doi:10.1017/S1431927619003015
Microsc. Microanal. 25 (Suppl 2), 2019

Semiconductor and Soft Material Analysis with Low-kV TEM

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New developments in soft- as well as carbon-based materials, polymers and catalysts are rapidly evolving in today's research. In order to analyze and advance such fields, implementation of transmission electron microscopy (TEM), in particular, operation at low accelerating voltages is key. This approach provides higher scattering contrast and less knock-on damage therefore mitigating many obstacles encountered by other methods.

To effectively address this growing area of research, the HT7820 and HT7830 20-120 kV TEM platforms were developed. While both of these models in the HT7800 series employ a dual mode HC/HR objective lens, the HT7820 specifically utilizes an architecture for versatile application including not limited to tilting/tomography, EDS, STEM and more [1]. The HT7830 builds upon these aspects utilizing an ultra-high resolution lens configuration with on-axis lattice resolution of 0.19 nm and STEM resolution of 1 nm [2]. Figure 1 demonstrates an example of high resolution 120kV TEM imaging for single crystal Silicon (Si) with clear observation of lattice fringes for Si (022) (spacing: 0.19 nm). Figure 2 shows a TEM image of beam sensitive, single-walled carbon nanotubes (SWCNT) observed at 20 kV. The each walls of nanotubes are clearly distinguished with excellent contrast whereby eliminating many artifacts experienced at high accelerating voltages. The HT7820/HT7830 have the capability for *in situ* based TEM studies with dynamic observations of Pt/CB electrode catalyst degradation of polymer electrolyte fuel cells (PEFC) having been studied effectively [3].

Additionally, the demand for high contrast observation is of great importance for modern evaluation of semiconductor devices with 120 kV TEM. With scale down and high integration of semiconductor device advancements, it is necessary to thin a TEM specimen below several tens of nanometers while still being able to maintain contrast. In this article, improved techniques based on novel 120 kV high-resolution / high-contrast TEM platforms as well as applications for the evaluation and analysis of thin-film 3D NAND flash memory are reported. Figure 3 demonstrates a TEM image of 3D NAND flash memory in planar view. The specimen was processed by a NX2000 FIB-SEM and observed at an accelerating voltage of 120 kV by a HT7800 series TEM. Figure 3(a) shows the multi-layered concentric circle structure of the inner memory cell and crystal grain of Tungsten (W) gate electrode in the surrounding area. Figure 3(b) shows a partially magnified and processed image of the circular memory cell. Lattice fringes of Si (111) (lattice spacing: 0.31 nm) are clearly observed. Using the crystal lattice image of Poly-Si, a magnification calibration was performed and the thickness of each layer was measured. For the study of crystal grain distribution of W gate electrode, hollow cone dark field (HCDF) TEM was utilized. The HT7800 series provides functionality for HCDF TEM image observation as standard. Figure 4(a), (b) and (c) show a bright field (BF) TEM image, the corresponding dark field (DF) TEM image and the HCDF TEM image, respectively. By selecting the optimum precession angle and objective aperture, the HCDF TEM image can be observed with sufficient contrast from not only

crystal grain of W gate electrode, but also multi-layers in the memory cell resulting in a more complete understanding of the device.

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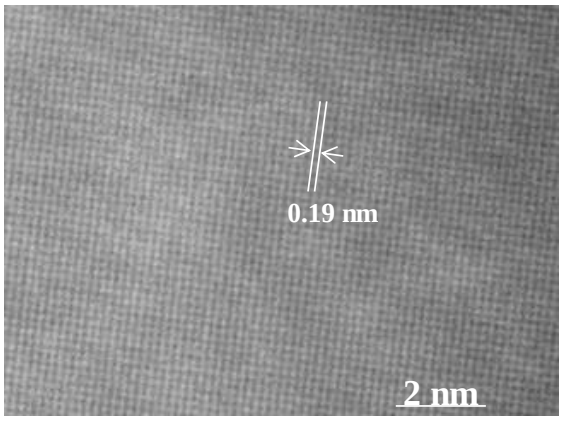

Figure 1 High resolution TEM image of Si observed at 120 kV.

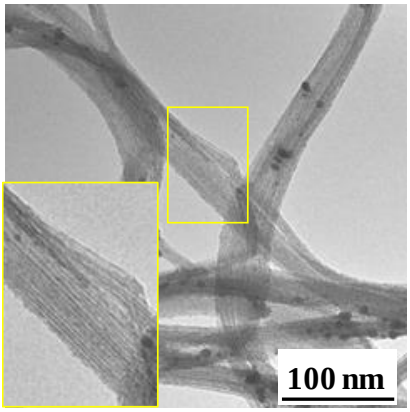

Figure 2 TEM image of SWCNT observed at 20 kV.

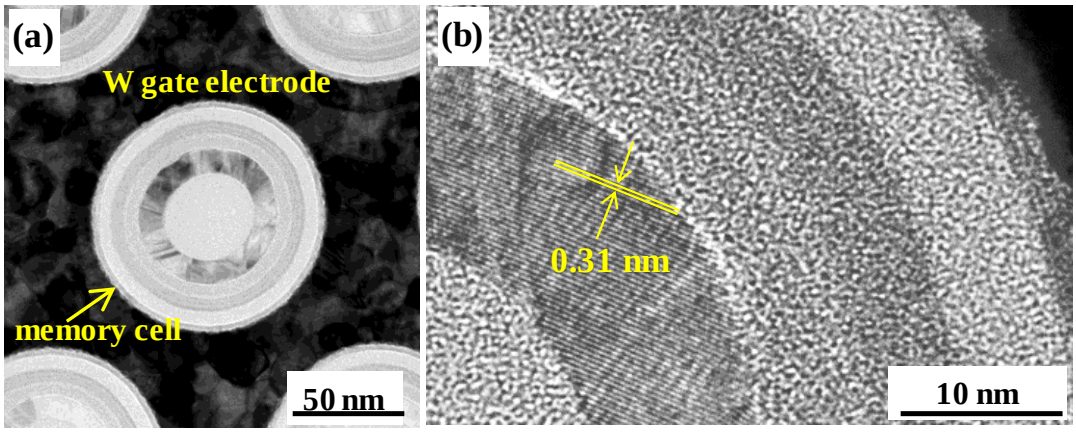

Figure 3 (a) TEM image of a 3D NAND flash memory in planar view.
(b) Partially magnified and processed image of the circular memory cell.

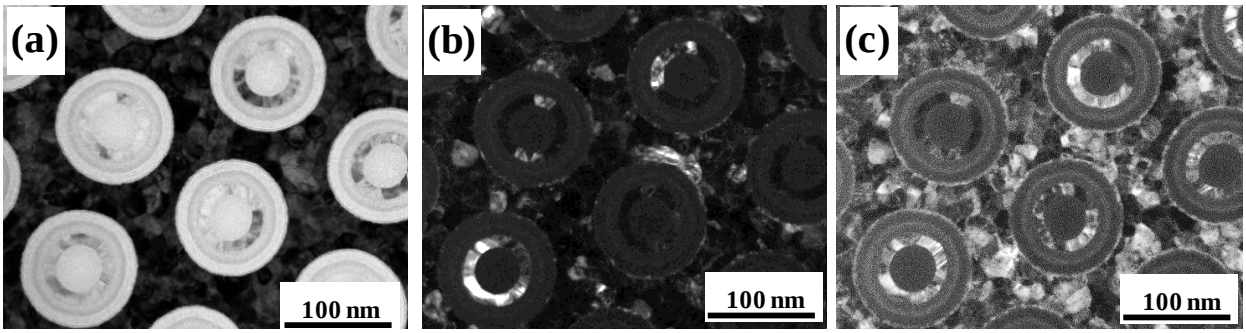

Figure 4 (a) (b) and (c) show a BF TEM image, the corresponding DF TEM image and the HCDF TEM image of a 3D NAND flash memory in planar view, respectively. .

https://doi.org/10.1017/S1431927619003015 Published online by Cambridge University Press