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BRIEF REPORTS AND COMMENTS

This section is intended for the publication of (1) brief reports which do not require the formal structure of regular journal articles, and (2) comments on items previously published in the journal.

Nanostructure patterns written in polycarbonate by a bent optical fiber probe

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An atomic force microscope operated in tapping mode using a homemade bent optical fiber probe was used to pattern nanometer-scale features. Trenches of different dimensions were written on polycarbonate that was pre-exposed to an excimer laser. Lines with widths varying from 260 to 600 nm and depths ranging from 30 to 120 nm have been made. The present technique as a complementary tool to other lithographic processes has been demonstrated to be potentially suitable for low-cost and high-precision applications.
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Bent optical fiber probes are widely used in the application of near-field optics.[1] Furthermore, due to its high flexibility in geometric structure and variable spring constant, it can be deployed in other areas of research. For example, it has proved to be a valuable tool in analyzing the bottom surface roughness of microstructures[2] and measuring the surface elastic intensity distribution of polymers. In this article, we made use of the unique features of bent fiber probe operated in an atomic force microscope (AFM) to produce nanostructure patterns on polycarbonate. Compared with the common LIGA (in German: Lithographie, Galvanoformung, Abformung) technology,[3] scanning probe microscopy (SPM) has shown to be a very promising alternative for nanolithography due to its low cost and flexibility. Using SPM lithography,[4,5] it is possible to reach a resolution that may exceed the standard of other lithography processes.

The bent probe was fabricated by a combination of laser heating pulling[6] and electric arc bending.[7] A commercial CO_2 laser fiber puller (P-2000, Sutter Instrument) was used to produce a straight fiber probe from a 125 μm telecommunication single mode optical fiber (SMV 130, Prime Optical Fiber Corporation, Taiwan). The geometric structure of the fiber probe was controlled by five parameters of the fiber puller.[8] The straight probe was then bent by a homemade electric arc puller. A 5 nm Pt/Pd film was then coated on the back of the bent fiber probe by ion sputtering (E1010, Hitachi, Japan) to increase the reflectivity that was necessary for normal force detection. Finally, this bent fiber probe was glued to a Si substrate for suitable placement in an AFM cantilever holder and the result is shown in Fig. 1. The cantilever length, i.e., the length measured from the bent point to the edge of the substrate, and the bent length, i.e., the length from the bent point to the tip end, were around 950 μm and 550 μm, respectively. Its spring constant was measured as 150 N/m using an innovative method.[9]

In the experiment, polycarbonate was pre-exposed to an excimer laser micromachining station (Series 7000, Exitech, England). The operating wavelength was 248 nm. The exposed are formed a thin and soft transitional layer. According to an AFM measurement,[2] the root-mean-square roughness value of this area was approximately 0.8 nm. A trench might be cut by simply drawing a bent optical fiber probe across this region with enough force applied to penetrate into it. Patterns, shown in Fig. 2, were then written by the bent optical fiber probe as indicated in Fig. 1 operating in tapping mode AFM (Dimension™ 3100, Digital Instruments) with a drive amplitude[10] of 1500 mV. Each cut was drawn for five cycles with a scan rate of 0.1 Hz for a writing rate of 0.2 μm/s. By mean of cross section analysis, the average depth and width of these trenches were measured as 328 ± 16 nm and 37 ± 2 nm, respectively. Note that we have not compensated in these images for the fiber tip size.

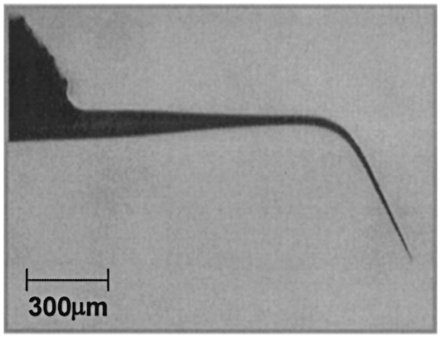

FIG. 1. Photograph of the bent fiber probe with a bend angle of 70°.

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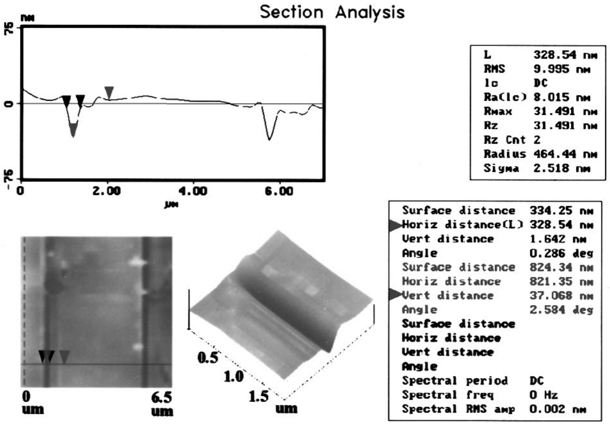

```
L          328.54 nm
RMS        9.995 nm
lc         DC
Ra(lc)     8.015 nm
Rmax       31.491 nm
Rz         31.491 nm
Rz Cnt     2
Radius     464.44 nm
Sigma      2.518 nm
```

```
Surface distance    334.25 nm
Horiz distance(L)   328.54 nm
Vert distance       1.642 nm
Angle               0.286 deg
Surface distance    824.34 nm
Horiz distance      821.35 nm
Vert distance       37.068 nm
Angle               2.584 deg
Surface distance
Horiz distance
Vert distance
Angle
Spectral period     DC
Spectral freq       0 Hz
Spectral RMS amp    0.002 nm
```

FIG. 2. Topography and cross section plot of the nanometer-scale trenches obtained by an AFM in tapping mode using a bent optical fiber probe (as shown in Fig. 1).

We made use of various drive amplitudes to control the interaction force between the tip and the sample surface. It was observed that, increasing the drive amplitude would in turn raise the force applied to the polycarbonate surface. In consequence, uniformity of the nano-trenches would be severely affected. Twisted patterns with large steps and ripples formed at edges emerged with drive amplitudes above 2200 mV. On the other hand, furrows could not be produced when drive amplitudes fell below 1200 mV. Therefore, it was possible to choose a downward force that would obtain a good topographical image without writing. There is no need to use different AFM probes and settings for the writing and imaging. Figures 3(a) and 3(b) compare the width and depth of the trenches against the drive amplitude of the fiber probe varying from 1200 to 2200 mV. Generally, the width of these trenches depended on both the oscillation amplitude (drive amplitude) and the thickness of the tip fiber probe of the Minimum achievable width of this fiber probe was 260 nm. In contrast, the depth of these trenches depended solely on the oscillation amplitude of the fiber probe, which was varied from 30 to 120 nm in this experiment.

In summary, the main advantages of this technique are (i) no need for etching and (ii) the dimensions of the structures are solely defined by the geometry of the tip and the oscillation amplitude of the fiber probe. Furthermore, this technique could facilitate some research areas, such as the study of microchannels. In the meantime, an indepth study of this technique was carried out to achieve precision control of the dimension of nanoscale trenches.

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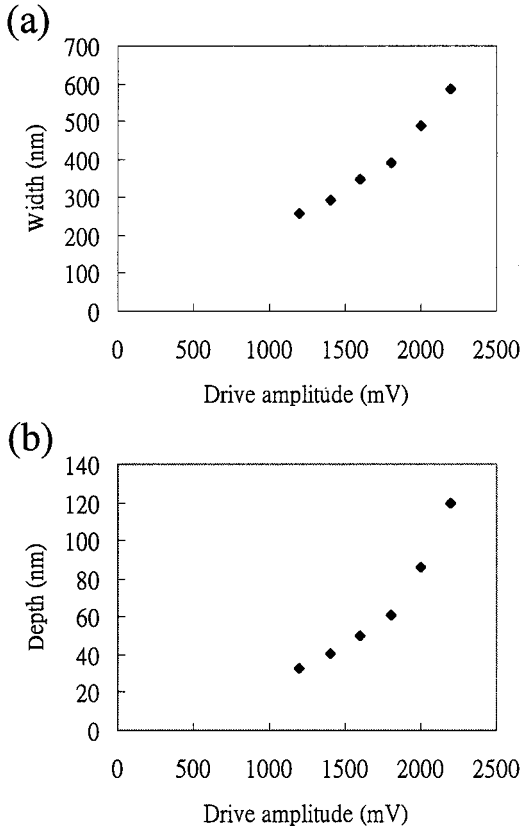

FIG. 3. Comparisons of the drive amplitude of the fiber probe against the corresponding (a) width and (b) depth of the trenches.

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[8] The brief descriptions of the five parameters are: "HEAT" controls the laser power, "FIL" is the length being scanned by the laser, "VEL" is the velocity when the laser is turned off, "DEL" is the time between the laser turn-off and the second pull, and "PULL" determines the strength of the second pull.

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[10] This parameter defines the amplitude of the voltage applied to the piezosystem that drives the cantilever vibration of the fiber probe.