Changing the face of materials research

Professor Carlo Segre employs various techniques to explore the function of an array of structurally complex materials. Here, he discusses his multiple roles and the potential applications of his work

To begin, could you elaborate on your current roles and responsibilities?

As Director of the Center for Synchrotron Radiation Research and Instrumentation (CSRRI), I have the responsibility of coordinating our efforts in constructing and operating synchrotron beamlines, and promoting synchrotron radiation techniques across the Illinois Institute of Technology (IIT) campus. In addition, I have been the Principal Investigator on our Graduate Assistance in Areas of National Need grant for training PhD students in physics to become the future builders and innovators of synchrotron facilities, rather than simply synchrotron users. I am also involved in raising awareness of the strength of IIT in synchrotron radiation research.

I'm Deputy Director of the Materials Research Collaborative Access Team (MRCAT) and the Biophysics Collaborative Access Team (BioCAT), but while I have operational and supervisory roles in both CAT's my roles in each are slightly different. For MRCAT, I plan all the scheduling and staff supervision as well as being the CAT Safety Coordinator, and am involved in all construction and beamline development. For BioCAT, I help supervise staff, direct the X-ray optics and beamline technical developments and train new staff in operating an X-ray beamline.

What are your current research interests?

I have a wide variety of ongoing research projects. My current National Science Foundation Materials World Network grant focuses on the study of local structural effects on physics properties of perovskite-based materials. I also research fuel cell catalysts and battery materials, where I am primarily involved in the *in situ* or operando X-ray characterisation of these materials. These projects are highly collaborative and varied. For example, I am engaged in a long-term project using X-rays to non-destructively study archaeological specimens such as Bronze Age arrowheads and figurines. Finally, because of my technical involvement with MRCAT and BioCAT, I have several projects on X-ray instrumentation, including photocathode materials for detectors and X-ray optics.

How does your research benefit from being based at IIT's Department of Physics?

In the late 1980s, when it was determined that the Advanced Photon Source (APS) was to be built at Argonne National Laboratory, the IIT Physics Department made a significant investment in hiring faculty who would take advantage of this facility only 25 miles from campus. Being located at IIT – where there is a supportive departmental administration – permitted CSRRI to build and operate five beamlines at the APS. We are still actively operating three of them, and we now have 10 tenure track faculty – seven of whom are in physics. There are also seven research faculty of which five are in physics and make synchrotron radiation techniques a significant part of their research programme.

MRCAT is building and operating X-ray beamlines at the APS. What activities are currently being carried out here and have there been any significant results so far?

The MRCAT beamlines have evolved into the premiere X-ray absorption facility for the study of catalysis and environmental science, and have produced many significant research results. Over 350 archival publications have used MRCAT beamlines, and these have been cited over 6,300 times, with at least 30 PhD students having used MRCAT as a significant part of their dissertation research. The most cited publications include some fundamental work on the structure of metal nanoparticles, speciation of metals in the environment and, more recently, lithium battery materials. In the next 10 years, that balance will likely tip towards *in situ* catalysis studies.

Are any other exciting technological developments underway?

Over the past three years, I have been collaborating with one of my beamline scientists, John Katsoudas, and Elena Timofeeva at the Argonne National Laboratory, near Chicago, on what we believe will be a breakthrough battery technology for automotive applications. We have recently filed a provisional patent on this technology and are seeking funds from the Advanced Research Projects Agency-Energy to develop a prototype system. We are using our combined expertise in nanotechnology, electrochemistry, materials characterisation and instrumentation design to bring this idea to fruition. We believe that the technology can potentially extend the range of an electric vehicle to at least 500 miles, and provide a straightforward and rapid method of refuelling.

Illuminating complex structure-property relationships

Cutting-edge materials science research by a number of bodies within the **Illinois Institute of Technology** is expected to have important implications for a wide variety of significant technologies

IN THE LATE 1980s, the decision was taken to build the Advanced Photon Source (APS) at the Department of Energy's Argonne National Laboratory near Chicago, Illinois. Since then, the device – which provides the brightest storage ring-generated X-ray beams in the Western Hemisphere and has been used by over 5,000 researchers from an enormous variety of disciplines worldwide – has encouraged the establishment of a number of research institutions in the vicinity. Among those making use of the APS are various groups at Illinois Institute of Technology (IIT) – the Materials Research Collaborative Access Team (MRCAT), the Biophysics Collaborative Access Team (BioCAT), and their umbrella organisation, the Center for Synchrotron Radiation Research and Instrumentation (CSRRI).

Since its creation, the X-ray beams produced by the APS have enabled scientists from multiple fields to gather new knowledge about the structure and function of manmade and natural materials, and biological systems. The new insights offered by this technology are expected to have a significant impact on diverse areas of research, including combustion engine design, microcircuit development, pharmaceutical research and the evolution of nanotechnologies. Through these pursuits, research at CSRRI, MRCAT and BioCAT is having wide-ranging technological, economic, health and social benefits.

ESTABLISHING MULTIPLE INSTITUTES

Among the researchers responsible for leading the creation of the three groundbreaking groups in Illinois is Professor Carlo Segre, who is now the Director of CSRRI and the Deputy Director of both MRCAT and BioCAT. "In the process of designing and fundraising for three different multi-million dollar projects," Segre recalls, "it became clear that, though our scientific missions were quite different, we could take advantage of economies of scale on the engineering and technical sides by collaborating." This decision led to the establishment of CSRRI in 1988. Initially the Center employed scientists and engineers to work across the different beamline construction projects, developing technical and management skills which have proven to be of benefit to both MRCAT and BioCAT.

Subsequently, CSRRI became the driving force behind the design of novel optical systems for multiple beamlines including, most notably, the 'hockey puck' – a cryo-cooled crystal monochromator – and the bent Laue crystal analyser. Following the successful establishment of the beamline projects, the efforts of Segre and his colleagues have turned towards utilising the MRCAT and BioCAT facilities, along with other APS beam lines, for research and education. CSRRI has run a number of summer schools, international conferences and training events for PhD students and postdoctoral researchers from all over the world. CSRRI, MRCAT and BioCAT also enjoy major collaborations with a number of leading researchers including, in Segre's case, Professor Dipankar Das Sarma of the Indian Institute of Science; Dr Elena Timofeeva at Argonne National Laboratory; and Professors Adam Hock and Aditya Unni, both at IIT. "In addition to this," Segre adds, "I also have ongoing and fruitful collaborations with a number of researchers who use our beamlines and need to work with a group of experts to collect and analyse Extended X-Ray Absorption Fine Structure (EXAFS) data."

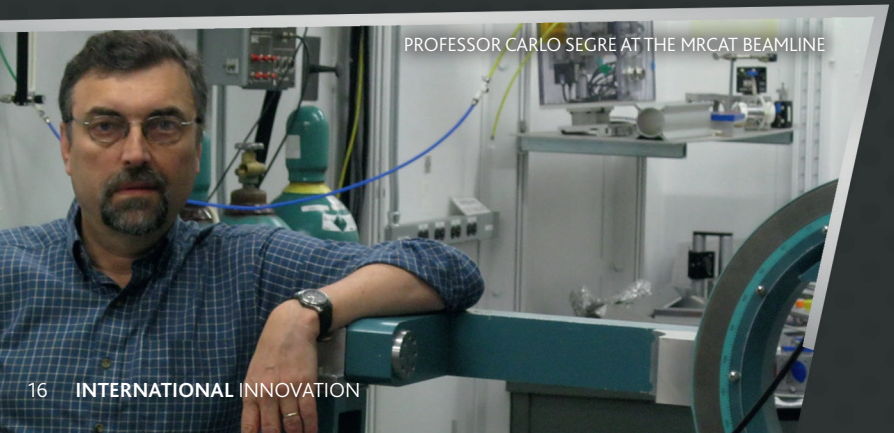
X-RAY ABSORPTION SPECTROSCOPY

Segre and his colleagues have frequently made use of the exceptional X-ray Absorption Spectroscopy (XAS) facilities at MRCAT as part of their efforts to further elucidate the link between the structure and property of materials. Having worked with XAS since the early 1980s, Segre is fully aware of its strengths, and is eager to exploit the technique wherever it can be of benefit. XAS began to feature in MRCAT's projects in the early to mid-1990s, and is widely acknowledged to be one of the only ways of studying systems in which there is little or no long range order. As Segre explains: "Using XAS, one can deduce the local structure around the target atom and its electronic structure, both of which play a key role in the physical properties of interest to us". Given the broad application of XAS to fields from physics and chemistry to biology and environmental science, CSRRI – led by Segre's IIT colleague Professor Grant Bunker – holds an annual summer school to provide the next generation of researchers with a basic understanding of the technique.

NATIONAL SCIENCE FOUNDATION FUNDING

Following two decades of field-leading research between CSRRI, MRCAT and BioCAT, Segre and his students are undertaking a National Science Foundation project concerned with analysing the local structural effects on physical properties of perovskite-based materials which display metal-insulator transitions, magnetoelectric properties and a number of other collective phenomena as a function of compositional changes. The investigation aims to help answer a number of unresolved questions regarding the fundamental properties of transition metal perovskites which are likely to prove highly useful both for the manipulation and storage of data. As part of the project, a long-term collaboration is being nurtured between IIT and the Indian Institute of Science in Bangalore, India. A key focus of the research is the critical issue of sample quality – variations which can lead to contradictory and inaccurate results. By gaining a greater degree of control over sample quality, the researchers will have a better platform from which to understand the manifestly different physical behaviours of the materials they are studying.

Within this broad mission, the study has set itself several specific research objectives, including: the synthesis and characterisation of a number of complex oxides, both in the US and Indian laboratories; the determination of the electronic properties of the materials using photoelectron spectroscopy; the assessment of the local structure of materials using X-ray diffraction and XAS with synchrotron radiation; the generation of high impact scientific and technological results; and a greater understanding of many-body interactions.



PROFESSOR CARLO SEGRE AT THE MRCAT BEAMLINE

COLLABORATIVE ADVANCES

In addition to their collaborations with IISC, the IIT researchers manage MRCAT in partnership with the University of Notre Dame in Indiana, the University of Florida, the Chemical Sciences and Engineering Division and the Environmental Research group of Argonne National Laboratory, the Environmental Protection Agency, Honeywell UOP and BP. "Alongside these productive and inspiring collaborative ventures, we are also a partner institution of the Advanced Test Reactor National User Facility and, as with all CATs at the APS, we provide 25 per cent of the available beam time to the most highly rated General User proposals," Segre explains. The majority of this General User base comes from researchers within the catalysis, electrochemistry and environmental science communities, and the allotted General User time is constantly oversubscribed by a factor of around five or six.

LOOKING TO THE FUTURE

There is much for IIT researchers to look forward to in the years ahead, particularly with the upgrades planned at MRCAT and BioCAT. CSRRI is set to continue to educate a new generation of synchrotron researchers and produce results and publications of enormous significance to many fields, ultimately leading to improvements in a host of technologies, generating widespread and long-lasting economic, environmental and health benefits for society.

CSRRI, MRCAT and BioCAT enjoy major collaborations with a number of world-leading researchers at other organisations

CSRRI is the umbrella organisation for all synchrotron radiation activities at Illinois Institute of Technology. It staffs and operates the MRCAT and BioCAT facilities located at the Advanced Photon Source.

MRCAT is a multi-institutional partnership which operates two beamlines specialising in X-ray absorption spectroscopy applied to materials science, catalysis and environmental science.

BioCAT is a National Institutes of Health Research Resource whose mission is to study the structure and dynamics of partially ordered biological systems by small angle X-ray scattering, fibre diffraction and X-ray microprobe.

Other key CSRRI Faculty at IIT:

Professor Thomas C Irving, Biology & Physics – Director of BioCAT; Professor Grant B Bunker, Physics; Professor David Gidalevitz, Physics; Professor Jeff Terry, Physics; Professor Joseph P R O Orgel, Biology; Professor Andrew Howard, Biology & Physics; Professor Keith J Bowman, Materials Engineering; Professor Adam S Hock, Chemistry.

INTELLIGENCE

MATERIALS WORLD NETWORK: LOCAL STRUCTURE, FUNCTION AND THE EXOTIC PROPERTIES OF TRANSITION METAL PEROVSKITES

OBJECTIVES

To develop a long-term international collaborative research and education effort among teams at Illinois Institute of Technology, Chicago, USA and Indian Institute of Science, Bangalore, India. The research focuses on investigating the influence of local structure on the physical properties of complex oxides.

KEY COLLABORATOR

Professor Dipankar Das Sarma, Indian Institute of Science, Bangalore, India

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CARLO SEGRE is the Director of the Center for Synchrotron Radiation Research and Instrumentation, and Deputy Director of both the Materials Research Collaborative Access Team and the Biophysics Collaborative Access Team, all based at the Illinois Institute of Technology, where he is the Duchossois Leadership Professor of Physics. Segre received a BSc in Physics from the University of Illinois at Urbana-Champaign in 1976, an MSc in Physics from the University of California, San Diego (UCSD) in 1977 and a PhD in Physics also from UCSD in 1981. His research interests focus on the structure and electronic properties of complex materials including superconducting, magnetic and catalytic materials.

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