Assessing rechargeable batteries with 3D X-ray microscopy, computed tomography, and nanotomography

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ABSTRACT

In the last three decades, significant advances have been made in rechargeable battery technologies. However, battery cell manufacturers still face quality and process control challenges when attempting to non-destructively map the microstructure of battery electrodes, their inhomogeneities, and their effect on battery ageing and performance degradation. This paper introduces workflows that combine computed tomography and 3D X-ray microscopy to generate a detailed three-dimensional visualisation of the interior of battery cells and assemblies, without destroying them, to enable the study of their internal structure before and after charging/discharging cycles. These imaging workflows can be run independently or complementary to other multiscale correlative microscopy evaluations and provide valuable insights into the inner workings of battery systems at multiple length scales, from macroscopic features on battery packs (i.e. hundreds of mm) to microscopic details in electrode materials (in the tens of nm). Understanding battery systems through X-ray imaging can speed development time, increase cost efficiency, and simplify failure analysis and quality inspection of lithium-ion batteries and other cells built with emerging new energy materials.

1. Introduction

About thirty years have passed since the first commercialisation of lithium-ion batteries (LIBs) by Sony Corporation in 1991 [1] (In 2019, the Nobel Prize in Chemistry was jointly awarded to John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino for their contributions to the development of LIBs). Today, rechargeable LIBs play an essential role in a world that relies heavily on portable electronic devices such as smartphones and laptops. Additionally, LIBs have propelled recent developments and commercialisation of electric vehicles. As more and more attention is being paid to humanity’s future energy sustainability, the electric vehicle industry is becoming the largest market for high-performance rechargeable batteries [2], to the point in which nearly every major automaker has announced a transition away from internal (petrol-powered) combustion engine cars to electric vehicles in the next ten to thirty years.

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Still, further advances in cell design and manufacturing processes are required to improve the energy density, capacity, energy storage retention, cycle performance, lifetime, and safety of rechargeable batteries. On par with the increasing demand for sustainable energy technologies and the extension of the LIB applications to transportation systems, advanced characterisation methods are required to study new energy materials, cell performance, cell degradation and other aspects that could improve battery technology.

Recently, advanced imaging techniques have become powerful tools to study and improve the performance of LIBs. The development and introduction of new materials, chemistries, and processes have brought LIB technology to where it is today. However, developing new ways of extending battery lifetime, ensuring consistently safe operation in a variety of environments, and maximising charging and discharging performance all hinge on understanding the contributions of microstructure and its evolution to battery operation. As such, advanced technologies such as 3D X-ray microscopy will play an important role in advancing the development of rechargeable batteries. While LIBs have become an important driver in the transition to a carbon-free future, methods similar to those described in this paper can certainly be applied to other battery systems, e.g. solid-state batteries built with other emerging energy materials.

Of the various techniques that can be used to image battery components (e.g. visible light, ultrasound, X-rays, electron beam, neutron beam, etc., see Figure 1), X-ray imaging is the only technique that can non-destructively inspect the interior of battery cells across multiple length scales – from centimetres (battery packs and cell-level analysis) to sub-millimeter volumes (material microstructure-level analysis)—and capture relevant

Figure 1. Techniques typically used to image LIBs, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), coherent X-ray diffraction imaging (CDI), and atomic force microscopy (AFM) (adapted from Ref. [3]): (a) wavelength and penetration depth in LIB electrodes of several information carriers; (b) resolution of various imaging techniques compared to the size scale of structural features within LIBs.
structural details with spatial resolutions ranging from several tens of micrometres down to tens of nanometres [4,5]. Although X-ray imaging techniques can be used to scan various types of batteries, for practical purposes this document limits its discussion to LIBs only.

In traditional flat panel-based X-ray systems using simple geometric magnification, which is determined by the size of the sample and the working distance from the X-ray source and detector, the high spatial resolution requirements tend to limit the size of the sample that can be scanned. Such a limitation can be overcome with the use of X-ray microscopes (XRM) that use geometric and optical magnification with “resolution-at-a-distance (RaaD)”[6,7]. This paper presents workflows for the non-destructive evaluation of the interior of battery cells, through three-dimensional (3D) images generated from computed tomography (CT) reconstructions, using high-resolution 3D XRMs with RaaD capabilities.

Section 2 presents the most common methods for inspecting batteries using 3D X-ray imaging technologies, with references to the relevant literature for further expansion by the interested reader. Section 3 presents battery inspection examples with 3D X-ray measurement workflows along with a discussion of the results. Concluding remarks are provided in Section 4. Overall, the main results presented in the article show how 3D X-ray imaging technologies enable the analysis of energy materials and electrode structures in battery cells, detailing features with scales spanning several orders of magnitude (from macroscopic features in battery packs to microscopic characteristics at the particle level).

2. Methods for battery inspection with 3D X-ray imaging technologies

Although the use of 3D X-ray imaging technologies to inspect LIBs is relatively recent, it has rapidly gained ground in recent years. Requirements for spatial resolution and sample size generally set the limits of X-ray imaging setups. While traditional flat-panel-based high-energy CTs are suitable for inspecting large battery packs and battery assemblies, they generally lack the resolution needed to inspect fine-scale features that are below 10 μm. With the addition of optical lenses after X-ray detection, 3D XRMs can overcome these challenges; however, due to power and energy limitations, higher spatial resolutions will limit the sample’s field of view. XRMs are ideal for inspecting small battery cells and components, in the 0.1 to 200 mm range, including individual electrodes and separators. This section introduces the most common laboratory setups used for 3D X-ray imaging of LIBs.

2.1. X-ray computed tomography

In traditional industrial X-ray systems, designed for non-destructive evaluation and industrial metrology tasks, the main approach has been to use projection-based architectures in which two-dimensional images are created by the projection of divergent X-ray beams passing through an object and producing radiographs on a flat-panel detector (Figure 2). A CT processing algorithm can create a virtual 3D volume reconstruction of the object from multiple radiographic images, collected at different angular positions as the object is rotated by certain angular increments, typically covering 180 or 360 degrees. From the reconstructed volume, internal and external features can be extracted to reveal the object’s 3D structure and morphology [8–10].
With flat panel-based CT systems, the object must be placed as close as possible to the X-ray source, while remaining within the cone beam, to obtain magnified radiographic images at the detector and produce 3D data reconstructions with the highest resolution possible. The geometrical magnification \( M_g \) is a function that depends on the source-to-object distance \( d_{SO} \) and the object-to-detector distance \( d_{OD} \),

\[
M_g = \frac{d_{SO} + d_{OD}}{d_{SO}}.
\]

The image can be magnified by adjusting the relative positions of the source, object, and detector on the main optical axis. The maximum operating \( M_g \) value in industrial and laboratory-based X-ray projection instruments is typically determined by the minimum working distance \( d_{SO} \), which is limited by the sample size – the sample must rotate on the turntable without colliding with the X-ray source (Figure 2). With an X-ray source focal spot on the order of 2 to 5 μm, the best achievable spatial resolution is generally limited to the 4 to 10 μm range for cylindrical objects with diameters in the 2–25 mm range. Larger samples limit the geometrical magnification \( M_g \), reducing the best achievable resolution of CT scans to several tens of micrometres.

### 2.2. 3D X-ray microscopes

There are two common approaches to further increase the image resolution capabilities of flat-panel CT instruments: a reduction in the X-ray focal spot and/or the use of a higher resolution flat panel detector. However, this would not remove the geometric magnification limitations imposed by larger samples (>25 mm diameter). An alternative would be to incorporate optical lenses after X-ray detection to create a scintillator-lens-CCD\(^1\) detector coupling that optically magnifies the image (Figure 3). The scintillator-lens-CCD coupling is used for the indirect conversion of X-ray photons into electrically charged signals. The X-rays hit a scintillator, which converts the X-ray photons into visible light. The visible light then passes through an optical lens that projects a magnified

![Figure 2. Schematic representation of a cone-beam X-ray CT setup with a flat panel detector.](image)

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\(1\) This coupling can be used for 2D image magnification, but it is not limited to the indirect conversion of X-rays.
onto the CCD (charge-coupled device). This strategy enables effective detector pixel sizes down to 150 nm, producing XRM images with spatial resolutions of less than 700 nm [11].

In X-ray CT, the resolution of the system worsens as $M_g$ decreases (i.e. when the sample size increases). On the other hand, by taking advantage of optical magnification, XRM make it possible to preserve (and improve) the system’s spatial resolution as $M_g$ decreases. This is possible without major limitations on sample size, as long as the sample physically fits inside the instrument, when RaaD capabilities are introduced in the XRM system’ design (e.g. see Figure 3 or Refs. [6,7]).

### 2.3. 3D X-ray nanotomography

The low X-ray absorption coefficients of low-density materials make it difficult to obtain high-contrast images with conventional absorption/contrast X-ray imaging, especially at nanometre length scales. But there are ways to improve the contrast and resolution of XRM into the nanometre range, e.g. by using X-ray focusing elements such as Fresnel zone plates or Kirkpatrick-Baez mirrors [12–15]. As an example, Figure 4 shows the optical schematics of a ZEISS Xradia Ultra 3D XRM, in which a high-brightness X-ray source is focused on a sample by a capillary condenser lens. The purpose of the condenser lens is to provide uniform illumination of the sample throughout the field of view. A Fresnel zone plate² objective then forms a magnified image of the sample in the X-ray camera (detector). As the sample is rotated, images are collected at a variety of projection angles which are then reconstructed into a 3D tomographic dataset.

X-ray nanotomography techniques have been used to visualise microstructure details in battery electrode materials with spatial resolution down to tens of nanometres. While typical pixel resolutions of commercial flat panel detectors are in the range of 75–200 μm, effective detector pixel sizes in modern 3D XRM systems can be as low as 16 nm [11,16].
2.4. Data visualisation and analysis

For each of the 3D X-ray imaging techniques presented above, the output data is a three-dimensional greyscale image composed of voxels representing the X-ray absorption in the 3D volume elements located in the battery. A voxel is the smallest volume element used for sampling the data into discrete entry units addressable/controllable in a 3D digital image, which is stored in computer memory as a numeric representation of intensity or grey level output from three-dimensional functions fed as input by spatial coordinates; it represents a ‘3D pixel’ in the volumetric data set [17,18]. The greyscale distribution is largely related to the density of the material that makes up the battery. The image may contain the entire battery or battery material sample, or a sub-volume of the sample. Volumes at different locations or resolutions obtained from the same instrument contain coordinate information that ensures they align well with each other when viewed in three-dimensional image visualisation and analysis software. Images from different instruments (e.g. X-ray CT and 3D XRM) can be aligned with each other using an image registration step to enable co-visualisation, see Figure 5. Segmentation algorithms can be used to identify different layer components in a battery and separate them by assigning false colours to cathode, anode, and aluminium and copper collectors. Commercial and open-source software packages are available to address these needs.

3. Battery inspection results and discussion

3D X-ray imaging is a powerful technique for inspecting battery cells and their components (e.g. anode, cathode, and separator) providing qualitative and quantitative details on batteries’ internal morphology and macroscopic design parameters. A few common parameters of interest include material distribution, geometry, packing volume, and electrode alignment. Such information is essential to study the influence of the design on battery performance and ageing degradation, and to establish strategies to improve manufacturing processes. This section presents examples of X-ray microscopy workflows for imaging battery cells containing components with scales spanning several orders of magnitude, from centimetres to micrometre lengths (Figure 6–10), as well as individual battery components with scales ranging from micrometres to nanometres (Figure 11-12).
3.1. Multiscale whole-cell analysis

Due to the non-destructive nature of X-ray microscopy, the interior arrangements of complete battery cells can be imaged without cutting into the cells. This allows engineers and researchers to observe the arrangement of internal features of intact batteries, such as layer stacking alignment, electrode thickness distribution, microscopic inhomogeneities in electrode materials, and the existence of electrode defects from the production processes. Figure 6 shows images of a 21700\(^3\) automotive cylindrical LIB obtained from a 3D XRM (ZEISS Xradia 620 Versa). The entire battery cell was scanned for an initial overview/survey using a flat-panel extension and the instrument’s vertical stitching feature at 34 µm/voxel. After identifying a potential region of interest, the full width of the cell around that region of interest was scanned using a 0.4X objective at 11.5 µm/voxel. This scan helped to further optimise the region of interest which was scanned at 4 µm and 2 µm voxel sizes with 0.4X and 4X objectives, respectively. All of these tomographies were collected at an X-ray source setting of 160 kV and 25 W.

Figure 6 illustrates a typical XRM measurement workflow with the RaaD\(^4\) capabilities available on the ZEISS Xradia Versa instrument. By using lenses of different optical magnifications (see Figure 3), smaller regions of interest can be zoomed in to scan at higher image resolutions, without major limitations on sample size and working distance (position) from the X-ray source [6,11]. Low-resolution XRM scanning, with voxel sizes of 34 µm and 11 µm, showed the general structure of the battery and cell assembly. The different layers in the cell’s jellyroll structure (including the anode, cathode, and separator) were distinguishable from each other and appeared to be in good condition regarding
mechanical stability. These low-resolution scans were useful for large-scale investigation, such as bulk defect evaluation and assembly manufacturing quality inspection and served to guide the high-resolution scans. In the higher resolution scans, with voxel sizes of 4 µm and 2 µm, the difference between the electrode layers, such as active materials and current collectors, was achieved, and inclusions of high-density particles were observed within the cathode layer without the need for any sample manipulation or destruction. Additionally, high-resolution 3D X-ray images enabled visualisation of a crack/fracture defect within the active layers of the assembled 21700 battery, see Figure 6.

In smaller-scale cells, such as pouch cell batteries used in consumer electronics (e.g. smart watches and cell phones) detailed views of the electrode microstructure can be observed. Figure 8 shows 3D XRM images of pouch cell batteries. The centre image

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**Figure 6.** XRM measurement workflow using resolution-at-a-distance (RaaD) capabilities. By using a 3D X-ray microscope with a set of different magnifying lenses, detailed images can be obtained in different regions of interest in a 21700 automotive LIB, across multiple length scales and resolutions, without disassembling the sample.

**Figure 7.** Thin fracture defect through the cathode layer of a 21700 automotive battery cell imaged on a ZEISS Xradia 620 Versa X-ray microscope. The high magnification RaaD capabilities of the X-ray microscope can resolve such fine features without cutting into the battery cell.
shows the detailed microstructure of the cathode layer (thick bright bands) and the associated particles that make up the layer (inset of centre image). Cracking defects can also be seen in the cathode layers due to electrode bending in pouch cell packaging, as shown in the image to the right of a commercial cell phone battery. These types of microstructure defects are generally associated with volume expansion and contraction of active material particles during lithiation/delithiation cycles, mechanical stresses, thermal fatigue, or other saturation conditions leading to charge capacity deterioration and power fading [19–22].

3.2. Battery ageing and degradation

In addition to observing the internal characteristics of the battery in its static state, non-destructive 3D imaging with X-ray microscopy makes it possible to observe microstructural evolutions as batteries cycle and age. Since battery performance is closely related to internal microstructure, this can be useful in determining the cause of performance degradation with cycling and in designing methods that mitigate these effects. Figure 9 shows an example of an imaging investigation scale on pouch cell batteries containing a silicon plus graphite mixed anode that have been aged at different numbers of cycles. In the fresh state, the silicon particles are clearly visible (bright spots), while after 200 cycles the silicon has been completely consumed. At 100 cycles we can see that the silicon particles are being consumed, with reaction products forming and microcracks developing in the particles. This information is useful in understanding battery degradation and failure mechanisms after hundreds of charge cycles by providing a microstructural explanation for the observed battery performance loss. The effects of ageing and degradation of the electrode materials (cracks, fractures, loss of the interface between the active material and the electrolyte, lithium plating, and electrode pulverisation) can influence the capacitance and impedance of the electrodes. Battery researchers and manufacturers can work to improve and extend the life of these batteries by introducing new material arrangements or processing methods to mitigate the degradation mechanisms seen in the images. This type of analysis can avoid the frequent trial and error approach by giving
insight into the responsible mechanisms as they occur and avoiding complicated post-mortem analysis. By accelerating this development cycle, this can lead to rapid advances in battery performance and manufacturability.

3.3. Battery cell assembly

Imaging macroscale features in assembled batteries is important to capture design parameters and assess issues that can affect performance and reliability due to mechanical and electrochemical instabilities during the charge/discharge cycles. In the assembled
battery, overhang (i.e. anode and cathode alignment) and deflected anodes are some of the critical quality check points to assess for capacity fading rate and poor performance of the batteries. A bent electrode is a potential for an internal short circuit, one of the main causes of battery failure. Anode and cathode thicknesses are also often checked. In addition, the collector tab connecting the electrodes (current collectors) to an external electronic circuit should be inspected for adherence, as it is one of the most fragile

Figure 11. Images of an NMC cathode (left) and a graphite anode (right). The 3D representations are displayed in colour behind and to the left of the 2D virtual slice images of the 3D datasets. Images like these provide high-resolution views of the microstructures of individual components and give researchers insight into how their manufacturing and processing parameters affect the final microstructure of the components that are used to assemble the final batteries.

Figure 12. 3D X-ray microscopy images of a separator material used in LIBs (scanned at 32 nm voxel size). Images show segmentation of polymer fibres and 3D rendering of the diffusion simulation of the pore space.
components in a single cell and can easily break during assembly. Incorrect location of the tabs could result in a localised high temperature in a cell, causing thermal runaway that could lead to an explosion or fire.

Since rechargeable batteries can be used as a power source in a car, harsh conditions of use (e.g. vibrations and high or low temperatures) require robust welding and casing on battery modules or pack assemblies. Metallic inclusions, which can also create safety risks, must be avoided during assembly. Also, a faulty electronic component would cause the entire battery module to fail. Once the battery is in use, after hundreds of charging cycles, the electrodes may physically deform (the gap between the electrode and the active material may increase), which can lead to delamination of the electrode material from the current collector, making it difficult to conduct electrons and causing a voltage drop across the electrodes. LIB swelling, caused by various factors such as age, number of charge cycles, or exposure to high temperatures, also leads to structural damage to the electrodes and delamination of the current collectors and separator, reducing cycle life.

All these potential problems or defects can be inspected using X-ray CT to assess (non-destructively) the integrity of the cell assembly and prevent deterioration and safety hazards of rechargeable LIBs. Figure 10 shows an example of the inspection of various battery cell and module components, using images obtained from a flat panel-based CT system (ZEISS Metrotom 1500), highlighting macroscale features and defects commonly looked after in quality assessments of cells and battery modules.

3.4. Battery component analysis

In addition to imaging assembled batteries, 3D X-ray microscopy can provide valuable insights into the complex microstructures of battery components, such as particle distribution, porosity, and tortuosity that can affect the electrochemical performance of electrodes and, therefore, their functional and operational capacity. Such information is crucial in optimising 3D electrode microstructures to improve battery performance and its lifetime, e.g. by optimising processes such as calendaring – the compression of dry electrodes used in battery manufacturing – which plays an important role in reducing porosity and improving the contacts of the particles at the electrodes to improve their energy or power density.

Nanoscale 3D X-ray microscopy has recently proven useful in providing detailed 3D views of battery components to visualise electrode pore structure, particles shape and surface degradation, dendrite formation, intraparticle cracks, the morphology of lithium protrusions within short-circuited solid electrolytes, and other changes in material structure that can lead to faster capacity fading affecting the operational reliability of the battery [22–25]. Figure 11 shows 3D renderings and 2D virtual slices of a nickel-manganese-cobalt (NMC) cathode (left) and graphite anode (right) imaged by a nanoscale 3D XRM (ZEISS Xradia 810 Ultra) using a voxel size of 64 nm. Individual NMC or graphite particles can be easily viewed, with sufficient resolution to observe and quantify interparticle pores and cracks (typically a few hundred nm in size), as well as a detailed view of the pore network between the particles (ranging from about 100 nm to a few µm in size).
Information gained from nanoscale 3D XRM provides microstructural insights to predict and understand performance characteristics of batteries and their degradation and failure modes [23,26–28]. An example of a separator material in which the fibres and pores are segmented is shown in Figure 12 for use in a diffusion simulation to gain a quantitative understanding of material morphology after performing the simulation. By applying segmentation algorithms to the data represented in Figure 12, a porosity of 42% with an average pore size of 150 nm was calculated. The tortuosity factors in the x, y, and z directions were 2.87, 3.67, and 2.16, respectively.

This type of information can help researchers determine critical metrics about separator materials to compare with different types of materials [29–31]. Electrode samples that have the same average tortuosity and porosity factors, but different interconnections, can lead to different LIB power densities and cycle efficiencies. There are several reports relating the specific energy of a battery to the porosity of an electrode [32–34]. With this information, full battery charge simulations can be run that track the movement of lithium ions through the electrolyte and system pore space to optimise battery performance and cycling lifetime.

3.5. Multiscale correlative microscopy

Since it is desirable to simultaneously study micro- and macro-structures in LIBs, multimodal imaging techniques are often needed. This multiscale challenge can be addressed through correlative workflows that integrate multiple complementary imaging techniques, such as optical microscopy, scanning/beam electron microscopy, and helium ion microscopy along with 3D micro- and nano-XRM [19,35–37]. Different imaging techniques are sensitive to different LIB features. Figure 13 illustrates different types of information – related to battery geometry and structure electrode materials – that can be obtained at different length and resolution scales, for different stages of battery/material manufacturing, using a combination of different imaging modalities (some paired with modeling/simulation approaches), to characterise features in commercial battery products. The use of correlative microscopy would integrate the evaluation of the complete cycle, from the basic research required to investigate new energy materials to the quality control of assembled batteries for industrial commercialisation.

In some cases, the mere combination of correlative X-ray imaging, i.e. the integration of techniques such as nanotomography, microscopy, and CT, would provide enough details to inform the multiscale behaviour of battery models, as shown through Sections 3.1–3.4. The main advantage of X-ray techniques is, of course, their non-destructive imaging capabilities compared to other techniques, e.g. focused ion-beam SEM, which may involve milling battery components into small target samples (of millimetre or submillimeter dimensions) that must be placed in a vacuum chamber.

4. Concluding remarks

Concomitantly with developments in new energy materials needed for increasing the performance of rechargeable battery cells, decreasing their weight and size, and maintaining safety while minimising cost, there is a need to integrate new developments of battery characterisation techniques into correlative measurement/inspection workflows. Of the
various techniques that can be used to assess batteries, recent advancements in 3D X-ray imaging allow spatially resolved imaging of fine details within battery cells, e.g. using resolution at a distance (RaD), without disassembling them. Therefore, 3D X-ray imaging can provide morphological information about the energy materials and electrode structures in battery cells, on a wide range of length scales, from the macroscopic features in battery packs (in the hundreds of millimetres) down to microscopic details at the particle level (in the tens of nanometres), non-destructively. The multiscale imaging capability of the X-ray imaging methods discussed in this paper (computed tomography, microscopy, and nanotomography) present a key advantage over other imaging techniques, see Figure 1 and Section 3, for characterising microstructures and macrostructures of batteries, e.g. the distribution of electrode materials and packing density, delamination, cracking and deformation of anodes. Table 1 summarises the most typical use cases of 3D X-ray imaging for battery characterisation and quality control.

The non-destructive imaging capability of X-rays permit investigating and understanding energy efficiency, the effects of ageing, and battery cell degradation and failure after multiple charge/discharge cycles, to aid in the design and quality assessment of battery cells. Due to the multiscale nature of rechargeable batteries, with relevant feature dimensions ranging from nanometres to centimetres, as illustrated by the examples presented in Section 3, the use of correlative imaging workflows that include imaging methods other than X-rays may be beneficial. Though, as mentioned in Section 3.5, in some cases the mere use of correlative X-ray imaging may be sufficient.
Lastly, it is worth noting that there are also several challenges that require further development of non-destructive imaging technologies. Larger battery cells and packs (>300 mm) are the biggest challenge. For instance, XRM still requires a small pouch cell or coin cell for high spatial resolution scanning (<10 µm). It would be a big step if electric vehicle batteries, including prismatic cells, could be placed directly into a commercial XRM or CT for imaging results down to 1 µm spatial resolution. Additionally, higher resolution imaging (<0.5 µm) on small form factor batteries can be challenging. Other challenges would include the need for more comprehensive nanoscale in-situ XRM capabilities and automated CT analysis.

### Endnotes

1. A CCD, or charge coupled device, is a metal oxide semiconductor sensor. A CCD is divided up into a large array of small light-sensitive cells (known as pixels) to capture light via the photoelectric effect and create a digital image.
2. Zone plates are circular diffraction gratings with radially decreasing line width, acting as a focusing lens for X-rays [9,38]. The spatial resolution that can be achieved – largely determined by the numerical aperture (NA) – is about the same as the width of the finest, outermost zone width (typically a few tens of nanometres).

3. Like other lithium-ion cells the 21700 battery is named after its dimensions to identify size: 21 mm in diameter and 70 mm in length.

4. RaaD (Resolution at a Distance) is a feature of ZEISS Xradia two-stage magnification microscopes that enables non-destructive imaging of an object’s interior – even for large samples – while maintaining the highest resolution over large working distances (independent of the distance to the source).

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