HITACHI SCIENTIFIC INSTRUMENT
TECHNICAL DATA STEM

SHEET NO. 4

SUBJECT: ELECTRON DIFFRACTION IMAGE OBSERVATION ATTACHMENT FOR THE HD-2000 ULTRA-THIN FILM OBSERVATION SYSTEM AND SOME APPLICATIONS

INSTRUMENT: HD-2000 ULTRA-THIN FILM OBSERVATION SYSTEM
ELECTRON DIFFRACTION IMAGE OBSERVATION ATTACHMENT

CONTENTS:

1. INTRODUCTION

Associated with the higher integration and density of electronic and semiconductor devices, there are increasing requirements for high resolution observation in atomic scale and analysis of chemical compositions as well as their bonding information in nanometer scale. The HD-2000 has been developed to comply with these requirements in the industry. The HD-2000 has versatile imaging modes which include bright field scanning transmission microscopy (BF-STEM), dark field scanning transmission microscopy (DF-STEM), and secondary electron microscopy (SEM). It is already used extensively for evaluation and failure analysis of electronic devices.

Recently we have completed the development of an electron diffraction image observation attachment for improved analytical capability of the HD-2000. It allows analysis of crystal structures of various materials using the HD-2000.

For initial applications, we have used the electron diffraction image observation attachment on semiconductor devices and ceramic materials. We report on the details here.

2. INSTRUMENT

Fig. 1 shows a general view of the HD-2000 with the electron diffraction image observation attachment. When the electron diffraction mode is selected, BF-STEM and DF-STEM detectors of the HD-2000 are automatically moved out of the electron optical axis. The electron diffraction image formed by the objective lens is magnified by the projector lens and projected on the target of the UTK-2500 CCD digital TV-camera. The acquired diffraction image is displayed on a PC monitor.

The resolution index (diameter of electron diffraction spot/camera length or distance between the specimen and the diffraction image plane) depends on the convergence angle of the electron beam illuminating the specimen. The HD-2000 has been designed to allow the convergence angle of the beam to be smaller in the diffraction mode than in the normal STEM mode. Fig. 2 is an electron optical ray diagram showing the STEM mode and the electron diffraction mode.

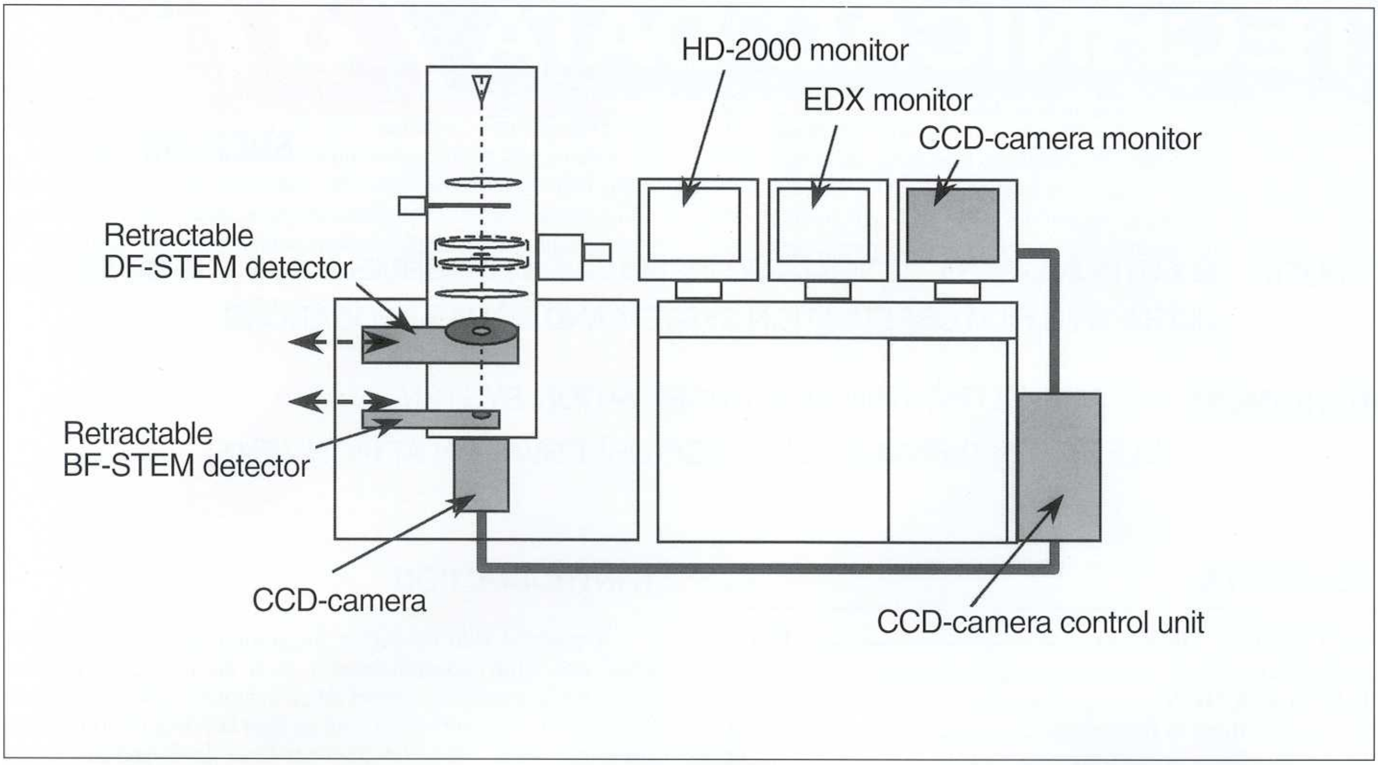


Fig. 1 A configuration of the HD-2000 with the electron diffraction observation attachment.

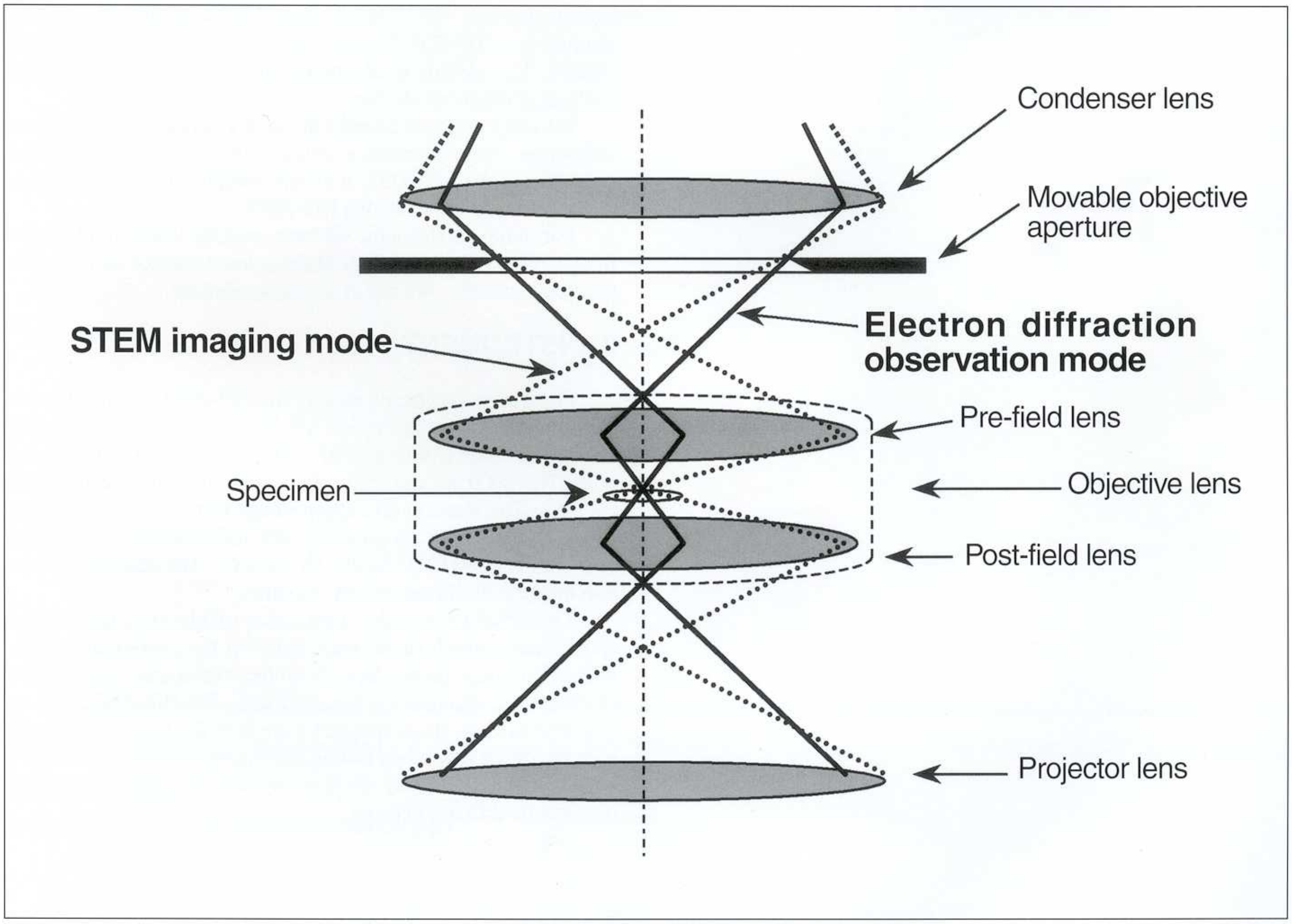


Fig. 2 A ray diagram showing STEM imaging and electron diffraction observation modes.

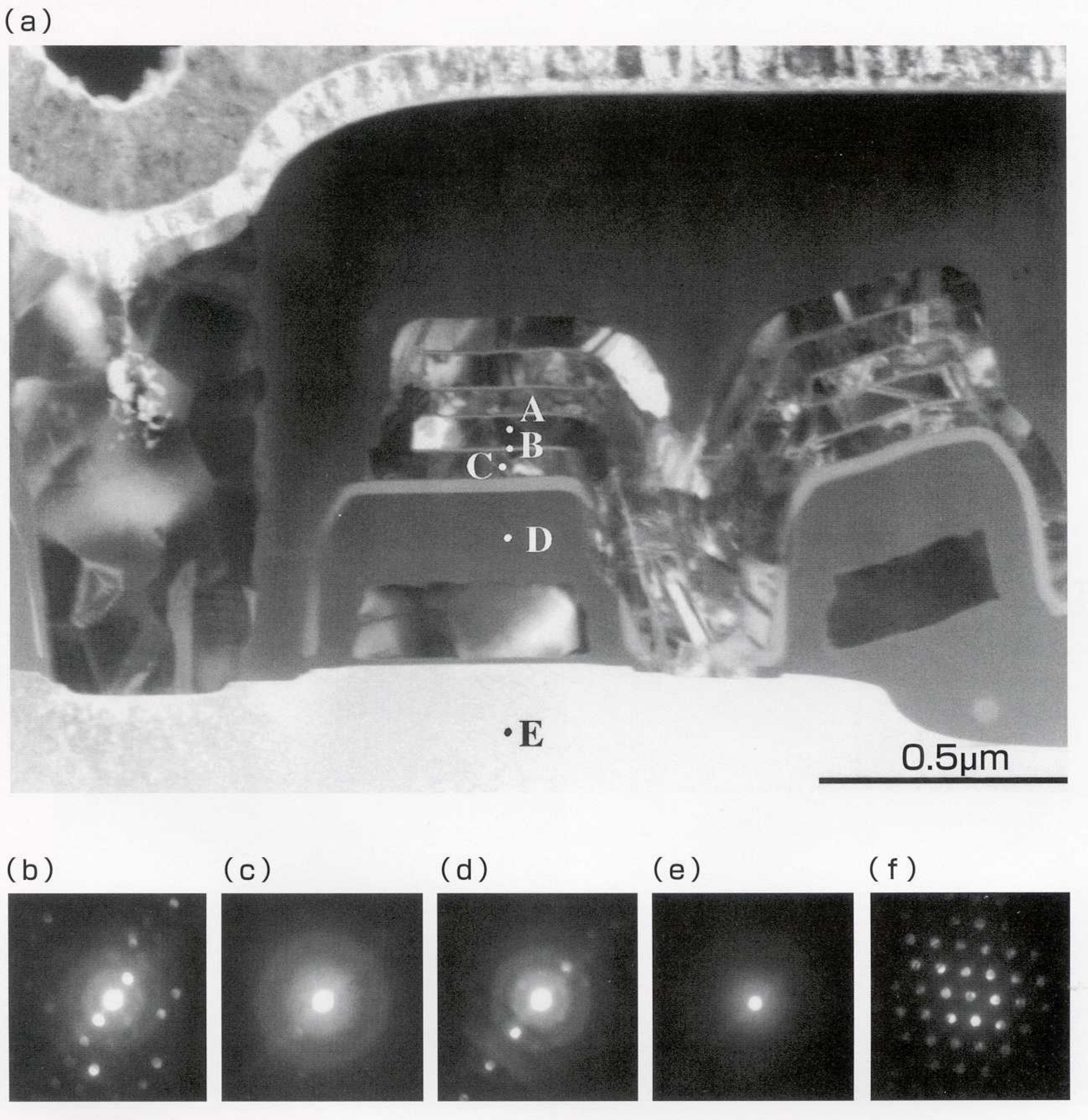
3. APPLICATIONS

Here we report on some examples of nano-probe electron diffraction images taken for observation of crystals and their orientations in selected small areas on a semiconductor device and a high resolution electron diffraction image taken for studying crystal structures using a ceramic specimen.

3.1 Applications for Si-device

Since the semiconductor devices have fine and complicated structures, a finely focused electron beam is required for illuminating the selected point of interest for electron diffraction work. The HD-2000, in the electron diffraction mode, allows a fine probe of a few ten nanometers on the specimen so that it permits electron diffraction images of small selected points of interest. Fig. 3 shows a DF-STEM image (a) and various electron diffraction images (b ~ f) of an Si-device (64 M DRAM) taken using a nano-probe.

The nano-probe diffraction image (b) was taken from crystal grain A in a capacitor. The diffraction image (c) was taken from insulation layer B of a capacitor, (d) from crystal grain C, (e) from insulation layer D and (f) from Si-substrate respectively. The electron probe used for observation of E was about 5 nm diameter on the specimen. From these observations, we can tell crystals and their orientations of each grain in poly-Si around the capacitor. We can also tell that insulation layers (SiO/SiN/SiO) in the capacitor are amorphous. Thickness of each insulation layer is only about 5 nm which is the same size as the probe so that electron diffraction images do not show any diffraction spots generated from the neighboring poly-Si layer. It shows that the beam broadening in the specimen is negligibly small and that this thin film electron diffraction technique has a high spatial resolution.



(a): DF-STEM image
(b): Nano-probe electron diffraction from position A
(c): Nano-probe electron diffraction from position B
(d): Nano-probe electron diffraction from position C
(e): Nano-probe electron diffraction from position D
(f): Nano-probe electron diffraction from position E

Accelerating voltage: 200 kV
Operation mode: Nano-probe electron diffraction
Illumination angle: α= 1.5 mrad
Camera length: ~ 0.5 m
Resolution index: ~ 3×10^{-3}

Fig. 3 DF-STEM image and nano-probe electron diffraction images of Si-device

3.2 Applications for ceramic materials

Electron diffraction work for ceramic and other materials requires high resolution diffraction images for determination of crystal structures rather than high spatial resolution which is required for semiconductor devices. Fig. 4 shows a BF-STEM image and a corresponding electron diffraction image of β-Si_3N_4 crystal grain.

The BF-STEM image was recorded after alignment of electron beam and crystal orientations to illuminate (001) plane of the specimen at right angles. The HD-2000 with the electron diffraction observation attachment allows alignment of the beam against a zone axis of interest for STEM imaging. Resolution index of the recorded diffraction image is about the same as that available with selected diffraction image in normal or conventional transmission electron microscopy.

In structure analysis of materials such as Si_3N_4 which has 2 crystal phases and the phase transformation has a great effect on the material's property, diffraction intensity distribution from each crystal plane is considered important. The diffraction image of β-Si_3N_4 shown here indicates characteristic intensity distribution of the specimen. It indicates that this diffraction observation attachment is useful for analysis of crystal structures of various materials.

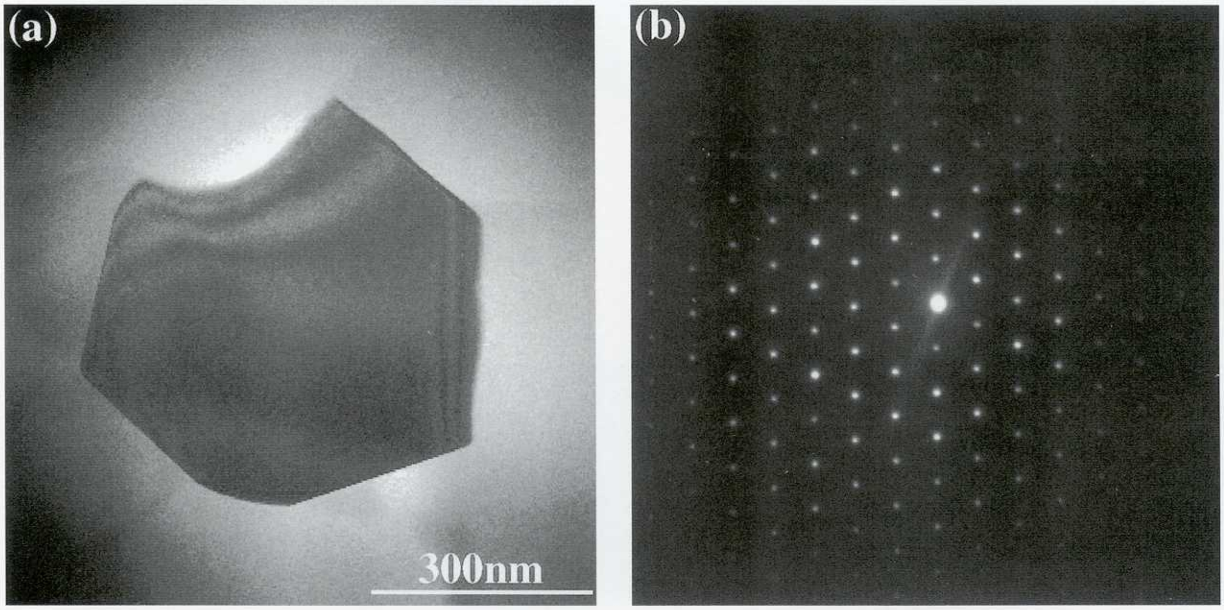


Fig. 4 BF-STEM image (a) and high resolution electron diffraction image (b) of Si_3N_4 specimen
Accelerating voltage: 200 kV
Operation mode: High resolution electron diffraction
Illumination angle: α= 0.4 mrad
Camera length: ~ 1.0 m
Resolution index: ~ 0.7×10^{-3}

4. CLOSING

We have introduced a new electron diffraction observation attachment for the HD-2000 and some initial applications for semiconductor devices and ceramic materials. The HD-2000 has a high voltage secondary electron image mode that allows 3D observation of inner structures of materials, a BF-STEM mode that allows observation of crystal materials at high contrast, a DF-STEM mode that allows observation of specimen compositions at high resolution, etc. which are not available with conventional TEMs. With these unique observation modes, the HD-2000 is extensively used for evaluation and analysis of various materials. The electron diffraction observation attachment for the HD-2000 will extend the analytical capability one step further. Finally, we would like to thank Associate Prof. Yuichi Ikuhara, Engineering Department, The University of Tokyo for providing us with precious specimens and permitting us to publish the results of our microscopy.

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