half of past and current RSs have origins outside of the UK.
Our RSs are all registered with SUPA, which is of great benefit in terms of their education and socialising with students from the other 7 partner universities. Most importantly, SUPA has a pooled postgraduate course programme with a mix of technical courses and core skills, delivered via broadband video links to the 8 sites. There are over 60 courses across 7 research themes. All students are required to take 40 hours of technical courses and 20 hours of core skills during the first two years of their PhD, and to pass the assessment at the end of each course. These courses contain some level 10 undergraduate material to allow the students to fill any gaps in their knowledge. This is important as the multidisciplinary nature of our work attracts students from a variety of backgrounds. The director of the SUPA graduate school visits each university annually to meet with RSs as a group, without their supervisors, to discuss the student experience and to act on suggestions. Students also attend induction and networking events and specialist lectures from SUPA distinguished visitors and have the opportunity to meet students from other universities and to present their work by poster at the SUPA annual general meeting.
The university now also has a graduate school with extensive researcher development programme attended by our RSs, encouraging career planning and including initiatives such as an annual poster competition with monetary prizes. RSs also benefit from an internal seminar and colloquium programme organised within the physics subject development group. RSs are encouraged to give paid assistance in undergraduate laboratories, after bespoke training.
We operate standard good practice in allocating first and second supervisors to RSs with the first closely associated with the project and the second providing more general support. Additionally, each student is also allocated an assessor who monitors progression in each year. RSs are supported by our IRO office and the School for travel to attend conferences/schools and a more general budget is provided to each Institute for activities including support of RSs. Students write a report every year, compete for poster prizes and have a progression event organised by their assessor at the mid-point stage. Submitted theses are examined by a viva with an external examiner, and one or more internal examiners, all independent of the project.

d. Income, infrastructure and facilities

i) Provision of, and investment in, specialist infrastructure and facilities.
Significant investment from the Scottish Funding Council, Scottish Enterprise, local and international industry and UWS means that this group holds first-class highly specialist equipment and infrastructure, which now has a total value of over £5M. This includes unique commercial-scale magnetron sputtering and hollow-cathode CVD systems developed with Californian-based companies (DSI Inc and Sub-One Inc) and a novel plasma-assisted e-beam (developed with TFS Ltd) that are not available in any other university. We also have a range of laboratory-scale deposition systems, including 3 sputtering systems and 2 CVD/RIE systems. These are complemented by a very wide range of characterisation tools including FEGSEM/EDX, XRD, AFM, nano-indenter, EIC, Surface energy, UHV Kelvin probe, spectroscopic ellipsometer and multiple spectrophotometers. These facilities and infrastructure require continuous investment to maintain and keep up-to-date, however with the specialist technicians and staff expertise available within the unit, this has been managed by an average spend of £40,000 per year plus £12,000 on external service contracts.
Recent support from the university has enabled purchase of a Raman microscope, NIR/MIR/FIR Fourier Transform spectrometer and an Aquila NDK-9000 Transmittance/Reflectance spectrometer. These facilities are made available to pool members from SUPA and to other researchers within UWS.

ii) Future investment plans
In order to exploit opportunities in advanced thin film coatings, the group has plans to acquire additional coating facilities for IBS (ion-beam sputtering) and ALD (atomic layer deposition). These would extend our capabilities in state of the art optical filters for high laser damage threshold applications and are also in great demand for industrial collaborations in optical filters and ultra-barrier applications. These would be unique in the UK (IBS) and in Scotland (ALD) but require capital funding of close to £2 million. Funding is actively being sought from SFC and through CENSIS and industrial partners.
Replace of our FEGSEM is top of the Faculty priorities for research in the current academic year.

iii) Information on research funding portfolio, including future plans

Since RAE2008, the group has obtained funding of around £2.2 million from a wide variety of sources, including EPSRC, STFC, DTI, Scottish Enterprise, Scottish Government, Scottish Funding Council, Royal Society, Royal Society of Edinburgh, the Carnegie Trust and industry. Projects of note within the period and researchers involved include “High temperature ultrasonic measurements of plant and components for defect detection and monitoring” (EPSRC, **Kirk, Hutson** and **Placido**), “Ultrasonic arrays for ultrahigh resolution real time biomedical imaging” (EPSRC, **Kirk** and **Hutson**) “Low Cost Flexible Active Matrix Backplane for Flexible Substrates”, (EPSRC, **Placido** and **Song**), “Hollow Cathode DLC Coatings for Interiors of Pipelines”, (Sub-One Inc, **Placido** and **Ogwu**).

With three new appointments since 2012, it is anticipated that research income will continue to grow and our research will continue to have international impact. The excellent facilities available to the group allow initial exploratory research to be carried out very quickly, but external funding is absolutely necessary to stay at the forefront of materials research. We intend to grow the research student and RA members of the group through leverage of international contacts and industrial demand, in particular within the opportunities offered by Horizon 2020. The very recent award from STFC to **Reid** and **Placido** for contributions to gravitational research (£319K) and a Royal Society Industry Fellowship to **Reid** (£159K) are the first successful grants for the next REF period.

e. Collaboration or contribution to the discipline or research base
i) Research Collaborations

All staff have both UK and international collaborators, with 188 of the 210 papers published since

2008 involving international partners drawn from more than 14 countries.

Strong UK university collaborations exist with 6 of the other members of SUPA; Glasgow, Strathclyde, Heriot-Watt, Edinburgh, Aberdeen and Dundee, and also with Bristol, Cambridge, Northumbria and Bolton. **Kirk** and **Hutson** have pioneered work on fast adaptive optics using piezo-driven mirrors with UK Astronomy Technology Centre. International collaborations leading to more than three papers each arise from : **Placido**, wide-ranging international collaborations including China, Portugal, Turkey and Iran, **Fu**, very strong relationships with leading groups in China and Singapore, including Chinese Academy of Science, Lanzhou and Nanyang Technological University, Singapore, **Morozov,** collaborates with Groningen University, Netherlands and McMaster University, Canada. **Reid,** has been a member of the international gravitational waves community over the entire period, with involvement in LIGO and GEO. More recently, **Song** has begun collaborations with SouthWest Jiaotong University, Chengdu and Institute of Microelectronics, Beijing.

ii) Information on support for and examples of interdisciplinary research

Few areas of research offer more opportunities for interdisciplinary research than thin films and sensors, since application areas cover optical filters, anti-corrosion coatings, hard coatings, electrochromics, solar cells, bio- and haemo-compatible coatings, SAW and FBAR devices, catalytic surfaces, thin film batteries, MEMS devices, gas sensors, lab-on-chip devices and many more. Staff in the group have qualifications in physics, mathematics, chemistry, materials and mechanical engineering and they work with other colleagues in biology and electronic engineering to carry out interdisciplinary research. Examples of interdisciplinary research within the period include work on the biological response of human microvascular endothelial cells seeded on Si-DLC films (**Ogwu**), osteogenesis of mesenchymal Stem Cells by nanoscale mechanotransduction (**Reid**), the theory of miniature laser sources based on circular microresonators (**Morozov**), flexible displays (**Placido** and **Song**), surface enhanced Raman scattering sensors (**Song**), ultrasonic sensing (**Kirk** and **Hutson**), anti-corrosion coatings for oil and gas pipelines (**Placido** and **Ogwu**), surface acoustic wave sensors (**Fu**), nanowire lithography on silicon (**Fu**), shape memory devices (**Fu**).

iii) Information on how research collaborations with research users, including industry users, have informed research activities and strategy

Practically all of the materials research carried out in this group is driven by real applications and realisable commercial-scale outcomes. It follows that a major strategy of the group revolves round interaction with research users and industry users. Since RAE2008, through two SFC funded knowledge exchange programmes (SEEKIT Innovation in thin films and SEEKIT Inspired) we were able to meet with, develop contacts with and carry out preliminary work with over 120 companies. Industrial users now know that they will find receptive minds and excellent facilities to solve problems and to develop innovative ideas and products. Examples of our recent research that was driven by industry include Rolls Royce and Babcock's need for high temperature ultrasonic sensors, Plastic Logic's need for coatings on flexible substrates, the need for corrosion-resistant coatings for down-well drilling pipes, safe electrochromic coatings for eyewear, and improvements to gas sensors. Many other suggestions for research are currently being followed up, including anti-bacterial coatings, anti bio-fouling coatings, energy harvesting devices and explosives detection.

iv) Indicators of esteem

Fellowships of learned societies: **Placido** is FInstP and FInstN, **Ogwu** is FInstP and FIMMM, **Kirk** is FInstNDT.

Personal Fellowships: During the REF period, **Reid** has held a fellowship from RSE and now has a Royal Society Industry fellowship.

Leadership roles in research councils/learned societies/professional bodies:

Staff have served on IoP committees (**Placido**, **Reid**, **Ogwu**), **Placido** was a founder member and sat on the advisory board of the Institute of Nanotechnology.

Invited talks: Since 2008 staff have given invited talks in many international conferences and institutions in Beijing Xi'an, Chengdu, Singapore, Perth Australia, Hangzhou Groningen, Barcelona, . Totals are approximately **Placido** (5), **Fu** (20), **Reid** (12), **Morozov** (10), **Ogwu** (3)

Visiting Professorships/Academic roles: **Ogwu** spent two years from 2008 to 2010 as rector of Kagali Institute of Technology, Rwanda. **Placido** is visiting professor at Beijing Institute of petrochemical Technology

v) Public Engagement

Staff have been active in public engagement with science, helping with IoP demonstrations during the Edinburgh International Science Festival, and **Reid** has given invited talks at the British Science Festival (2013) and to various Astronomical societies (2009, 2010, 2011).