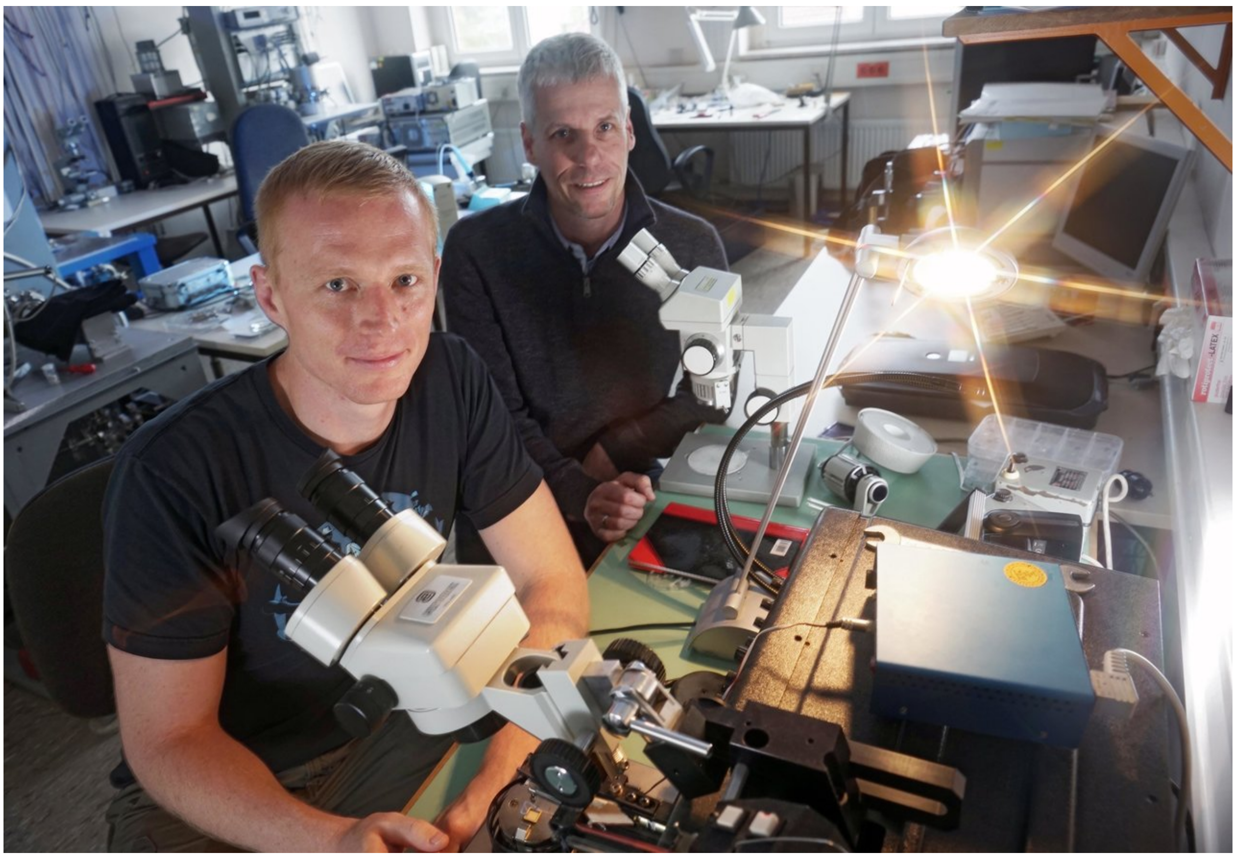
Three kinds of information from a single X-ray measurement

December 11 2017



The physicists Dr. Andreas Johannes (l.) and Professor Dr. Carsten Ronning in a laboratory at the Institute of Solid State Physics of Friedrich Schiller University Jena. Credit: Jan-Peter Kasper/FSU Jena

Whatever the size of mobile phones or computers are, the way in which such electronic devices operate relies on the interactions between materials. For this reason, engineers as well as researchers need to know exactly how specific chemical elements inside a computer chip or a transistor diode behave, and what happens when these elements bond. Physicists of Friedrich Schiller University Jena, Germany, have now developed an innovative method that enables them to obtain several different types of information simultaneously from the interior of a nanoscale building block—and this while it is in the active state. The researchers from Jena and their partners have reported their findings in the current issue of the specialist journal *Science Advances*.

"Using our method, we can obtain information at one and the same time about the elements' composition—the fraction between the elements; about their oxidation grade, which means their valence state or the nature of the bond; and finally, about internal electrical fields that have thus been created," explains Prof. Dr Carsten Ronning of the University of Jena. "These are all elementary indicators for the component's function," adds Ronning, who heads the project. However, in the procedure developed by the physicists, the components investigated do not have to be elaborately prepared or possibly even destroyed. "In principle, we can X-ray the diodes of a mobile phone while it is switched on, without damaging it," says Ronning.

X-ray beam from the particle accelerator

A decisive feature of the research approach is a very finely focused X-ray beam, with which the Jena physicists initially X-rayed a device specially made for their experiments. "We introduced arsenic and gallium atoms into a silicon wire around 200 nanometres thick. When heated, these atoms agglomerate at one point, that is to say, they mass together, which produces a functional component," explains Prof. Ronning. "We then ran a 50-nanometre-wide X-ray beam along the wire, thus irradiating it bit by bit."

The researchers established that this arrangement mixture of materials, similar to a solar cell, converted the X-rays into electric current, which flowed only in one direction, as in a diode. In this way, the researchers made the essential internal electrical fields visible. In addition, the component emitted light. "The X-rays excite the atoms in the building block, which emit a characteristic radiation," explains Dr Andreas Johannes, who conducted the experiments. "In this way, we obtain a spectrum, which gives us valuable information about the individual elements present and their relative ratios." If the energy of the X-rays is altered, so-called X-ray absorption spectra are produced that enable researchers to make assertions regarding the oxidation grade of the elements—and by extension, regarding the bonds themselves.

"Now, it is possible to obtain all these types of information through one measurement by using our method," says Andreas Johannes. Although comparable results are possible using electron microscopy, in these cases, the devices have to be specially prepared and possibly destroyed, as the penetration depth of the electron beam is substantially more limited. Moreover, such measurements can only take place in a vacuum, whereas the X-ray method is virtually independent of any specific environment.

Until now, such narrow X-ray beams could only be generated by particle accelerators, which is why the Jena University physicists have been working together closely with the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, to develop the new measuring method. These facilities are available to both scientific researchers and industry in order to X-ray existing components with greater precision, and above all, to try out new combinations of materials in order to create better performing components. "For example, our method can be of value in developing new batteries," says Andreas Johannes. "Because researchers would also like to examine these, especially while in use and fully operational, for example to determine the oxidation grades of the elements."

More information: Andreas Johannes et al. In operando x-ray imaging of nanoscale devices: Composition, valence, and internal electrical fields, *Science Advances* (2017). DOI: 10.1126/sciadv.aao4044

Provided by Friedrich Schiller University of Jena