Institution: Glyndŵr University [GU]

Unit of Assessment 13: Electrical and Electronic Engineering, Metallurgy and Materials

a. OVERVIEW:

The information presented below covers the area of Advanced Materials and describes progress since the 2008RAE submission. It includes staff from the Departments of 'Chemistry' and 'Engineering and Applied Physics'. It encompasses three broad themes: **Functional Polymers;** *(Al-Assaf, Fang, Phillips, Ratcliffe, Williams, Yang*);* **Functional Thin Films;** *(Barrioz, Day*, Hu, Irvine, Lebby, Musk, Osanlou, Wright, Yang*);***Composite Materials and Ultra Precision Surfaces;** *(Day*, McMillan, Walker, Yu) (*collaborate across themes)*

b. RESEARCH STRATEGY:

Vision

Glyndŵr University seeks to develop a dynamic, sustainable and internationally-leading research base in the area of Advanced Materials through collaboration with Industry for the benefit of the region and the UK as a whole.

Achievement of strategic aims over the assessment period and future strategic plans:

Advanced Materials research was initiated in the 1980's with research on Functional Polymers. This area has established a world class reputation through a combination of fundamental research, enabling the underpinning of research capability, together with applied research in collaboration with industry. Other research areas have since been developed along the same lines. Thin film research using 'chemical vapour deposition' (CVD) started in the 1990s and has recently been strengthened by the development of photovoltaic research which has received significant EPSRC funding and involves many industrial partners. The application of thin films for colour holography started in 2004 and involves a number of industrial partners. More recently research in advanced composites and ultra-precision surfaces has been established as a result of collaboration with Airbus and the European Southern Observatory (ESO) respectively. In all cases the research is underpinned with excellent facilities and high levels of funding with a close engagement with key manufacturing industry.

Functional polymers: The Team is one of very few concerned with the characterisation, modification and functional properties of natural and synthetic ***water soluble polymers*** and the research has a clear industrial focus. They led a BBSRC project (BB/I005315/1; £477K) in collaboration with Bangor and Aberystwyth concerned with developing a range of high-value fructan derivatives using green chemical routes for application as biosurfactants (Biomacromolecules 14 2830 (2013)) and have been partners in a TSB project in conjunction with Durham, UCL and MI-Swaco (TP/8/OIL/6/I/Q2506L; £1.6M), concerned with gaining a fundamental understanding of the role of polymeric inhibitors for drilling muds and developing alternative biodegradable polymers (Patent GB1119367.9 (2011)). A further TSB project (TP14/SMP/6/I/BA143E; £1.79M) in collaboration with Bangor, Reading and industrial partners, including Marks&Spencer and Innovia Films, involved developing a protocol for the extraction and modification of chitin from prawn shells (Food Hydrocolloids 31 166(2013)) to produce derivatives with enhanced antimicrobial activity for application in 'active' packaging and in seed coatings. Chitosan research will continue through a new TSB project (Project no. 101440; £929K) led by Unilever. Collaboration with San Ei Gen FFI Inc (Japan) (£2.3M; 2003-2014) has been extended with the overall objective of developing new materials based on the manipulation of structure-function properties of hydrocolloids. Additionally, collaboration with Reckitt Benckiser has led to a new denture fixative formulation (Patent WO 2009016362 (A2)) which is being considered for commercialisation. Collaboration with US Department of Agriculture, USA has involved the development of a novel emulsifier based on corn fibre gum (US Patent SN:13/768,036) for potential application as an emulsifier for flavour oil emulsions. A formal research link was developed with Hubei University of Technology, China in 2010 involving staff and student exchanges focussing the structure and bioactivity of polysaccharide materials and their health benefits (Carbohydr. Polym. 86 844 (2011)). Future plans will be to establish processes using green chemistry for the extraction and physical and chemical modification of biopolymers from biomass and waste streams. This will be achieved through involvement in BBSRC initiatives including the BBSRC Networks in Industrial Biotechnology & Bioenergy, TSB and direct Industrial funding.

Functional thin films: Research activity includes, ***carbon nanotubes***, ***colour holography*** and more recently ***photovoltaics***. ***Carbon nanotube*** research has focussed on synthesis, manipulation and utilisation of one-dimensional materials such as nanowires and nanofibers. It has included the development of a lithography-free technique for the direct patterning of vertically aligned arrays of free-standing metal nanowires and the demonstration of a field emission display device. Collaboration with Keele, has led to the application of carbon nanotubes for development of nanotextured substrates for the growth of highly aligned muscle cells [Mat. Sci. Eng. C 33 (2013) 4274] and a multi-shot printing process has been developed for the creation of mechanically robust electrically conductive tracks on elastomer substrates (Patent GB1309317.4). Work has been undertaken to create a microtextured light trapping substrate for polymer solar cells building on technology originally developed at RAL, using organic photovoltaic materials [STFC,ST/K002198/1;£58K]. Research on carbon nanotubes and nanowires will continue to focus on their development through collaborations with companies working in the displays and electronics sector. The processing of carbon nanotube-based composites using microwave heating is also being explored using unique equipment previously developed (EPSRC:GR/M65069/01).The effect of resin formulation on the kinetics and properties is being investigated building on previous work (EP/E059317/1). Research in ***colour holography*** has involved the design and development of a "Full Colour Holographic Copier" in collaboration with View Holographics Ltd. The technology involves forming thin films using silver halide nanoparticle emulsions produced using a process previously developed (COOP-CT-2004-5901). Work has been undertaken to optimise the nanoparticles in terms of their recording exposure sensitivity and to develop an economical large scale manufacturing process. The nanoparticles are also being used to optimise a process for 'True colour optical biopsy'. The ***Photovoltaic*** (PV) team led the UK PV SUPERGEN Consortium of nine universities (£6.2m) which has overseen the establishment of a world class capability in thin film PV across the UK with a number of notable world firsts that include the in-line CVD process and demonstration of quantum dot down conversion. The team also led a collaborative project with Swansea and Bangor (Welsh European Funding Office (WEFO); £4.3M) working on PV solar energy. This has built interdisciplinary links across organic and inorganic PV and includes the link to power electronics to establish a more interdisciplinary approach to achieving higher energy yield from PV systems. Further research projects include partnerships with Swansea SPECIFIC IKC (EP/1019278/1;£439K), Liverpool involving sinter-free inkjet printing of metal interconnects for thin film PV (EP/K009478/1; £237K) and high-power, low-weight, flexible thin film photovoltaics for space application (EP/K019597/1;£332K). PV research will build on the success as the only applied research facility in the UK to be dedicated to solar PV research. It is intended to study atmospheric pressure MOCVD of thin film materials for PV solar energy. This will be achieved through industrial partnerships with, for example, Scanwel Ltd, Tata Steel, NSG, Qioptiq Space Technology and Surrey Satellites together with RCUK, EU and TSB funding. The impact of this research so far has been to initiate research collaboration with the world's largest thin film PV manufacturer, First Solar who are interested in our unique doping technology for CdTe solar cells. Research in PV is complemented by research on the large scale integration of renewable energy by the team in Electrical Engineering working in collaboration with Guangdong Telecom Engineering Co, Ltd, and Shenzhen Academy of Science, China and Aalborg University, Denmark involving power quality and system efficiency. This is of major significance since many renewable energy-based power generation units, including PV, are connected into power systems and operate under an electricity market environment constituting an important part of the future smart grid.

Composite materials and ultra precision surfaces: GU acquired the National Facility for Ultra Precision Surfaces in 2009 and established advanced composites in 2010 in collaboration with Airbus. ***Advanced composite*** *research* is concerned with the formulation and characterisation of resins through to rapid composite manufacture. Microwave heating has been used to produce simple shapes and the process has been modelled in collaboration with colleagues at Bauman Moscow State Technical University. This extends the previous state of the art where only manufacture of flat specimens has been reported. Other work has been based around developing materials selection methodologies which have been evaluated by application to real industrial applications where weight and performance are critical. A relatively new area is the application of composites in lightweight mirror systems thus linking into the

expertise in ultra-precision surfaces. Future research is to develop an understanding of the microwave processing of composites and to develop realistic processes to make this possible industrially. This will involve resin formulation, modelling and development of microwave techniques and will be extended to radio frequency and rapid processing techniques. The ***National Facility for Ultra Precision Surfaces*** has the largest optical R&D and manufacturing facility in the UK. It is producing 1.4m hexagonal mirror segments under contract to the ESO, as prototypes for the planned 39m European-Extremely Large Telescope, E-ELT [http://www.eso.org/public/]. It has developed the *only* metrology capability in Europe satisfying the exceptionally-challenging nanometre-level requirements to measure mirror segments and the *only* capability world-wide to polish edges of optics such as segments directly without edge-roll. A significant output of the research is a comprehensive understanding of the issues of scale-up to the 931 segments. TSB funding has been awarded to develop further automation of processes in collaboration with Zeeko Ltd (Ref: 101550; £198K). Other key developments include increasing the dynamic range of Computer Numerically Controlled (CNC) polishing machines and the development of comprehensive on-machine metrology, revolutionising traditional processes with significant cost/time/risk reduction. A significant knowledge-base has been built up through this and other projects including the EU FP7 Far Infrared Space Interferometer Critical Assessment project (Ref: 312818; £41K), involving development of large deployable composite mirrors in collaboration with UCL. This has enabled identification of a series of platform capabilities to address emergent market opportunities for challenging optics in the fields of optical grinding, smoothing, polishing and associated metrology. Future areas include opto-mechanical design; software and controls; numerical modelling; ultra-precision surface-processing; metrology and data analysis; industrial robotics; and optical instrumentation systems. The University is developing a strong opto-mechanical design consultancy business based on its extensive experience gained through E-ELT and other projects.

c. PEOPLE:

Staffing strategy and staff development

GU recognises the significance of Materials Research to Industry in the region and this is reflected in the fact that the staffing base has increased from 6.8FTE in 2008RAE to 13.9FTE is this submission. Each Group is led by an experienced researcher with a track record of winning and managing major research projects and supervising staff and students. Professors ***Williams*** and ***Al-Assaf*** continue their leadership role in the area of Functional Polymers. Dr ***Wright*** continues to lead on carbon nanotubes and Dr ***Osanlou***, has taken over from Bjelkhagen to lead on colour holography. Professor ***Irvine***, joined from Bangor University in 2008 to head a group working on photovoltaics. This area is further enhanced by the recent appointments of Professor ***Lebby***, OneChip Photonics Inc., Canada, with expertise in optical communications, optoelectronics, concentrated PV and photonics and ***Musk,*** Entroptix Ltd, with expertise in semiconductor device packaging and photonics. They are working with IQE, UK to design, refine and characterise multiplexed laser transmitters for very high capacity optical communications (400 Gbit/s), which will be key components of the next generation of the internet. Professor ***Day***, from the University of Manchester, joined in 2010 to lead a collaboration with Airbus in the area of Advanced Composites and was joined in 2012 by Professor ***McMillan*** from Rolls-Royce where she was responsible for the development and implementation of the composites methods strategy including all aspects of material development, composite component design, stress and impact analysis, manufacture process modelling, NDE, in-service requirements and end-of-life. Professor ***Walker***, with expertise in the polishing of ultra precision surfaces joined in 2009 to work in the National Facility for Ultraprecision Surfaces involved in the E-ELT project. Other research staff appointments over the period are: Dr ***Yu*** [Ultraprecision surfaces], Dr ***Barrioz*** and Dr ***Yang***, [Functional thin films], Dr ***Fang*** and Dr ***Ratcliffe*** [Functional Polymers]. Dr Ratcliffe is included as an Early Career Researcher**.** Dr ***Hu*** has a background in Electrical Engineering with a particular emphasis on renewable energy and there is synergy between her team and the 'Photovoltaics' group. Professor ***Phillips*** has directed research activities in the area of functional polymers in collaboration with San Ei Gen F.F.F. Inc, Japan since 2003 and is included as a Category C

member of staff.

GU's recruitment policy requires newly appointed staff to possess a doctoral degree and be able to demonstrate appropriate research expertise. Their track record is taken into consideration when making new staff appointments. This is exemplified by the appointment of Day as Head of Department of Engineering and Applied Physics because of his research in the area of composite materials and GU's wish to further develop its collaboration in this field with Airbus. There have been over 30 international visiting researchers at GU in the field of materials over the period. They have been involved in various research projects and have contributed to the research base through their additional skills and knowledge and interaction with young staff. In many cases the research has led to joint publications and examples include; **Fissore** (University of Buenos Aires, Argentina); Food Hydrocolloids 31 172 (2013); **Li** (Shanghai Jiao Tong University, China) Food Hydrocolloids, 25, 293 (2011); **Luan** (Shanghai Jiao Tong University, China) Polymer, 52, 5648 (2011)**; Karazhiyan** (Ferdowsi University of Mashhad, Iran) Food Hydrocolloids, 23, 2062 (2009); **Nwokocha** (Ibadan University, Nigeria); Carbohydr. Polym. 90 833 (2012); **Zhang** (Southeast University School of Medicine, Nanjing, China) Carbohydr. Polym. 84, 894 (2011).

'Materials' researchers are members of the University Materials, Engineering and Manufacturing Research Centre which provides leadership and academic support and promotes research excellence. It is a vehicle for the enhancement of research capacity, capability and environment. It oversees the research seminar programme which includes lectures from academic staff, PGR students and notable speakers from other Universities. The Graduate School has the responsibility for supporting and developing staff and research supervisors and provides a programme of generic skills training and personal development events. Early Career Researchers are encouraged to participate as Second Supervisors for research students under the mentorship of experienced colleagues. Since 2009, GU has been a member of the Consortium for Research Excellence, Support and Training (CREST), which encourages cross- and interdisciplinary discourses, researcher mobility and research training for staff and PGRs. GU has a dedicated fund to support young researchers to attend and present their research results at national and international conferences. Such participation enables them to become aware of the latest developments and to engage with their peers. The Human Resources Department ensures that GU policies and processes are consistent with the principles of the Concordat to support the career development of researchers. GU's Equal Opportunities Policy sets out the commitments regarding staff recruitment, training, career development and promotion, the admission and progression of students, and their implementation, including staff training, and monitoring.

Research students

Research staff have been successful in recruiting high quality PGR students by advertising internally or nationally, depending on the funding source. There are currently 20 PhD and 4 MPhil students funded through a variety of sources including RCUK, Industry and EU. The Graduate School provides support for PGR students in terms of induction and training to ensure that they have the appropriate generic skills. It also monitors their progress to facilitate successful and timely completion of their studies. There have been 7 PhD and 2 MPhil completions over the period. The quality of the graduates and their training is evidenced by the fact that their work is published in international peer reviewed journals, for example, **Gulrez**; Carbohydr. Polym. 90 1235 (2012) **Juna**; Carbohydr. Polym. 83 1384 (2011); **Hodgson**; Nano Energy 2 21 (2013)**; Kokubun**; Biomacromolecules 14 2830 (2013); **Li;** J. Agric. & Fd Chem. 61 1388 (2013); **Padala**; J. Agric. & Fd Chem.57 4964 (2009); **Vinayahan**; Biomacromolecules 11 3367 (2010). Furthermore PG students are able to find significant positions in Industry or Academia: **Andres-Brull;** Leatherhead Food Research, UK; **Gulrez;** King Saud University, Saudi Arabia; **Kiong**; Petronas, Malaysia, **Li;** University Sci. and Tech. of China; **Vinayahan**; Teva UK Ltd, UK; **Hodgson;** Glyndŵr University.

Staff and student profiles on 31/10/13.

Functional Polymers**:** *Leads;* Williams and Al-Assaf; *Academic staff*; Fang, Ratcliffe, Yang; *Visiting Professors;* Nishinari, Phillips; *Research Assistants;* Burr, Mohamed, Maza, Nazarzadeh, Richardson, Viebke; Edwards *Research Officer;* Senan; *PGR;* Evans, Davies, Hu, Kokubun, Han, Yi, Hamoda, Eldigair, Davies, Surabhi, Vadodaria; *Visiting researchers;* Gunning, Patil, Tretzel, Greene. ***Functional Thin Films*****:** *Leads;* Irvine, Osanlou, Wright;

Academic staff; Barrioz, Day, Hu, Lebby, Musk, Yang; *Research Fellows;* Lamb, *Research Associates*; Clayton, Kartopu, *Research Assistants;* Rugen-Hankey, Brooks, Rowlands-Jones, Black, Hodgson *Research Technicians;* Jones, Siderfin; *PGR;* Jones, Hodgson, Monir and Belloc ***Composite Materials and Ultrprecision Surfaces*****:** *Leads;* Day and Walker; *Academic staff;* McMillan,Yu; *Research technician;* Winnington, *PGR;* Wang, Barufke, Chen, Podkopaeva, Jones, Brifcani, Bobkova, Luhyna, Ashworth, Rumyantsev, Roberts.

d. INCOME, INFRASTRUCTURE AND FACILITIES:

Provision and operation of specialist infrastructure and facilities:

Functional Polymers is based in Wrexham where there are five chemistry labs equipped with an extensive range of specialist instrumentation to investigate the structural characteristics and physicochemical properties of water soluble polymers including: GPC/MALLS, MALDI-TOF, Dynamic Light Scattering, Laser Diffraction, Laser Doppler Velocimetry, Isothermal Titration Calorimetry, DSC, ESR, Rheometry, Dynamic Surface Tensiometry, AFM, Flow particle Image Analysis, HPLC, GC, Fluorimetry, FTIR and UV Spectroscopy. ***Composite Materials*** is based at the Advanced Composites Training & Development Centre, Broughton, developed in response to industrial need and funded by the Welsh Assembly Government, Airbus and GU. It has a lab for the formulation of resins, the manufacture of composites and their characterisation and there are specialist facilities for processing of carbon nanotube composites. Facilities include, mechanical testing, microwave digestion, DSC, DMTA, TMA, plus specialist low and high power microwave and radio frequency heating systems for rapid processing. There is a microwave calorimeter developed by the team which is unique and can be used for measurement of dielectric properties as a function of temperature and time as well as simultaneously following chemical kinetics (Measurement Sci.&Tech.15 2313 2004). There is also a unique drum winding manufacturing facility and a large combination microwave oven ($3m^3$). ***Ultraprecision surfaces*** is based in the National Facility for Ultra Precision Surfaces at Optic Glyndŵr, St Asaph which houses three polishing machines and a CNC grinder which provide surface-processing capability and a robot processing lab is under development. These are supported by extensive metrology equipment, including a 10m high optical test tower above the 1.6m machine. The metrology and handling infrastructure is complex, and draws heavily on the opto-mechanical design office on site with eight technical staff. The facility underpins research in novel materials, processes, metrology and their interactions, taking steps towards the ultimate and ambitious objective of the fully-integrated and automated Manufacturing Cell. ***Photovoltaics***, at Optic Glyndŵr, includes a 100 m^2 clean room lab with a range of thin film deposition equipment (3 batch reactors and 2 in-line reactors), thermal evaporators, PixDro inkjet printer, plasma cleaner, wet chemical substrate cleaning, class AAA solar simulator with I-V measurement, PV device quantum efficiency measurement, screen printing and mechanical scribing for monolithic PV module fabrication. There is a dedicated materials characterisation lab with a Dektak profilometer, UV and NIR spectrometers, an environmental chamber for lifetime testing, spreading resistance and Hall probe measurement, SEM with X-ray analysis and device encapsulation facilities. ***Holography***, at Optic Glyndŵr, has three materials development and processing labs with a comprehensive suite of processing equipment. There are five fine-optic labs equipped with state-of-the-art lasers. ***Carbon nanotubes*** has a dedicated facility in Wrexham for the growth of thermal and plasma-assisted carbon nanotubes enabling a wide range of types (single walled, multi-walled) to be produced. It is complemented by a facility for the production of metal nanowires by electrotemplating. These facilities have enabled staff to attract major sponsorship supporting high quality research.

Evidence of investments:

The OpTIC Technium was established in St Asaph in 2004 by the then Welsh Development Agency to grow the opto-electronics cluster in North Wales. GU took over the building and its activities in 2009 and purchased it outright in 2012. This investment exemplifies GU's strategy to expand its applied research activities relevant to local business. Now known as 'Optic Glyndŵr' it has established itself as a world class centre for applied research in optics and opto-electronics and houses the National Facility for Ultra Precision Surfaces, established under £4.2m RCUK Basic Technology funding. The award of a €5m contract to manufacture prototype 1.4m mirror segments for the 39m E-ELT project attests to its esteem. Other

investment includes establishment of the Advanced Composites facility in Broughton in collaboration with Airbus as a consequence of a £28M Welsh Government grant to support training and development of composite materials for aircraft wings. GU has provided additional funds to equip the labs and purchase equipment. The vision is to develop rapid manufacturing of carbon fibre composites and involves formulation and chemistry of resins and the development of characterisation, microwave and radio frequency techniques.

Research funding portfolio and future plans:

The world class reputation of the research teams has been developed through a combination of fundamental and applied research, funded through RCUK, TSB, Welsh Government, EU and Industry. Total research income was £6M and this is attributed as follows: ***Functional Polymers***, £2.54M, ***Functional Thin Films***, £2.88M and ***Composite Materials and Ultra-precision Surfaces,*** £579K. The importance of Advanced Materials research to Industry and the UK economy coupled to the expertise of staff and their close links with researchers in Academia and Industry puts them in an ideal position to continue to bid successfully for major project funding.

Consultancies and professional services; Staff have strong connections with Industry and examples include: ***Al-Assaf;*** Consultant, Valmar LLC, USA; Proctor & Gamble UK; ***Hu;*** Consultant, Hohner Automation, UK; ***Irvine;*** Director, ORS Ltd; ***Lebby;*** CEO, President, OneChip Photonics Inc, Canada; ***Musk;*** Director, Entroptix Ltd; ***Phillips;*** Chairman**,** Phillips Hydrocolloids Research Ltd; ***Walker:*** Director, Zeeko Ltd & Optical Investments Ltd, ***Williams;*** Consultant, Teva UK Ltd, ***Wright;*** Consultant, Ellison Sensors Ltd

e. COLLABORATION AND CONTRIBUTION TO THE DISCIPLINE OR RESEARCH BASE:

Exemplars of research collaborations:

Al-Assaf collaborates with the Institute of Radiation, Lodz University, Poland on a Coordinated Programme funded by the International Atomic Energy Authority to establish methodologies for polymer characterisation [http://www-naweb.iaea.org] ***Irvine*** led a major EPSRC project PV SUPERGEN (GR EP/F029624/1 £6.2M) involving collaboration with nine UK Universities concerned with establishing a world class capability in thin film solar photovoltaics. ***Fang*** leads a research programme in collaboration with Hubei University of Technology, China which involves the exploration, characterization and utilization of Chinese materials-based hydrocolloids and is supported by the National Natural Science Foundation of China (Project Nos 31322043, 31171751, 31101260)

Exemplars of interdisciplinary research:

Williams/Ratcliffe led a major interdisciplinary BBSRC project [BB/I005315/1] with Bangor and Aberystwyth involving researchers with expertise in chemistry, materials and plant biology. The results have been presented at regular BBSRC Dissemination events organised with a view to creating a network of researchers from a broad range of disciplines from plant genetics through to engineering but with the common interest of using biomass to produce biofuels and chemicals. ***Barrioz/Irvine*** collaborated with Yang [Aeronautical Engineering, Glyndŵr] on fluid flow modelling of gas delivery in thin film deposition which led to the filing of a UK patent application [GB1302306.4.] ***Osanlou*** collaborates with Gooch & Housego, Moor Instruments, Vivid Components and Peninsula Medical School, Exeter in a project to produce full colour holograms of human cell samples which are essentially indistinguishable from the object human cells and can be routinely recorded, for example, at the tip of a holo-endoscopic probe inside the body [US 7653269B1]. ***Walker*** led the establishment of the National Facility for Ultra Precision Surfaces through EPSRC Basic Technology funding, with Cranfield and Zeeko Ltd, to develop and exploit optical fabrication technologies. The technology has been applied to polishing knee and hip joints with Huddersfield, and has been exploited through a leading prosthetic joint manufacturer. ***Yang*** collaborated with the Russian Academy of Sciences on supercritical fluid diffusion embedding of functional quantum dots into polymer substrates, funded by the Russian Foundation for Basic Research (Grants 11-02-12041, 08-02-00823), Russian President Grant (MK-.2010.3) and Royal Society International Joint Project Grant.

Influence of research collaborations with research users on informing research activities and strategy:

Advanced Composites**:** was set up jointly by Airbus, GU and the Welsh Government. The Team is involved in the Advanced Sustainable Manufacturing Technologies (ASTUTE; Ref: 80380) programme, led by Swansea, which supports SMEs in the convergence area of Wales

to improve their businesses. The research is thus directly informed by the needs of industry focussing upon the rapid manufacture of composite materials in particular. ***Ultra Precision Surfaces*****:** work closely with Zeeko Ltd and the commercial optical fabrication business, creating new economic activity in North Wales. Outputs of joint R&D projects have strengthened the commercial offering in manufacturing optics and in Zeeko selling manufacturing equipment. The largest contract (€5M) is the manufacture of 1.4m hexagonal prototype mirror segments for the E-ELT. Steps are being taken to establish an industrial consortium to tender for a share of the serial manufacture of 931 segments for the telescope, with a capital value of perhaps €100m. ***Photovoltaics:*** NSG Pilkington, industrial partners on the PV SUPERGEN project, have assisted in the establishment of a high efficiency PV cell capability at GU. This has led to assisting NSG to develop a new transparent conducting oxide (TCO) product suitable for thin film CdTe solar cells. This collaboration is continuing as partners in the SPARC and SPECIFIC projects. Collaboration with Sharp has led to establishment of full spectral measurement capability of high efficiency triple junction solar cells and the development of a revolutionary optical method for rapid screening on silicon solar cells for defects in module manufacture.

Exemplars in Leadership roles in Academia:

Research Councils, Learned Societies, Professional Bodies: Al-Assaf; Consultant; International Atomic Energy Agency, ***Barrioz;*** Member, Engng and Sci. Group, North Wales ***Irvine;*** EPSRC Panel Member, UK-India programme; Chair, Energy Materials Group ***Williams*****;** Member, EPSRC Peer Review College, Member, SCI, Colloid & Surface Chemistry Group Committee, ***McMillan;*** Vice President-Business, Inst. of Physics Council, Royal Society Industry Fellowship, at University of Bristol (2007/11) ***Osanlou;*** Member, Inst. of Engng & Tech. North Wales Committee, ***Ratcliffe*****;** Member, Royal Soc. of Chem., North Wales Section Committee, ***Walker;*** Member, Parliamentary and Scientific Committee (Westminster), Founder, National Facility for Ultra-Precision Surfaces

Conference programme organisers and chairs: Day**;** Chair, Advanced Composite Materials for Aerospace Applications, 2011 & 2012 ***Irvine;*** Organiser, EUROMAT 2013 Sevilla, Int. Conf. MOVPE; Metz, France, 2008, Lake Tahoe, USA, 2010, Busan, South Korea, 2012; European Workshop, MOVPE; UIm, Germany 2009; Wroclaw, Poland, 2011; Aachen, Germany 2013; ***Williams;*** Organiser & Programme Chair, 43rd IUPAC World Polymer Congress, Glasgow, 2010, American Chemical Society, San Francisco, 2010. Organising Committee, Gums & Stabilisers for the Food Industry 2009, 2011, 2013

Selected invited keynote lectures: Al-Assaf*;* International Hydrocolloids Conference, Shanghai, 2010 ***Barrioz*****;** MRS, San Francisco, 2009; Euro CVD Conference Cork 2011 ***Fang;*** International Hydrocolloids Conference, Shanghai, 2010 ***Hu;*** Dalian Nationalities University, China, 2009, 2011; Southwest Nationalities University, China 2010. ***Irvine;*** International TCM conferences 2010 and 2012, Distinguished Lecture Symposium Advances in Solar Energy 2012, ***McMillan;*** Leichtbausymposium, Dresden, 2009, ICMAC, Belfast, 2009, JEC, Boston, 2012; ***Osanlou****;* SPIE Conference, San Francisco, USA 2011, 2013, 2014, ***Walker;*** Optonet conference, Jena, Germany 2012, Photonex, Coventry 2013, ***Williams;*** Belfort Lecture, International Hydrocolloids Conference, Purdue University, USA 2012; International Conference on Halal Gums, Malaysia 2012, ***Yang;*** Dalian Nationalities University, China, 2010, Beifang Nationalities University, China, 2012. ***Yu*** 6th International Symposium, Advanced Optical Manufacturing and Testing Technology, Xiamen, China 2012.

Journal Editorships: Irvine*;* Editor, Energy Materials Journal (IOM3) ***Williams;*** Editor-in-Chief, Food Hydrocolloids (Elsevier)***,***

Editorial Board Membership, Al-Assaf; Int. J. of Fd Sci.&Tech, Int. J. Biol. Macromolecules ***Fang;*** Food Hydrocolloids ***Williams****;* Carbohydr. Polym.

Awards: Williams, Food Hydrocolloids Trust Medal, 2013 (www.gumsandstabilisers.org).