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Laser pulse induced micropatterning on sandwiched thin films

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ABSTRACT

We introduce a routine for surface micropatterning. Our samples are sandwiched "$ZnS–SiO_2/PtOx/ZnS–SiO_2$" thin films. The driving energy comes from a laser pulse. The sample is initially exposed to the laser pulse. When the laser pulse is switched off, a bubble is formed. The stain inside the bubble generates a stress wave which diffuses radially along the surface. The stress wave induces concentric micropatterns on the surface and the process of micropatterning lasts a considerably long time. Finally, concentric and periodic patterns are formed permanently on the sample surface, and the experimental results also demonstrate that the routine is feasible for surface micropatterning.

Patterned surfaces in mircometric or nanometric scales have been found to be important applications in various areas such as high density data storage, microelectronic fabrication, photonic devices, etc. Self-assembly and similar technologies have a number of advantages over traditional processes based on template-printing and lithography, as they are relatively simple, inexpensive and repeatable. Among others, dewetting polymer films for micropatterning surfaces via heating or spinodal procedures have been recently developed [1,2]. Other useful methods include self-assembly by polymer sub-layer, anisotropic buckling, self-organization, and stressed wrinkling, etc. [3–13].

We introduce here a routine for surface micropatterning different from the above. Our samples are sandwiched "$ZnS–SiO_2/PtOx/ZnS–SiO_2$" multilayer thin film structure. The driving energy comes from a laser pulse. The sample is initially exposed to the laser pulse. When the laser pulse is switched off, a bubble is formed. The stain inside the bubble generates a stress wave which diffuses radially along the surface. The stress wave induces concentric micropatterns on the surface and the process of micropatterning lasts a considerably long time. Finally, concentric and periodic patterns are formed permanently on the sample surface. Note that, unlike other micropatterning methods, the proposed routine requires a relatively long time to finish, usually hours or even days, which distinguishes the routine from other self-assembly processes, and enables formation of permanent patterns with low inputs.

Schematics describing the experimental process and principle are shown in Fig. 1 with a sequence of steps in the procedure of the surface micropatterning. The sample is a multilayer thin film deposited on a substrate of polycarbonate with the following thicknesses for each layer: $ZnS–SiO_2$(40 nm)/PtOx(4 nm)/$ZnS–SiO_2$(40 nm)/substrate. The center layer PtOx contains the oxidation degree mostly $x \sim 1.6$. The depositions were done with different sputtering methods. The $ZnS–SiO_2$ layers were deposited with radio-frequency sputtering, whereas the PtOx layer was coated with reactive sputtering using Pt target and O_2 gas. The laser is a continuous laser with a wavelength of 405 nm. Single laser pulse is generated by modulating the laser with a function generator. Each time, only one pulse of duration 2.4 μs is output to hit the sample surface. The laser power was about 10 mW and the focused light spot varies 400–1000 nm in diameter. The choice of focus diameter depends on the features of the micropatterns one intends to form, whereas the energy concentration can be easily modified with the pulse duration. It was generally observed as follows. Higher pulse concentration allows the patterns to be formed faster. However, lower inputs are generally favored because it brings about less damage to the samples and the formed patterns appear in better shapes. In Fig. 1(a) the laser pulse is focused by an optical lens upon the center layer (PtOx) of the sample. The film absorbs the laser energy and converts it into heat. It was known [14] that PtOx would undergo a decomposition process if the temperature rises higher than the decomposing temperature, and substantial decomposition may take place when the temperature rises up to a few hundreds degree. After a hit of the laser pulse, the center layer (PtOx) material is therefore decomposed into Pt particles and O_2 gas as

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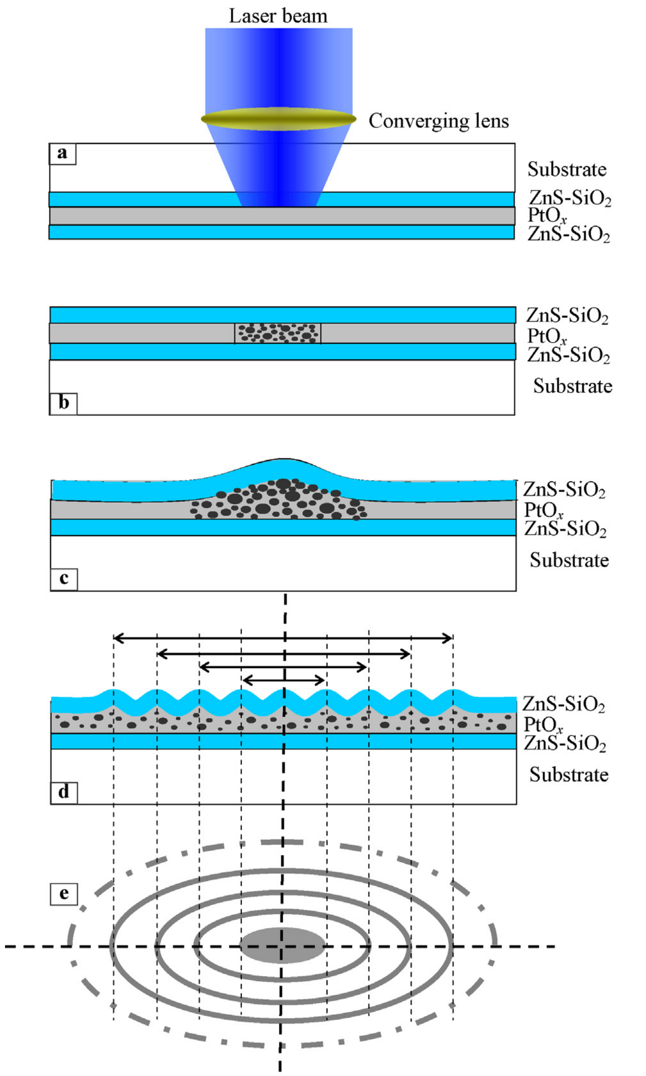

Fig. 1. Schematics showing the surface micropatterning in a sequence of steps, Laser pulse irradiation to the sample, Decomposition of PtOx layer, Formation of bubble, Induced stress wave diffusion (front view), Induced stress wave diffusion (top view).

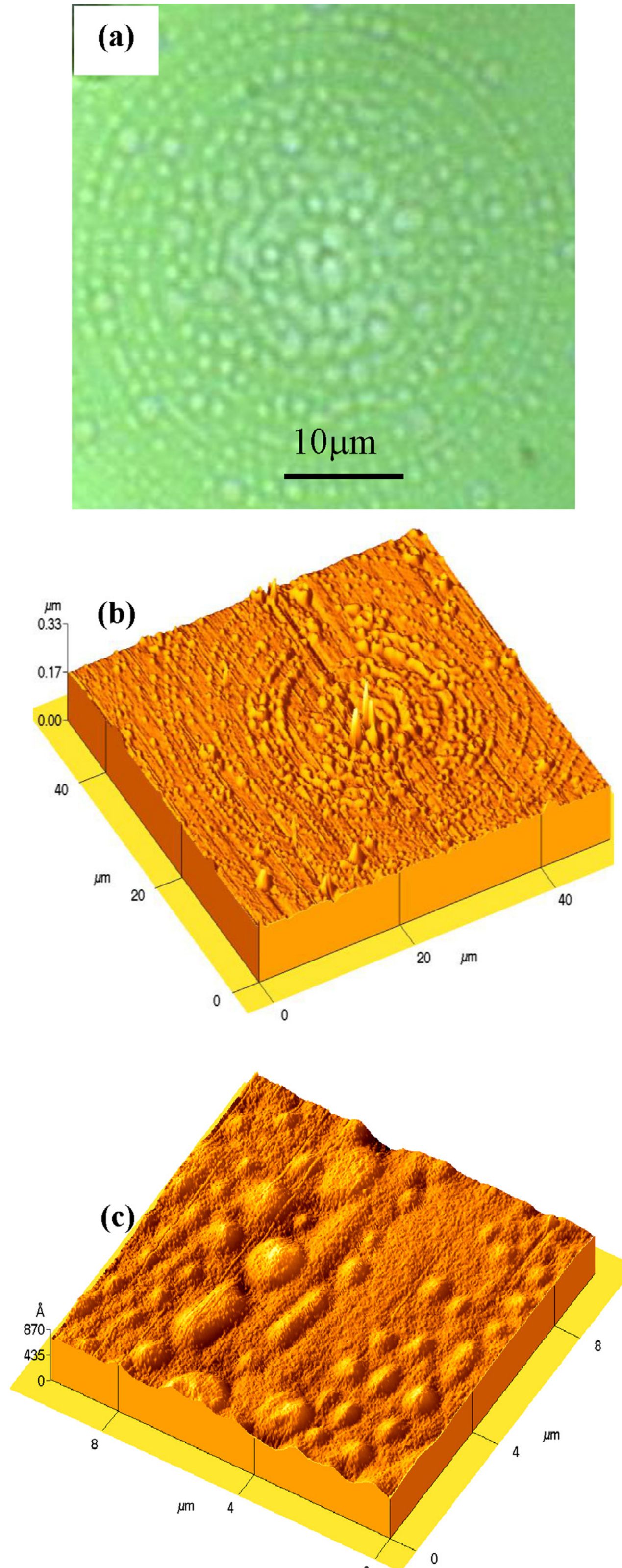

Fig. 2. The laser pulse induced surface micropatterning, (a) CCD image, (b) AFM image, (c) The AFM image of enlarged bubbles.

demonstrated in Fig. 1(b). The O_2 gas requires a bigger volume and thus a bubble is formed due to the expansion of the gas, a phenomenon similar to the bubble formation described in other experiments [15–17]. During the expansion, gas exchange may take place between the O_2 inside the bubble and the air outside the bubble. When the laser is switched off, the temperature inside the bubble is to decrease slowly toward the room temperature. With the decrease of temperature, the gas pressure inside the bubble decreases too. In order to maintain the gas balance between inside and outside the bubbles, air flows spontaneously into the bubble. Therefore, when the temperature returns to the level of room temperature, the bubble remains [see Fig. 1(c)]. The bubble causes the top ZnS–SiO_2 layer to deform. The deformation depends on the amount of laser energy absorbed by the central PtO_x layer as well as the mechanical properties of the top ZnS–SiO_2 film. Like in the buckling deformation, the tensile stress generated in the top ZnS–SiO_2 film tends to form a mechanical stress wave that diffuses along the surface. The diffusion of mechanical stress wave on different materials and configurations were theoretically studied previously [18–20]. In our experiments, the ZnS–SiO_2 films are homogeneous and isotropic, and the diffusion of the stress wave and formation of the circular micropatterns took more than several hours even several weeks, which depends on the experimental parameters such as laser pulse energy, etc. The cross-section of the stress wave induced patterns is shown schematically in Fig. 1(d), and the mathematical description of the wave can be written as

$$H(r) = H_0 \sin(kr), \quad (1)$$