Attosecond TECHNOLOGY

Light sources - Metrology - Applications

Basic Technology Project GR/S22400 + Translation Grant EP/F034601

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Overview

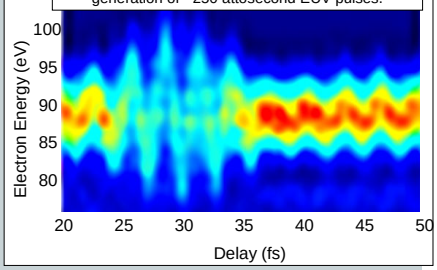
The fundamental processes of chemistry, biology and material science are mediated by electronic and nuclear motions of the constituent atoms. The electronic motions inherent to these systems have attosecond time-scales (1 attosecond = 10^{-18} sec). Measuring and ultimately controlling electron dynamics on the attosecond timescale is one of Science's frontline challenges with huge potential impact.

This Research Project (Basic Technology + Translation Grant) has developed the technological tools to study electron motion in matter with both attosecond time-scale resolution and sub-Ångstrom spatial resolution.

Underpinned by extreme-ultraviolet (EUV) light sources producing attosecond duration light pulses (right), these tools open the door not only for real-time observation but also time-domain *control* of electron dynamics on the atomic scale.

This project has successfully tackled a number of front-line technological challenges in laser engineering, optical pulse diagnostics, extreme ultraviolet optics, molecular physics and energy/momentum resolved electron detection.

Direct measurement of light wave oscillations using "atomic streak camera" method. This confirms the generation of ~250 attosecond EUV pulses.

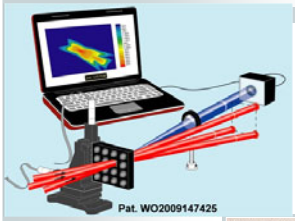


Our team comprises scientists from Imperial College London, University College London, the universities of Oxford, Reading Birmingham, and the Rutherford Appleton Laboratory (CCLRC). As we have developed the technology, new science has followed, for example we have made the fastest ever measurement of molecular dynamics.

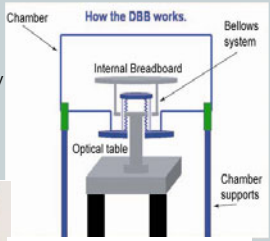
The project has also succeeded in training more than a dozen doctoral students and fostering a new UK attosecond science community. It has also transferred new technology to the UK science base thereby greatly increasing both the expertise and the capacity to do attosecond science in the UK.

New Technology

(Right) Hollow-Fibre Pulse Compressor: We developed an optical system that compresses high power (100GW) near IR femtosecond pulses to the "few-cycle" limit, i.e. to durations approaching 5 fs, with carrier-envelope phase stabilisation. These pulses- amongst the shortest, highest power pulses in the world - are used to generate attosecond EUV pulses via the process of High Harmonic Generation.



(Left) Set-up for Angle Resolved Coherent (ARC) optical wavemixing. ARC is a powerful new technique for time-resolving molecular energy transfers. It relies on the broadband hollow-fibre source. It has been used to make new measurements on photosynthesis.



(Above) We developed a vibration isolation technology to allow optics in vacuum beamlines to be stabilised with interferometric stability relative to external optics. This is vital for attosecond resolution pump-probe experiments.

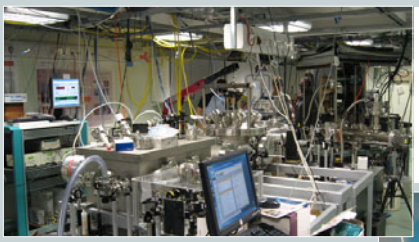
(Right) "Jitter-free" EUV delay stage. This highly stable piezo-actuated two-part Mo/Si mirror allows optical and EUV (13nm) pulses to be precisely delayed with respect to each other (<50 attosecond resolution). This is used to measure the duration of attosecond EUV pulses.

New Science

More than 50 papers in top journals including Science, Nature Physics and Physical Review Letters

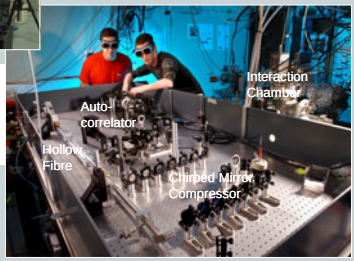
More than 50 invited talks at leading international conferences

New UK Capability



(Left) Attosecond beamline at Imperial College London. This state-of-the-art vacuum beamline is used for the generation, filtering, focusing and delivery of attosecond EUV and few-cycle near-IR pulses in pump-probe configuration to a range of experiments (e.g. molecular physics and surface science studies).

(Right) Our pulse compression technology has been transferred to the Rutherford Appleton laboratory giving this user facility high-power sub-10fs capability. This technology has also been transferred to Birmingham university and the Manchester Photon Science Institute.



(Left) Our beamline and laser systems technology as well as expertise has been transferred to Astra-Artemis at RAL. This new user-facility provides few-cycle, carrier-envelope phase stabilised pulses at a range of wavelength (including EUV) to user experiments. Attosecond capability will be operational in 2011.

New Teams, Training of Young Scientists Public Engagement, International Visibility

(Right) Centred at Imperial College London, the project has connected a number of UK universities and institutes – in many cases creating new bridges between research areas and research groups.

(Above) PhD students directly connected with the project. Training of researchers has been one of the most important outcomes of the project.

(Right) An international workshop was held as part of this Project. It attracted more than 120 delegates from the UK and overseas. This has now become a regular conference series, most recently held in Ischia in 2009.

(Above left) The science developed in this Project was showcased at the Royal Society Summer Exhibition in 2008. This is one of the premier public engagement events in the UK which attracted thousands of school students and members of the public.

Attosecond Light Sources, Metrology and Applications GR/S22400 (2004-2008)
Next Generation Attosecond Techology EP/F03460 (2008-2012)

This ongoing project has succeeded in developing new technology and carrying out world-class new science. It has built up almost from scratch significant infrastructure and expertise in this exciting new field to serve a growing UK community. Huge strides have been made in our understanding of how to generate, characterise and control attosecond pulses.

The research carried out in this project is providing the tools to enable scientists to observe directly the dynamics of atoms and molecules on their natural length (Ångstrom) and time (attosecond) scales. Electronic motion on this timescale underpins many microscopic natural phenomena, such as charge transfer within molecules and at surfaces. Therefore, the research promises to have impact and application across the fields of physics, chemistry and eventually biology, as well as in nano-science and engineering.

Quality of technology research

- World-leading technology established and new expertise gained that is generating high impact science.
- Transfer of technology to user facilities to benefit growing user community.
- World-record measurement made (fastest ever measurement of molecular dynamics)

Academic Impact

- Two BBC News Stories on research.
- > 50 research papers in leading journals, including Science, Nature Physics and Physical Review Letters.
- > 50 invited talks at international conferences.
- > 8 special issues of journals edited.
- Final Report for BT project received overall grade of “5” (maximum score) by evaluation panel.

Crossing discipline boundaries

- Long lasting collaborations formed that span existing BT project and current Translation Grant,e.g. between Imperial College, Oxford, UCL and RAL.
- New collaborations formed during Translation Grant. e.g. ETH Zurich, Nanoplasmonics Group at IC, Quantum Chemistry Group at IC.
- Ongoing technology transfer to user facilities, e.g. Artemis at RAL, Manchester Photon Institute.

Contribution towards the provision of trained people and future research leaders

- 12 PhDs students trained within Project
- PhD students taking up positions in industry (e.g. GE, Shell) and as post-docs in this project or within other leading international groups (e.g. Berkeley, ICFO Barcelona)
- Tisch & Smith promoted to Professor of Laser Physics at IC during project
- Marangos appointed head of UK New Light Source project.

Exploitation of technology research – user community and economic impact

- 1 patent awarded, 2 further pending.
- The project is focused on fundamental research, so significant economic impact is likely to occur in the longer term.
- PhD students organised their own 1 day symposium to discuss their research
- International Conference Series (“Ultrafast Dynamic Imaging”) founded as direct output of this project.
- > 10 popular science talks given to school groups by project team members
- Science generated in project showcased at prestigious Royal Society Summer exhibition attracting thousands of school students and members of the public
- Project website (attosecond.org) is the first hit (after Wikipedia) for a Google search of “attosecond”