JJAP Series 3
Proc. of 1989 Intern. Symp. on MicroProcess Conference pp. 377–379

Linewidth Measurement by a New Scanning Tunneling Microscope

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(Received July 3, 1989; accepted for publication October 12, 1989)

We have developed a new STM using monolithic parallel spring mechanisms with flexture hinges. The STM is equipped with a two-dimensional optical interferometer to calibrate the motion of the scanner with subnanometer accuracy in real time. Distortion-free images of a grating pattern have successfully been observed.

KEYWORDS: STM, linewidth measurement, nanometrology, heterodyne interferometer, submicron metrology, micropattern, xy scanner, flexture hinge mechanism

§1. Introduction

The feature size of micropatterns on semiconductor devices has already been reduced to submicrometer range by recent progress in ultrahigh-density semiconductor technology. For example, the minimum linewidth of 64 Mbit DRAM devices which are under development is less than 500 nm. The linewidth measurement with nanometer accuracy is indispensable in the evaluation of microfabrication technology.

In this paper, we report on a new STM for nanometer metrology. The STM is equipped with a two-dimensional interferometer to measure subnanometer displacement.

§2. Tools for Submicron Metrology

The scanning electron microscope (SEM) is widely used to evaluate submicrometer patterns. The SEM, however, does not directly give vertical dimensions of the pattern. In order to obtain actual line shape, the experimental data must be compared with the result of complicated Monte Carlo computation[1] which requires many simulation parameters that cannot be decided accurately. Therefore, the linewidth obtained contains some uncertainty of the order of 10 nm.

The scanning tunneling microscope (STM) has subnanometer lateral and vertical resolution.[2] It is a candidate for nanometer metrology. STM profiles sample topography by scanning a tip along the surface while detecting tunneling current between the tip and the surface. A tripod or a tube scanner formed out of piezoelectric material is widely used in an STM for moving the tip in three dimensions. The X and Y coordinates parallel to the surface are derived from applied voltage to the scanner. Large distortion is inevitable in the topography obtained by these scanners.[3] The distortion mainly results from

(1) interference in the motion of X, Y, and Z piezoelements of the scanner,

(2) nonlinear response of the piezoelement to the applied voltage, and

(3) hysteresis and creep in the element.

To eliminate the distortion, we have developed an STM with a high-precision positioning stage. Distortion-free images of a grating pattern have successfully been observed.

§3. Positioning Stage

A monolithic parallel spring mechanism,[4] as shown in Fig. 1(a), is used as a two-dimensional(X-Y) scanner for the STM. It provides pure orthogonal motion. The tunneling tip is guided in the Z-direction by another monolithic mechanism (Fig. 1(b)). The lowest mechanisms were cut from aluminum alloy. The scan area is $15\times15\ \mu m^2$ and the mechanical resonant frequency is about 600 Hz. The mechanism is free from stick-slip and lost motion and shows negligible pitching, yawing and rolling. PZT2 and PZT1 are laminated piezoelectric actuators for X and Y translation, respectively. A sample is fixed at point C in Fig. 1 and is moved in the X-Y plane while the tunneling tip is controlled in the Z-direction to keep the tunneling current, i.e., tip-sample distance, constant. The motion of the actuator is amplified by a lever arm. The displacement of P1 in Fig. 1 produces the resultant displacement of point C with a gain of ratio $l_2/l_1(=2.0)$. The largest displacement can be easily expanded by changing the ratio.

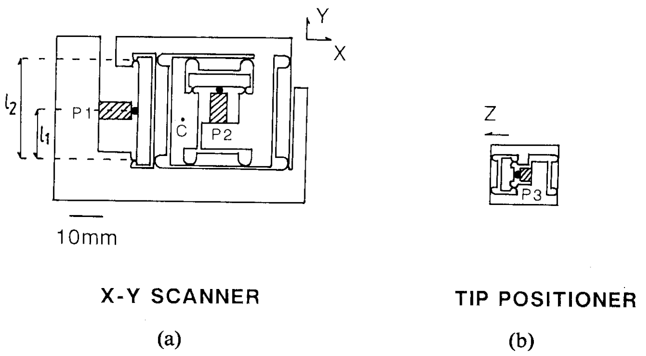

Fig. 1 (a) A new STM scanner using a monolithic parallel spring mechanism. P1, P2 denote piezoelectric actuator(hatched region). (b) Tip positioner.

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§4. Optical Interferometer

Heterodyne interferometry is applied to displacement measurement of the scanner. Figure 2 shows a schematic diagram of the Michelson interferometer. M3(M2) is a reflecting mirror attached to the moving element of the $X(Y)$ scanner. M4(M1) is a reference mirror. A beam from the acoustooptic modulators has two orthogonally polarized frequency components. The frequency difference between these components is 100 kHz. A polarization beam splitter (PBS2) separates the components into the measurement and reference arms, and the two components are combined collinearly by the same PBS1 after reflecting from M3 and M4. X-displacement of mirror M3 corresponds to phase change (2πrad$=316.4$ nm) in the beat signal from photodetector D2. Y-displacement is measured by the same procedure. Thus, the motion of the piezoactuators is calibrated in real time. Currently, the measured output phase noise is 6×10^{-5}rad$/\sqrt{\mathrm{Hz}}$, and the smallest detectable displacement corresponds to 100 pm in 1 kHz bandwidth. The periodic error of the phase,[5,6] which is the difference from the linear dependence on the displacement, is reduced to 0.15% by the balanced detection. Thus the accuracy is better than 0.5 nm.

A block diagram of the STM and optical interferometry system is shown in Fig. 3. X, Y phase data and Z-controlled voltage Vz that corresponds to vertical information are digitized simultaneously and stored in the memory of the computer. Thus, each Vz has accurate two-dimensional coordinates. Consequently, the distortion due to the piezoelements is corrected.

§5. Performance

The STM is operated in the ambient atmosphere of a laboratory environment. The room temperature was controlled within 0.1 K to reduce thermal drift.

Firstly, graphite (0001) surface was observed to check the resolution. Figure 4 shows the STM image of graphite. Dark(H) and bright(B) spots represent hollow sites and B-atom sites, respectively. This hcp structure

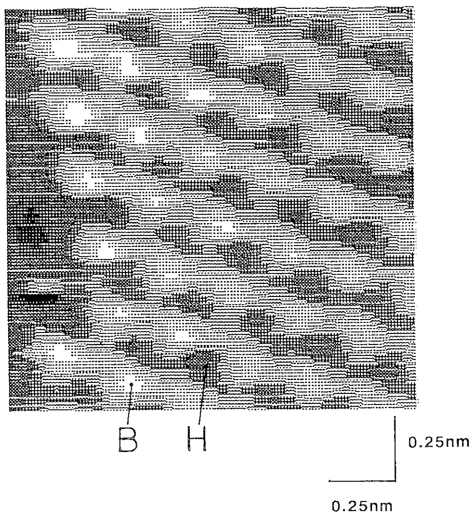

Fig. 4. An STM image of the graphite (0001) surface.

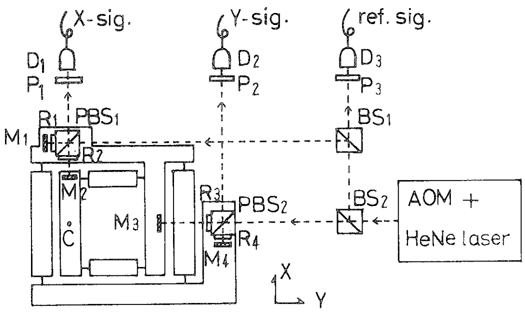

Fig. 2. Schematic diagram of the two-dimensional Michelson interferometer. D_i: photodetector, P_i: polarizer, R_i: $\lambda/4$-plate, M_i: mirror.

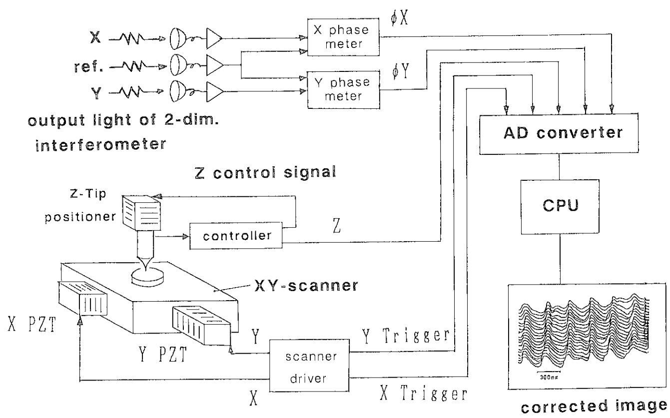

Fig. 3. Block diagram of the STM and optical interferometry system.

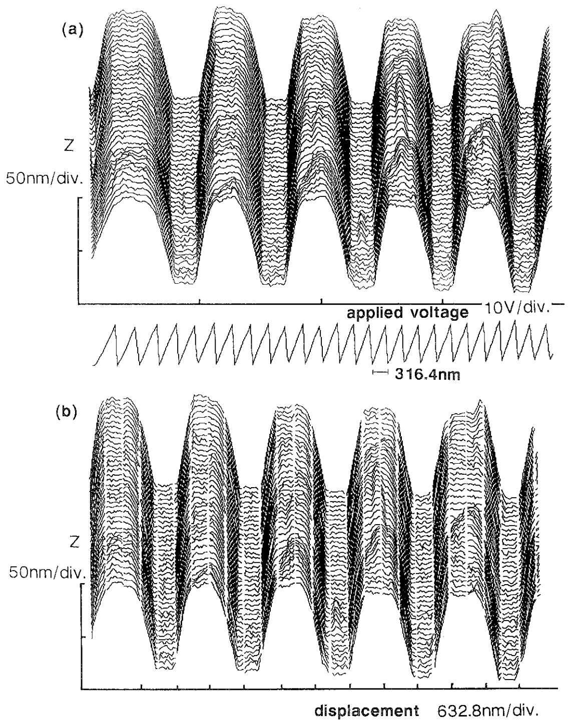

Fig. 5. (a) A "raw" STM image of the grating pattern on the compact disk surface and (b) the laterally calibrated image.

has a good three-rotational symmetry. This means orthogonality of the motion of the scanner. Secondly, a grating pattern on a compact disk surface was observed. The sample surface was coated with a thin layer of platinum. The grating grooves were adjusted to be perpendicular to the scan axis. Figure 5(a) is a "raw" STM image of the grating pattern. The horizontal axis is applied voltages to the piezoelement. A sawtooth wave in the lower part of the figure is the phase output from the interferometer. The spacing of the wave is one half-wavelength of the laser. The spacing in the left side of the figure is clearly wider than that in the right side. The distortion is caused by hysteresis of the piezoelement.

Figure 5(b) is an STM image where the horizontal axis is the displacement measured with the interferometer. Distortion due to hysteresis is clearly corrected. The pitch size of the grating is 1570 ± 5 nm. These results demonstrate the ability of the STM to measure micropatterns with nanometer accuracy.

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