The Beamteam

Physicist **Professor Alexander Moewes** spends his time exploring the electronic structure of new materials by monitoring and understanding the outer electrons to develop potential applications in materials science

To start, how did you become interested in this research field?

From a very early age, I was fascinated by the question of how matter interacts with radiation. As an undergraduate student, I naively envisioned that my knowledge would be 'complete' once I was able to accurately predict all of the processes that take place when a radiation of certain energy impinges on a given material. Synchrotron radiation was later the natural choice because it offers an unprecedented energy range of the light and because one of the leading synchrotron radiation laboratories at the time, HASYLAB, was based in Hamburg, Germany – the city where I was studying physics.

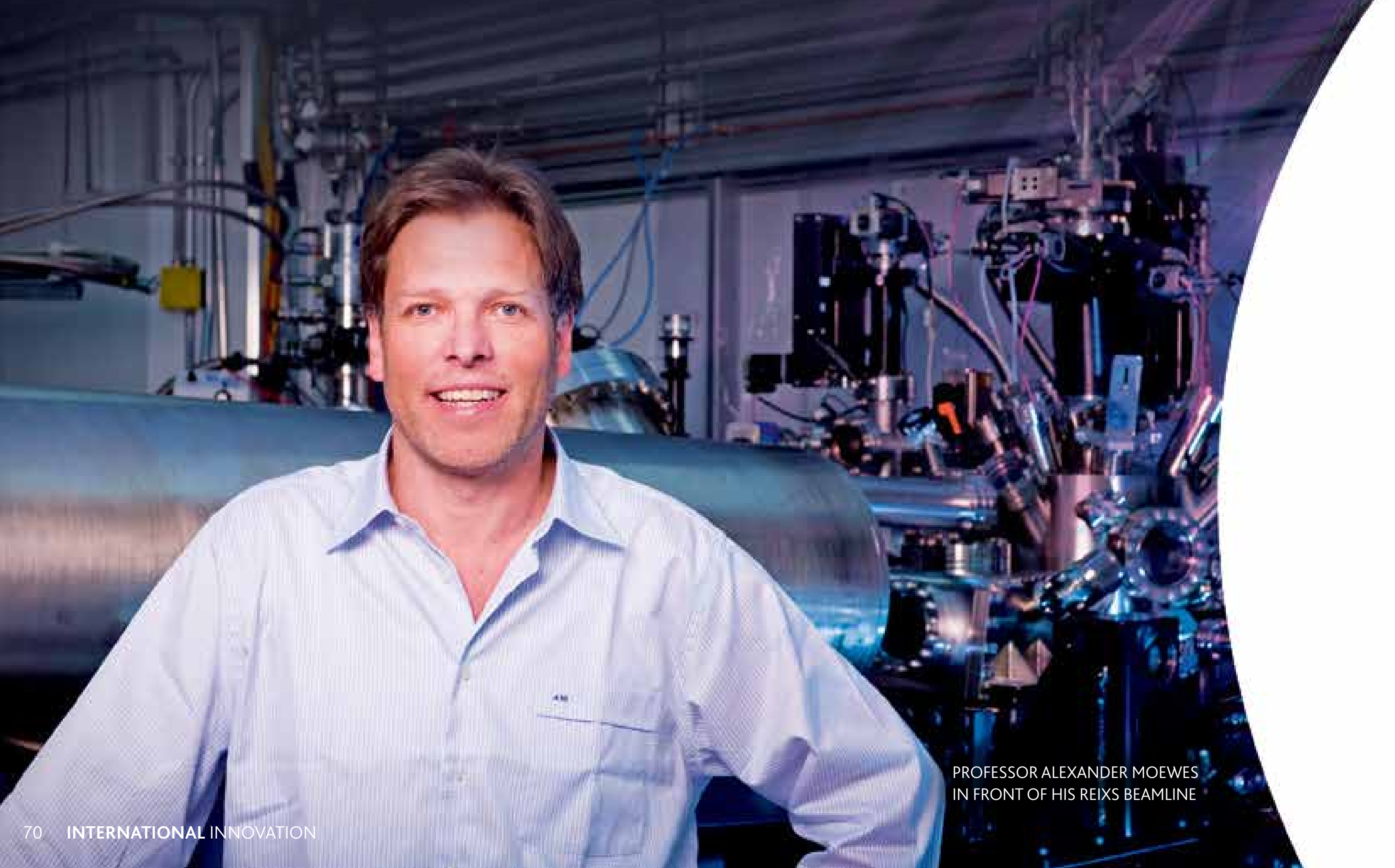
What continues to attract you to the study of materials?

My interest in material sciences developed much later in my career when I realised three key factors: first, the almost limitless opportunities new materials offer; second, how materials surround us and shape our daily lives; and third, the exciting physics questions that materials raise. An important point that continues to draw me to this field of research is what is frequently referred to as 'scientific firsts', in other words the challenge of studying a system or sample that has never been looked at, or at least never with one of the techniques my group uses. Today, I know that I am very fortunate that this fascination is also shared by my graduate students when carrying out experiments and even in their theoretical calculations. This excitement and passion is invaluable and continues to drive us all.

Could you briefly describe synchrotron radiation?

Synchrotrons provide an unprecedented bandwidth of radiation from microwaves to hard X-rays that no other source in the world can provide. The user of the synchrotron can now choose the energy (or wavelength) of the radiation they want to use to probe a sample – in other words the radiation can be tuned to the needs of the user's experiment.

The behaviour of the outer electrons and their interplay in any material are responsible for nearly all of its properties. Whether we consider electric or heat conductivity, magnetism, energy gap, optical properties, chemical bonding, catalytic activity, hardness, tensile strength, crystal structure or superconductivity, all of these very different properties are governed by the weakly bonded electrons. So if one has the means to study these electrons – and this is where synchrotron radiation comes in – then one holds the key to understanding all of these listed parameters in a fundamental way. By fundamental I mean that one can use this understanding of the underlying physics laws to design new materials.



PROFESSOR ALEXANDER MOEWES IN FRONT OF HIS REIXS BEAMLINE

In what way are the experimental techniques you are using helping to further the study of new materials?

Graphene, for example, is an extremely exciting material with many possible electronic and structural uses, but making large pieces is very challenging. How can the defects or impurities in graphene sheets be identified and understood (so they can be avoided in refined synthesis techniques)? With X-ray spectroscopy we can identify the influene of defects on the electronic structure of graphene, and since X-ray spectroscopy is atom-selective we can easily identify the presence, and form, of impurities (like oxygen) in graphene.

Are you focusing on any materials and properties in particular?

Since my group rarely synthesises a material, and the experimental and theoretical techniques we employ apply to a very broad range of systems, we study a large variety of exciting materials. The general focus of my group has been on the electronic structure of the outer electrons. The work of my group covers various spintronic materials, ultra-hard materials, graphene and related materials as well as superconductors, in particular those that have transition metal atoms in them.

What fascinates you about physics research in general?

A broad aspect of research that keeps surprising and captivating me is that the outcome of each research project is unpredictable. From my own experience and discussion with colleagues and collaborators, we all know that in research you need to expect the unexpected. Often it almost seems that the better an experiment is designed, the less guarantee we have that our objectives will be fulfilled. In turn, it appears that experiments which are driven by our sheer curiosity advance our knowledge significantly, this is of course because one cannot predict the outcome of research in general.

Brilliant photons

By employing advanced synchrotron radiation techniques, the Beamteam at the University of Saskatchewan, Canada is studying the characteristics of new and complex materials that will be necessary to further develop them for novel applications in a wide range of fields

AT THE UNIVERSITY of Saskatchewan, groundbreaking research is underway into the electronic structures of new and advanced materials. The electronic structure is determined by the interaction of molecules and atoms within complex materials, which in turn heavily influences many properties important to materials researchers and device fabricators. Such properties range from hardness to superconductivity. The research group uses a range of innovative synchrotron radiation tools such as soft X-ray emission and absorption spectroscopy measurements to explore a variety of important properties in important materials such as superconductors, spintronic and ultra hard materials.

Called the Beamteam, this Material Research Group in Condensed Matter Physics is led by Professor Alexander Moewes, who is a Canada Research Chair in Materials Science using Synchrotron Radiation. Moewes explains that the key objective of their latest research is to garner an understanding of materials, specifically on the electronic structure: "This includes a full understanding of where the electrons are located in a material, how their spin and charge interact and what their energies are". This research will enable the team to tailor materials that will exhibit unique properties, and ultimately, lead to the development of new sensors and devices.

DEVELOPING CUTTING-EDGE TECHNIQUES IN SPECTROSCOPY

Because synchrotron-based emission spectroscopy requires highly efficient instrumentation, the group has designed and built a new spectrometer for their new beamline at the Canadian Light Source on the University Campus. The Canadian Light Source synchrotron creates light that is millions of times brighter than sunlight, meaning it can act akin to an incredibly powerful microscope. The new spectrometer design was a challenge in that it had to achieve simultaneously high throughput efficiency and spectral resolution.

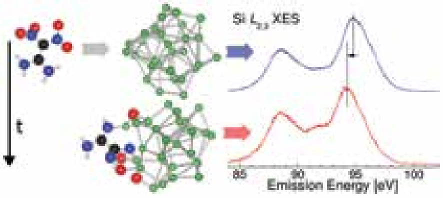
The synchrotron-based technique of resonant inelastic soft X-ray scattering is a subject of intense research focus as well for the Beamteam. This method utilises the energy loss in the incoming radiation's energy after that radiation is scattered from the sample of interest. The energy of this radiation has been exactly aligned with a particular energy threshold intrinsic to the material under study, a process referred to as resonant excitation. "This means that the gain in scattering signal under resonant excitation is tremendous and it is possible to probe charge and spin ordering specifically for the electronic transitions, which is a very important process that we are keen to learn more about," explains Moewes. The researchers use synchrotron radiation to probe the outer electrons materials in a way that is very specific to each element studied and is sensitive to the electron and its different states. "I often characterise these spectra as fingerprints of the material's behaviour," he adds.

The group has been experimenting on graphene oxide to look at how multilayered graphene oxide ages, in particular how it changes physically and chemically. Results show that the chemical bonding, which takes place between the graphene and the oxide parts changes over time, and in the process, the graphene oxide sheets break. "However, this process can be interrupted and the graphene oxide sheets kept intact if you add other chemical compounds," emphasises Moewes. The researchers also discovered that the conductivity of multilayered graphene oxide is impacted by how the sheets are stacked and that this dictates the voltage at which the graphene conducts, essentially the turning on and off mechanism. This information holds much importance as it helps explain how this particular oxide can operate within an electronic device. "These are both highly valuable results when discussing how we can use graphene oxide, as the conductivity and the longevity of a device strongly impact its performance and cost effectiveness," underlines Moewes.

Continuing on from this work, the team is now looking at the impact of graphene sheets on other important properties, such as the energy gap of graphene and how one tune this gap. The knowledge gained has been recently published in the *Advanced Functional Materials* journal, which earned the team a nomination for the prestigious industrial ENI Award that aims to encourage more efficient use of energy sources and increased environmental research.

SUPPORTING FURTHER TECHNOLOGICAL DEVELOPMENT

Spintronics has the potential to significantly advance computing power, which is a very important goal given that society is constantly demanding an increase in computation speed and information storage density. The conventional approach to increasing the speed of processing has been to make transistors smaller, thus packing more into a given amount of space; modern computer chips now contain billions of transistors. However, the size of silicon-based transistors is rapidly approaching the fundamental size limit imposed by quantum physics. Emerging technologies such as spintronics hold the potential of making considerable progress in this field by making an entirely new kind of transistor. "The key to spintronics is the use of magnetism to measure and control electron spins, ultimately meaning faster computation times and higher storage density," points out Moewes. The challenge is finding the appropriate materials that can offer simultaneously the required magnetic and semiconducting properties.



Silicon (Si) L emission spectra of pure porous Si before and after a large airborne nitrogen-containing molecule is adsorbed on the Si surface. The comparison of measurements and calculations allows to determine exactly how the molecule is bonding to the Si cluster, which is sketched on the left side.

Looking for these materials has been a focal point for some intensive research in the last few years. The Beamteam has identified some potential candidates and been undertaking a number of synchrotron radiation studies on these materials. Some of the traditional semiconducting materials, including zinc oxide, cerium oxide and indium oxide, can become magnetic after they have been doped with magnetic ions, such as iron, cobalt and nickel. The question remains why these doped semiconductors exhibit the properties, and how to improve upon the synthesis procedures. Their findings show some important linkages between several measurable characteristics (including oxidation states and specific location of the dopant atoms), the synthesis procedures used and observed magnetic properties. "These results are an exciting step towards both fully understanding these materials and the ultimate realisation of practical spintronic devices," notes Moewes.

BROAD POTENTIAL APPLICATIONS

The team's research aims to lead to tailored novel sensors, detectors and other devices with new or improved magnetic, electric, optical and chemical properties. From this work a wide range of specific applications are anticipated. One instance is a discovery that nanoporous silicon can be used to detect and monitor airborne molecules and, in particular, different explosives, for which a patent has now been filed. The team exposed nanoporous silicon to vapour molecules of different explosives without having any physical contact between the silicon and the explosive. Through this process it was possible to distinguish the fragments of the molecules which were deposited on the silicon by taking spectra. "This discovery was surprising because we estimate the concentration to be in the order of one part out of one billion," explains Moewes. "Even more surprising and important is the finding that the spectral fingerprints we detect are characteristic for each material and therefore we can not only detect those adsorbed molecules but also distinguish different molecules."

This research has enabled the team to distinguish between two highly similar chemicals of which only one is a dangerous explosive. Such insights ensure key steps are being made towards having the capability to develop small, inexpensive and portable sensors that can detect airborne explosive molecules in air. Ultimately, all of these research efforts are aiming to improve the knowledge of complex materials properties.

INTELLIGENCE

MATERIALS SCIENCE USING SYNCHROTRON RADIATION

OBJECTIVES

- To develop and employ cutting-edge techniques of spectroscopy with synchrotron radiation to study the characteristics of new and advanced materials, both independently and in collaboration with researchers worldwide
- To lay the groundwork for the design of materials with novel electronic, magnetic, optical and structural properties
- To measure, understand and predict the electronic band gap for a wide range of materials like transition metal compounds and magnetic semiconductors

Ultimately, these research findings will be used across a spectrum of fields, such as in the development of improved solar cell materials, light emitting devices, improved nanoelectric circuits, and harder, longer-lasting coatings used for example in modern turbines

KEY COLLABORATORS

Research groups in Canada, Germany, France, UK, US, Japan, Russia, Korea

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ALEXANDER MOEWES is Professor and Canada Research Chair for Materials Science with Synchrotron Radiation at the University of Saskatchewan, Canada. He holds a Diploma and a PhD in Physics from the University of Hamburg where he conducted his graduate work at the Hamburg Synchrotron Radiation Laboratory (HASYLAB) at DESY. He has authored/co-authored over 210 publications in peer-reviewed journals. Since joining the University of Saskatchewan in 2000, his group has published over 160 peer-reviewed publications and his graduate students are co-authors on over 100 publications.

His research interests include the study of electronic, atomic and chemical structure of advanced materials among them, ultra hard and superconducting materials as well as materials for spintronic applications. The ultimate goal of his research is to understand new materials in order to tailor them for novel applications.

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