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#### Denver X-Ray Conference Awards (August 9, 2023)

The following awards were presented during the 72<sup>nd</sup> Annual Denver X-Ray Conference, held August 7-11 at The Westin Chicago Lombard, Lombard, Illinois, USA. The Barrett Award, given biennially to recognize the outstanding contributions to the field of powder diffraction, was presented to Dr. Ashfia Huq (Sandia National Laboratories, USA) for her commitment to and leadership in the advancement of spallation neutron powder diffraction, and for her service to the neutron powder diffraction community. The Jenkins Award, given biennially to recognize scientists who exhibit lifetime achievement in the advancement of the use of X-rays in materials analysis, was presented to Dr. Tim Elam (University of Washington, USA) for his contributions to X-ray fluorescence spectrometry in the development of instrumentation and methods of X-ray analyses in challenging environments, including the PIXL micro-XRF spectrometer on the Mars rover Perseverance. The award also recognized his many contributions to educating and teaching others in the field of X-ray spectroscopy. The Hanawalt Award, recognizing distinguished, recent work in the field of powder diffraction, was presented to Dr. Karena Chapman (Stony Brook University, USA) for her contributions in developing X-ray diffraction capabilities in the study of challenging materials problems in sustainable energy and environmental remediation. For more information, visit the Web page, http://www. dxcicdd.com/

# The 17<sup>th</sup> Asada Award (october 21, 2023)

The recipient of the 17<sup>th</sup> Asada Award, which is presented by the Discussion Group of X-ray analysis, Japan, in memory of the late Professor Ei-ichi Asada (1924– 2005) to promising young scientists in X-ray analysis fields in Japan, is Hitomi Nakano (Horiba Techno Service Co., Ltd.), "Optimization of X-ray optical system in microscopic X-ray fluorescence analyzer and application to internal non-destructive analysis"). The ceremony was held at Tokyo City University during the 59<sup>th</sup> Annual Conference on X-Ray Chemical Analysis.

How to cite this article: K. Sakurai, *X-Ray* Spectrom 2024, 53(1), 87. <u>https://doi.org/10.1002/</u> <u>xrs.3413</u>

Check for updates

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## First beam at the Japan's new synchrotron (December 7, 2023).

The first beams have been successfully observed at the BL13U and BL10U undulator beamlines of NanoTerasu, Japan's new 3 GeV synchrotron source currently under construction at the Aobayama campus of Tohoku University in Sendai, Japan. The facility is scheduled to officially open in April 2024. For more information, visit the Web page, https://nanoterasu.jp/

How to cite this article: K. Sakurai, *X-Ray* Spectrom 2024, 53(2), 159. <u>https://doi.org/10.1002/</u> xrs.3419

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#### Deciphering Burnt and Carbonized Scroll Books with Deep Learning-Assisted X-ray Imaging (February 5, 2024).

There is a program called the Vesuvius Challenge in which investors are funding the deciphering of what was written in the extremely fragile scrolls that were carbonized when Mount Vesuvius erupted in 79 A.D., some 2000 years ago (https://scrollprize.org/). Pompeii is famous for the eruption of Mount Vesuvius, which was buried by volcanic ejecta, etc. Not only Pompeii, but also towns near Mount Vesuvius were buried in the same way. The city of Herculaneum is one of them. The scrolls discovered in Herculaneum in the 1750s are one of the most important research subjects. Looking back in history, one would immediately think of using nondestructive methods of analysis such as X-rays, but in the days before the discovery of X-rays, this was obviously not possible. The method of dismantling the scrolls was unavoidable, and it seems that actual dismantling was done. Afterwards, they were probably restored by hand, but it is still difficult to read the text on them. In 2015, other ancient scrolls, though not from the Vesuvius eruption, were successfully read by X-ray imaging without touching them at all. A commercially available micro X-ray CT device was used (for details, see the paper, William Brent Seales, Clifford Seth Parker, Michael Segal, Emanuel Toy, Pnina Shor, and Yosef Porath, "From damage to discovery via virtual unwrapping: reading the scroll from En-Gedi", Science Advances, 2, e1601247 (2016). https://doi.org/10.1126/sciadv.1601247). Using X-ray imaging, it is possible to read the inside of a scroll-like book without touching it to open it and reveal its contents.

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The Vesuvius Challenge program appears to have been inspired by this 2015 success story. Furthermore, while X-ray CT simply images three-dimensional electron density contrasts, deep learning techniques can be used to read text from them (for details, see the paper, Yannis Assael, Thea Sommerschield, Brendan Shillingford, Mahyar Bordbar, John Pavlopoulos, Marita Chatzipanagiotou, Ion Androutsopoulos, Jonathan Prag and Nando de Freitas, "Restoring and attributing ancient texts using deep neural networks", Nature 603, 280–283 (2022). https://doi.org/10.1038/s41586-022-04448). Recently, the Vesuvius Challenge experiment was conducted using the imaging beamline of the Diamond Light Source synchrotron radiation facility in the UK to collect a large number of 3D CT images of carbonized scrolls. Deep learning was used to decipher the text.

Eventually, the first success was achieved, although only a small part of the text was deciphered. What was written on the scroll turned out to be a philosophical statement about sensation and pleasure. It was announced that three 21-year-old graduate students from Egypt, Switzerland, and the U.S. were awarded \$700,000 for their success in using X-rays to decipher what was written in such extremely fragile ancient burnt scrolls. For more details, see the article "First passages of rolledup Herculaneum Scroll revealed", Nature 626, 461–462 (2024). https://doi.org/10.1038/d41586-024-00346-8

How to cite this article: K. Sakurai, *X-Ray* Spectrom 2024, 53(3), 212. <u>https://doi.org/10.1002/</u> xrs.3424

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#### X-RAY SPECTROMETRY WILEY

#### New phase of X-ray lasers (May 1, 2024)

Recently, an article on the latest advances in X-ray lasers was published. It summarizes the progress of X-ray freeelectron lasers (XFELs) to date, following the launch of Stanford's LCLS-II, California, USA in August 2023 and the subsequent success in ultra-short time analysis on the order of attoseconds (see, e.g., Shuai Li et al, "Attosecond-pump attosecond-probe X-ray spectroscopy of liquid water," *Science*, 383, 1118–1122 (2024). https://doi.org/10. 1126/science.adn6059; S. Severino et al., "Attosecond core-level absorption spectroscopy reveals the electronic and nuclear dynamics of molecular ring opening," *Nature Photonics* (2024). https://doi.org/10.1038/s41566-024-01436-9).

With the introduction of the LCLS-II, the pulse width of the XFELs is now 1/1000 of their original value, that is, less than one femtosecond, and the time resolution is in the attosecond range. This has made it possible to provide answers to scientifically important open questions about the H<sub>2</sub>O molecules by analyzing them for such ultra-short periods of time that they appear to be almost stationary. These capabilities are extremely competitive and attractive compared to any other measurement technique. Not only the pulse width, but also the repetition frequency of the X-ray pulses is important for the actual measurement time required for a single pump-and-probe experiment. What was initially in the order of 10 Hz is now in the kHz range and is expected to be in the MHz range in the future, leading to a reduction of the measurement time by orders of magnitude. In other words, more data can be obtained with the same beam time as before, increasing the potential for significant advances in research. In addition, the kHz to MHz repetition rate of the pulsed X-ray laser makes it possible to distribute the X-ray pulses over a large number of beamlines by switching the pulses one after the other. In the future, the XFEL facility could therefore be equipped with many beamlines, like a synchrotron radiation ring, and X-ray lasers will be used by many more users.

The performance of the new XFELs is largely due to innovations in their accelerator technologies, in particular the niobium-based superconducting accelerating cavity. Until now, conventional technologies have struggled to pack so much power per pulse, and there are obvious limits to increasing the repetition rate. However, the use of superconductivity now consumes less power than conventional technologies, no matter how much the repetition rate is increased. There are two X-ray free-electron lasers in the world that use superconducting accelerating cavities: LCLS-II and the Euro XFEL in Hamburg, Germany, and China is currently building the world's third such facility.

It is well known that Japan, Korea, Switzerland, and Sweden use normal conducting copper accelerating cavities. In the context discussed so far, high repetition rate and ultrashort pulses are undoubtedly wonderful. Although not mentioned in the article, there are several other possible applications of XFELs besides attosecond structure analysis and spectroscopy, such as X-ray photon correlation spectroscopy, coherent diffraction imaging, various types of nonlinear optics experiments, and X-ray spectroscopy with controlled inner-shell levels and lifetimes. It would be possible to find solutions to problems such as the atomic-level structure of materials that have been lumped together under the term "amorphous" simply because sharp peaks are not observed in conventional X-ray diffraction patterns. Some detailed discussions of the physical atomic-scale shape of surfaces and interfaces can also be resolved. Some XFELs are considerably smaller than LCLS-II and the Euro XFEL. In the case of Japan's SACLA, the facility can also serve as an injector for a storage ring for synchrotron radiation experiments. Such a feature makes it easy to pursue integration with conventional synchrotron radiation experiments and X-ray laser experiments. In addition, X-ray lasers that do not use accelerators are making significant progress. This would also be important for many fields of research.

Of course, it is very significant that LCLS-II has been a great success and has a lot of potential, and we are entering an era where X-ray lasers will have a stronger presence in the future. For more information, see the article, Edwin Cartlidge, "New Era for X-Ray Lasers," *Optics and Photonics News*, 35 (5), 28–35 (2024). https://opg.optica.org/opn/viewmedia.cfm?uri=opn-35-5-28&seq=0 (Open Access, free to read in full).

# New exciting 2D material made of single atomic layer of gold (April 16, 2024)

2D materials have been one of the most important research topics in materials science since the discovery of the unexpected exotic properties of graphene. They are also expected to have a variety of applications, such as catalysts that effectively detoxify toxic substances or sensors with ultra-high sensitivity. Goldene is a 2D material composed of gold atoms and is, so to speak, a gold version of graphene. A research group at Linköping University in Sweden recently succeeded in creating a single atomic layer of gold. Although there have been other reports of two or more atomic layers, this is the first report of single atomic layer gold. The research team chose Ti<sub>3</sub>SiC<sub>2</sub> as the starting material and replaced Si in  $Ti_3SiC_2$  with Au, then the material becomes like  $Ti_3AuC_2$ . Next, Ti<sub>3</sub>C<sub>2</sub> was removed by wet chemical etching, resulting in the success of extracting only gold with a single atomic layer thickness. Ti3SiC2 is known as one of another interesting group of materials, the so-called MAX phase (M is mainly transition metals, such as Ti, V, Cr, etc., A is elements of groups IIIA and IVA of the periodic table, such as Al, Si, Ga, Ge, etc., and X is nitrogen or carbon). This property is also interesting (see, e.g., Sowmya Arunajatesan and Altaf H. Carim, "Synthesis of Titanium Silicon Carbide," Journal of the American Ceramic Society, 78, 667–672 (1995). https://doi.org/10. 1111/j.1151-2916.1995.tb08230.x). It has been noted that electron microscopic observations of single atomic layer gold show that the interatomic distance has shrunk by about 9% compared to three-dimensional gold crystals. Also, the Au 4f binding energy from photoelectron spectroscopy has increased by 0.88 eV. Perhaps more interesting details will be revealed in the future by X-ray spectroscopy and various other analytical methods. For more information, see the paper, S. Kashiwaya et al., "Synthesis of goldene comprising single-atom layer gold," Nature Synthesis (2024). https://doi.org/10.1038/s44160-024-00518-4.

#### In vivo investigation of nanoparticles in the body by laboratory XRF imaging (March 22, 2024)

Nanoparticles have often been used to deliver drugs and other substances to specific sites in the body. In reality, however, the delivery rate is low because the particles stop at other sites or accumulate in different organs. Recently, a Swedish research group showed how laboratory-based X-ray fluorescence imaging can help solve this problem. A 24 keV microbeam X-ray beam is scanned over the entire body of an animal injected with a X-RAY SPECTROMETRY-WILEY

nanoparticle drug to detect X-ray fluorescence from the metallic nanoparticle. The beam size is 200 microns square. Mice are used as samples in this study. Although not explicitly stated in the paper, 24 keV would be the  $K_{\alpha}$ radiation from In, contained in a liquid metal jet X-ray source. The nanoparticles contain Mo, and the Mo Ka X-rays are imaged. The study claims to have established a methodology for rapid iterations in the preclinical evaluation of contrast agents using X-ray fluorescence spectra and X-ray fluorescence computed tomography (CT) imaging. Compared to other imaging techniques, X-ray fluorescence imaging is considered highly promising because it is essentially artifact-free and, in the present system, has virtually no escape depth constraints. They have also been able to study the effects of macrophage depletion on the biodistribution of nanoparticles. For more information, see the paper, Giovanni M. Saladino et al., "Iterative nanoparticle bioengineering enabled by X-ray fluorescence imaging", Science Advances, 10, eadl2267 (2024). https://doi.org/10.1126/ sciadv.adl2267.

# Multimodal X-ray imaging of single cell (March 7, 2024)

For many years, a large number of biological research using X-ray imaging have been reported. However, many of them are a kind of stand-alone applications of specific X-ray imaging technique. Integrated interpretations of images obtained by these more than two techniques for the same sample have been quite rare. Recently, at the NSLS-II synchrotron radiation facility at Brookhaven National Laboratory in the United States, a new method for the analysis of single biological cells has been presented that focuses on the correlation between elementspecific 2D X-ray fluorescence image data and 3D X-ray CT image data.

The sequence of schemes presented in this study is as follows. First, techniques for chemical fixation and preservation of living cells and freeze-drying techniques were introduced to avoid the risk of radiation damage. Second, to correlate the two imaging techniques, the observation field of view is established and labeling is performed to identify the positional relationship. Third, image reconstruction calculations including correlation information are performed. For the same cell, 3D visualization of the overall and cellular structure including intracellular organelles by X-ray CT (using 7 keV monochromatic X-rays with a spatial resolution of about 30 nm) and 2D imaging of the distribution of the six elements Ca, Cl, Cu, Fe, P, and Zn by X-ray fluorescence imaging (using 12 keV monochromatic X-rays with a beam size of about

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100 nm) were performed. The correlation of this information will help elucidate the role of each element and associated proteins in cellular structure, signal transduction, and other biological processes. In this research, attention is paid to the risk of radiation damage from intense synchrotron radiation, the effects of which are assessed from X-ray CT images, and the conditions under which such effects can be avoided are discussed. Experiments using synchrotron radiation have traditionally tended to neglect such aspects. It is considered an important direction to elucidate the biological function (or chemical function if the target is a chemical material) by correlating such multiple images. For more information, see the paper, Zihan Lin et al., "Correlative single-cell hard X-ray computed tomography and X-ray fluorescence imaging", *Communications Biology*, 7, 280 (2024). https:// www.nature.com/articles/s42003-024-05950-y.

**How to cite this article:** K. Sakurai, *X-Ray* Spectrom **2024**, *53*(4), 294. <u>https://doi.org/10.1002/</u> xrs.3437

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#### Semantic Segmentation of X-Ray CT Images (June 21, 2024)

The technology of semantic image segmentation, which is considered essential for so-called automated driving, in which cars and other vehicles are driven unmanned or nearly unmanned, is now being used in a wide range of other fields. Recently, a research group at the Ruprecht-Karls-University in Heidelberg, Germany, developed a tool for automated interpretation of X-ray CT images of biological samples. Although much of the interpretation of X-ray CT images is still done manually, a transition may be coming in the not-too-distant future. In this study, they developed a threedimensional cytoplasmic segmentation model, ACSeg, and trained it on X-ray CT images of 43 immune T cells and six other cell types to segment X-ray CT images of unknown samples. This enabled high-throughput analvsis of cell volume and cytoplasmic structure in multiple cell types. In this research, the target images are biological cells, but it is possible that almost the same technique could be applied to industrial materials. For more information, see the paper by Ayse Erozan, Philipp D. Lösel, Vincent Heuveline and Venera Weinhardt, "Automated 3D cytoplasm segmentation in soft X-ray tomography Automated 3D cytoplasm segmentation in soft X-ray tomography", iScience, 27, 109,856, (2024). https://doi.org/10.1016/j.isci.2024.109856.

It may be useful for the reader to know that essentially the same method has been well applied to the automatic interpretation of particle shape and size in electron microscope images. See, for example, Jonas Balsa and Matthias Epple, "Deep learning for automated size and shape analysis of nanoparticles in scanning electron microscopy", RSC Adv. 13, 2795-2802 (2023). https://doi.org/10.1039/D2RA07812K; Rashad Baiyasi, Miranda J. Gallagher, Lauren A. McCarthy, Emily K. Searles, Qingfeng Zhang, Stephan Link, and Christy F. Landes, "Quantitative Analysis of Nanorod Aggregation and Morphology from Scanning Electron Micrographs Using SEMseg", J. Phys. Chem. A, 124, 5262-5270 (2020). https://doi. org/10.1021/acs.jpca.0c03190.

#### Glass-Ceramic Scintillators for X-Ray Imaging (May 21, 2024)

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A research group at Northwestern Polytechnical University in China has recently developed film-like glassceramic scintillators suitable for X-ray imaging applications. The new scintillators are film-like materials (typically 0.25 mm thick) in which CsPbBr<sub>3</sub> nanocrystals (typically 400-500 nm rectangular per side) are dispersed in a polymethyl methacrylate (PMMA) polymer matrix. The fabrication method has been disclosed in detail, and the data of all materials prepared under different conditions are systematically compared and discussed. The emission wavelength of the phosphor, CsPbBr<sub>3</sub> nanoparticles, is about 520-530 nm (green). Upon cooling, the band gap decreases and both the emission wavelength and the emission lifetime change. While a rather long luminescence lifetime is acceptable for use as a fluorescence plate for X-ray imaging, a short lifetime (= fast response time) is extremely important for counting applications. The luminescence lifetime is 550 nsec at room temperature, but it is about 250 nsec at about 270 K (close to that of NaI:Tl, a typical X-ray scintillator for laboratory X-ray diffractometers), about 50 nsec at about 220 K (close to that of YAG:Ce, a rather fast X-ray scintillator), and several tens of nsec. As an example of an X-ray imaging application, an X-ray beam is passed through the sample, a glass-ceramic scintillator film is placed behind it, a mirror is used to reflect its fluorescent image at 90°, and a separately prepared camera is used for recording. The spatial resolution obtained in this experiment was 13.9 LP/mm, which is about 30 µm in line width. The research group plans to mount this glass-ceramic scintillator film directly on top of a silicon photodiode array and use a TFT sensor to image the image, rather than the indirect method described above. For more information, see the paper by Ruizi Li, Weiguo Zhu, Haoyang Wang, Yitong Jiao, Yuan Gao, Ruikun Gao, Riheng Wang, Hongxiao Chao, Aimin Yu, and Xiaowang Liu, "Ultrastable and flexible glass-ceramic and flexible glass-ceramic scintillation films with reduced light scattering for efficient X-ray imaging", npj Flex. Electron. 8, 31 (2024). https://doi.org/10.1038/s41528-024-00319-x.

#### Radiation Imaging Detectors Inspired by Tetris Game (April 9, 2024)

Gamma-ray cameras and similar radiation imaging devices that can measure the location and distribution of radioactive materials released into the environment are valuable tools in the event of a nuclear disaster. A research group at the Massachusetts Institute of Technology in the United States has recently developed a unique technology that may be effective for such applications. It is a unique radiation imaging technique inspired by the tetromino shapes in the classic video game Tetris. The detector has only 4 pixels but can process the data using machine learning algorithms to create a map of the radiation source.

The tetromino figure consists of four squares of the same size connected at their edges. There are five types of tetromino shapes, called  $2 \times 2$ , J, T, S, and I, where the shapes that become the same by rotation and mirroring operations are considered identical. Tetris is a game in which these tetromino shapes are combined to form a sequence of shapes. The idea is that a tetromino shape detector can achieve the same level of accuracy as a detector with a much larger square array. The I shape is excluded because it is one-dimensional and has little directional dependence. In the construction of this 4-pixel tetromino shape detector, the boundary part is firmly divided with lead to make it easy for each pixel to have a clear azimuthal dependence. A machine learning algorithm was developed to extract more accurate information about the direction of incidence of the radiation and the distance between the detector and the radiation source. The experiment was performed at Lawrence Berkeley Laboratory using a <sup>137</sup>Cs radiation source and moving the newly developed Tetris-type 4-pixel detector in a circular motion around the source. The results show that the spatial distribution is comparable to or better than that obtained with conventional pixel detectors. For more information, see the paper by Ryotaro Okabe, Shangjie Xue, Jayson R. Vavrek, Jiankai Yu, Ryan Pavlovsky, Victor Negut, Brian J. Quiter, Joshua W. Cates, Tongtong Liu, Benoit Forget, Stefanie Jegelka, Gordon Kohse, Lin-wen Hu, and Mingda Li, "Tetrisinspired detector with neural network for radiation mapping", Nat. Commun., 15, 3061 (2024). https://doi.org/10. 1038/s41467-024-47338-w.

#### Latest Self-Driving Laboratories (February 27, 2024) Self-Driving Laboratories are systems that automatically conduct research, particularly in synthetic chemistry and

materials engineering, with the goal of significantly accelerating the development of new materials in companies, universities, and public institutions by making full use of AI and robotics technologies. With AI already beginning to permeate the business world, especially in large urban areas in the United States, and in the early stages of streamlining the work of professional office workers, previously considered a high-paying, elite occupation, applications such as automated driving labs are likely to spread to a wide variety of places within a few years or less. Once the properties and functions are defined as targets, the AI proposes the candidate groups of the best materials with a prioritized list of recipes for their synthesis. There have been many attempts reported using databases (https://next-gen. materialsproject.org/materials/gnome and https://github. com/google-deepmind/materials\_discovery etc.). Since 2023, such system has become more advanced by using Large Language Models (LLMs), which makes the process interactive. The remaining work is the actual synthesis of the materials, which has long been done by scientists and engineers with some training, but the self-driving laboratories are designed to automate this part of the process by using robotics. Progress is rapid. For more information, see the following papers: J. A. Bennett et al., "Autonomous Reaction Pareto-Front Mapping with a Self-driving Catalysis Laboratory," Nat. Chem. Eng., 1, 240-250 (2024). https://www.nature.com/articles/s44286-024-00033-5; Amanda A. Volk et al., "Performance metrics to unleash the power of self-driving labs in chemistry and materials science. Performance metrics to unleash the power of self-driving labs in chemistry and materials science," Nat. Commun., 15, 1378 (2024). https://doi.org/10. 1038/s41467-024-45569-5; Gary Tom et al., "Self-Driving Laboratories for Chemistry and Materials Science," https:// doi.org/10.26434/chemrxiv-2024-ri946; N. Szymanski et al., "Autonomous and dynamic precursor selection for solidstate materials synthesis," Nat. Commun., 14, 6956 (2023). https://doi.org/10.1038/s41467-023-42329-9; A. Merchant et al., "Scaling deep learning for materials discovery," Nature 624, 80-85 (2023). https://doi.org/10.1038/s41586-023-06735-9; N. Szymanski, et al., "An autonomous laboratory for the accelerated synthesis of novel materials," Nature 624, 86-91 (2023). https://doi.org/10.1038/s41586-023-06734-w.

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How to cite this article: K. Sakurai, X-Ray Spectrom 2024, 53(5), 430. https://doi.org/10.1002/

xrs.3445

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#### NEWS

### **News Article**

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Accepted: 18 September 2024

#### 1 | 3D Stress Mapping of Plastically Deformed Metallic Materials Using X-Rays (August 30, 2024)

A joint research team from the Technical University of Denmark, Lund University in Sweden and the European Synchrotron Radiation Facility (ESRF) has developed a non-destructive method for mapping the three-dimensional stress distribution inside plastically deformed metallic materials using x-rays. The sample studied is a plastically deformed polycrystalline aluminum alloy AA1050. The experiments were performed at the ESRF synchrotron beamline ID11 using 48.5 keV microbeam x-rays  $(3\mu m \times 3\mu m)$  and the sample was mounted on a device integrating a tensile tester and a diffraction goniometer. Using the Debye-Scherrer camera principle, x-ray diffraction spots from the sample are recorded by a two-dimensional x-ray detector. The stress-strain curve of the AA1050 alloy is measured in situ and the relationship between deformation and fracture is studied under plastic deformation conditions, where a load of approximately 85 MPa is applied and the alloy is elongated by 32%, which is close to the ultimate elongation. Microbeam xrays are scanned over the sample in the XY direction to obtain x-ray diffraction data for many different points on the sample. In addition, a rotational scan is performed to collect data at many different projection angles, even at the same point of x-ray exposure. Thus, using the same image reconstruction method as x-ray computed tomography, three-dimensional data on crystal structure and stress distribution can be obtained.

Although similar experimental studies have been performed in the past, most of them have been limited to the study of the macroscopic stress distribution. As a result, in the case of large plastic deformation, x-ray diffraction patterns from different parts of the sample overlap, making it difficult to interpret the data correctly. One of the key points of this study was the use of microbeams, which allowed us to separate the stress distributions of different grains. For more information, see the article, A. Henningsson, M. Kutsal, J. P. Wright, W. Ludwig, H. O. Sørensen, S. A. Hall, G. Winther, and H. Poulsen, "Microstructure and Stress Mapping in 3D at Industrially Relevant Degrees of Plastic Deformation," *Scientific Reports* 14 (2024): 20213, https://www.nature.com/articles/s41598-024-71006-0.

## 2 | Machine Learning Improves Image Quality in XAFS Imaging (June 18, 2024)

XAFS imaging is one of the most popular methods in synchrotron radiation experiments. In particular, by focusing on chemical shifts at the absorption edge, it can visualize differences in chemical states, such as the valence of elements in a sample, and is often used to obtain useful information in chemistry and materials science. Currently, many synchrotron radiation facilities around the world are equipped with transmission x-ray microscopes and beamlines for nanobeam XAFS imaging. The transmission x-ray microscopes used in modern XAFS imaging are projection-type microscopes that acquire information over the entire field of view at once, rather than scanning-type microscopes that scan each point of the sample. While this method is very good, it does not always produce satisfactory images when analyzing real samples. A research group at the NSLS-II synchrotron radiation facility at Brookhaven National Laboratory in the United States has developed a method to overcome such problems and greatly improve the image quality of chemical state imaging by XAFS. At their beamline, a single exposure on the order of 0.01s is used to take a snapshot of the absorption contrast image of a sample in the field of view, and the imaging is repeated while sweeping the incident x-ray energy near the absorption edge of an element. These data can be acquired rapidly with a spatial resolution of 20-30 nm over a field of view of up to several hundred microns. Tools for data analysis are publicly

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available. (See the article, M. Ge and W.-K. Lee, "PyXAS—An Open-Source Package for 2D x-ray Near-Edge Spectroscopy Analysis," *Journal of Synchrotron Radiation* 27 (2020): 567–575, https://doi.org/10.1107/S1600577520001071).

One of the practical problems with XAFS imaging is that the goal of high spatial resolution with a large number of pixels to obtain excellent quality images results in a significant reduction in signal-to-background per pixel. These problems were well-known before the advent of nanobeam and other advanced optical devices. They are particularly severe for relatively low concentrations of elements in the sample. In some cases, the samples that could be measured were limited, or compromises had to be made in the images and quantitative information that could be obtained. In this study, we focused on the statistical variation due to inhomogeneity of the beam profile and low counts as the main causes of image quality degradation. Since normalizing the data as it is under these conditions is likely to result in large errors, a new normalization method using deep learning was introduced. Since XAFS is a spectral change when the incident energy is varied, each pixel in an XAFS image also spans a series of images and should have XAFS information. Although each acquired image is separate data and can be degraded by statistical variations due to inhomogeneities in the beam profile and small counts, since pixels at a given coordinate across a series of images have fixed XAFS spectral information, each image data are actually not independent, but rather in a certain mutually constrained relationship. Therefore, the research group performed processing using deep neural networks, which are trained to take into account information about physical properties, such as the shape of the spectra for each element and chemical state.

In this study, the LiNi<sub>x</sub>Mn<sub>y</sub>Co<sub>1-x-y</sub>O<sub>2</sub> system, a model sample of battery materials, is used as a material and it is shown that the valence of Ni and Co can be evaluated with high confidence. For more information, see the article, Z. Li, T. Flynn, T. Liu, S. Liu, W.-K. Lee, M. Tang, and M. Ge, "Highly Sensitive 2D X-Ray Absorption Spectroscopy via Physics Informed Machine Learning," *npj Computational Materials* 10 (2024): 128, https://www.nature.com/articles/s41524-024-01313-7. The source code for this data processing is included in the PyXAS public package. https://github.com/gmysage/pyxas.

#### 3 | X-Ray Tomography With 4 nm Resolution (July 31, 2024)

X-ray tomography is a technique that uses mathematical operations to create a three-dimensional image of the electron density distribution inside an object based on a large number of images taken by irradiating the object with x-rays. Fifty-three years ago, in 1971, Godfrey Hounsfield, an electrical engineer at EMI in England, performed the world's first 3D x-ray imaging of the brain at Atkinson Morley Hospital in London (for more details, see the article, J. Boone and C. McCollough, "Computed Tomography Turns 50," *Physics Today* 74, no. 9 (2021): 34, https://physicstoday.scitation.org/doi/10.1063/PT.3.4834). The spatial resolution of early x-ray tomography was very limited by today's standards. The optical elements used to focus and image the x-rays, and the detectors used to image the x-rays were insufficient to achieve high spatial resolution.

Today, in the 21st century, there have been very significant advances in all of these areas. The most promising modern x-ray imaging technique is now considered to be the use of coherent x-ray sources, such as ultra-brilliant synchrotron radiation or x-ray free-electron lasers, in the form of ptychographic techniques. This method is designed to achieve the highest spatial resolution, and images are obtained by phase recovery from diffracted images of the object without the use of optical elements. x-ray ptychographic tomography is a well-established 3D imaging technique capable of identifying volumes as small as a few 10 nm cubic. Recently, a team of researchers at the Paul Scherrer Institute in Switzerland achieved an even better spatial resolution, setting a new record of 4 nm.

Their work introduces two new methods: burst ptychography and tomographic back-propagation reconstruction. Burst ptychography is an ultra-fast image acquisition method with speeds of up to 14,000 images per second. This method overcomes the instability of the absolute coordinates (X, Y, Z) caused by various factors. The new spatial resolution record of 4nm can be attributed to the success of this method. Tomographic backpropagation reconstruction allows imaging of objects approximately 10 times larger than the conventional depth of field. In this study, the researchers successfully imaged integrated circuits manufactured using Intel's 7-nm process. The advantage of x-ray tomography is that it can acquire 3D images of the interior in a non-destructive manner, and each tomographic image can be evaluated without sectioning. However, its spatial resolution lagged behind that of other techniques, particularly electron microscopy. At some point, however, the spatial resolution broke through the 1-µm barrier and reached the tens of nm range, leading to many real-world applications, and since then further progress has been made to reach around 10 nm and now 4 nm. The level of difficulty may continue to increase, but the competition to reach the 1 nm barrier is likely to heat up. For more information, see the article by T. Aidukas, N. W. Phillips, A. Diaz, E. Poghosyan, E. Müller, A. F. J. Levi, G. Aeppli, M. Guizar-Sicairos, and M. Holler, "High-Performance 4-nm-Resolution X-Ray Tomography Using Burst Ptychography," Nature 632 (2024): 81-88, https://www.nature.com/articles/s41586-024-07615-6.

#### **Conflicts of Interest**

The author declares no conflict of interest.