Faraday Partnerships

smartmoves

The Newsletter for the Smart Optics Faraday Partnership

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New Director for Smart Optics

Now in its second tranche of sponsorship from the DTI, Smart Optics' active business/academic network continues to grow—promoting the innovation and exploitation of advanced optical and photonic technologies in the UK.

Our membership now exceeds 100 companies and research groups, and we have leveraged over £13M to support 23 exciting collaborative projects in many new commercial applications.

Changes in the Sira Group, one of the three hub-partners, have meant a significant promotion for Steve Pickering, our Director, and now CEO of the Sira Group. Steve writes: "Smart Optics is an underpinning technology with huge potential to generate wealth in many sectors of industry. The Partnership has grown to become an effective tool in the promotion and expansion of the UK's optics industry, and I am proud to have been its Director during this vital formative period. However, I must now, reluctantly, stand down as its Director in order to concentrate on my increased responsibilities at Sira".

Steve Pickering congratulates Jon Holmes on his appointment as Smart Optics Director

Steve has appointed partnership manager Jon Holmes as his successor: "My thanks to Steve, who has led us with determination, enthusiasm and wisdom through our initial term. In the next few years, we must ensure that the projects we supported in 2001–4 bear fruit in terms of commercially exploitable products and processes. Our Technology Translators will be particularly active in helping project consortia find and negotiate further funding to take their work from 'capability demonstrator' to 'marketable product'. For example, I am delighted to report that the UK-led KMOS-1 multi-integral field spectrograph instrument has been funded by ESO for their Very Large Telescope. A key step in winning this £6.5M project was the successful development of POPS, a demonstrator cryogenic pick-off arm, funded through PPARC and supported by Smart Optics.

As well as sustaining the exploitation phase of our current projects, Smart Optics must explore new markets and adapt to changes in government and industry priorities for funding R&D"—Jon Holmes.

Mission: Entirely Possible

During November 2004 Smart Optics led a UK industry delegation to France on a Globalwatch fact-finding mission entitled **Optical Fabrication and Metrology**. The 10-strong team spent a week visiting companies, national laboratories and networking with local optics associations including Optics Valley (Paris), Pole Optique (St Etienne) and Popsud (Marseille). An ambitious itinerary saw the delegation visit 13 different organisations including Sagem (Reosc), Thales Angenieux and SESO. As a result of participating in the mission, all delegates felt that new opportunities for partnering with France have opened up along with a greater insight into how the French Optics industry is structured. In response to the mission a Framework 6 proposal for a 'European Network of Optical Clusters' has since been submitted and in May/June 2005 French delegation is planning to visit the UK. Smart Optics members interested in meeting the French delegation should contact Mark Bonnar **mpb@roe.ac.uk**. The full mission findings report is available on the Smart Optics website. For information on DTI Globalwatch missions visit: **www.globalwatchonline.com/missions**

Seeing France in a new light

DTI support for optics and photonics

The new DTI Technology Strategy is taking shape with the appointment of a Technology Strategy Board, and although optics and photonics technologies still figure, the mechanism of support is changing.

The Technology Strategy now focuses on the needs of society, such as healthcare, security, energy, and the environment and the DTI funding for R&D will be targeted on these needs. The question is

Continues on page 4

CONTENTS:

The Need for Smart X-ray Optics

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X-rays were discovered by chance 110 years ago, and they were very quickly put to use—yet their full capabilities remain to be explored. This article considers some of the significant application areas for X-rays and how improvements in the capability to focus and manipulate X-ray beams could affect them.

Introduction

X-rays have applications in many areas of science, technology and everyday life. The medical, dental and security uses are well known, but X-rays are also used in diverse areas of research from archaeology and astronomy, through the environmental and materials sciences to zoology. So X-rays are already used in lots of applications—but there could be many more if only we could focus them properly.

Our ability to manipulate visible light is pretty good, and visible light optics often operate at or near the diffraction limit. It is the energetic nature of X-rays that makes them much harder to handle, and our ability to produce and manipulate them lags very significantly behind their visible light counterparts, even though they are potentially so useful. The best low-energy X-ray optics currently available are around an order of magnitude away from being diffraction limited, and as the X-ray energy increases the situation rapidly deteriorates. The best X-ray optics made to date have f-numbers of around 20, and again this gets much worse as the energy increases.

Adaptive Optics for X-rays

The Smart X-ray Optics team have been applying and developing the techniques of adaptive optics to this challenging domain. Adaptive optics have revolutionised our use of optical systems, and while initially driven by the need to remove atmospheric distortion in optical images, the technique is increasingly being used to overcome other distortions such as dynamic mechanical stress brought about by changing thermal loads. When the time constants of change are long (>0.1s) it is usual to refer to this as *active* rather than adaptive. The Smart X-ray Optics work has so far been in the active domain, however, several groups are now working with very short pulse/high repetition rate sources and the optics for these will need to adapt between pulses.

At X-ray wavelengths shorter than 1nm, focusing is only possible either by grazing incidence reflection or by the use of zone plates.

Not only have adaptive techniques the potential to deliver very high resolution systems—i.e. focal spots significantly below 1μm and imaging resolutions <<1 arc second—they also permit scanning or image optimisation in different parts of the field of view. The quality of the image across a traditionally focused X-ray image plane is inevitably a compromise and it would be a major advance to be able to locally improve the image quality around an object of interest during a targeted investigation.

Applications

(i) Micro irradiation of cells

One important biological use of X-rays is in the investigation of the so-called 'bystander effect' where damaging effects of ionising radiation are seen in non-irradiated cells that are close to the target cells. The bystander effects predominate at low doses and have important consequences for our understanding of low-dose radiation risk. The Gray Cancer Institute (GCI) has also demonstrated that significant signalling events occur *within* cells. Using microprobe targeting methods it has been shown that irradiating just the cytoplasm can lead to nuclear DNA damage and the bystander effect in unirradiated cells.

There is of course considerable interest worldwide in the application of micro-irradiation techniques for radiobiological applications, and a few fully operational facilities exist for this purpose—but none, apart from GCI, are currently exploiting focused X-rays.

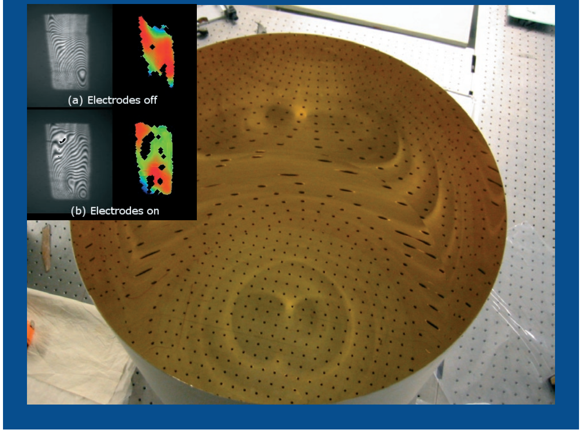
The GCI is using microprobes with 4.5nm C_K, 0.83nm Al_K, and 0.27nm Ti_K X-rays. Increasing the X-ray energy is highly advantageous for a number of reasons. X-rays with higher energies can have substantially greater penetration, which leads to a reduced dose variation as the X-ray beam passes through the cell (C_K X-rays are almost fully attenuated within one cell thickness), and enables cells beyond the first cell layer to be irradiated when using 3-D tissue-like samples. The ability to irradiate model tissue systems will allow testing of the hypothesis that the bystander effect is relevant *in vivo*. Optimising the facility for higher energies (shorter wavelengths) is challenging, as a number of factors contrive to reduce the dose-rate to the cells. In particular, zone plate optical devices are less efficient at these energies, and require monochromatic radiation to achieve proper focusing. Furthermore, zone plates for use at short wavelengths have long focal lengths and the achievable focal spot size, which is limited by the demagnified source size rather than by the inherent resolution capabilities of the zone plate, therefore becomes larger. The ability to irradiate specific sub-cellular components is thus compromised. Other methods for focusing short wavelength X-rays that offer improved efficiency and are preferably achromatic are therefore of great interest.

The ability to deliver rapidly such X-rays with micron or sub-micron precision (maintained by the adaptive optics) would enable a number of important questions relating to the mechanisms of radiation damage to tissues to be addressed, particularly in the important low-dose region, where little experimental evidence supporting current risk estimates exist.

Based on a simple model, an arrangement based on grazing incidence focusing could provide a factor of 100 increase in focused intensity for Ti_K X-rays. Similar enhancements might be expected for higher energies.

Grazing Incidence X-ray Optics

It is possible to reflect X-rays if the angle of approach to the mirror surface is very shallow: this is *grazing incidence*. In a telescope it is usual to nest mirrors concentrically to increase their collecting area, but so far the practical difficulties of figuring, aligning and supporting the shells has meant that a system will have either large collecting area or high resolution. Note that as the wavelength decreases, so the grazing angle decreases also, hence the effective collecting area is smaller. The photograph shows an experimental mirror shell under test at UCL. The shell has a gold surface on an electro-formed nickel substrate, and it is activated with piezo-electric actuators able to adjust the form.

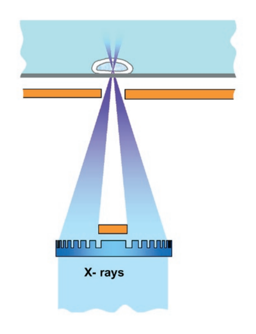


Zone Plates

A Zone Plate is a circular diffraction grating with radially increasing line density. The basic properties of a zone plate were first described by Soret in 1875, and their use for X-rays was first suggested in 1948 by Albert Baez, the father of the folk singer Joan Baez.

This circular diffraction grating can be used to focus X-rays, and the position of adjacent zones reproduces that of Fresnel half period zones. A zone plate can be thought of as a circular lens with focusing behaviour approximating the thin lens formula $1/p + 1/q = 1/f$. However, a zone plate has different diffraction orders and therefore several focal spots. For zone plate based systems the minimum resolvable structure size is limited by the width of the outermost zone of the lens.

While zone plates can provide reasonably high performance they are limited both by their size (typically <0.2mm in diameter) and their efficiency. Furthermore, the focal length of a zone plate is strongly wavelength dependent (proportional to $1/\lambda$) and so refocusing is needed whenever the wavelength is changed. Below 0.1nm zone plates pose problems since the zones have to be thick (for efficiency) and outer zone widths have to be wide so that aspect ratios are reasonable, typically limiting spatial resolutions to a few microns.



The diagram illustrates a zone plate being used to focus X-rays on a living cell.

(ii) X-ray lithography in microfabrication

Although X-ray lithography was first demonstrated in the early 1970s, it has yet to be applied in the commercial fabrication of microelectronic devices. The main reason for this so far has been the steady evolution of optical lithography, with shorter wavelength sources, photoresists and optical techniques resulting in "sub-wavelength imaging" in a production environment. Whilst dimensions below 100nm are being printed with 193nm radiation, it is recognised that X-ray sources with wavelengths of around 1-10nm would offer a significant advantage since some of the limitations of optical systems scale with the wavelength.

The difficulty of fabricating the masks for X-ray lithography should not be under-estimated. The simplest exposure technique would be proximity printing with a 1:1 mask, implying the creation of mask structures with dimensions in the order of nanometres with due allowance for the penumbral and magnification effects from the exposure system. An attractive alternative would be a demagnifying X-ray projection system using mirrors, i.e. an X-ray equivalent of an optical wafer stepper. The masks for such a system would be easier to fabricate at the increased scale, whilst the X-Y stage technology of optical steppers would be used to pattern large areas.

From the above it is clear that the fabrication and control of X-ray mirrors to the required tolerances holds the key to the widespread application of X-rays in microfabrication. It may even prove possible to vary the focal length of the X-ray mirrors to provide different demagnifications, alleviating the need to change optics when a new dimension scale is required. The ability to create structures with dimensions in the order of nanometres using the inherent high throughput of a "parallel transfer" exposure system would have widespread application in microelectronics, MEMS and associated industries. [Choudhury (1997), Sheats (1998)].

(iii) X-ray astronomy

X-rays are very exciting for astrophysicists as they are created in some of the most extreme environments in the Universe, such as supernova remnants and near the event horizons of black holes. X-rays from cosmic and solar sources are completely absorbed by the Earth's atmosphere, and so observatories for X-rays must be in space. The construction of X-ray mirror configurations must therefore meet the twin problems of limited mass and mechanical robustness—leading inevitably to compromises between collecting area and resolution when using conventional static designs. The two principal observatories presently in orbit are the NASA Chandra Observatory and ESA's XMM-Newton.

Chandra achieves an angular resolution of 0.5 arc second using 4 stacked Zerodur reflectors, with an outer mirror diameter of 120cm. These provide a geometrical sensitive area of just 1145cm^2, an aperture filling factor of only 0.1. In the XMM-Newton Observatory, 5 arcsecond resolution is achieved using 3 modules of 58 stacked reflectors with an outer shell diameter of 70cm. Each module has a geometrical area of 1750cm^2 and an aperture filling factor of 0.45. While problems of micro roughness cannot be addressed by active optics, the scale size of the mid-spatial frequency structure (1–5mm for Aluminium shells) could be addressed with a very significant improvement in performance. Similarly the very small alignment errors involved could also be ameliorated. Active X-ray optics have the potential to provide Chandra-like imaging in an XMM-Newton-like configuration, with significant implications for X-ray astronomy. They could even offer a practical alternative to X-ray interferometry.

(iv) X-ray Microscoscopy

High-resolution X-ray microscopes using synchrotron sources and zone plate optics have been developed over the last 20 years or so and have similar optical configurations to familiar visible light and electron microscopes. In some cases, specific features in the absorption of materials as functions of wavelength can provide elemental or chemical-state maps of specimens; comparison of images taken either side of an absorption edge of an element shows the distribution of that element in the feature, while tuning to specific near-edge absorption features can show the distribution of particular chemical states. But, unlike electron microscopes, the use of synchrotrons will not allow X-ray microscopy to become a routine analytical tool. It is therefore necessary to develop better optics to allow laboratory scale sources to be used. Also, to date it has not been possible to make a confocal X-ray microscope, which would offer similar advantages to its visible-light counterpart, owing to the low efficiencies of zone plates.

Participants in the Smart X-ray Project

The Optical Science Laboratory, UCL

OSL forms a major research area of the Department of Physics and Astronomy at UCL, having been founded in 1985 as a focus for optical instrumentation and associated activities. OSL brings skills in adaptive optics and large-scale optics fabrication to the project. **www.osl.ucl.ac.uk**

Scottish Microelectronics Centre

The Scottish Microelectronics Centre was opened in November 2000 as a world class Centre for Incubation, Research & Development in the semiconductor sector. The SMC is a joint venture between The University of Edinburgh, Scottish Enterprise and Scottish Enterprise, Edinburgh & Lothian and it provides a dynamic environment that links academia and hi-tech technology companies.

www.scotmicrocentre.co.uk

Continues on page 4

Continued from Page 3...

The Mullard Space Science Laboratory, UCL

MSSL is the UK's largest university space research group, working to unravel the mysteries of space through research in fields ranging from the Earth's climate to the most distant galaxies in the known Universe, using innovative space instruments. Since MSSL was established in 1966, it has participated in over 35 satellite missions and over 200 rocket experiments. **www.mssl.ucl.ac.uk**

X-ray Group, King's College London

The X-ray Group, led by Professor Alan Michette, is part of the Physics Department at KCL. The group has been active in soft X-ray research for over 20 years, with many national and international links. **www.kcl.ac.uk/kis/schools/phys_eng/physics**

The Gray Cancer Institute

Opened in 1957 by L. H. Gray, The Gray Cancer Institute is a leading centre for research applied to cancer treatment. Originally a radiobiology research unit with its focus on radiotherapy, research in tumour physiology has led to new initiatives in cancer chemotherapy and GCI is introducing new ways of exploiting modern molecular biology. **www.graylab.ac.uk**

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Diary

Details of these and other events are available on our website

17th March 2005 - Optical Fabrication and Metrology, Optic Technium, North Wales

22nd March 2005 - Smart Optics in High Throughput Methods, Queen Mary, University of London

3 May 2005 - DTI Technology Programme Call, closure date for full applications

7-9 June 2005 - Introduction to Opto-Mechanical Design, Sira, Chislehurst

10 June 2005 - Advanced Opto-Mechanical Design, Sira, Chislehurst

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Continued from Page 1...

then whether or not optical technologies can deliver solutions in these sectors, in competition with other technologies. Our discussions with the DTI indicate that they already see optics and photonics as strong contenders for their support in many areas—indeed, Smart Optics features especially in two of the nine calls, in **Imaging Technologies** and **Optoelectronics and Disruptive Electronic Technologies.**

Smart Optics Student Profile—Sarah Kendrew

I have been working for a PhD in astronomy at University College London since 2002 and been a Faraday Associate since September 2004. I am orginally from Belgium, was born and raised there in a Flemish town just outside Brussels. I moved to London in 1997 and settled into North London life, graduating in 2001 with a first class MSci. degree.

Sarah Kendrew

During my final year I worked on a research project with the college's lecturer in adaptive optics, Dr. Peter Doel, on the development of an atmospheric turbulence simulator. After a year out in the real world I came back to UCL to start a PhD in September 2002.

From the start I became involved in a project to develop a prototype deformable mirror in a carbon fibre composite material. This is a very promising new technology with applications in airborne and space-based imaging systems, as well as in adaptive optics-controlled telescopes on Earth. I am currently in my final year and hoping to complete my thesis in the autumn of 2005. **sarahkendrew@hotmail.com**

New Smart Optics Faraday Partners

Adriancon, applications of Optical Coherence Tomography (OCT) and biomedical optics; **Applied Optics Group, NUI Galway (Associate)**, applications of adaptive optics and polarisation imaging; **Andrew Dixon Consultancy**, consultancy in laser scanning microscopy; **Armstrong Optical Ltd**, opto-electronics products marketing; **Bristol University Dept of Electronic & Electrical Engineering**, applications of photonic Crystals and Lab-on-a-chip; **Center for Visual Science, University of Rochester (Associate)**, ophthalmic applications of optics and adaptive optics; **Lasermet Ltd**, consultancy in laser safety; **Mesophotonics Ltd**, supplier of photonic crystals; **Micro Circuit Engineering**, advanced micro-electronics design , especially for displays; **NanoSight Ltd**, manufacturer of nanoparticle imaging microscopes using surface plasmon resonance; **Optocap Ltd**, design and development of opto-electronic component packaging; **Procyon Instruments Ltd**, manufacturer of clinical pupillometers; **Scottish Enterprise**, business innovation in the Scottish region; **SEOS Ltd**; development & supply of advanced displays and simulators; **The Alba Centre**, Collaboration and development in micro- and optoelectronics.

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