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Effects of scratching parameters on fabrication of polymer nanostructures in atomic force microscope tapping mode

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Abstract

The nano scratching with an oscillating Atomic Force Microscopy (AFM) tip in tapping mode is called as the dynamic ploughing. The tip is vibrated in a high frequency and scratches the surface which is similar to the conventional vibration-assistant machining process. In the present study, the dynamic ploughing technique is utilized to scratch PolymethylMethacrylate (PMMA) polymer surfaces forming nanostructures with a commercial AFM system and two kinds of cantilevers. Effects of scratching parameters of the dynamic ploughing including scratching velocity, driving amplitude, pitch and the cantilever's elastic constant on the machined results are studied in detail. Finally nano ring structures with different radius are achieved successfully.

Keywords: Atomic force microscopy; Tapping mode; Ploughing; Nanostructures; Polymer

1. Introduction

Nanostructures are widely used in many research fields because of their unique optical, electrical or mechanical properties. Polymer nanostructures as masks or the isolated part are of importance in the nano manufacturing processes of nano imprint, wet etching and nanolithography etc. How to fabricate such kind of structure is a major concern for the manufacturing engineers. Recently, the Atomic Force Microscopy (AFM) tip-based nano machining method is a low cost and a potential way to fabricate polymer nanostructures. Up to now, there are many kinds of AFM tip-based nano machining methods which can modify the polymer surface directly, including the Dip-Pen Nanolithography [1], the thermal effect technology [2], the nano mechanical machining [3], the field emission method [4] etc..

Among these nanofabrication methods, the AFM tip-based nano mechanical machining method is investigated widely. There are two different kinds of tip's states: static and dynamic states which are in contact mode and tapping mode of AFM correspondingly. Using the tip-based static ploughing method, complex structures can be fabricated [5-6]. The tip-based dynamic ploughing method with the tip oscillating with a high frequency can also be employed to modify the polymer surfaces effectively [7-10]. This process is similar to the conventional vibration-assistant machining process. More recently, by the dynamic ploughing approach and the thermal-annealing treatment techniques, functional nano devices with a lateral feature size of 100 nm to an etching depth of 70 nm are demonstrated based on the wet etching with the scratched PolymethylMethacrylate (PMMA) nanostructures as the mask [11]. This method is also used to modify graphene on silicon dioxide substrates [12]. All these works show that it is an easy way to fabricate soft materials like polymer and soft metals which are widely used as masks in the conventional nano fabrication process. However, previous studies mainly focus on the static ploughing process and little researches are carried out on the dynamic ploughing process and the effects of scratching parameters including the driving amplitude, scratching velocity, the

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elastic constant of the cantilever and the pitch on the fabrication process on the polymer surfaces. Therefore, in the present study, effects of these parameters are studied in detail in order to achieve optimized scratching parameters and obtain perfect nano polymer structures with a high vibration tip.

2. Experimental details

The commercial AFM system (Dimension Icon) is provided by Bruker Corporation, USA. The two kinds of AFM silicon probes are TAP525 and TAP300 provided by the Budget Sensors Company, Bulgaria. The elastic constant and the resonance frequency of the TAP525 probes are 200 N/m and 450 KHz, respectively. The elastic constant and the resonance frequency of the TAP300 probes are 40 N/m and 325 KHz, respectively. All imaging and fabrication tests are carried out in AFM tapping mode. The driving amplitude of the probe is changed by the software to achieve the transition from the imaging to the fabrication process. The driving amplitude in the fabrication is about 10-50 times larger than that in the imaging process. The scratching direction is perpendicular to the long axis of the cantilever. The complex motion traces of the tip are programmed by the Nanoman module of the system. The detail probe and scratching parameters are summarized in Tab. 1. The injected molded PMMA polymer plate is used as the sample. Before tests, the sample is washed with ethanol to get rid of the large dirty particles on the surface. Then it is immersed in ethanol, and cleaned in ultrasonic bath for 3 min. After drying in air, it can be used for following tests.

Table 1. Probe and scratching parameters

AFM mode	Tapping mode		
Probe material	Silicon		
Parameters of probes	Model	Elastic constant	Resonance frequency
	TAP525	200 N/m	450 KHz
	TAP300	40 N/m	325 KHz
Sample material	Polymer PMMA		
Scratching direction	Perpendicular to the long axis of the cantilever		
Driving amplitude	The ratio of the driving amplitude in the fabrication and that in the imaging process is 4-50.		
Scratching velocity	0.1 µm/s-1000 µm/s		
Pitch	10 nm, 30 nm, 50 nm and 100 nm		

3. Effect of the scratching velocity on the dynamic ploughing process

The TAP300 probe is used in the tests. In the imaging test, the driving amplitude is 120.8 mV. The amplitude setpoint of the control system is 341.1 mV. In the nano fabrication process, the driving amplitude is 6000 mV and the amplitude setpoint is fixed at the value of 341.1 mV. Figs. 1 (a) and (b) show the AFM image and the sections of the nano grooves scratched by the dynamic ploughing with different scratching velocities. As shown in Fig. 1 (a), the scratching velocities are 0.1 µm/s, 1 µm/s, 10 µm/s, 100 µm/s and 1000 µm/s. The corresponding scratched depths of the grooves are 16.6 nm, 9.5 nm, 2.7 nm, 2.6 nm and 0 nm, respectively. As shown in Fig. 1 (b), an increase in the scratching velocity results in a shallower scratched depth. For the scratching velocity of 100 µm/s, only uneven grooves can be found. When the scratching velocity increases to 1000 µm/s, the groove is only formed at the beginning of the tip's trace. This indicates that larger scratching velocity leads to failure of the fabrication because the materials can not be removed effectively.

The TAP525 probe is used in the tests. In the imaging test, the driving amplitude is 65.0 mV. The amplitude setpoint of the control system is 377.2 mV. In the nano fabrication process, the driving amplitude is 3000 mV and the amplitude setpoint is kept at the value of 377.2 mV. As shown in Fig. 1 (c), the scratching velocities are 0.1 µm/s, 1 µm/s, 10 µm/s, 100 µm/s and 1000 µm/s. In Fig. 1 (d), when the scratching velocity is less than100 µm/s, the corresponding scratched depths of the grooves are 21.1 nm, 21.5 nm, 18.3 nm and 13.1 nm, respectively. When the scratching velocity is 1000 µm/s, the groove is only formed at the beginning of the tip's trace. Under this condition, it is the same situation with using the TAP300 probe.

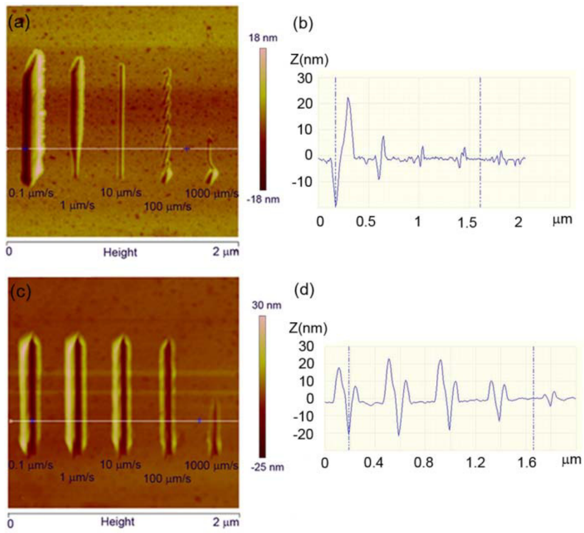

Fig.1. (a) and (b) are two dimensional AFM image and the section data of the scratched groove with the TAP300 probe; (c) and (d) are two dimensional AFM image and the section data of the scratched groove with the TAP525 probe.