Noise Reduction Process for Atomic Image Projection Electron-Beam Lithography (AIPEL)

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We proposed a novel concept of projection type electron-beam lithography using the image signal of high-resolution transmission electron microscopy (HRTEM) as a mask, which technique is named by atomic image projection electron-beam lithography (AIPEL). For the formation of quantum dot and wire through the AIPEL process, we modified the transmission electron microscope with a field emission gun (JEM-2010F, JEOL Ltd.). The proof of concept of AIPEL was successfully demonstrated[1].

As we are using the crystalline lattice image observed by HRTEM to make patterns, the quality of image is a key factor. Now, we use the conventional TEM sampling method using polishing, dimpling, and ion-milling for the AIPEL mask preparation. Therefore, there exists the nonuniformity of mask signal (i.e. "noise signal"). We extract the noise signals from HR image signal (Fig. 1) using the image filtering by Fourier transformation. The low frequency noise [Fig. 1(c)] is due to the thinckness non-uniformity and electron radiation damage and the high frequency noise [Fig. 1(d)] is due to the surface damage layer and carbon contamination.

To experimentally realize the Fourier filtering, we introduce the noise reduction objective aperture (NR aperture) at the back-focal plane of objective lens. The NR aperture only passes through the transmitted and diffracted spot with phase information of mask signal at the back focal plane of objective lens. We fabricated the NR aperture by focused ion-beam (FIB) etching of Mo thin sheet with 10 µm thickness. Fig. 2 shows the SEM image of NR aperture with 10 µm hole and 5 µm hole. When NR aperture is introduced, the beam current is reduced to 50% and the modulation transfer function value is increased from 0.3 to 0.4. Fig. 3 shows the experimental patterning results at 160 times using NR aperture with 5µm hole and previously reported result[1].

In this presentation, I will present the origin and fabrication of NR aperture and the nano-patterning results using NR aperture in detail. Additionally, I will introduce about the image forming aperture producing a mask signal.

[1] H.-S. Lee, B.-S. Kim, H.-M. Kim, J.-S. Wi, S.-W. Nam, K.-B. Jin, Y. Arai, K.-B. Kim, *Adv. Mater.* **19**, 4189 (2006)

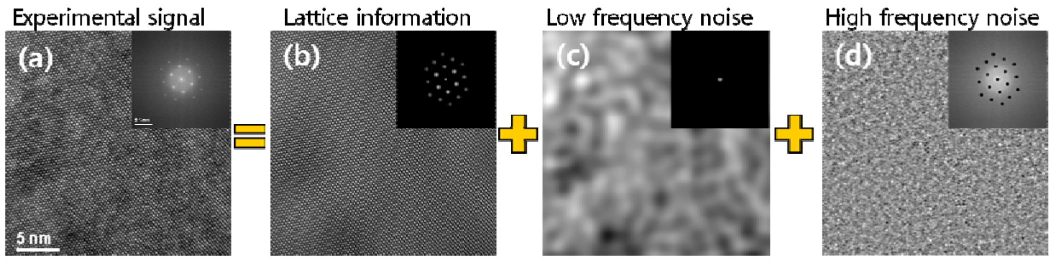

Fig. 1. Noise analysis of HRTEM image; (a) experimental HRTEM image (mask signal), (b) lattice information signal, (c) and (d) noise signal. (c) is the low frequency noise and (d) is high frequency noise.

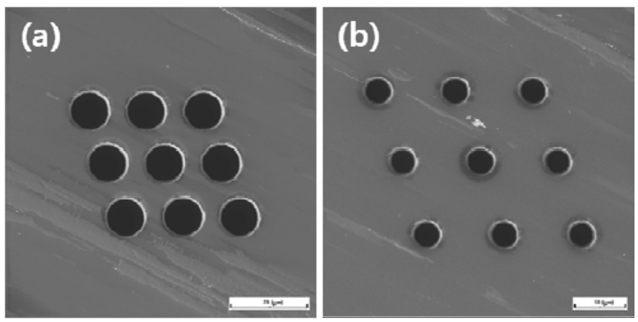

Fig. 2. Noise reduction objective aperture made by focused ion-beam. (a) 10 µm hole and (b) 5 µm hole NR aperture for Si (110) mask.

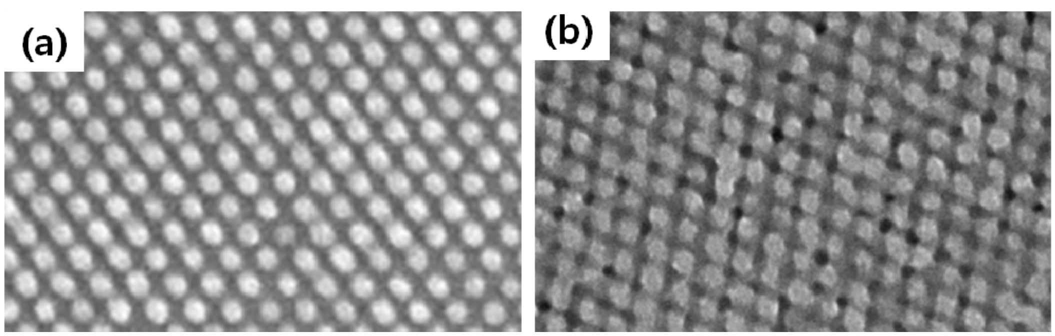

Fig. 3. (a) Experimental results using NR aperture with 5um hole and (b) previously reported results.