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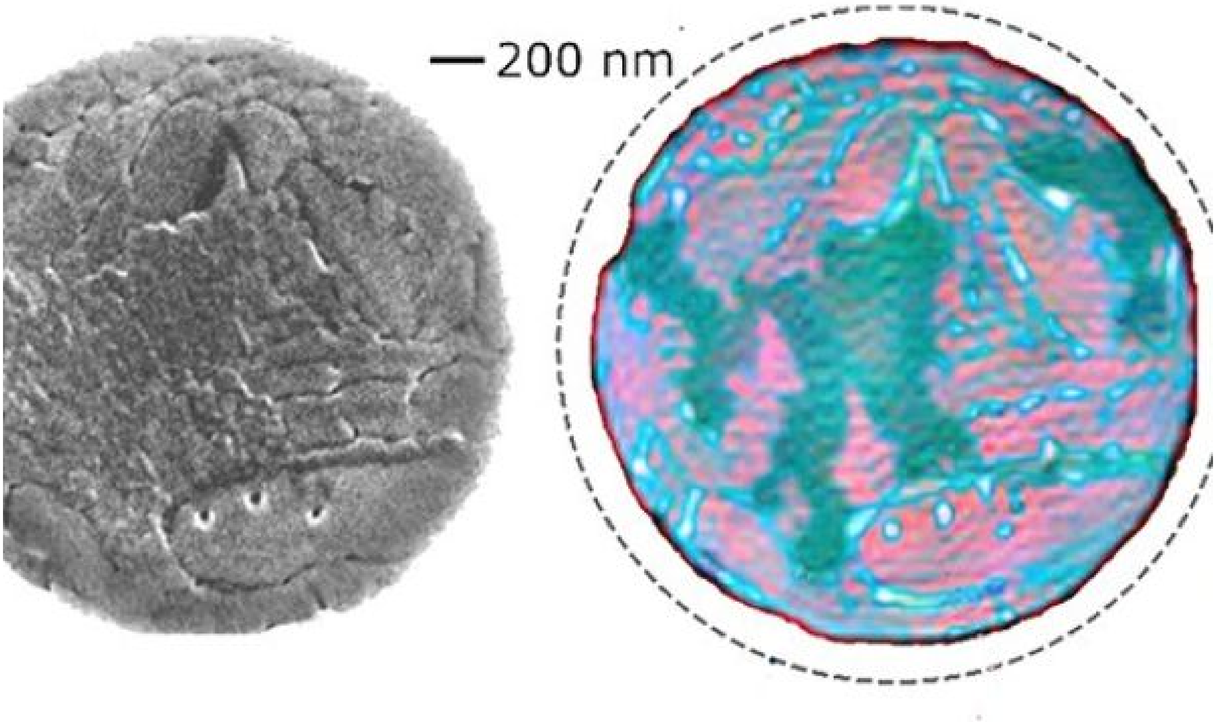

Multicolor X-ray imaging gives amazing insights to quantum materials

An international team of researchers reports in Science Advances on an imaging technique that could allow to see nanoscale phases transitions in quantum materials.

August 11, 2021

X-rays are such a powerful tool for imaging objects. But while X-rays themselves are fantastic due to their short wavelengths, the optics we use to manipulate them are the real limiting factor. To overcome this, scientists developed lensless imaging methods. Instead of using a lens to gather light and send it to a camera, they capture the scattered light from the object and analyse it by using a computer to act as the lens, with algorithms turning the scattered light back into a crisp image.

Lensless cameras and shadows

Although fantastic as it may seem, there have been limitations with this lensless technique. A routine method called holography, works by casting shadows onto the detector. Numerical processing then can tell you where those objects are. If you only want to know the shape and position of the objects, this is fine but, just like in Plato's cave, a shadow can easily misinterpreted. When you do not know the makeup of the object you are trying to see it can be hard to interpret. This is exactly the problem faced when trying to understand the properties of quantum materials. These are materials that exhibit spectacular properties like superconductivity, but are still poorly understood. One of the reasons is that they show nanoscale phase separation, where the same material can exhibit different properties at different points in space. Key to understanding these materials is being able to observe and interpret the coexisting phases in these materials with high spatial resolution.

In a study recently published in Science Advances, ICFO researchers Dr. Allan Johnson, Jordi Valls, Dr. Luciana Vidas, Daniel Perez-Salinas, led by ICFO Prof. Simon Wall, in collaboration with researchers from Max Born Institute, Technical University Berlin, Vanderbilt University and Aarhus University recently made a breakthrough in lensless X-ray nanoscale imaging, enabling them to unambiguously interpret the shadows clearing up the picture for quantum materials.

Coherence and multi color X-ray images

In their work, the team of researchers pioneered a new technique named coherent diffractive imaging spectroscopy. Instead of imaging at one colour in the X-ray spectrum, they collected a whole stack of images in a range of different X-ray frequencies, which coincided with specific absorption properties of the material. They then built up a hyperspectral image where they were able to identify which object was related to each pixel. Instead of looking at silhouettes, as conventional lensless technique often do, they were able to see the sample in full technicolour light.

As Dr. Allan Johnson recalls, **ï¿½It wasn't as straightforward as it sounds. Coherent diffracti e imaging requires light with a particular property called coherence, essentially how we l behaved each part of the beam is compared to the other parts. Lasers are nearly perfect y coherent, lightbulbs are nearly totally incoherent, but our best X-ray sources, synchrotron , are somewhere in betweenï¿½**What was outstanding is that ...ï¿½**The COVID lockdown actually gave us all the time we needed to work out the kinks in the reconstruction processes and be able to adapt the algorithms to handle this in order to get good images back; if we hadn't been confined at home for over 8 weeks, we might have never been able to achieve these resultsï¿½.**

A surprise to all eyes

For such experiment, the team used vanadium dioxide (VO2) since it is used to make nanoscale optical switches that show nanoscale phase transitions after being excited by light or heated. When looking at the sample during heating, they saw several surprising things. Firstly, the material switched locally on the nanoscale in a direct transition from the insulator to the metallic state. As Prof Simon Wall emphasized, **ï¿½Many works have taken indire t evidence to suggested that an intermediate state, with the structure of the insulating stat , but with the properties of the metallic phase might appear on the nanoscale, but by looki g directly we can confirm that this does not happeniï¿½**Secondly, and contrary to their expectations, observations with the technique revealed that what seemed to be pure VO2 turned out to have considerable amounts of V2O5 in it, which could be indicative of the manufacture challenges and failures when developing nanoscale optical switches with this material, since V2O5 does not act as an optical switch.

The results of the work signify a great step forward in the development of hyperspectral imaging techniques, in particular, in monitoring and obtaining detailed information on the phase transitions of different materials. This discovery paves the way to using this technique to try and observe new exotic material phases and transient phases in a quantum material, something that has never been achieved before.

Caption: Hyperspectral imaging of a vanadium thin film. The right image is a scanning electron microscopy image compared to a false composite coherent diffractive image that shows the mixture of V2O5 in VO2, proving that the material is not pure VO2.

Acknowledgments: This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 Research and Innovation Programme (grant agreement no. 758461) and under the Marie Sk?odowska-Curie grant agreement no. 754510 (PROBIST) as well as the Ministry of Science, Innovation and Universities (MCIU), State Research Agency (AEI), and European Regional Development Fund (FEDER) PGC2018-097027-B-I00 and was supported by Spanish MINECO (Severo Ochoa grants SEV-2015-0522 and SEV2015-0496) as well as Fundacio Privada Cellex and CERCA Programme/Generalitat de Catalunya. L.V. acknowledges financial support by the HZB. Research at Vanderbilt was supported by the NSF EECS-1509740.