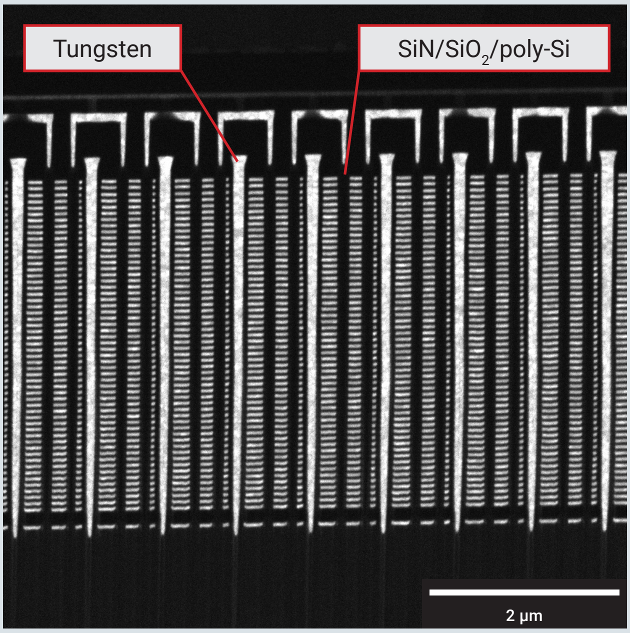
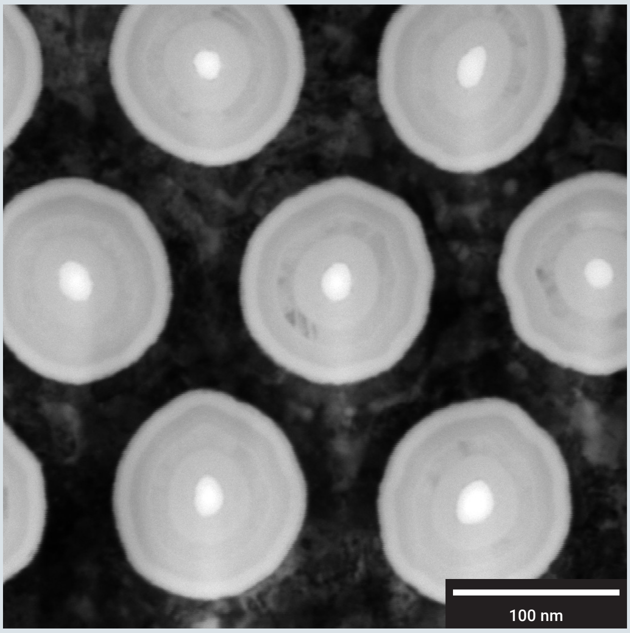
High-resolution 3D reconstruction of 3D NAND memory using TESCAN SOLARIS

In this application note, we demonstrate the use of TESCAN's FIB-SEM Tomography module, an integrated 3D dataset collection wizard operating within the TESCAN Essence™ GUI. When combined with the TESCAN SOLARIS, the FIB-SEM Tomography module provides a powerful solution for collecting multi-modal, multi-region 3D datasets of semiconductor structures. TESCAN SOLARIS`s SEM imaging capabilities allow visualization, with strong material contrast, of details to the tens of nanometers, while the Orage™ FIB column can mill ultrathin slices down to ~5 nm in thickness. Together, these capabilities create a perfect solution for nanoscale 3D volume reconstruction of 3D NAND and other electronic devices.

For the purpose of this case study, we analysed a Samsung SSD Pro 250 GB V-NAND device using the TESCAN SOLARIS Ga FIB-SEM system. 3D NAND is a type of flash memory that is a non-volatile storage medium. Such vertical NANDs typically are found in solid-state drives (SSD). They utilize the general NAND principle based on the floating gates thus, the memory cells inside the device can be electrically erased and reprogrammed.



▲ **Fig. 1:** Cross section of the analyzed 3D NAND device imaged using LE BSE detector.



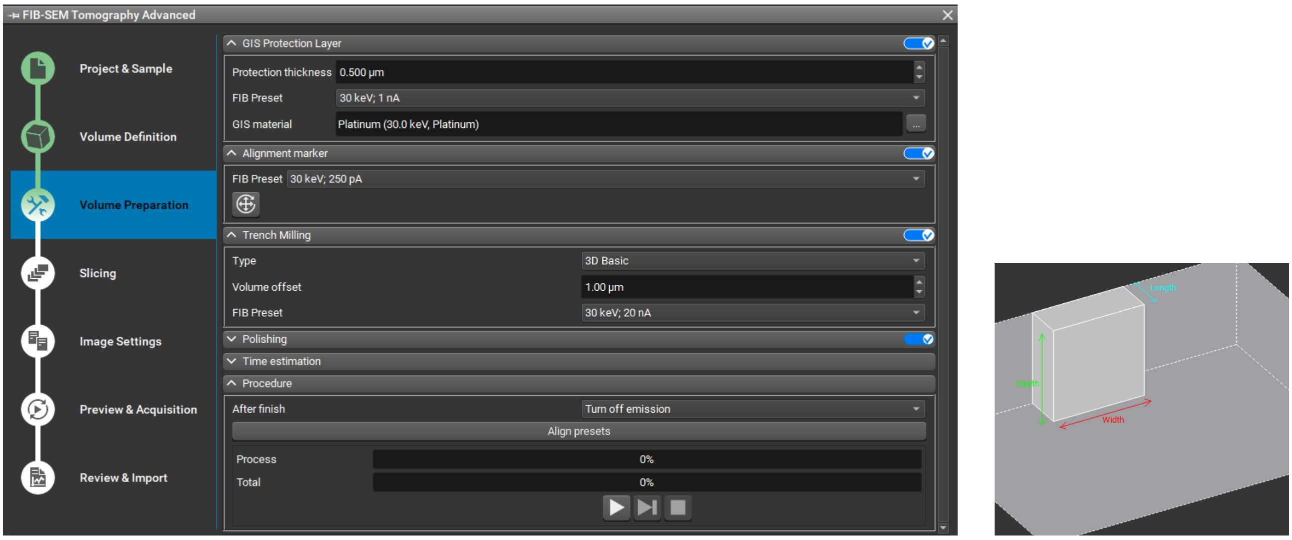
▲ **Fig. 2:** TEM lamella was prepared parallel to the sample surface of the 3D NAND device to show the memory cells in a single layer.

The device was decapsulated to expose the die with the memory cells. In a 3D NAND device, the memory cells are stacked vertically; therefore, it reaches larger areal bit densities without the need to decrease the size of the individual cells. This particular die's architecture consisted of 32 vertically stacked layers of cells.

The cross-section of this device is shown in **Fig. 1.** The tungsten layers (the brightest structures) alternate with the oxide layers. At first glance, one notices the elongated tungsten lines. In addition, long vertical structures of SiN floating gates with poly-Si channels are visible (the dark contrast in the image). To produce such high aspect ratio structures requires chemical etching. During production, it is very important to maintain uniformity in the channel's diameter throughout its entire depth. Also, it is important to verify the alignment of the memory cells in a single layer and the spacing between the cells. **(Fig. 2)**. The high number of interfaces and structures can result in the formation of defects such as shorts between the layers or voids inside the stack.

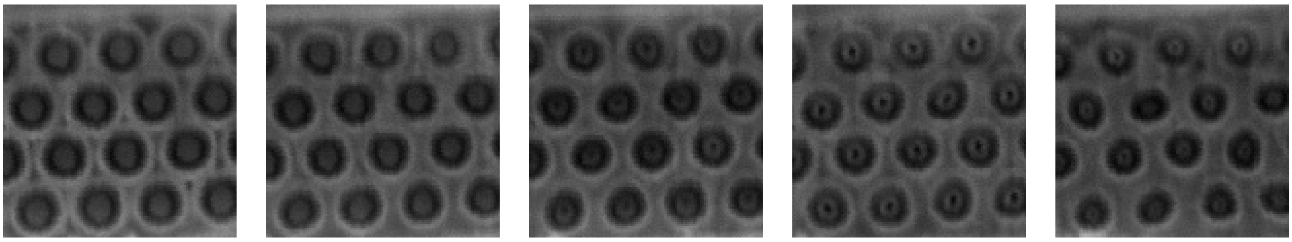
FIB-SEM tomography is an advanced technique consisting of repetitive serial SEM imaging of progressive FIB cross sectioning, followed by offline 3D reconstruction and visualization using dedicated software. To ensure consistency throughout the entire dataset collection process, all steps are automated.

The FIB-SEM Tomography module within TESCAN Essence™ software guides users through all process step settings, following the logical workflow for the experiment **(Fig. 3)**. The process starts with deposition of a thin protective layer of platinum, followed by trench milling to prepare a cubic volume. Drift correction marks are added during this step. For the tomography itself, in this experiment the slice thickness was set to 7 nm. The diameter of a single memory cell is approximately 100 nm so the slice thickness must be small enough to achieve sufficient resolution for the 3D reconstruction. The FIB-SEM Tomography module also enables acquisition of SEM images using different detectors. For this experiment, images of the FIB-produced slices were acquired at 2 kV using In-Beam SE and In-Beam BSE detectors simultaneously. Pixel size of each SEM image was set to 7 nm to maintain cubic voxels. Once all settings are defined, the tomography module operates with full automation. All process settings can be saved as a project and recalled for future experiments, which is useful for repetitive analysis of similar samples.



▲ **Fig. 3:** Screenshots of the FIB-SEM tomography module within the TESCAN Essence™ software.

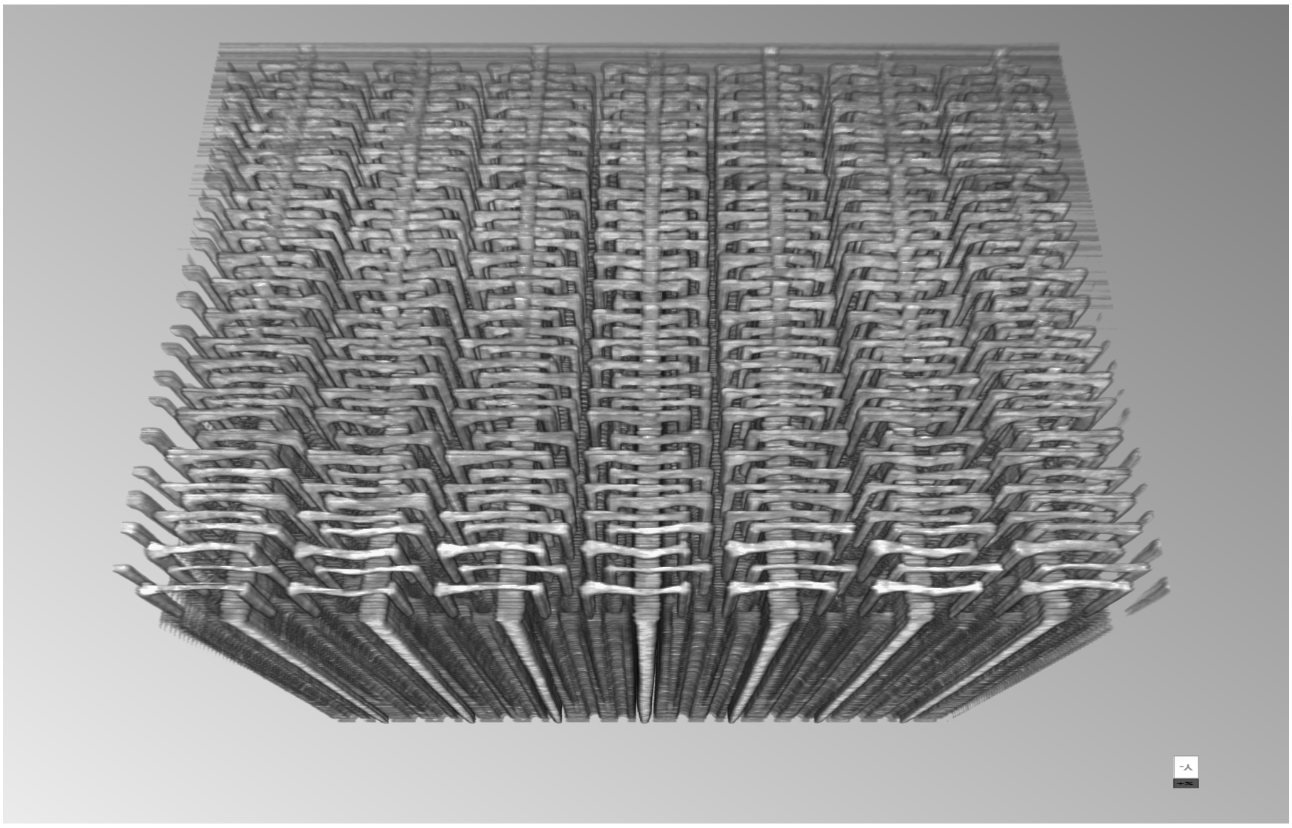
After dataset collection is complete, the next step is post-processing and reconstruction which is done with TESCAN 3D reconstruction software. The software automatically reads the parameters from the collected data and initiates post-processing and optimization, for example, drift-correction of slices, shading correction, cropping or other corrections prior to visualization. Once slices are reconstructed as the 3D volume, the software can produce virtual slices in arbitrary planes **(Fig. 4)** or provide visualizations of required structures based on a specific range of intensity **(Fig. 5, 6)**.



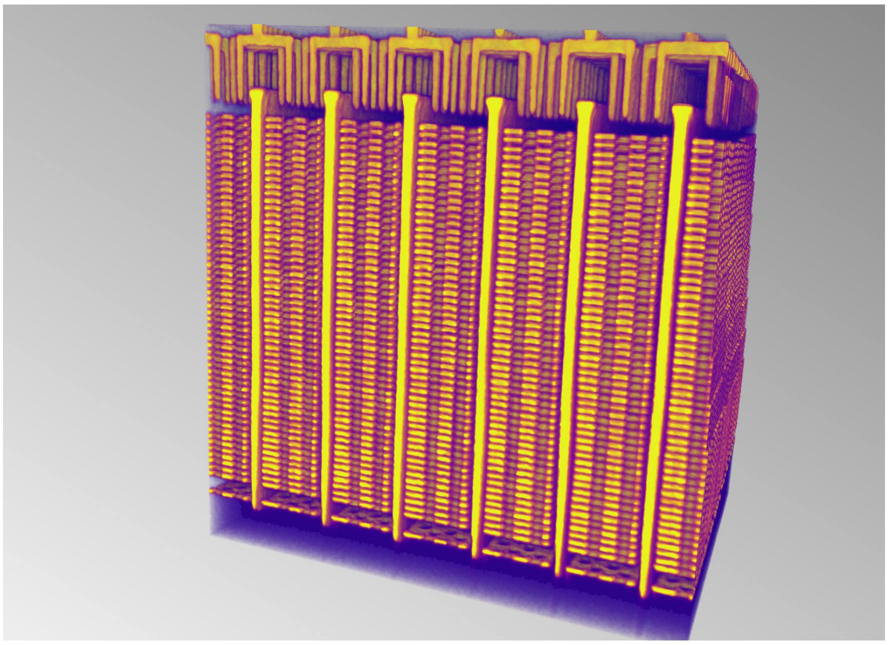
▲ **Fig. 4:** Extracted plan view cross sections from the In-Beam SE images collected at different depths of the device (left image, top level; right image, bottom level). This visualization reveals non-uniform dimensions of the cells closer to the bottom level

In addition to the core tomography function, the software allows creation of isosurface structures and can model the structures of interest **(Fig. 7)**. The structures are again selected based on their intensity range, then can undergo additional post-processing, such as smoothing or filtering of fine particles, for improved visualization. Finally, it is possible to record a movie of the entire reconstruction process and demonstrate clipping, change of contrast, camera movement, etc. Often, this form of presentation provides the context that makes the data easier to understand.

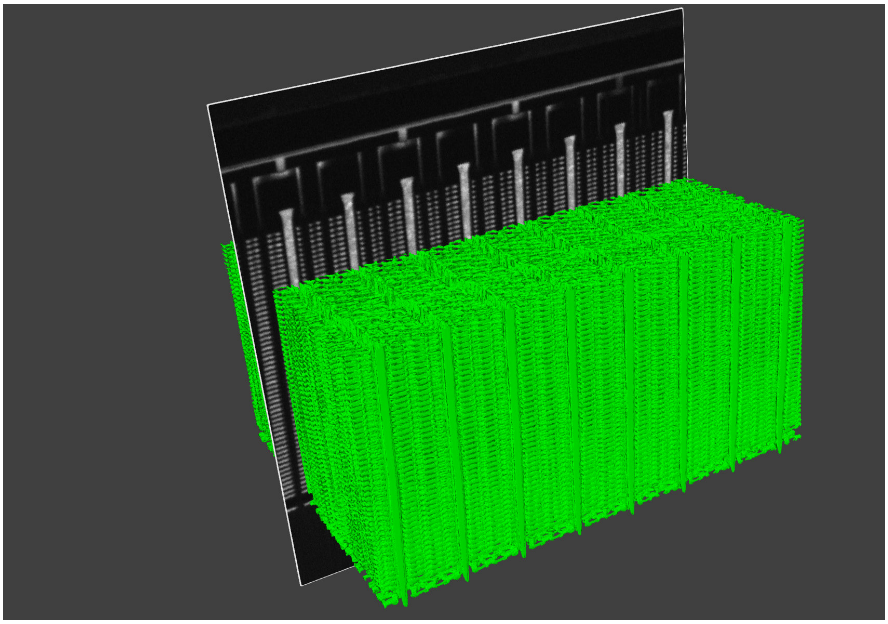
This application note demonstrated the capabilities of TESCAN's FIB-SEM Tomography module in combination with TESCAN's SOLARIS FIB-SEM to create a high-resolution 3D reconstruction of 3D NAND structures from a commercial SSD device. The reconstruction and visualization were done using TESCAN 3D software which has all necessary functions for processing of such datasets. Both the tomography module and the 3D software for post-processing allow jobs to be scripted and automated, assuring consistency for all experiments and ease of use for each operator.



▲ **Fig. 5:** Tomographic visualization of 3D NAND. The Intensity interval of the tungsten is based on the In-Beam BSE signal, which was selected to see the architecture of the die.



▲ **Fig. 6:** Tomographic visualization of 3D NAND. The colored volume is based on the In-Beam BSE signal for easier differentiation of the memory cells and contacts.



▲ **Fig. 7:** Tomographic visualization of 3D NAND. The colored volume is based on the In-Beam BSE signal for easier differentiation of the memory cells and contacts.

TESCAN ORSAY HOLDING, a. s.
Libušina tř. 21, 623 00 Brno - Kohoutovice / Czech Republic
(phone) +420 530 353 411 / (email) sales@tescan.com / marketing@tescan.com

TESCAN