Electron beam projection nanopatterning using crystal lattice images obtained from high resolution transmission electron microscopy

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The fabrication of nanometer-scale features such as quantum dots and quantum wires, in a controllable and economically viable manner is one of essential requirements for the production of highly functional devices. Here, we propose a new electron beam projection lithography technique for patterning nanometer scale, periodic structures. The novelty of this technique is that the crystalline lattice image observed by high resolution transmission electron microscopy (HRTEM) is employed as the ultimate mask to define nanometer scale pattern. Namely, the Ångstrom-scale lattice image of a crystalline material is magnified within the electron microscope, and is projected onto an electron-beam-resist-coated substrate. This technique is tentatively called AIPEL (**A**tomic **I**mage **P**rojection **E**lectron-beam **L**ithography).

To experimentally prove this concept, we developed the specially designed hardware based on the modification of a 200 kV TEM with a field emission gun (JEM-2010F, JEOL Ltd.). The patterning lenses for controlling the patterning magnification (50 to 300 times) were inserted below objective lens, and the wafer stage for loading the resist-coated wafer was installed in the lithography plane, as shown in Fig. 1. Using this technique, we successfully fabricated periodic arrays of dot and line patterns with feature sizes of about 25 nm using single-crystalline Si as the mask materials. Moreover, the HRTEM images which can be obtained from crystalline samples can be far more complicated. Fig. 2 shows the various patterned structures obtained from crystalline β-silicon nitride (β-Si_3N_4) sample with hexagonal crystal system (P63/m). The patterning results of these complicated and interesting nanostructures not only demonstrate the uniqueness of this method but also open up a whole new area of investigating a variety of electrical, optical, and magnetic properties of nanostructures.

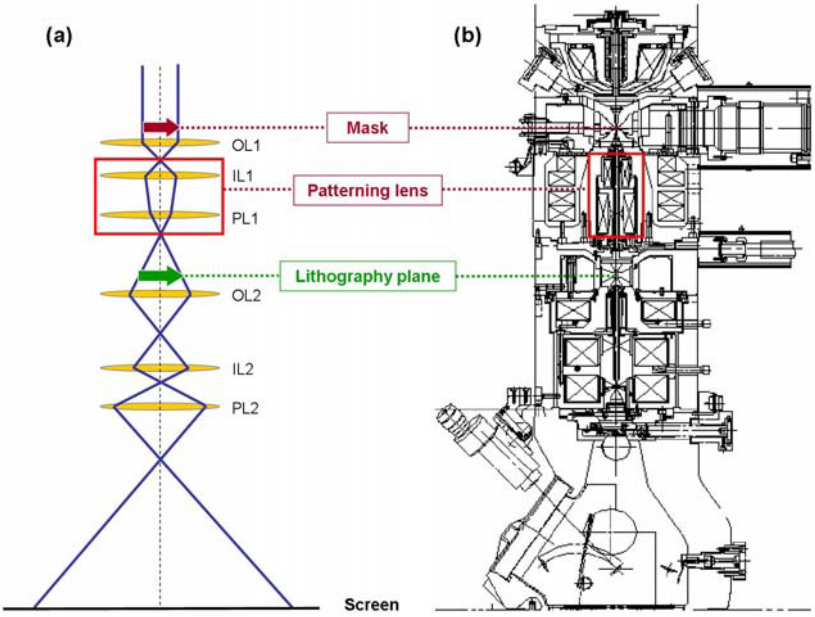

Fig. 1. (a) Schematic ray diagram and the basic lens system of AIPEL system. (b) AIPEL hardware developed based on the modification of a 200 kV TEM equipped with a field emission gun.

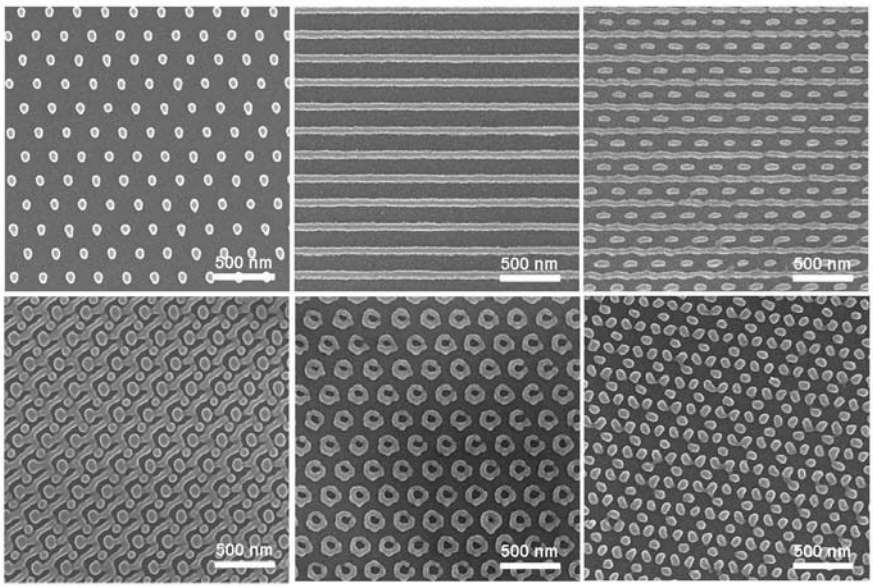

Fig. 2. SEM images for patterned Si substrate from various β-Si_3N_4 lattice images obtained by changing the defocus value at or close to the [001] zone.