Fast fabrication of three dimensional polymer nanopatterns induced by the atomic force microscope

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Abstract

In the present study, the AFM tip based nanomechanical machining method is employed to perform a single scratching test on the polycarbonate (PC) surface in order to fast achieve the nanobundle structures. Effects of the tip traces on the perfect nanobundles formation are studied. The experimental results show that the raster scan mode is feasible for nanobundles formation. Based on the raster scan and the bundle formation modes, the nano-dots structures are formed by a two-step scratching method. Moreover, complex three dimensional nanopatterns, inculding disc bundles and ring bundles, are realized by employing different tip traces in the AFM Nanoman system.

1 Introduction

Polymers are important materials for future micro/nano devices due to their low density, easy moulding and low production cost. At present, fabricating complex micro/nano three dimensional (3D) structures on the polymer surface have significant applications, such as micro/nano gratings of sensors, complex surface nanostructures of binary optics, and so on. Currently, the Atomic Force Microscope (AFM) tip based nano-mechanical method is a relatively convenient method with good repeatability and high resolution, which is looked on as a novel way of forming complex nanostructures.

From the previous works, bundle structures existed in reciprocal scanning (more than 10 times in general) by a very small normal load (nN) with an AFM tip on most thermoplastics polymers, such as poly(tert-butyl acrylate) (PtBuA), polyesters (PE), polyacetylene, polycarbonate (PC), and polystyrene (PS) [1-2]. And such bundle structures are actually the quasi-sinusoidal nanostructures which are looked on as typical 3D nanostructures by some scholars. However, up to now, no perfect nano-bundle structures which can be used as templates have been achieved by this way. This might be due to the effects of the tip trace of the AFM system itself.

Therefore, in this article, a novel scratching trace with a diamond tip is provided and used to fabricate the perfect 3D nano-bundle structures, and the two-step scratching method is utilized to realize complex 3D nanodot arrays formation on the polycarbonate (PC) surface. Based on the bundle structures formed mode, complex disc bundle and ring bundle structures are realized by using different tip traces.

2 Experiment details

An injection-moulded PC sample is selected as the sample material. PC is known as a typical engineering plastic for its impact resistance, size stability, temperature resistance and other good mechanical properties. All the experiments are carried out using a commercial AFM (Dimension Icon, Bruker Co., USA) with a three dimensional precision stage (P517-3CD, PI Co., Germany) under the atmospheric conditions. The triangular trace can be provided by the AFM system itself, as shown in Fig. 1 (a). The raster scan trace can be provided by the precision stage, as shown in Fig. 1 (b). Based on the AFM Nanoman system, different tip traces can also be achieved, as shown in Fig 1 (c) and (d), including the disc scan and the ring scan. All the scanning directions are parallel to the long axis of the cantilever. In addition, the two-step raster scan can be carried out by successively scratching the same area with the angle of 0° and 90° to the long axis of the cantilever. All nano-machining operations are conducted in contact mode with a diamond tip (PDNISP, Vecco Inc., USA) with the force constant of 212N/m provided by the manufacture. Tapping mode is utilized to perform imaging tests with a silicon tip (RTESP, Vecco Inc., USA).

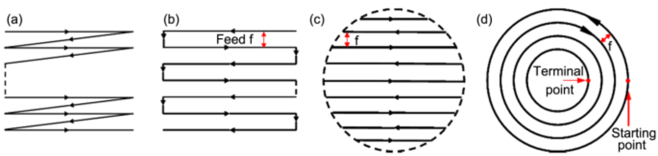

Figure 1: Schematic images of the different tip traces including triangular scan (a), raster scan (a), disc scan (b) and ring scan (c).

3 Results and discussion

3.1 Nanobundles and Nano-dots formation

Using the tip trace of Fig. 1 (a) and (b), the morphologies and cross-section of the machined structures are presented in Fig. 2. The scan sizes are 10 μm ×10 μm and 8 μm × 8 μm, the feed is 10 nm and the normal load is 5.2 μN. The typical bundle structures perpendicular to the scratching direction are both formed on the PC surface. As shown in Fig. 2 (a), the bundles obtained with the triangular trace are distort. And the sections have an awful superposition from Fig. 2 (b). Howerve, as shown in Fig. 2 (c) and (d), the bundles obtained with the raster scan trace present a perfectable feature, with the approximate period and height of 536 nm and 27.3 nm, which is verified by two-dimensional fast Fourier transform (2D-FFT) and Power Spectral Density (PSD) analysis (The corresponding figures are not shown). It can be found that the scan trace is an important factor for perfect nanobundles foramtion with the AFM tip-based nanofabrication method.

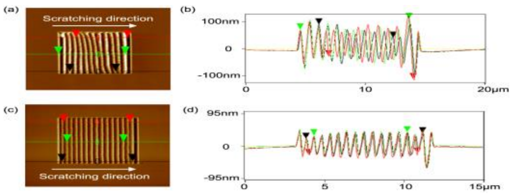

Fig. 2: The morphologies and cross-section of the PC surface with the triangular scan and raster scan.

Based on the nanobundles formation, the two-step tip raster scan is used to machine the PC surface with the scan size of 10 μm × 10 μm, the feed of 20 nm and the normal load of 15 μN. The tip is used to scratch the same area firstly with the angle of 0° and nextly with the angle of 90° to the long axis of the cantileverat the same position. The morphologies of the formed nano-dots are shown in Fig. 3. The pattern has high degree of alignment with the dot size of about 500 nm.

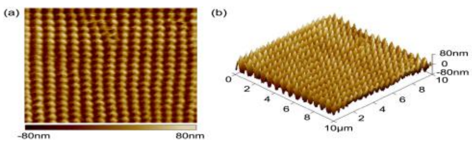

Fig. 3: Morphologies of the nanodots on the PC surface with the two-step raster scan.

3.2 Disc bundles and ring bundles formation

Using the tip trace of Fig. 1 (c) and (d), the morphologies of the fabricated structures are shown in Fig.4. For the disc bundles, the machining parameters are the scan size of 10 μm × 10 μm, the feed of 20 nm and the normal load of 7 μN. For the ring bundles, the tip scans along the circle from the outside to the inside with the radius of 4 μm and 3 μm, the normal load of 7 μN and the feed of 20 nm. It can be found that the bundle-type structures are also formed on the PC surface with the orientations of the patterns are perpendicular to the scartching direction. In addition, due to the border effect, the removed materials are distinctly accumulated on the circle and on the starting and terminal point, respectively.

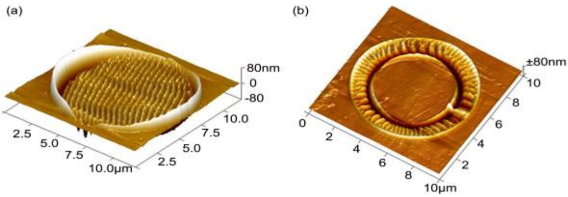

Fig. 4: The morphologies of the disc bundles and ring bundles on the PC surface.

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