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Technical Explanation

Triple Beam FIB-SEM-Ar(Xe) Combined System NX2000

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1. Introduction

FIB-SEM Systems (FIB: Focused Ion Beam; SEM: Scanning Electron Microscope) are widely used as tools for preparing thin samples for analysis by Transmission Electron Microscope (TEM) and other applications. In recent years, the increasing diversity and miniaturization of structures to be analyzed have spurred researchers to conduct higher-precision analyses. This has resulted in a demand for higher-quality sample preparation techniques, including FIB-SEM systems. To realize this objective requires surmounting a number of challenges, including the following:

1. Nominal thickness for analytical samples have decreased. Consequently, FIB irradiation induced damage has increased in significance when structures are observed at the atomic scale. Sample preparation for reducing these effects must be developed.

2. An increasing number of samples require high-resolution analysis by TEM or similar methods. High-quality sample preparation and high throughput for TEM analysis must be consistent and efficient.

3. Requirements for sample thickness uniformity have grown more stringent. As a result, thickness discrepancies due to curtaining effects caused by the material distribution at the sample surface or the interior structure must be resolved.

In this regard, FIB-SEM systems are playing an increasingly important role. At Hitachi High-Tech, we are developing technologies responding to the above issues. Multiple methods for resolving the above challenges are presented in this article by using the Triplebeam® NX2000 FIB-SEM system (Figure 1).

Fig. 1 NX2000 instrument

2. Triplebeam®

The strategy typically adopted for addressing challenge 1-1 above—by reducing damage due to FIB processing—is to apply low-energy argon ion beam at the final processing stage. With Hitachi High-Tech's system, the exposed cross section can be observed by SEM simultaneously during FIB etching process without sacrificing SEM resolution. This enables precise end-point detection at the user defined location.

The trend toward miniaturization of structures and the need for higher-precision analysis have increased the demand for higher-quality samples with less surface damage.

As shown in Fig. 2, the Triplebeam® system—a unique instrument configuration developed by Hitachi High-Tech—consists of a Focused Ion Beam (FIB), an Electron Beam (EB), and an argon ion beam (Ar) focusing at one coincidence point;[1)] the damage layer resulting from FIB processing can be removed by etching with the low-energy Ar ion beam.

The key advantages of the Triplebeam® system include the following:

- Ar ion-beam processing can be performed within the same instrument, reducing the time required for the overall sample preparation process. Since the majority of processing steps required for sample preparation are carried out by the FIB, the use of the Ar ion beam can be minimized. This allows curtaining effects—sometimes a problematic consequence of Ar ion-beam etching—to be minimized.
- During the preparation of thin samples, bending or curling can occur. It is practically impossible to continue FIB processing—which is based on raster scanning—for additional processing on bent or curled samples. However, with Ar ion-beam etching in the Triplebeam® system, the relatively large diameter beam allows thin samples to be exposed to Ar ion etching entirely, so that additional processing can be performed independent of the sample shape.
- The status of the Ar ion-beam processing can be monitored by SEM. This makes it possible for operators of the instrument—even those with relatively little experience—to avoid errors due to over- or under-etching, a frequent problem with dedicated Ar ion beam milling systems.

The design advantages of the Triplebeam® system's approach to address the challenges described in 1-1 and 1-2 can effectively yield superior high quality results.

Key specifications

(1) FIB
- Accelerating voltage: 0.5-30 kV
- Maximum beam current: 100 nA
- Resolution: 4 nm @ 30 kV,
  60 nm @ 2 kV

(2) SEM
- Accelerating voltage: 0.5-30 kV
  (or 0.7-30 kV when a voltage is applied to the cap electrode)
- Resolution: 2.8 nm@ 5 kV,
  3.5 nm @ 1 kV

(3) Ar
- Accelerating voltage: 0.5 - 2 kV
- Maximum beam current: 20 nA or more @ 1 kV
- Si etching rate: 10 nm / min @ 1 kV

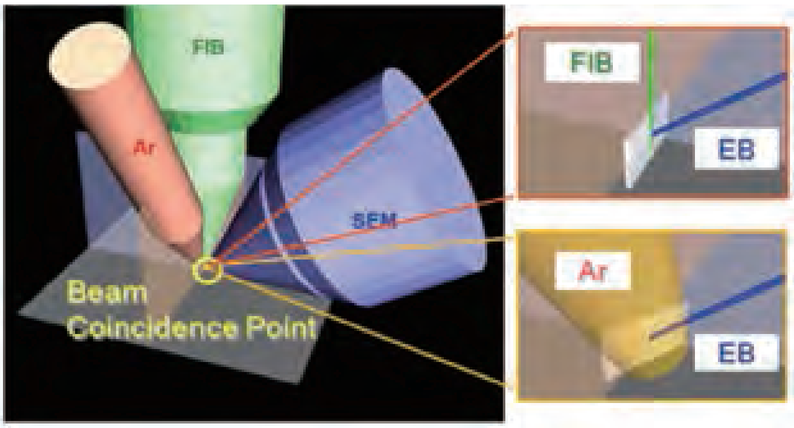
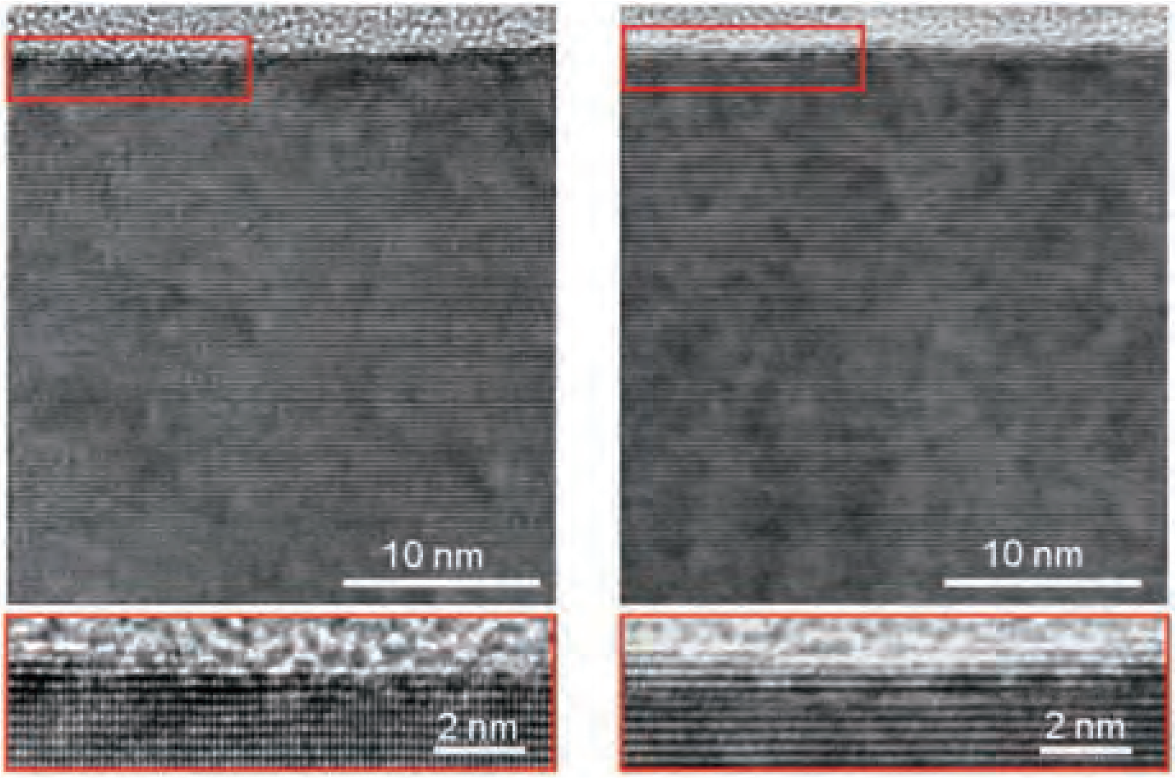


Fig. 2 Key specifications of NX2000 and basic configuration of the Triplebeam® system

3. High-quality TEM sample preparation using low-energy xenon (Xe) ion beam processing

The NX2000 system also includes a new option; a Xe ion beam, which has approximately 3.2 times the mass of Ar ions. Similarly to the Ar ion-beam system, the accelerating voltage of the Xe ion beam can be varied over the range of 0.5-2.0 kV. The added flexibility of the low energy ion system allows for the same system to supply either a Xe ion beam or an Ar ion beam simply by switching the supply gas for the ion source.

Fig. 3 shows TEM images of a GaN sample with final-stage processing conducted with an Ar ion beam and a Xe ion beam [2]. As is the case for the Ar ion beam, the underlying lattice is clearly visible in the TEM image for the sample using final-stage processing with the Xe ion beam.



(a) Sample processed with Ar ion beam (1 kV)

(b) Sample processed with Xe ion beam (1 kV)

Fig.3 TEM images with two final-stage processing methods.
Sample: Single-crystal GaN
Instrument: HF-3300
Accelerating voltage: 300 kV

4. ACE (Anti-Curtaining Effect) Technology

To mitigate curtaining effects, Hitachi High-Tech has been involved in the development of Anti-Curtaining Effect (ACE) technology. One component of this technology is a sample-orientation control using microsampling with an axis of rotation, this technique has been widely accepted[3]. However, in recent years such conventional methods are becoming insufficient for most advanced devices with increasing complexity of three-dimensional structures.

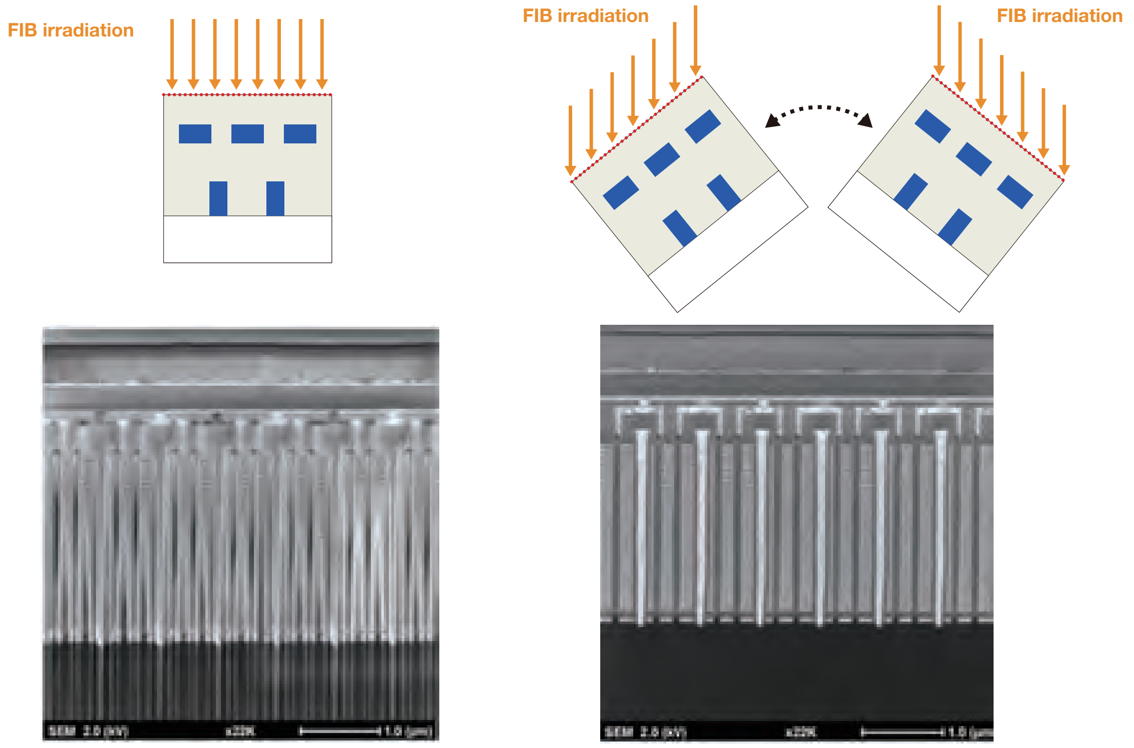
To address this difficulty, we have developed the double-tilt system as a new component for addressing curtaining effects in samples with complex structures typically found in today's cutting-edge high-performance devices.[4]

This section describes this new technique.

The double-tilt system consists of a standard 5-axis motorized sample stage which is mounted on a 2-axis tilting mechanism. This results in a motorized sample stage with a total of 7 axes of motion. Although each axis can be controlled independently, we have created a user-friendly software control environment to assist operators when carrying out procedures with the instrument. In addition, the double-tilt system can be mounted or unmounted by operators without breaking the vacuum in the sample chamber. Thus, the instrument can also be used as a conventional 5-axis motorized sample-stage instrument.

The adoption of the double-tilt system allows the change of direction and incidence angle of the incoming ion beam during TEM sample preparation while monitoring by SEM on a real time basis.

Fig. 4 shows a comparison of the preparation results for a 3D NAND flash-memory sample with and without the double-tilt system employed. In 3D NAND flash memory arrays, there are complex structures consisting of multiple differing materials across a wide area of the cross section. For this reason, there are significant curtaining effects under conventional conditions, as shown in Fig. 4(a). In contrast, the double-tilt system realizes multiple incidence angles during the etching process. This results in a drastic reduction of curtaining effects during sample preparation, as shown in Fig. 4(b).



(a) Without double-tilt system

(b) With double-tilt system

Fig.4 Reduction of curtaining effects using the double-tilt system.
Sample: 3D NAND flash memory

5. Conclusions

In this article we introduced the Triplebeam® system—a proprietary technology developed by Hitachi High-Tech—as well as two new features of the NX2000: the low-energy Xe ion-beam system and the double-tilt system. On the Triplebeam® system, ACE technology, such as the double-tilt system and low-energy Xe ion-beam processing, enables high-quality sample preparation with higher throughput.

Hitachi High-Tech is committed to meeting the R&D and quality-control needs of researchers and engineers by reducing the burdens associated with sample preparation and building higher-precision analytical technologies.

Notes

・Triplebeam® is a registered trademark of Hitachi High-Tech Science Corporation in Japan. (Registered trademark #5136729)

References

1) H. Takahashi et al, The 63rd Annual Meeting of The Japanese Society of Microscopy
2) T. Sato et al, The 72nd Annual Meeting of The Japanese Society of Microscopy
3) K. Kondo et al. The 28th Annual LSI Testing Symposium
4) S. Torikawa et al. The 34th Annual NANO Testing Symposium

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