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Brief introduction to what we can measure with TEM for TEM beginner users

Version 1

TEM-bright field (BF) and TEM-dark field (DF) images
ED, Electron Diffraction
SAED, Selected Area Electron Diffraction
HRTEM, High Resolution TEM
STEM, Scanning Transmission Electron Microscopy
EDS, X-ray Energy Dispersive Spectroscopy
EELS, Electron Energy Loss Spectroscopy

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Quick guide

- TEM, HRTEM

Morphology, particle size, thickness, lattice image

- Electron Diffraction

Crystal structure

- STEM

Morphology, particle size, thickness, lattice image

- EDS, X-ray Energy Dispersive Spectroscopy

Element quantitative analysis and mapping (suitable for heavy elements)

- EELS, Electron Energy Loss Spectroscopy

Element quantitative analysis and mapping (suitable for light elements)

Target elements: from Li to Fe or Ni

TEM-bright field (BF) and TEM-dark field (DF) images

- A BF image in (a) is captured using mainly the direct beam transmitted from a specimen. With the BF mode, the shape and distribution of nanoparticles, the thickness and arrange of layers in multi-layer structure, the defects in crystal specimen, etc. can be observed.
- A DF image in (b) is captured using diffracted or/and scattered electrons from a specimen. With the DF mode, the part of a specimen where the electrons are diffracted and scattered is observable. Moreover, the local crystal structure can be identified with the selected area electron diffraction (SAED) in (c).

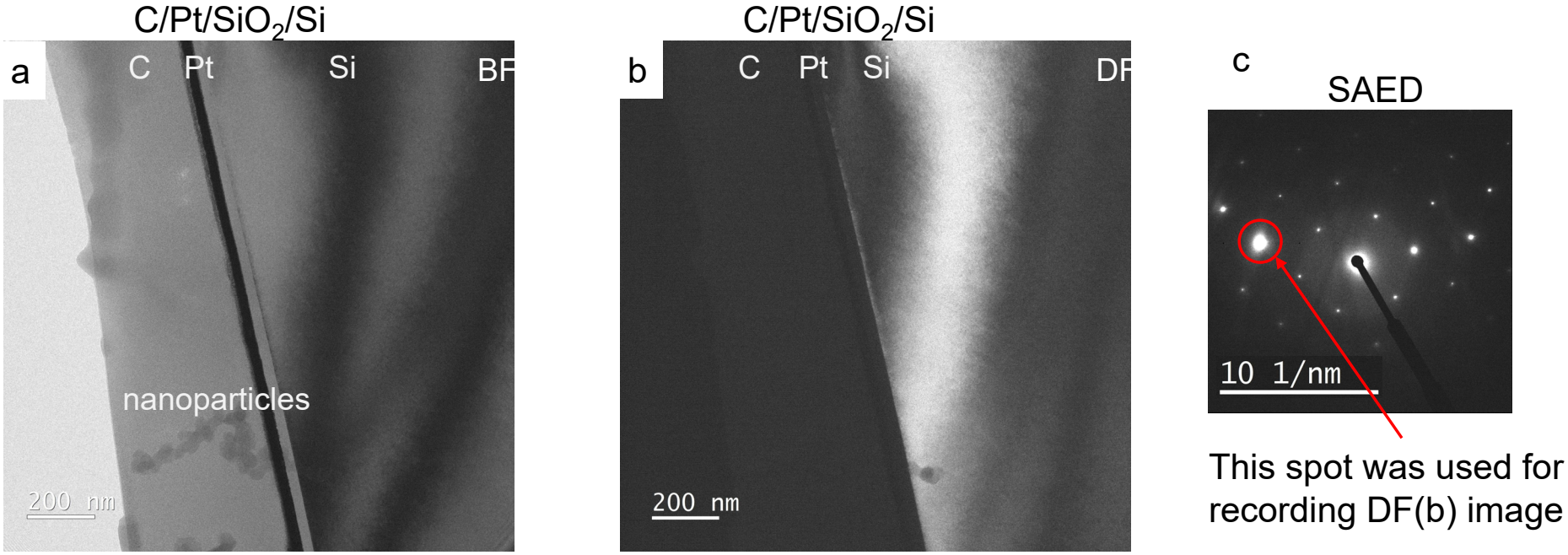

Fig. BF(a), DF(b), and SAED pattern(c) of a specimen of "C/Pt/SiO_2/Si multi-layer structures"

Electron diffraction (ED) and HRTEM

- The crystal structure and atomic arrangements of a crystal specimen can be identified with ED, SAED and HRTEM.
- The structure parameters (**a**, **b**, **c**, α, β, γ) of the crystal specimen can be determined from the SAED images obtained in one or more zone axes of a crystal specimen, or the SAED rings from a multi-grain crystal specimen in (b-c).
- Atomic or lattice images can be directly observed using the HRTEM mode in (c). The spacing and the angles between lattice planes measured with the digital micrograph software provide the more crystal structure information.

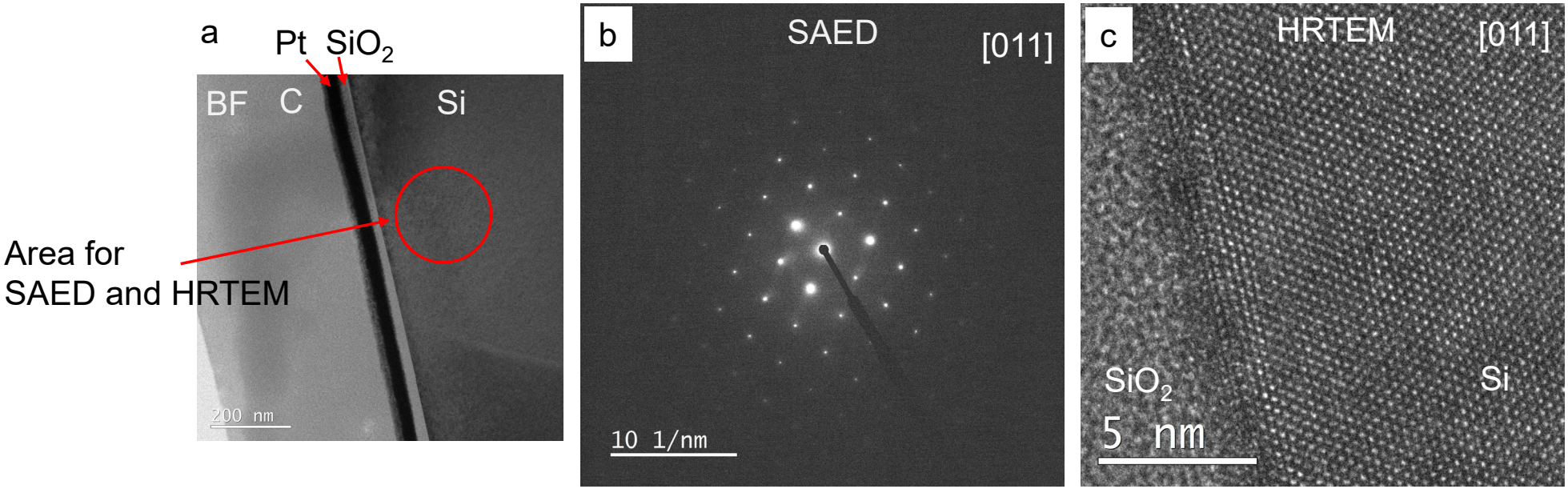

Fig. BF, SAED, and HRTEM images of a specimen of C/Pt/SiO_2/Si multi-layer structure

Scanning transmission electron microscopy (STEM)

- STEM images can be obtained of several types: HAADF (high angle annular dark field), LAADF (low angle annular dark field), BF (bright field), and ABF (annular bright field).
- HAADF (b-c): The intensity of image is approximately proportional to Z^2 (Z = atomic number of the target atom). The density or the thickness of a specimen, and the position of different atoms on an atomic HAADF image can be interpretated from the contrast of the image (i.e. intensity's differences).
- LAADF: The diffraction contrast of a specimen which captures the shape and distribution of crystal defects, such as dislocations, grain boundaries, can be observed.
- BF (a): The contrast on an image is the almost reverse relationship on a HAADF, or a LAADF image.
- ABF: The light elements (such as, O, B, N) in a light- and heavy-element containing compounds, such as a metal oxides, nitrides and borides, can be captured. (HAADF images cannot capture such light elements!)

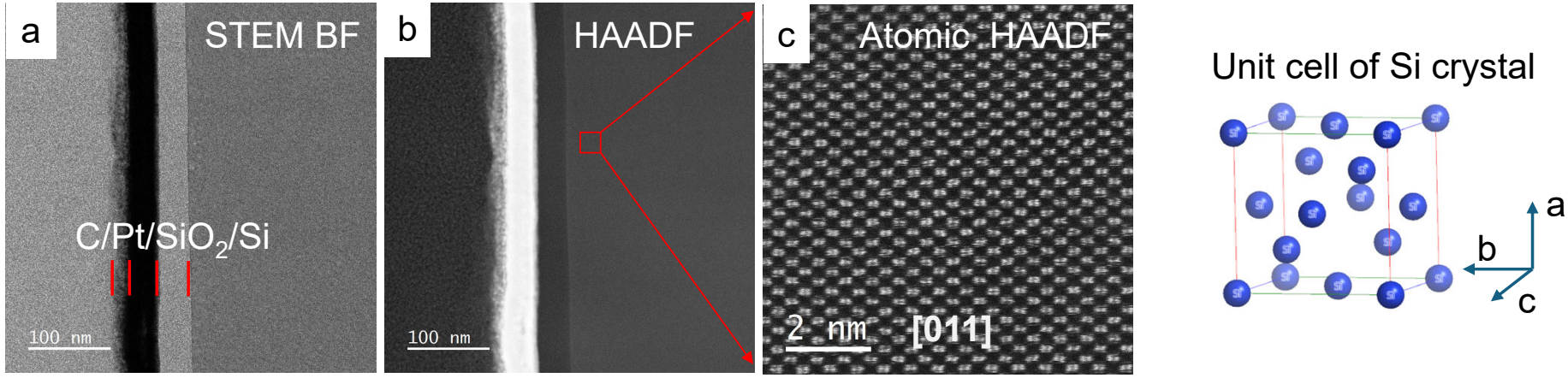

Fig. STEM-BF (a) -HAADF (b), and atomic HAADF (c) images of a specimen with C/Pt/SiO_2/Si multi-layer structure

EDS (X-ray energy dispersive spectroscopy)

- The incident electrons excite characteristic X-rays of elements from a specimen. EDS enables the analysis of the characteristic X-rays generated from the specimen, and the spatial distributions and concentrations of the target atoms in the specimen can be mapped with the STEM images.

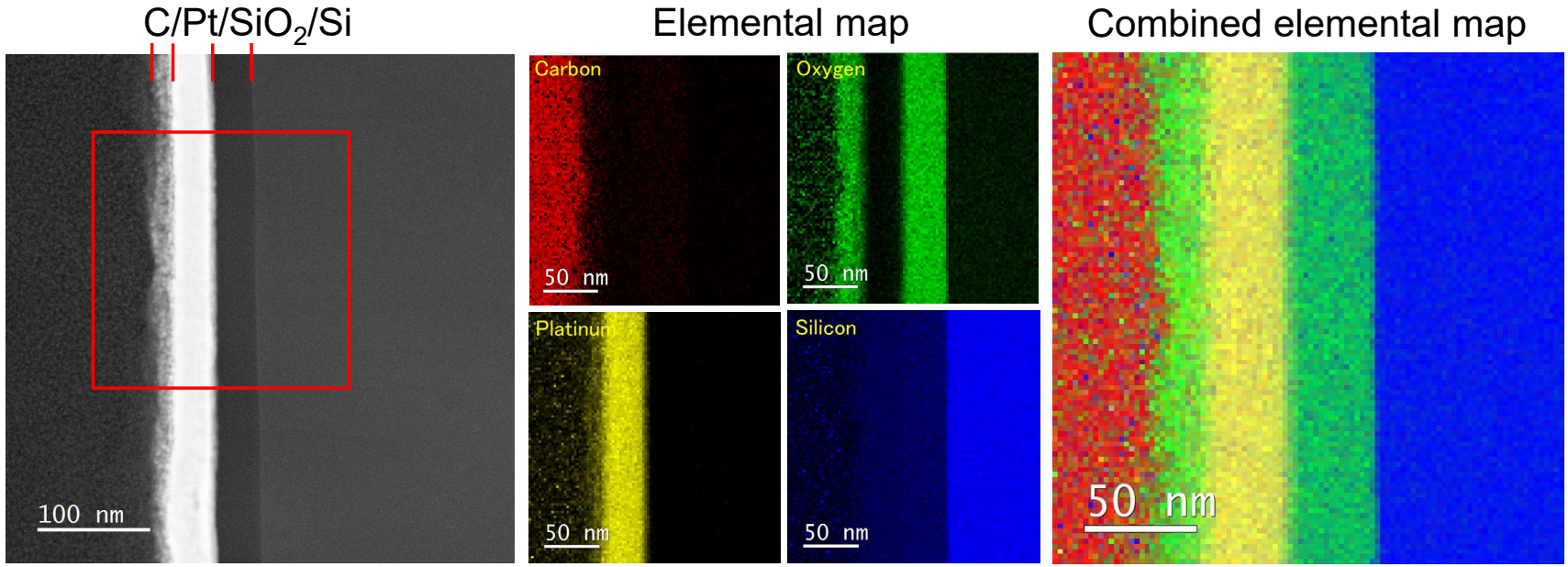

Fig. STEM-HAADF and elemental distribution maps of a specimen with C/Pt/SiO_2/Si multi-layer structure

EELS (electron energy loss spectroscopy)

- The incident electrons into a specimen loss a part of energy by interacting with the atoms in the specimen. EELS displays the intensity of energy-loss of such electrons.
- Each element possesses characteristic-energy-losses. The losses could be changed by different chemical binding of the atoms in the specimen. Therefore, EELS can be applicable to characterize the species of elements and chemical bond state of the elements.
- EELS features a high spatial resolution at sub-nanometers and a higher sensitivity for light elements than EDS.

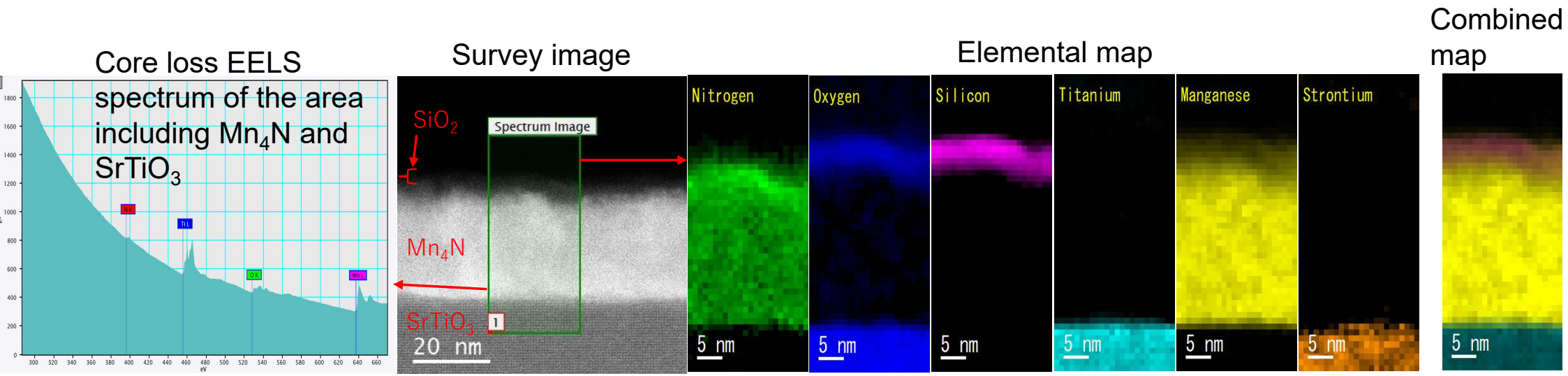

Fig. Core loss EELS spectra of elements and elemental maps measured with EELS of a specimen with a $SiO_2/Mn_4N/SrTiO_3$ structure. Distribution of elements is visualized.