Three-Dimensional Nanofabrication Using Electron Beam Lithography—The World's Smallest Globe with a Resolution 100 Times Higher than Previously Possible

NTT has created an electron beam (EB) lithography[*1] system that can fabricate extremely small three-dimensional (3D) structures with sizes measured in nanometers. NTT demonstrated the 3D nanopatterning and nanofabrication by exposing a small sphere to the beam to form the world's smallest globe. This highly advanced technique promises to become a technological foundation of nanotechnology[*2], which is expected to give rise to many new industries and new markets.

Key features

- 3D nanofabrication and nanopatterning down to the 10-nm level
- A drive that rotates a sample around two axes with high precision.
- A height sensor that enables the electron beam to be focused on a 3D sample with a focusing error of less than 1–2 μm.
- A new beam-positioning system that detects the outline of a sample using a transmitted-electron signal for accurate placement of patterns.

Background

EB lithography creates two-dimensional (2D) patterns for semiconductor integrated circuits. The resolution at present is on the order of 5–50 nm. On the other hand, 3D fabrication methods should have a much wider range of application. However, current 3D methods have found only limited applications because of some drawbacks. For example, deposition using a charged-particle beam is time-consuming, which makes it very difficult to build complicated structures. Many methods of 3D fabrication have been developed for microelectromechanical systems (MEMS)[*3]. However, since those methods use an optical or x-ray beam, the minimum size is limited by the wavelength or lithographic resolution, which is on the order of 1 μm. The new technique developed by NTT uses a special sample rotation drive and EB nanolithography, which has a resolution 100 times finer than methods using an optical or x-ray beam (i.e., 10 nm). This enables reasonably fast 3D fabrication and patterning. To demonstrate this technique, NTT used it to fabricate the world's smallest globe and a 3D nano-filter.

Overview of techniques

One key technique is the ability to rotate a 3D sample in such a way that any of its faces can be exposed to the electron beam. To accomplish this, NTT developed a two-axis-of-rotation drive system that can be loaded into the EB lithography apparatus (**Fig. 1**) and can rotate a sample around the R-axis by 360 degrees and the T-axis by 45 degrees. It has an accuracy of better than 0.1 degrees. Since the shape of the drive is similar to that of a semiconductor wafer holder, the drive can be easily mounted inside the apparatus. Another key technique is EB focusing on a 3D sample. This requires the ability to determine the height (Z coordinate) and horizontal position (X and Y coordinates) of any point on a sample. To measure the height,

*1 Electron beam lithography is a technique for making very fine patterns for fabricating semiconductor integrated circuits. An electron beam can be focused down to a diameter as small as a few nanometers, which can then be used to form fine patterns less than 10 nm in size.

*2 Nanotechnology refers to various technologies related to structures in the size range from 1 to 100 nm. Researchers in many fields are now focusing on techniques for fabricating and evaluating tiny structures and ways of using them in practical applications. The main technologies in this field concern fabrication.

*3 Microelectromechanical systems (MEMS) include micromachined parts, electrically controlled microdevices, and microsystems, but not microelectronic circuits. Some have very complicated three-dimensional structures.

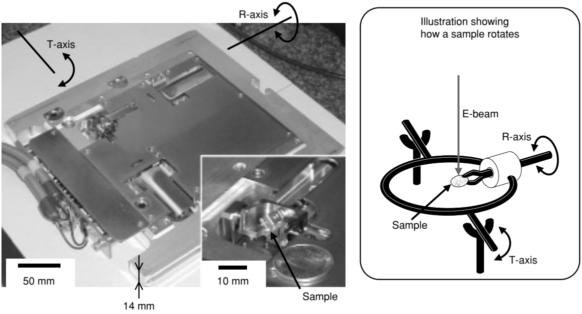

Fig. 1. Two-axis-of-rotation drive that can be loaded into an EB lithography apparatus.

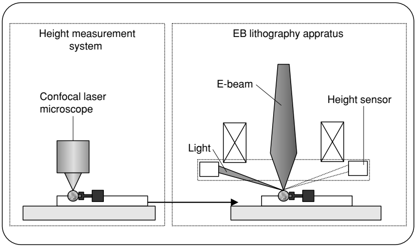

Fig. 2. Height measurement system (left) used to focus the electron beam on the sample surface and the EB lithography apparatus (right).

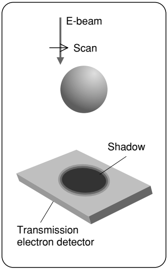

Fig. 3. Illustration showing how to determine the position of a point on a sample.

NTT developed a new height measurement system (**Fig. 2**) that uses a confocal laser microscope*4. The system makes a height map of a sample, thus enabling the height of any point on the sample to be determined, even if the sample is rotated. In addition, an outline of the shadow of a sample is mapped with a transmission electron detector, and patterns are written at the designed position relative to the outline (**Fig. 3**).

The world's smallest globe (**Fig. 4**) was made by writing a map of the world on a micro-sphere made of resin. This nano-globe has a diameter of about 60 μm, which is finer than a human hair. The smallest pattern is about 10 nm in size, which corresponds to 2 km on the actual earth.

Repeated EB patterning and development produced

*4 Confocal laser microscope: This microscope can measure the three-dimensional surface morphology of a sample by using a small aperture in the image plane. It provides a height resolution of better than 10 nm, and uses light from a high-intensity laser.

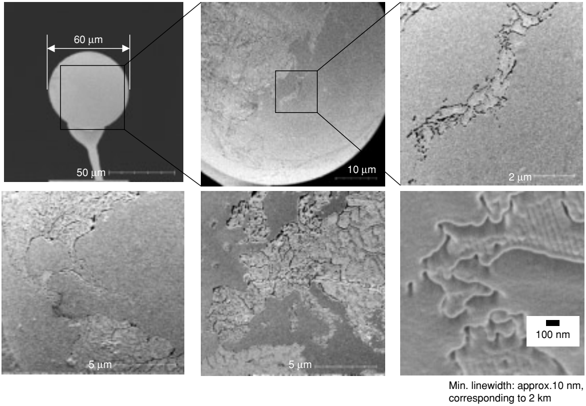

Fig. 4. The world's smallest globe (nano-globe). It displays coastlines and rivers, and there is some contrast between land and sea areas. The patterning (EB exposure) of the entire world map only took about two minutes.

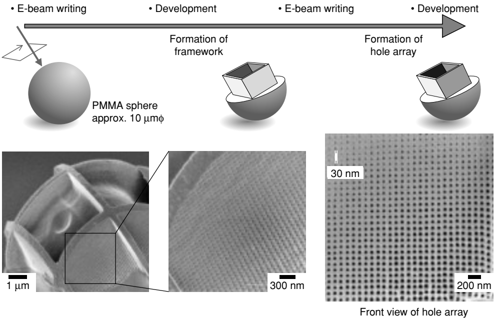

Fig. 5. Nano-filter with holes as small as 30 nm in diameter. (PMMA: polymethylmethacrylate)

the nano-filter shown in **Fig. 5**. The first exposure and development formed the framework of the filter, and the second formed an array of small holes on the sidewalls of the framework. The smallest holes have a diameter of about 30 nm.

Future prospects

Plans call for the development of methods of applying this technique to nanofabrication of various materials, such as semiconductors. In addition, investigations will be carried out to determine how this technique can be used to make new types of highly functional nanoelectronic devices.

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Compact Lasers Generate Light of any Desired Wavelength Filling the Wavelength Gaps of Semiconductor Lasers—Suitable for Applications in Biotechnology, Medicine, and Environmental Measurement

NTT has developed a technique for making solid-state lasers that can be designed to emit at a specific desired wavelength within a certain range, which had been impossible with semiconductor lasers. This new technology is being promoted through the "Comprehensive Producer Function[*1]", a program that was started in July 2003 to promote the commercialization of prominent research achievements. Alliances with other corporations should lead to commercial products on the market in summer 2004. This new technology provides a high output, a longer operating life, and easy maintenance in a palm-sized device. The lasers are also less expensive than conventional lasers. We expect great demand in the fields where large gas lasers are currently used and also in biomedical fields such as DNA or cell function analysis and environmental measurement of NOx or SOx (oxides of nitrogen and sulfur).

Background

Lasers are categorized by their emission sources. For example, there are gas lasers (e.g., the argon laser), solid-state lasers (e.g., the Nd:YAG laser), and semiconductor lasers. Semiconductor lasers have become more common because they are small, light, and inexpensive. They are used mainly for the visible and near-infrared regions for recording media including CDs and DVDs as well as in the telecommunication field (**Fig. 1**).

However, there are wavelength gaps for which semiconductor lasers are not available: the 0.5–0.6-μm region (green, yellowish-green, yellow, orange) and the 2–5-μm region (mid-infrared). For these wavelengths, other emission sources are used and they are more expensive and consume more power than semiconductor lasers. NTT has developed a series of compact lasers that cover these regions. Each laser can be designed to generate a specific

*1 Comprehensive producer function: Special producers appointed for commercialization directly promote the prominent research of NTT Laboratories to put products on the market in cooperation with NTT Group companies and other outside companies.