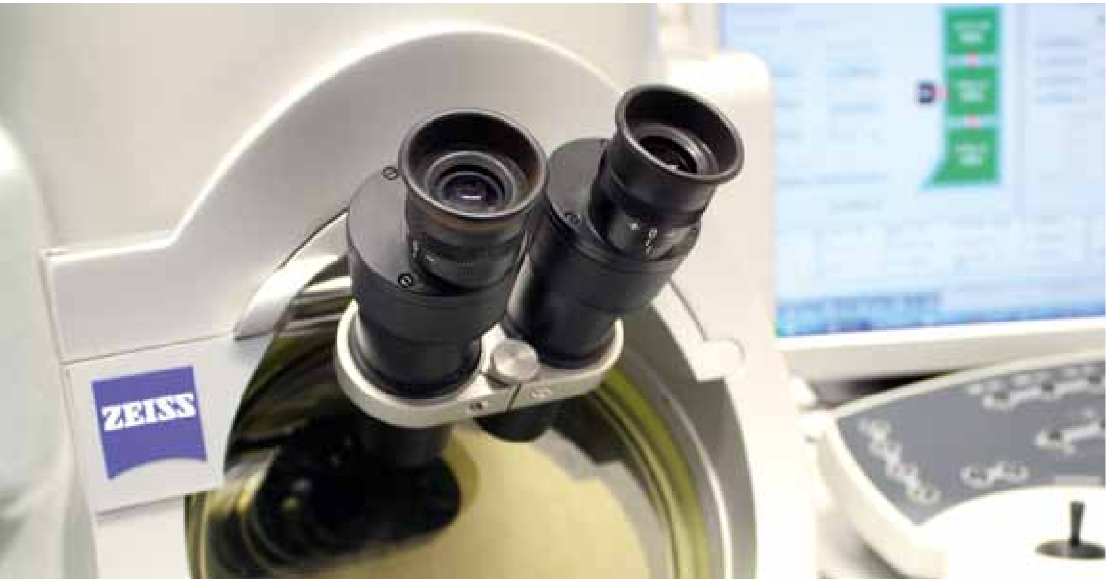
Delving Deeper into the "Nano Cosmos" of the Battery

The University of Ulm is backing low-voltage transmission electron microscopy – a new trend in electron microscopy with applications for battery research – the roots are in "Science City" Ulm



A microscope is being developed within the framework of the SALVE project that will increase resolution at low acceleration voltage – the microscope will essentially have some additional, stronger "glasses".

In order to develop new high-energy storage systems with high-energy density, new concepts of battery characterisation are required. Another current long-term objective is the atomic imaging of structural processes during the course of a battery's charging and discharging cycles and the defect-related changes in situ in a transmission electron microscope. Researchers in Ulm are striving for advancements in research and development in the area of low-voltage transmission electron microscopy.

Ute Kaiser, professor and head of the group of Electron Microscopy in the Material Sciences Department at the University of Ulm, begins with the basics: "The nano science of materials is characterised by the atomic and molecular structure of the materials." She and her team focus on addressing "nano questions": What is the location of which atom? What is the appearance of the chemical bonds? Are there intrinsic electric, magnetic or mechanical fields? How do structural processes work in situ at the atomic level?

Structure-property relationships can be explained and modelled using the knowledge of a material's atomic and molecular structure, which determines its mechanical, optical and electric properties. It is then possible to produce customised materials for the key technologies of today and optimise existing technologies.

One of the most efficient methods of analysis in materials science is transmission electron microscopy (TEM). This has been particularly true since aberration correctors for electron lenses became commercially available in 2005 (an aberration corrector is a pair of "glasses" for the electron lens). Aberration correction has enabled researchers to obtain images sharper than ever possible before. The University of Ulm faced the challenge of the new technology at an early stage, acquiring one of the first commercial devices of its kind worldwide. Since then, electron microscopists in Ulm have been pursuing the quantitative answers to the "nano questions".

In contrast to a light microscope, an electron microscope does not use beams of light to capture images; instead, it uses rapid electrons with a wavelength millions of times smaller than that of light. The fast electrons (they nearly reach light speed at an acceleration voltage of 300kV) go through the specimen being studied and interact with its atoms as they pass through. As a result, they are diverted from their trajectory or even slowed down. Information about the specimen's atomic structure can be ascertained from the arrangements and intensity of the electrons once they exit the specimen and following their imaging on the electron detector. It must be considered, however, that the lenses used for the experiment have a further influence on the trajectories of the electrons. Aberration correction now makes it possible to correct these errors. But what can be done when the atoms are displaced by the high energy of the electrons used to image them? This is the case with the lightweight materials important for batteries, such as carbon and lithium, whose displacement thresholds are significantly below 80kV, the current low-voltage limit of commercial aberration correction devices.

How exciting it would be, says Ute Kaiser, if we could image individual lithium atoms, for

Prof Dr Ute Kaiser

example, and explain their function throughout the charging and discharging cycles of a lithium ion battery at the atomic level. “Our motivation in developing low-voltage electron microscopy is to be able to study radiation-sensitive materials with atomic resolution”, explains the scientist who is also head of the SALVE project – Sub-Angstrom Low Voltage Transmission Electron Microscopy. “We want to use much slower electrons (‘only’ approximately a third of the speed of light) for imaging, diffracting and spectroscopic analysis.”

The SALVE project team is developing a microscope that will increase the resolution for lower voltages. Carl Zeiss NTS and CEOS GmbH, both companies from the state of Baden-Württemberg, are partners in this project. Kaiser continues, “The microscope is receiving much stronger ‘glasses’ that are optimised for the low-voltage area of 20kV to 80 kV!” This project is receiving funding in the amount of 17 million euros from the German Research Foundation, the state of Baden-Württemberg, both business partners and the University of Ulm.

The group of Electron Microscopy in the Materials Science Department in Ulm has been addressing the topic of electromobility for several years, focusing on questions concerning high-energy efficiency and a long lifespan. Why? Transmission electron microscopy enables researchers to obtain a wide range of information; a broad methodical palette can be applied in Ulm. From just one image or a series of images and the corresponding image calculations, electron microscopists here are able to determine the three-dimensional morphology, the two-dimensional atomic crystal structure and its tension, or, in special cases, the charge transfers (see image 1) at the atomic level. The researchers are also working on locally – and very precisely – determining the lattice constant from convergent electron diffraction patterns (see image 2) as well as ascertaining the local element distribution and electron structure using spatially resolved spectroscopy.

> ***“Low-voltage transmission electron microscopy is a brand new trend in microscopy, and we are in a position to say that we have an influence on it. There are now two big projects pursuing similar aims, in Japan and in the US. With its SALVE project, the University of Ulm is one of the lighthouses in this field.”***
> ***Ute Kaiser***

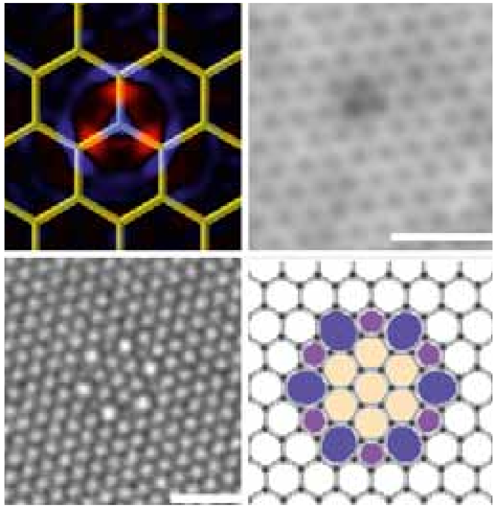


Image 1: Charge transfers due to substitution of a single nitrogen atom in graphene lattice, a monolayer of carbon atoms (above) and an associated flower defect in the graphene (below). Scale: 1nm

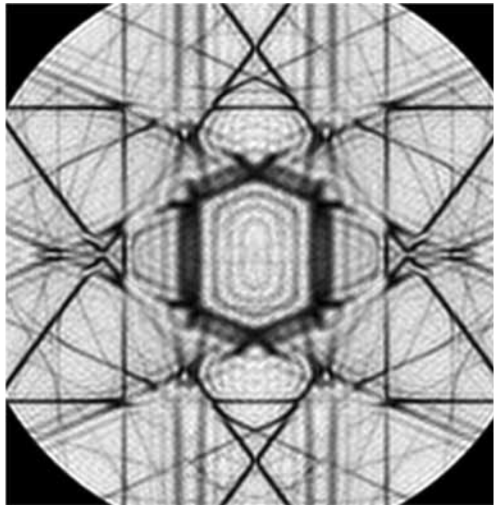


Image 2: Wide angle convergent beam electron diffraction on InGaAs in the [012] projection. Not only are the pictures aesthetically pleasing, the fine lines also enable scientists to determine lattice constants locally and with the greatest precision.

The hope is that TEM analysis, applied with its whole spectrum of methods, will enable researchers to delve much deeper into the processes inside battery materials in the future. Especially with the SALVE Initiative, researchers in Ulm are hoping to gain insights into the charging and discharging cycle, aging processes, diffusion and segregation processes at the atomic level.