Paper

Application of scanning shear-force microscope for fabrication of nanostructures

Andrzej Sikora, Teodor Gotszalk, Anna Sankowska, and Ivo W. Rangelow

Abstract—In view of the rapid growth of interest in AFM technique in surface property investigation and local surface modification we describe here an AFM microscope with optical tip oscillation detection. The modular shear-force/tunneling microscope for surface topography measurement and nanoanodisation is described. The measurement instrument presented here is based on the fiber Fabry-Perot interferometer for the measurement of the conductive microtip oscillation that is used as nano *e*-beam for local surface anodisation. An advantage of this system is that quatitative measurements of tip vibration amplitude are easily performed.

Keywords*— *AFM, nanostructures fabrication, shear-force microscopy.

1. Introduction

Scanning force microscopy [1] is one of the many scanning probe techniques developed after the invention of scanning tunneling microscopy (STM) [2]. In atomic force microscopy the force interaction observed between the microtip mounted on the cantilever and the investigated surface is utilized to characterize the surface. Several measurement techniques can be applied to the detect of force interactions acting on the microtip. One of them is the shear-force microscopy (SHFM). In this technique a wire tapered either by means of electrochemical etching or by pulling is mounted perpendicularly to the sample. This tip is oscillating laterally to the surface by a few nanometers near to one of its mechanical resonant frequency. The oscillations are damped out by shear forces at a distance of a few nanometers from the surface. This effect may then be used to adjust the tip-sample distance. It may also be used as a basis for high-resolution topographic imaging. Accurate measurement of the true oscillation amplitude of the tip yields very important information that allows this tool to be used more confidently. Moreover, high measurement sensitivity is desired to enable the use as low oscillation amplitude as possible. This is because of two reasons: in order not to loose the lateral resolution of surface measurements and in order to extend the lifetime of the microtip.

In this paper optical tip oscillation detection setup will be presented that includes a Fabry-Perot optical fiber interferometer. The advantages of the presented setup are extreme sensitivity and compactness. Using the described measurement system, quantitative measurement of the probe dither motion with the resolution of 0.1 nm is possible in the bandwidth of 100 Hz. Moreover, optical detection system allows electrical voltage to be applied to the conductive microtip. In this case the microtip can be used as an electron beam (*e*-beam) source for nanolithography processes or as a collector of tunneling or field emission current flowing between the surface and the microprobe.

In parallel to fundamental studies [3–7], several nanometer-scale devices, such as single electron [8] and metal-oxide [9] transistors, quantum wires [10], high-density memories [3, 11], and Josephson junctions [12], have illustrated some of the nanoelectronic applications. Machining of silicon structures has also been demonstrated by AFM oxidation [13]. Furthermore, local oxidation lithography is compatible with the operation of parallel tip arrays [14]. This allows single-centimeter area patterning to be performed.

2. Instrumentation

In our setup, a single-mode optical fiber is fixed at the distance of a few microns from the reflecting surface, the deflection of which is monitored. The interference between the light reflected from the fiber-air interface and the backscattered light from the reflecting surface is monitored with a optical detector. In our interferometer design we use a single-mode pigtailed semiconductor laser as the light source. Since the light backscattered from any junction in the optical fiber system may disturb the operation of the laser diode, we use a solid-state optical Faraday isolator to ensure proper emission of the laser light. In our system we utilize an isolator built into the laser diode, which accurately fits the wavelength of the light source and is insensitive to mechanical vibrations. One of the fiber ends of the bidirectional coupler is connected directly with the optical isolator. The wire with the microtip is mounted close to the well cleaved fiber end of the coupler. The signal photodiode (Fig. 1) detects the interference of the light reflected from the interferometer fiber end and from the microscope wire.

To obtain high resolution and high fringe visibility the interferometer light source is supplied using a high-precision current source built specifically for this purpose, which ensures the stability of the current supply in the range of 50 ppm. The temperature of the laser is controlled by a Peltier cooler with the stability of 10 mK. We tested the interferometer sensitivity by changing the distance between the wire and the interferometer fiber and simultaneously recording the interferometric fringes. If the amplitude of the fiber movement is bigger than $\lambda/4$ we observe the pattern shown in the Fig. 2.

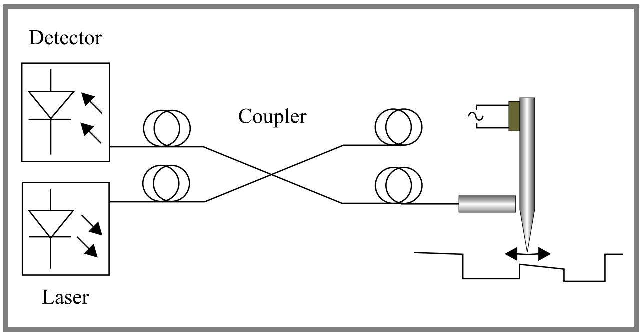

Fig. 1. Tip oscillation detection setup – optical fiber interferometer diagram.

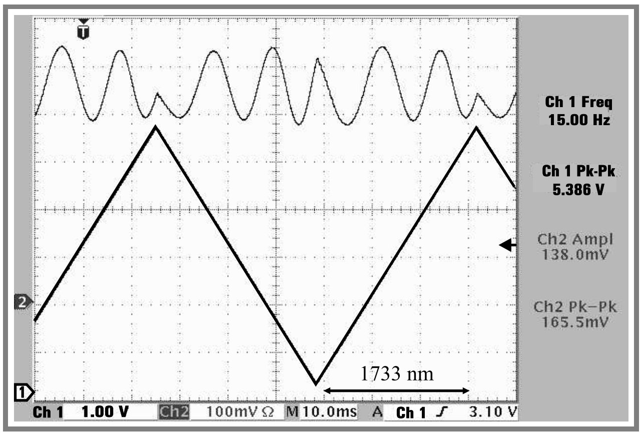

Fig. 2. Interferometric signal (thin line) versus tip movement (thick line).

The sensitivity of the developed interferometer may be obtained from the slope of the recorded signal – in our design we obtain the sensitivity 2 mV/nm. It should be noted that the distance between the interferometer fiber and the wire with the microtip must be adjusted using a piezoactuator, so that the working point is placed on the linear part of the slope. Our instrument reaches the resolution of 0.1 nm over a 100 Hz bandwidth.

The scanning tip is connected to a I/U converter built specifically for this purpose. The converter is placed next to the measuring head. Dielectric-insulation precision operational amplifier OPA111 was used as the main part of the converter. The I/U converter is connected to the amplifying/biasing module which may be controlled either remotely (scanning software) or manually.

The process controlling procedure is an integral part of the Topo-Scan program, which is used for scanning process control. The procedure was developed at the Laboratory of Scanning Probe Microscopy, Nanostructures and Nanometrology. The process data are placed in a .txt file and may be easily modified using, i.e., a standard word processor. The following parameters are available: X, Y are the start/stop point coordinates, t_1 – in-point waiting time, t_2 – tip moving time-constant, and U – voltage applied to the tip.

3. Experiment

In our experiments we used tungsten wires etched electrochemically (Fig. 3). The diameter of the tungsten tip was 120 μm and the length varied from 5 to 7 mm, which corresponds to the wire spring constant ranging from 1 N/m to 3 N/m.

Fig. 3. SEM photo of a tungsten tip.

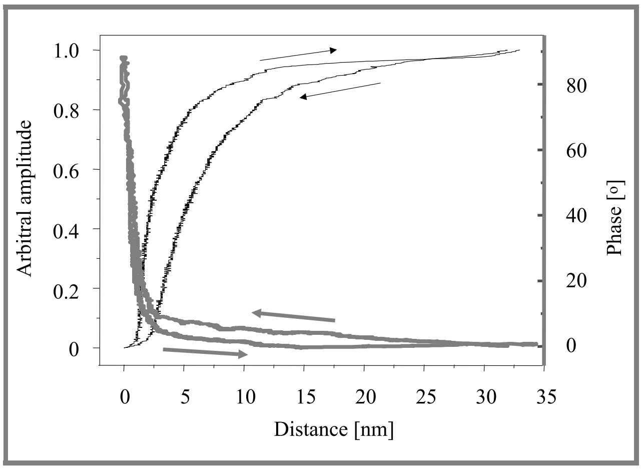

Fig. 4. Approach curves of the shear-force microscope.

The application of weaker wires enables detection of smaller forces but the scanning process is more time consuming and sensitive to acoustical disturbances.

The tip-sample distance is controlled using the shear-force detection method. When the tip approaches the surface-oscillation amplitude decreases and phase shift appears (Fig. 4). Highly accurate control of the tip-sample distance is possible when lock-in signal detection from the interferometer is used.

The emission-current module was tested using a sample of gold deposited on a glass substrate. The emission curve was measured for both bias polarizations. There is a clearly visible difference between the tip-emission surface-emission curves (Fig. 5). This setup offers a possibility to investigate local electrical material properties and correlate them with the surface topography [15].

Local oxidation was performed in the constant voltage mode. In contrast to the pulse mode – in the presented case the voltage was applied and the scanning tip was moved between the start and stop points.

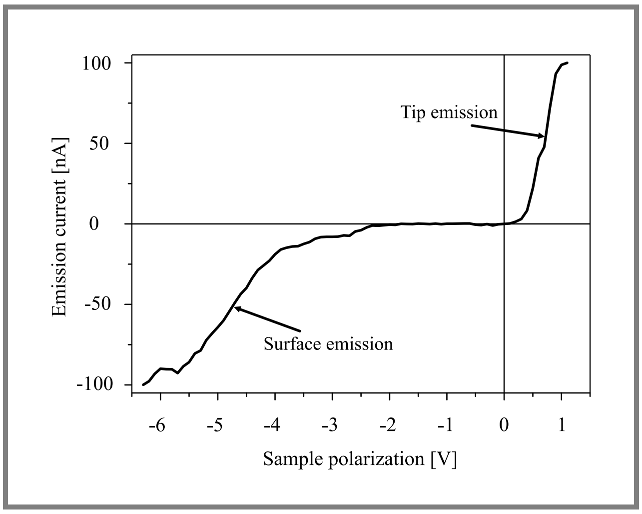

Fig. 5. Field emission current measured on gold film versus tip-sample voltage.

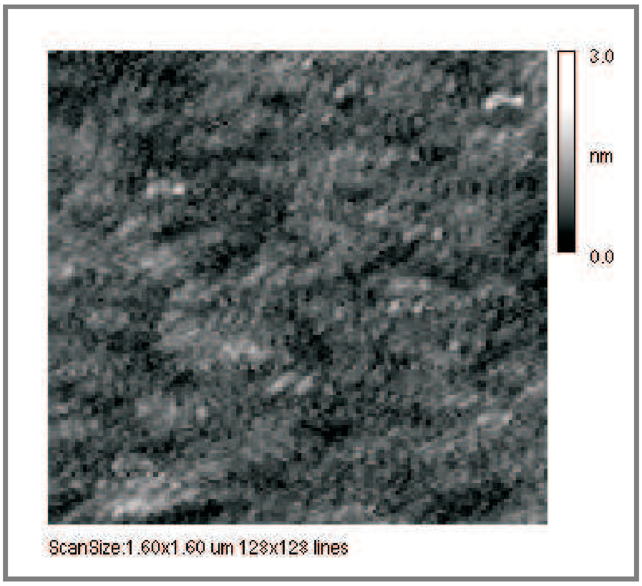

Fig. 6. Surface before process.

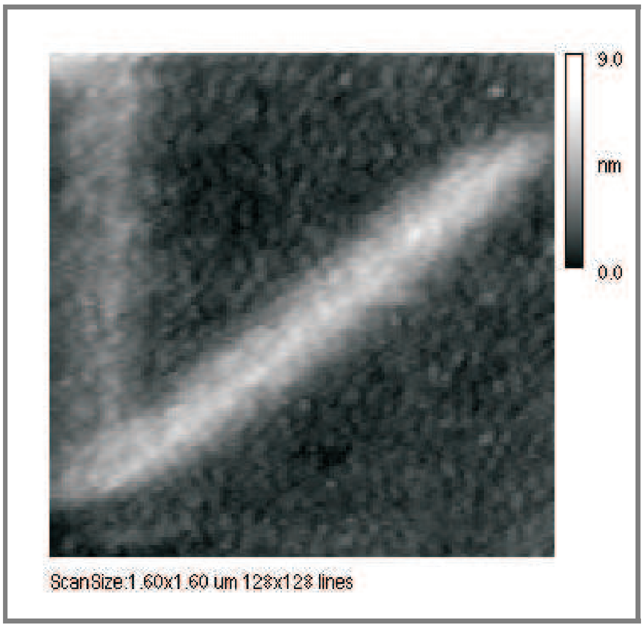

Fig. 7. Surface after process (Step 1).

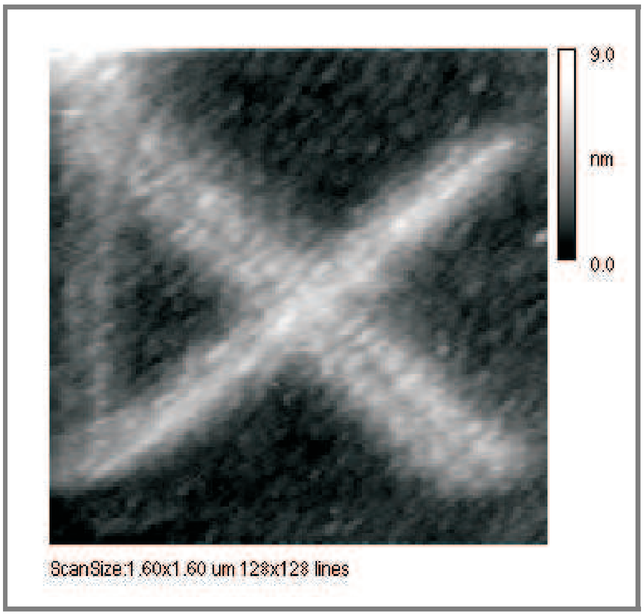

Fig. 8. Surface after process (Step 2).

Silicon surface was used for local anodisation. The process was performed in ambient conditions (air temp. 21°C and RH 42%).

The experiment was performed in five steps:

- scanning topography before the process (Fig. 6);
- process 1 (two lines: vertical and slanted line speed: 0.5 μm/s and 1.5 μm/s respectively, applied voltage 5 V);
- scanning topography after 1st process step (Fig. 7);

- process 1 (two parallel, slanted lines speed: 1.5 μm/s, applied voltage 5 V);
- scanning topography after 2nd process step (Fig. 8).

The obtained structures are typically 160 nm full width at half maximum (FWHM) and 5 nm high.

4. Summary

In this paper we presented experiments concerning the development and applications of SHFM based method for fabrication of nanostructures.
The major advantages of the described setup are low cost, possibility of handling very soft samples, and investigations of electrical surface parameters using the conductive tip.

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Ivo W. Rangelow – for biography, see this issue, p. 46.