Graphene hybrid materials for energy applications

Semiconductor photocatalysts that generate electrons and holes upon light irradiation are essential building parts of future energy devices. Photoinduced electrons can initiate either reduction of species on loaded co-catalysts or an electric current if the photocatalyst is assembled in a photoelectrode connected to an external circuit. However, the presence of photoinduced electrons is compromised by the recombination with holes in the photocatalyst bulk or surface. Suppressing the electron-hole recombination, it is therefore crucial to exploit the electronic properties of photocatalysts.

In this project, the aim is to prepare graphene-photocatalyst hybrid materials and capitalise on their synergy for future energy devices. Photocatalysts can generate electrons and graphene, a mat of sp2 carbon, can store, collect and rapidly transport the electrons to reduction active sites (Fig.1). To achieve this aim, you will have to develop methods to prepare novel particulate composites of graphene and photocatalysts active with solar light (Scheme 1). Test and characterisation of the materials will be an important part of the project, to relate their properties to their activity, allowing fundamental understanding and consequent optimisation.

Figure 1. Sketch of graphene-photocatalyst hybrid and the electron transport to reduction sites.

Scheme 1. Different steps and methods to be explored in the synthesis of photocatalyst-graphene hybrids.

Time of the research placement: >4 months

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Further Particulars about Imperial College London

The College

Imperial College London consistently achieves one of the highest rankings nationally and internationally, as listed in the Times Higher QS World University Rankings 2011-2012.

The Rector and President, Sir Keith O’Nions FRS, is the College’s academic head and chief executive officer. The Chairman of the Court and Council is Baroness Eliza Manningham-Buller.

The Mission

Imperial College embodies and delivers world class scholarship, education and research in science, engineering and medicine, with particular regard to their application in industry, commerce and healthcare. We foster interdisciplinary working within the College, and collaborate widely externally.

Strategic Intent

The College’s vision and intent is to:

Continue to be a world-leading institution for scientific research and education,

To harness the quality, breadth and depth of our research capabilities to address the difficult challenges of today and the future,

To develop the next generation of researchers, scientists and academics,

To provide an education for students from around the world that equips them with the knowledge and skills they require to pursue their ambitions,

To make a demonstrable economic and social impact through the translation of our work into practice worldwide,

To engage with the world and communicate the importance and benefits of science to society.

Formation and History

Imperial College was established in 1907 in London’s scientific and cultural heartland in South Kensington, as a merger of the Royal College of Science, the City and Guilds College and the Royal School of Mines. St Mary’s Hospital Medical School and the National Heart and Lung Institute merged with the College in 1988 and 1995 respectively.

Charing Cross and Westminster Medical School and the Royal Postgraduate Medical School merged with the College on 1 August 1997 to form, with the existing departments on the St Mary’s and Royal Brompton campuses, the Faculty of Medicine.

The Kennedy Institute of Rheumatology joined the Faculty of Medicine in 2000 and for over a decade was unique in Europe for its integration of basic science research and clinical facilities in rheumatology. On 1 August 2011, the
Institute moved to Oxford University to build a new centre for research into rheumatology and inflammatory and autoimmune disease.

In 2007, the Imperial College Healthcare NHS Trust, was formed by merging Hammersmith and St Mary’s Hospitals’ NHS Trusts with the College, forming the country’s largest NHS Trust. This also established the UK’s first Academic Health Science Centre (AHSC) bringing together healthcare services, teaching and research for maximum synergistic benefits.

Imperial College was an independent constituent part of the University of London until July 2007, when it was granted a new royal charter declaring it an independent university in its own right.

The academic structure of Imperial College is divided into three faculties, the Faculties of Engineering, Natural Sciences and Medicine. The College’s other major academic unit is the Business School.

**Staff and Students**

The academic and research staff of 3,397 includes 73 Fellows of the Royal Society, 77 Fellows of the Royal Academy of Engineering, 81 Fellows of the Academy of Medical Sciences, one Fellow of the British Academy, four Crafoord Prize winners and two Fields Medalists. Fourteen Nobel Laureates have been members of the College either as staff or students. The College has 14,927 students, of whom 39 percent are postgraduate. Thirty per cent of students come from outside the European Union. External assessment of the College’s teaching quality in many different subject areas has been judged to be of high standard. The proportion of women students has increased to 36 percent of the total.

**Research**

The quality of the College’s research has been judged consistently to be of the highest international standard and the proportion of income from research grants and contracts is one of the highest of any UK university.

The concentration and strength of research in science, engineering and medicine gives the College a unique and internationally distinctive research presence.

Generous support for the College’s work comes from a wide variety of sources. From industry there are donations towards certain senior academic posts, advanced courses, bursaries and scholarships. The single largest contribution to the College from industrial concerns is in the form of contracts to carry out research. The College also gains considerable support from research councils and charities to undertake research.

**Teaching and Learning**

The College’s overall educational aim is to ensure a stretching and exhilarating learning experience and, while maintaining its traditional emphasis on single honours degree courses, it also aims to give students the opportunity to broaden their experience through courses relevant to student and employer needs.

In its MSc. course provision, the College seeks to provide a wide range of specialist courses in areas in which it has particular expertise. Many of those offered by non-medical departments emphasise the valuable interaction between scientific/technological training and industrial experience, whilst those offered by the medical departments focus on subjects at the interface between basic science and medicine and on specialist education for doctors and other health professionals in training. In addition, the College’s wide range of PhD programmes reflect its aim of pursuing research at the frontiers of scientific, engineering, management and medical knowledge and the increasingly interdisciplinary nature of this research.
The Centre for Educational Development raises and consolidates the profile of learning, teaching and educational development throughout the College. Newly-appointed non-clinical lecturers will be expected to develop and expand their teaching skills, and there are many learning and teaching activities for more experienced staff.

On 1 October 2011, the Graduate School of Life Sciences and Medicine merged with the Graduate School of Engineering and Physical Sciences, to form a single entity. The merged Graduate School is the focus of postgraduate education and research and maintains, enhances and monitors quality, disseminates best practice, while initiating and developing new programmes, particularly those with an interdisciplinary slant. It also has quality assurance responsibilities for the two non-faculty departments of Humanities and the Business School.

The College’s teaching quality is audited regularly, both internally and externally. Recent external audit found teaching quality to be of a high standard.

2. The Faculty of Faculty of Engineering

The Faculty of Engineering is one of three faculties within Imperial College London and is led by the Dean, Professor Jeff Magee. The Faculty seeks to provide international leadership in engineering research and education and is widely recognised as a world-leading engineering school. In the Times Higher Education World University Rankings 2011-2012 the Faculty was ranked 4th in Europe and 10th in the world for Engineering and Information Technology. Our Faculty is unique in the UK in supporting world-class education and fundamental research across the full range of engineering disciplines. All nine of our academic departments are located on a single campus in South Kensington, giving a concentration of talent that creates a stimulating and vibrant research culture which promotes multidisciplinary collaborations and attracts internationally leading researchers and scholars.

Our academic departments deliver world-class education in engineering in order that our graduates possess the skills, knowledge and attitudes necessary to become international leaders in engineering industry and academia. We provide our students with an outstanding engineering education that brings together cutting edge researchers, exceptional teachers and state-of-the-art facilities in inspiring physical and virtual environments. Students at Imperial will meet, work and live with people studying every aspect of engineering.

The Faculty is home to 1,300 staff (360 academics, 630 researchers and 310 support staff) and 5,800 students (of whom 1,300 are research students). The Faculty is a powerhouse in research across the engineering sciences, with research funding in excess of £95M per annum.

Please see the Faculty of Engineering web pages for further information: http://www.imperial.ac.uk/engineering

The Faculty of Engineering is based at South Kensington and comprises nine Departments covering all aspects of Engineering:

- Aeronautics
- Bioengineering
- Chemical Engineering and Chemical Technology
- Civil and Environmental Engineering
- Computing
- Earth Science and Engineering
- Electrical and Electronic Engineering
- Materials
- Mechanical Engineering

The Faculty was formed in August 2001 and formally inaugurated in August 2002.

3. Department of Materials
The Department of Materials at Imperial College London is the oldest and largest department of its kind in the UK. We have a teaching quality assessment score of 24/24 and received an excellent profile in the 2008 RAE with 20% of our research being ranked world leading. Since 2006 we have expanded our teaching and research programmes significantly. **Current Departmental population is as follows:**

- **Academic Staff:** 34
- **Research Staff:** 78
- **Postgraduate Research Students:** 40-50 (intake per annum)
- **MSc Students:** 50-70 (intake per annum)
- **Undergraduate Students:** ~85 (intake per annum)

**Departmental Facilities**

The Department houses top class facilities for Materials processing, property measurement and characterisation. Major research equipment includes both scanning and transmission electron microscopes including a monochromated FEG-STEM Titan microscope with unique analytical capabilities, Secondary Ion Mass Spectrometer (SIMS) systems including a newly installed Time-of-Flight SIMS and Low Energy Ion Scattering unit, Focused Ion Beam (FIB) systems (Dual Beam and FIB-SIMS), a hot isostatic press, a vacuum hot press, and an isostatic compaction press. We have state-of-the-art X-ray equipment and thermal analysis suites (including a laser flash thermal diffusivity unit). We are presently in the process of preparing laboratories for an ambient XPS instrument and new thin film deposition apparatus. In addition, we have recently refurbished laboratory space for biomaterials, metals processing and functional materials and provided two new lecture rooms for MSc teaching. The thin film deposition facility includes three pulsed laser deposition chambers, sputtering, e-beam evaporation and MBE.

Our latest five-year plan includes expanding our current efforts in the following areas:

- Energy (including nuclear and fuel cells).
- Novel Electronic Devices (thin films, sensors, photonic crystals).
- Biomaterials, Tissue Engineering and Regenerative Medicine.
- Functional Materials
- Environment (clean up, pollution control and prevention).
- Metals
- Ceramics

**Interdepartmental Collaboration**

Interaction between the Department of Materials and other departments of Imperial College London is key to our research programmes. Much of the collaboration takes place through interdepartmental centres and groups including the College Institute the Energy Futures Laboratory, Thomas Young Centre for Theory and Simulation of Materials as well as LCN. The Energy Futures Laboratory was launched in November 2005 by the UK’s then Energy Minister Malcolm Wicks under the direction of Professor Nigel Brandon (in Earth Science and Engineering) and has been established to:

- Understand and solve wide ranging and cross-cutting energy problems via an interdisciplinary approach.
- Draw on Imperial’s wealth of knowledge in energy technologies and integrated systems design coupled with its impressive track record in innovation and entrepreneurship.
- Work with industry, Government and funding agencies to focus the extensive energy portfolio of one of the world’s top research Institutions on key energy issues.

Imperial has some £20M pa. in funding, over 200 projects, and around 250 staff and their research teams working in
the energy sector. The Department has a strong and leading role in the development of materials for energy conversion, being active in both the Supergen fuel cell consortia and cross-college solar energy activities. The Department houses the Centre for Nuclear Engineering which brings together staff across the college in one of the most comprehensive research and teaching groups dedicated to nuclear engineering and science.

The Department also has a strong involvement in the LCN a joint initiative with University College London. The Department further contributes to the LCN through the Thomas Young Centre for Materials Modelling under the direction of Professor Mike Finnis. Mike (like Peter Haynes, Arash Mostofi and Paul Tangney) is appointed jointly with the Physics Department.

Clearly, many opportunities exist for collaboration within the College but the successful candidate would be expected to develop national and international research links.

**Research in the Department**

The Department of Materials at Imperial College has expanded rapidly since its move into the newly refurbished Goldsmiths Wing of the Royal School of Mines in 2005. Of the 34 staff currently in the department 26 have been appointed since the move. Since 2009 we appointed Eduardo Saiz Gutierrez (from Lawrence Berkeley National Lab, USA) as Professor of Structural Ceramics, Norbert Klein (from Technical University, Dortmund, Germany) as Professor of Electromagnetic Nanomaterials, Professor Fionn Dunne (from Oxford) as Professor of Micromechanics, Dr Mark Oxborrow (NPL) as Reader in Functional Microwave Materials and Devices, Dr Rongshan Qin (from POSTECH, Korea) as Corus/RAEng Senior Lecturer in Steel Processing and Drs Iain Dunlop (from Max Planck Institute, Stuttgart and University of Heidelberg, Germany), Shelly Moram (Cambridge), David Payne (Oxford), Christopher Gourlay (University of Queensland, Australia), Martyn McLachlan (Imperial) and Cecelia Mattevi (Rutgers, USA) as Lecturers.

The Department has internationally-leading research programmes in the synthesis, processing, microstructure, properties and modelling of a broad range of materials (metals, ceramics, semiconductors, glasses, metal- glass- and ceramic- matrix composites) directed to diverse applications such as nuclear, solid oxide fuel cells, aerospace, biomedical, automotive and electronic. We continue to enhance the quality of our research by appointing people of international standing and by building on the already extensive links to other Departments and Research Institutes in the College including Imperial College’s Energy Futures Laboratory, the Composites Centre, the LCN; the Thomas Young Centre for Materials Theory and Simulation; the UK’s Keeping the Nuclear Option Open consortium; the UK Centre for Advanced Structural Ceramics.

Much of our research quality derives from our outstanding students. During the 2012-13 academic year, we enrolled 84 talented undergraduates bringing our current total to over 240. We now have over 150 PhD students and in 2012 we graduated our highest annual total of PhD students ever. The Department has excellent contacts with industry, and receives research support from over 60 companies either as research contracts or student support. The Department’s research income is currently in excess of £7M per annum from Research Councils, industry and Government bodies. Our current grant portfolio with EPSRC stands at around £37.3M across 36 awards.