HITACHI SCIENTIFIC INSTRUMENT
TECHNICAL DATA
SEM

SHEET NO. 100

SUBJECT: STEM IMAGE OBSERVATION USING THE S-5200 UHR FE-SEM

INSTRUMENT: THE S-5200 ULTRA-HIGH RESOLUTION FIELD EMISSION SEM
THE FB-2000A FOCUSED ION BEAM SYSTEM

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1. INTRODUCTION

Process evaluation of semiconductor devices requires cross-sectional observations using SEMs for optimizing exposures and/or etching conditions. For this purpose wafers need to be fractured for evaluation.

Failure analysis of semiconductor devices, on the other hand, requires evaluation of inner structures of specific points of interest. This is usually accomplished using FIB (focused ion beam system). Prepared cross-sections of the wafer are examined using SEMs. Associated with higher integration and density, the need for evaluation in nanometer levels has rapidly increased recently.

We have used an FIB-SEM compatible specimen holder for thinning the specimen and evaluating it using the S-5200 in STEM mode for evaluation of semiconductor devices. We report on details.

2. STEM MODE OF THE S-5200

The S-5200 allows operators to select image information for a specific purpose of evaluation. STEM operation mode (option) allows observation of inner structures using thinned specimens. The STEM mode is available by a simple addition of TE (transmitted electron) detector and STEM aperture below the objective lens. An FIB-SEM compatible specimen holder shown in Fig. 1 is available. This specimen holder allows use both on the S-5200 and the FB-2000A. It also allows the specimen to rotate 360° in the specimen chamber. This design allows observation and milling without repositioning the specimen as shown in Fig. 2. It permits thinning of any specific point of interest on the specimen without damaging it. With a simple manipulation of STEM aperture, operators can select bright field or dark field images. The bright field image is formed by transmitted electrons while the dark field image is formed by scattered electrons. These details are reported in the following sections.

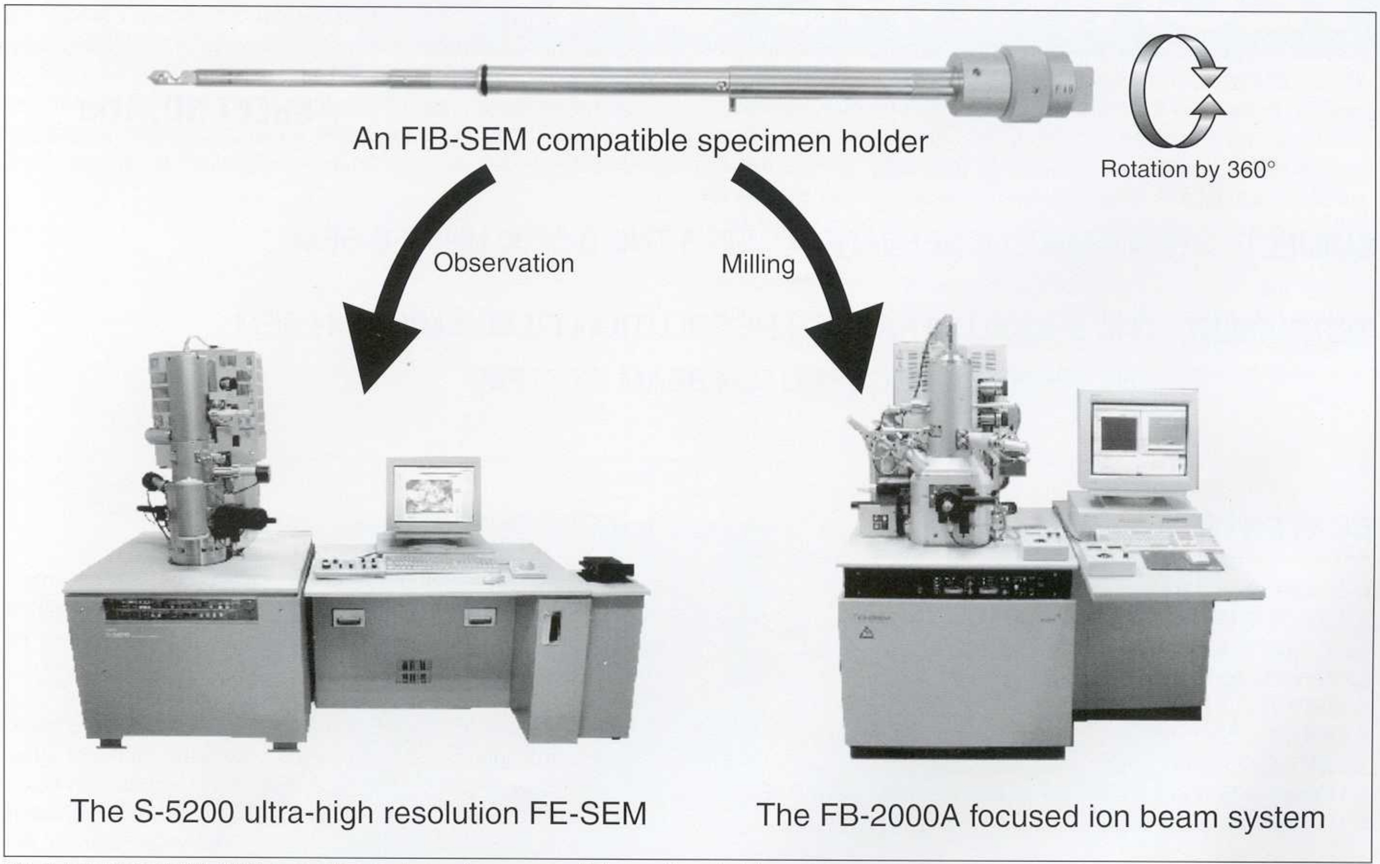


Fig. 1 A combined FIB-SEM evaluation system using a compatible specimen holder

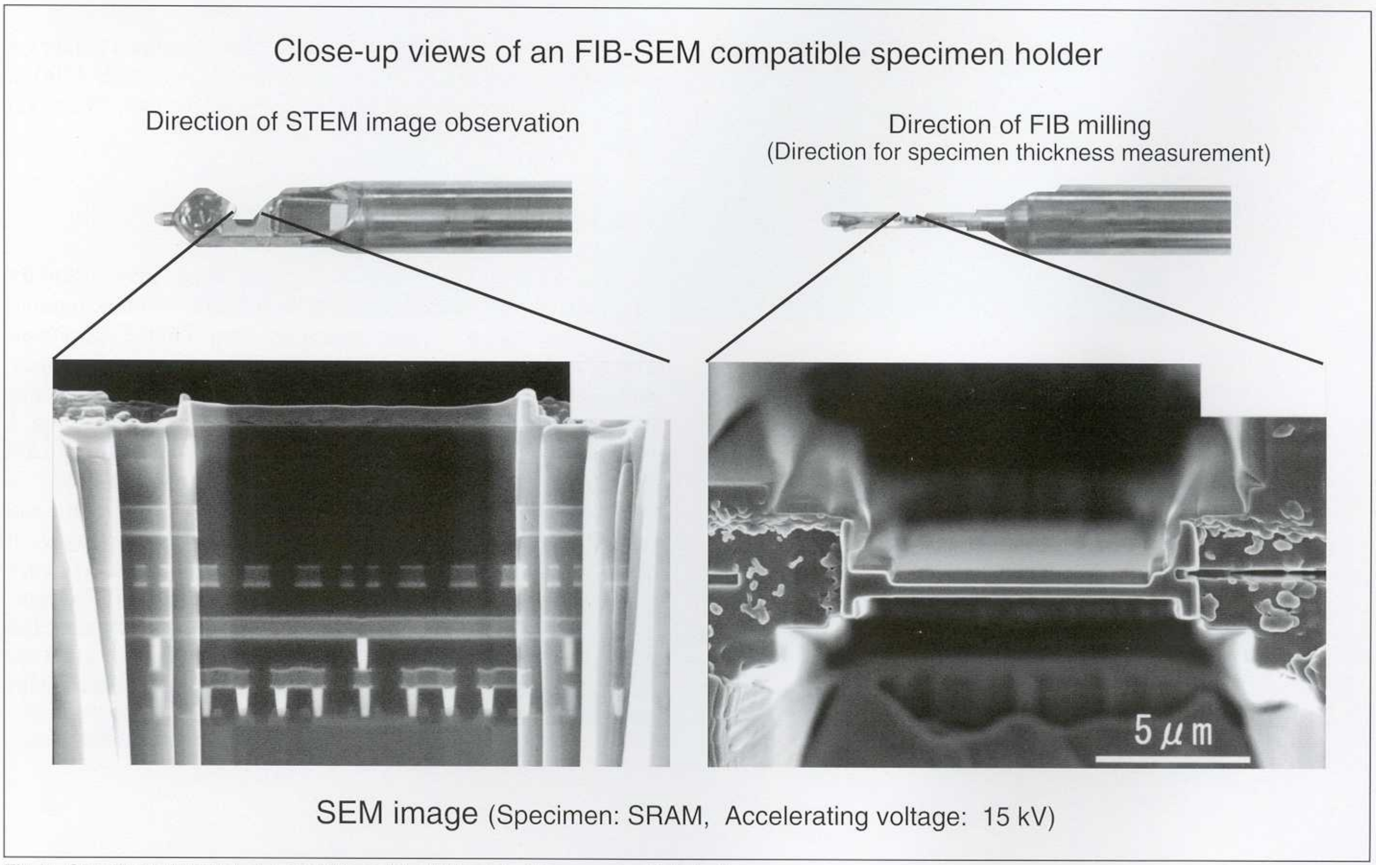
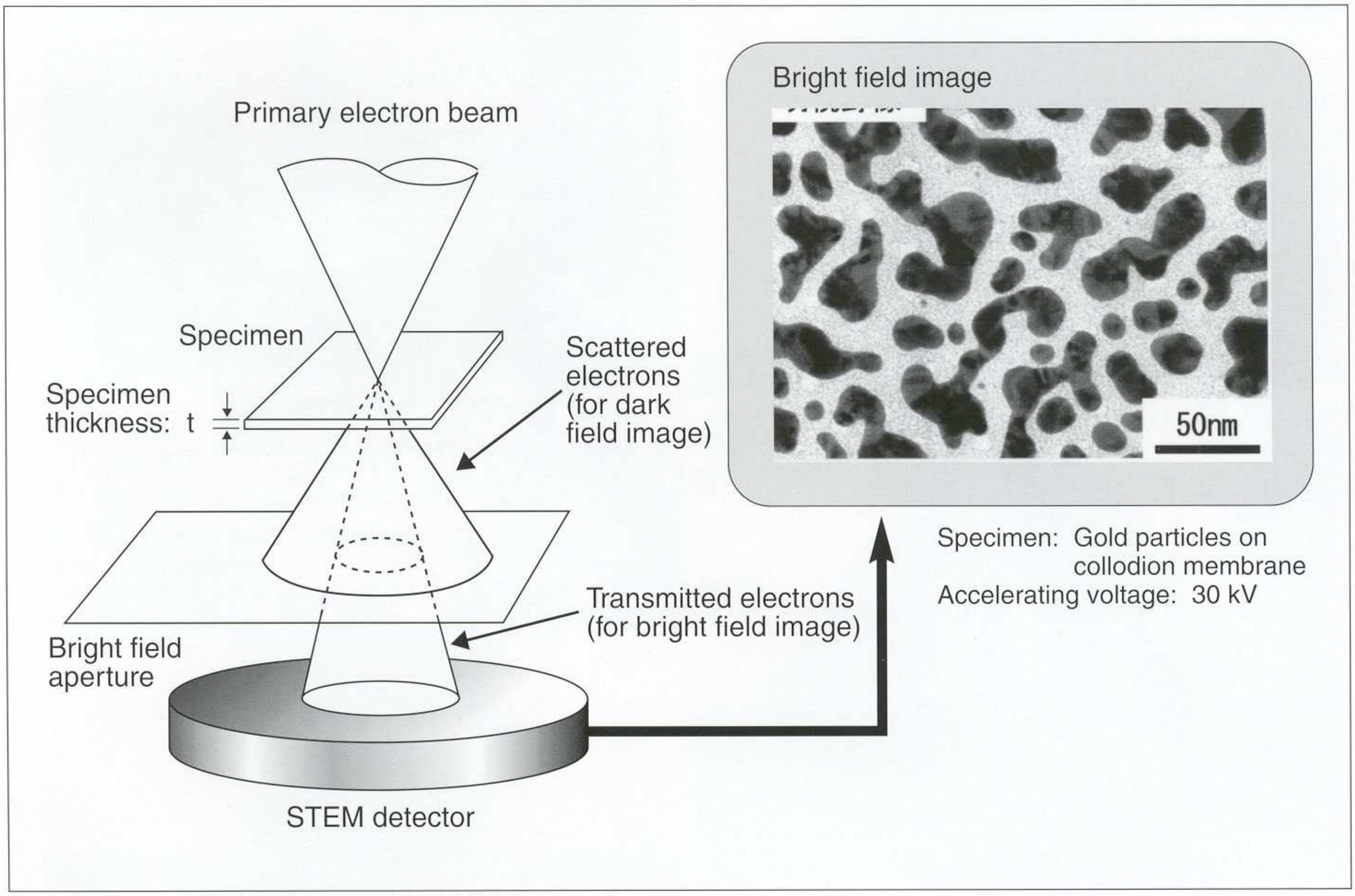


Fig. 2 Specimen thinning of a specific point of interest using a compatible holder

2.1 Bright field image

Fig. 3 shows an electron optical ray diagram showing the bright field image formation. When the beam of electrons strikes a thin specimen (thickness t), it penetrates through the specimen. Some electrons just transmit through it without interaction. Other electrons interact with atoms or atomic structures of the specimen and they are scattered. When the transmitted electrons without specimen interaction reach the STEM detector through the STEM aperture, bright field images are formed. The bright field image shown below was recorded at 30 kV using gold particles on collodion membrane. Electron diffraction contrast due to crystal orientations is seen within the gold particles.

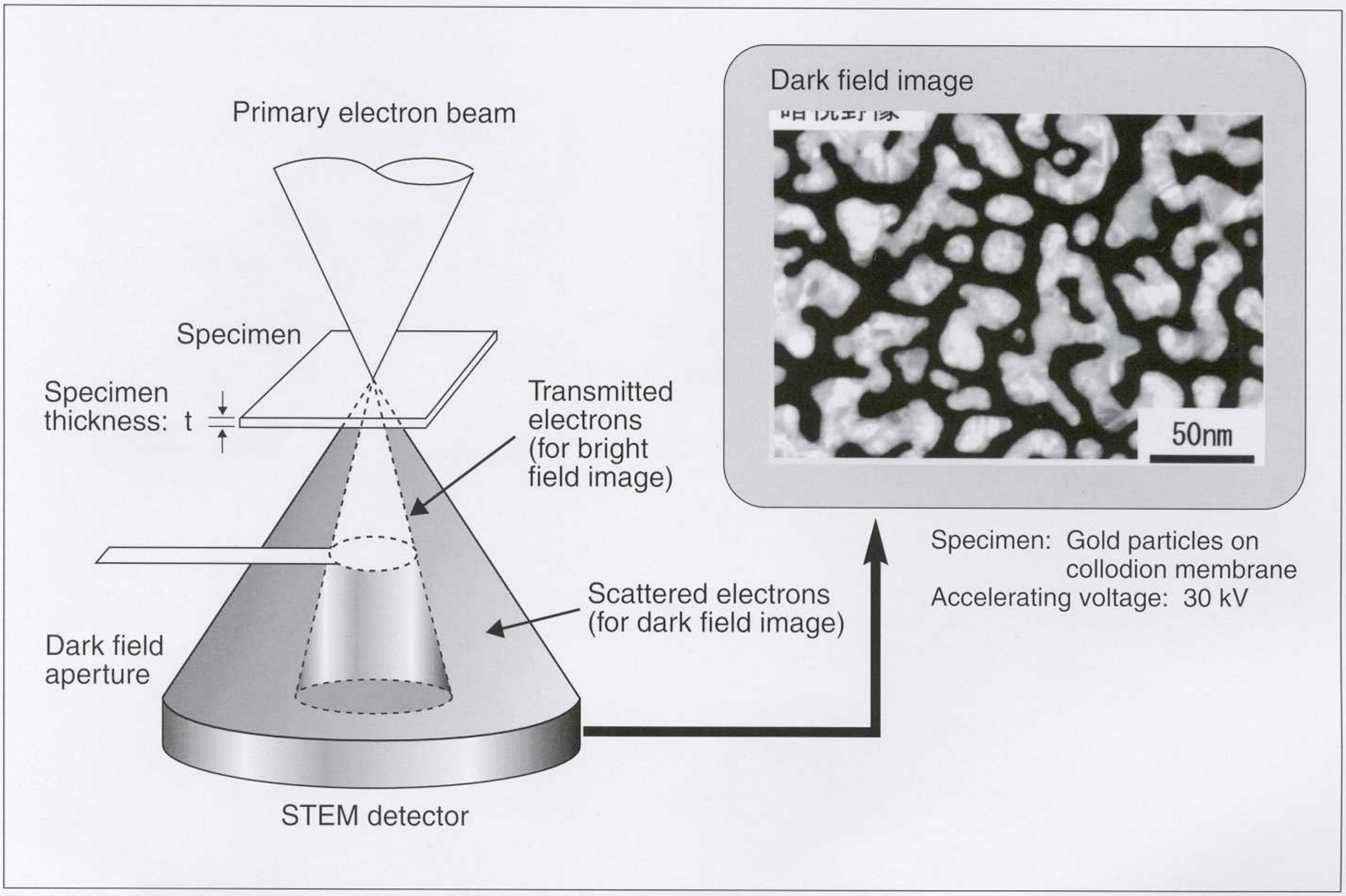


Specimen: Gold particles on collodion membrane
Accelerating voltage: 30 kV

Fig. 3 An electron optical ray diagram for bright field image formation

2.2 Dark field image

Fig. 4 shows an electron optical ray diagram showing the dark field image formation. In contrast to the bright field image, the dark field image is formed by allowing scattered electrons onto the STEM detector using the STEM aperture. The dark field image shown below was recorded at 30 kV using the same gold particles on collodion membrane. Scattered electrons provide compositional information on the specimen so that the gold particles are seen in bright contrast here.



Specimen: Gold particles on collodion membrane
Accelerating voltage: 30 kV

Fig. 4 An electron optical ray diagram for dark field image formation

3. APPLICATIONS

3.1 SRAM observation

Fig. 5 shows STEM (bright field) images of inner structures of SRAM specimen which was thinned to a thickness of about 100 nm. (a) shows a general view. (b) shows a recession (É¢), or inter-metallic compounds (Ti_xAl), and (c) shows barrier metal (Ti, TiN) layers very clearly. It has been difficult to observe (d) a general gate structure, (e) a junction of W-plug and wiring, and (f) grain structures of Poly-Si gate and oxide layers in secondary electron image. But all of these structures are clearly visible in STEM images. These images are promising for evaluation of inner structures of semiconductor devices.

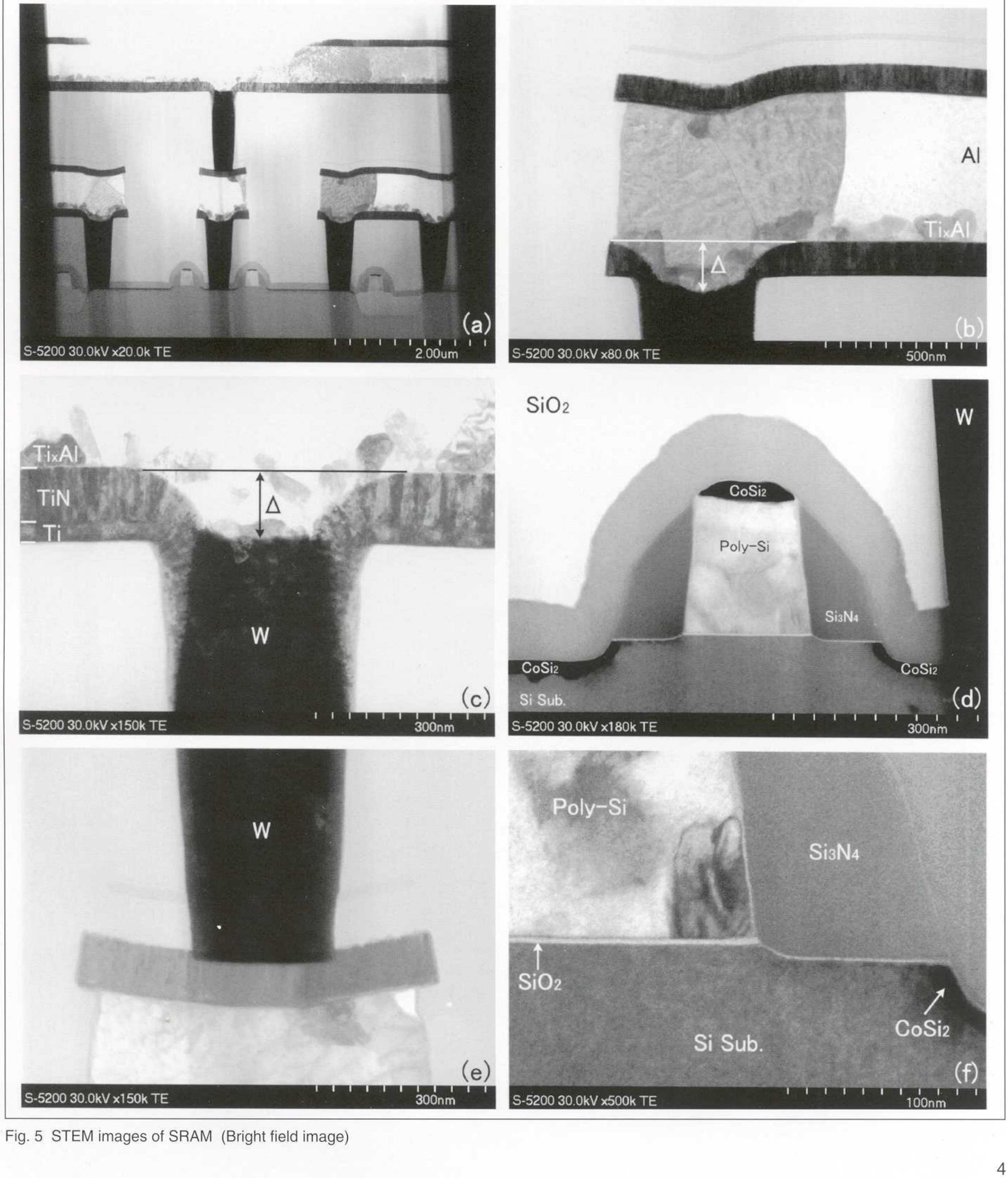


Fig. 5 STEM images of SRAM (Bright field image)

Fig. 6 shows dark field images of the same area shown in Fig. 5. The dark field images exhibit contrast information reflecting specimen compositions so that they could be used for evaluating layer thickness or uniformity of inner structures of multi-layer devices. When we compare Fig.5(c) and Fig. 6(c) and note the bright and dark field images, an interface of W-plug and barrier metal layers or inner structures of W-plug are better observed in the dark field image.

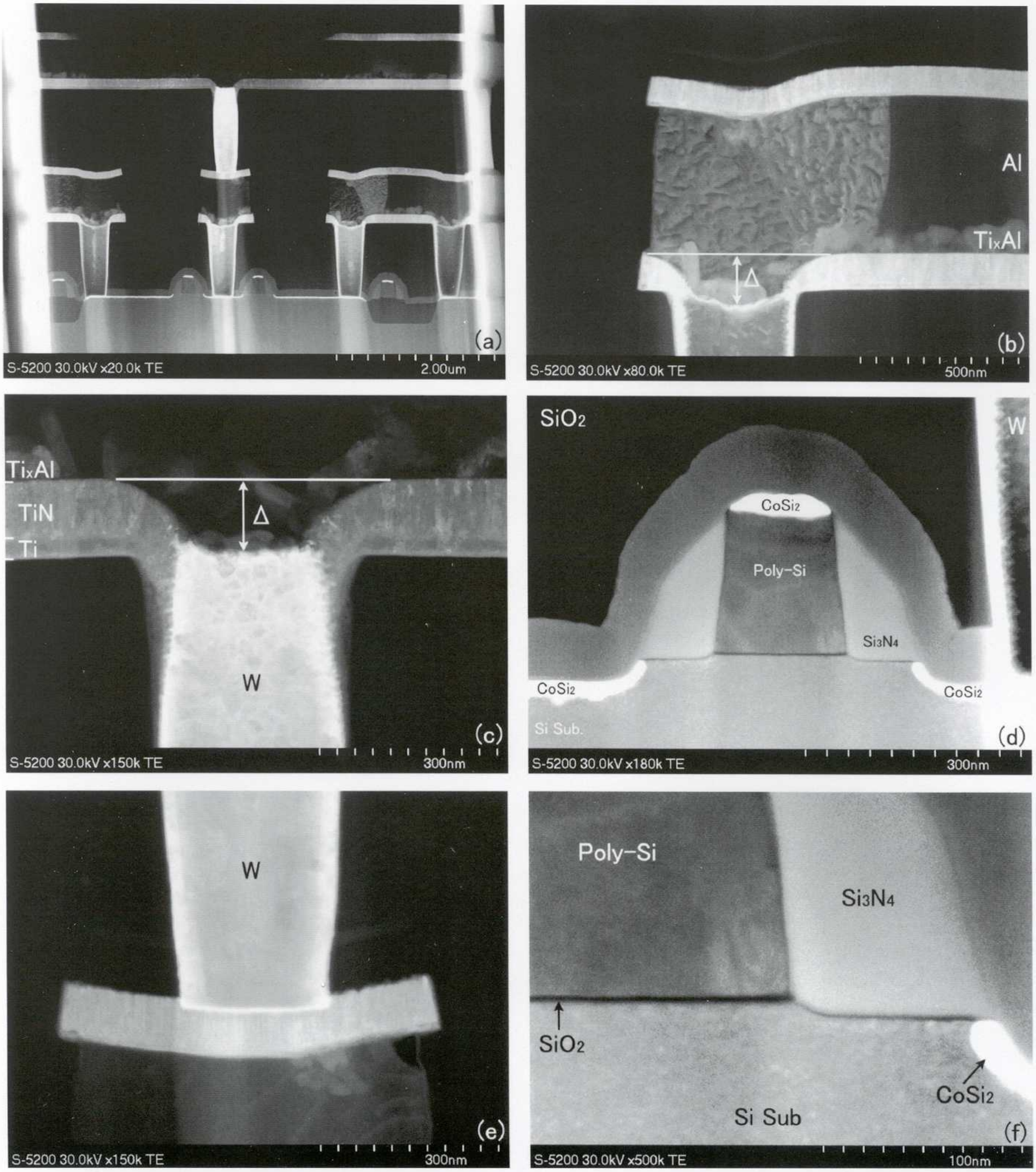
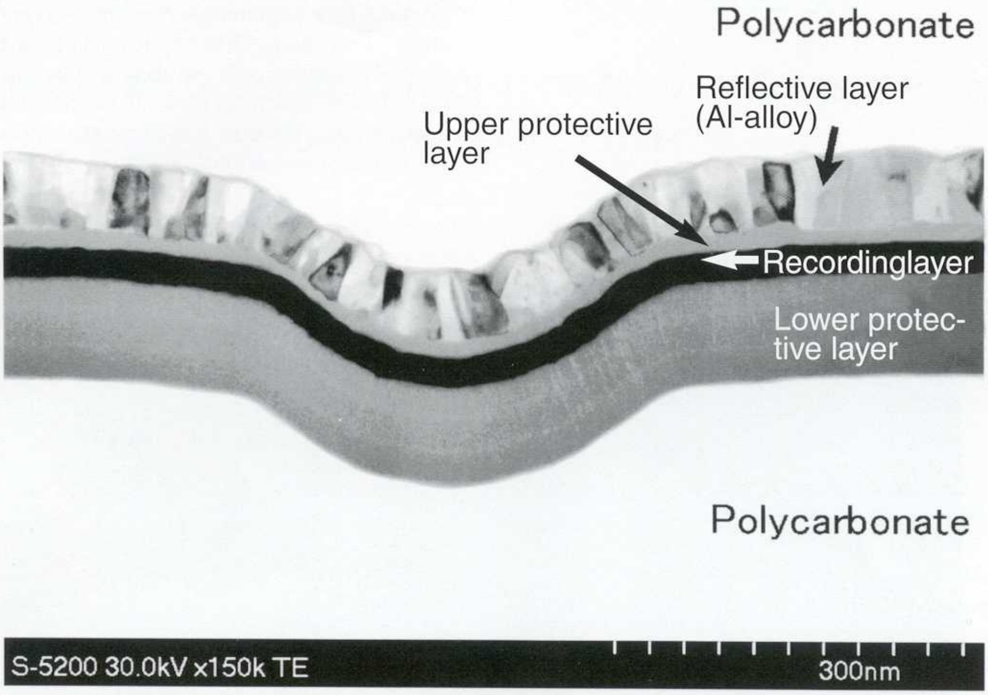


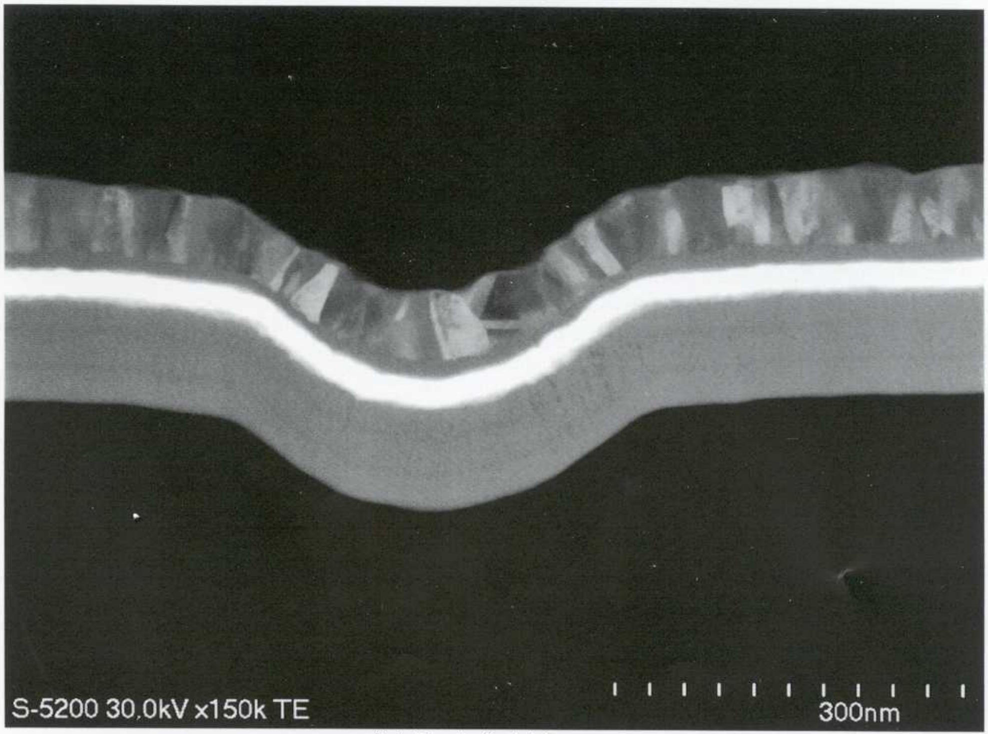
Fig. 6 STEM images of SRAM (Dark field image)

3.2 MO disk observation

Fig. 7 shows a pair of bright and dark field images of inner structures of MO disk which was thinned to a thickness of about 90 nm. Both images (a) and (b) clearly show each of layer structures which are held by polycarbonate material. The bright field image (a) shows crystal structures and their grain sizes of the reflective layer.



(a) Bright field image



(b) Dark field image

Fig. 7 STEM images of MO disk

3.3 Observation of compound semiconductor device

Fig. 8 shows a bright field image of multi-layer structures of a compound semiconductor device $In_{0.52}As/In_{0.53}Ga_{0.47}As$ which was thinned to a thickness of about 70 nm. It shows average atomic number contrast and a thin layer of 1 nm of InGaAs is clearly visible. It also shows crystal defects on InAlAs substrate.

6. CLOSING

We have shown that the STEM mode of the S-5200, when combined with an FIB system, is capable of evaluation of inner structures of any specific point of interest using various semiconductor devices which are moving toward higher integration and density as well as higher operating speeds. We have also shown that better evaluations are made available by choosing either bright or dark field images depending upon the purpose of evaluation. Until now, SEM applications have been devoted to surface observations only but they will be directed toward evaluation of inner structures as we have shown in some of our initial applications. We trust that these new applications of SEM will broaden the conventional limitations on the SEM.

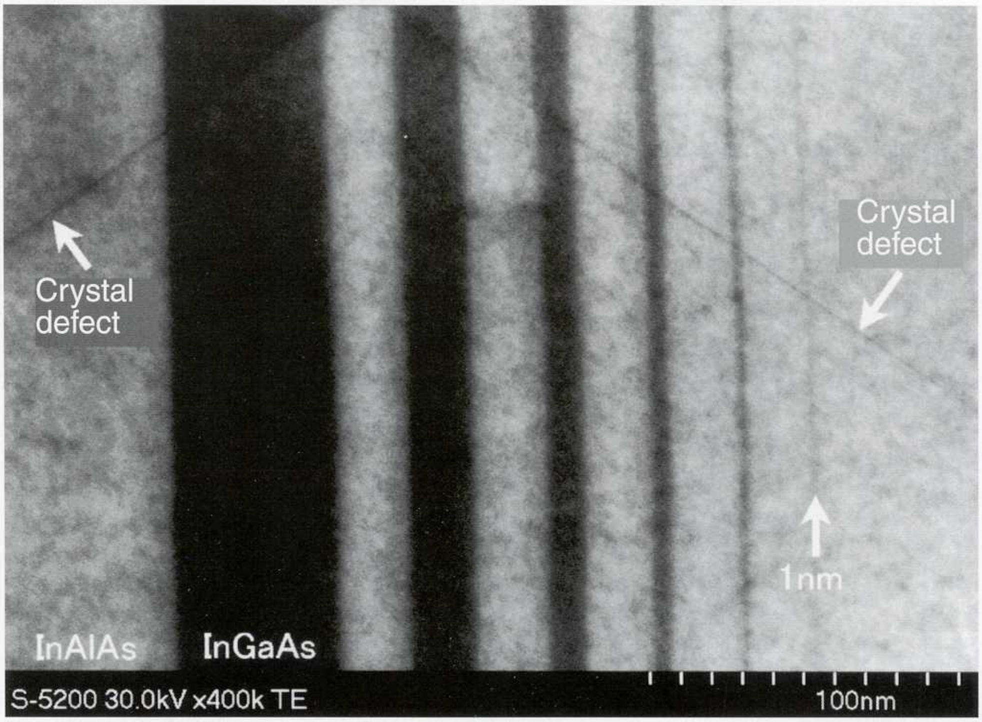


Fig. 8 STEM image of InAlAs/InGaAs (Bright field image)

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