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Dressed Photon-phonon Technology for Ultra Flat Surface

T. Yatsui*, M. Ohtsu

[1]School of Engineering, the University of Tokyo, 2-11-16 Yayoi, Bunkyo, 113-8656 Tokyo, Japan

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A reduction of the surface roughness, *Ra*, is required in various applications including electronic devices and / or optical devices. Although chemical-mechanical polishing (CMP) has been used to flatten the surfaces, it is generally limited to reducing *Ra* to about 2 Å because the polishing pad roughness is as large as 10 μm, and the polishing-particle diameters in the slurry are as large as 100 nm. We therefore developed a new polishing method, dressed-photon and phonon etching (DPP etching), that uses dressed photon based on an autonomous phonon-assisted process. DPP etching does not use any polishing pad, with which we obtained ultra-flat silica surface with angstrom-scale average roughness as small as *Ra* of 0.1 nm. Additionally, we succeeded in reduction of the Ra for the three-dimensional structures.

Keywords: Dressed-photon method, Phonon etching method, Surface roughness.

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1. INTRODUCTION

Ultra-flat substrate surfaces with sub-nanometer scale roughness are required for various applications, including optical components for the extreme ultraviolet (UV) region and high-power lasers, and future optoelectronics devices on a sub-100 nm scale. To obtain a flat surface, conventional methods have used chemical-mechanical polishing (CMP) [1]. We have studied the application of the optical near-field to nanostructure fabrication using its properties of resolution beyond the diffraction limit and a novel nonadiabatic photochemical reaction. For chemical vapor deposition, we demonstrated photodissociation with a light source, with a photon energy lower than the absorption band edge energy of the molecules. The optical near-field is a virtual photon that can couple with an excited electron. In the coupled state, it is known as a dressed photon. Additionally, it can be coupled with multiple-mode of phonons, and thus, the quasi-particles of coupled state as dressed-photon-phonon (DPP). Thus, the energy of the DPP, is larger than the energy of a free photon due to coupling with and excited electron [2]. This DPP theory has been used to explain numerous experiments on topics such as photochemical vapour deposition [3], photolithography [4], and visible-light water splitting [5], as well as studies on photovoltaic devices [6] and energy up-conversion devices [7].

2. DPP ETCHING

Chlorine gas was used as the etching gas source. A continuous wave (CW) laser ($\lambda = 532$ nm) was used as the light source to dissociate the Cl_2. Since its photon energy is lower than the absorption band edge energy of Cl_2 ($\lambda = 400$ nm [5]), this avoids conventional adiabatic photo-etching. However, since the substrate surface has nanometer-scale protrusions, depending on its roughness, a strong optical near-field can be generated at the edge of such a protrusion (Fig. 1a). Since the optical near-field has a steep spatial gradient, a higher molecular vibrational state can be excited in the Cl_2, although the photon energy is lower than the absorption band energy of Cl_2, which cannot be excited by a uniform optical far-field. As a result, Cl_2 is selectively photodissociated and the activated Cl atoms etch away the protrusions on the substrate. Finally, the etching process automatically comes to a halt when the surface becames sufficiently flat so that the optical near-field disappears (Fig. 1b).

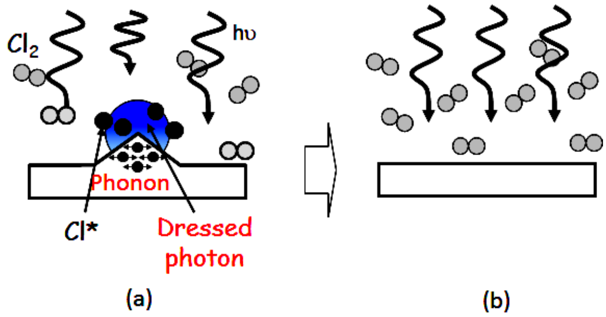

Fig. 1 – Schematic of DPP etching

We used silica substrates. The Cl_2 pressure was 100 Pa. Figures 2(a) and 2(b) show typical atomic force microscopy (AFM) images of a 10 μm × 10 μm of the scanning area of the silica substrate before and after DPP etching, respectively. By comparing these images, the drastic decrease in surface roughness was realized. Additonally, the cross-sectional profiles revealed this technique can reduced the pits, as well as bumps [8].

DPP etching does not require the polishing pad, it can be applicable to the three dimensional structures (Figs. 3(a) and 3(b)). We performed DPP etching on the grating structures of the soda lime glass. The comparison between Figs. 3(a) and 3(b) of before and after DPP etching confirmed that the DPP etching can etch the side wall of the three dimensional structures [9].

* yatsui@ee.t.u-tokyo.ac.jp

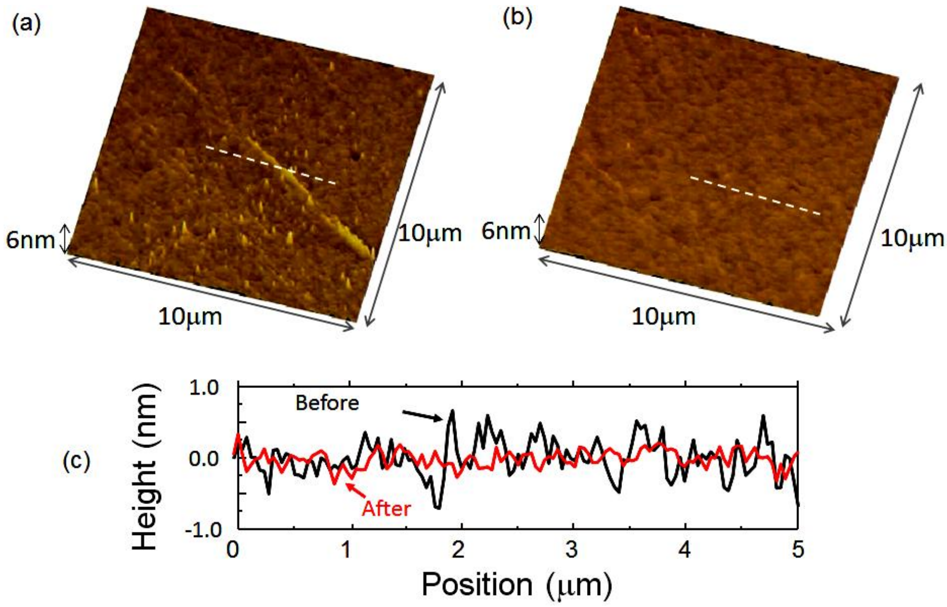

Fig. 2 – AFM images: (a) before and (b) after DPP etching. (c) Cross-sectional profiles along the dashed white lines in (a), and (b)

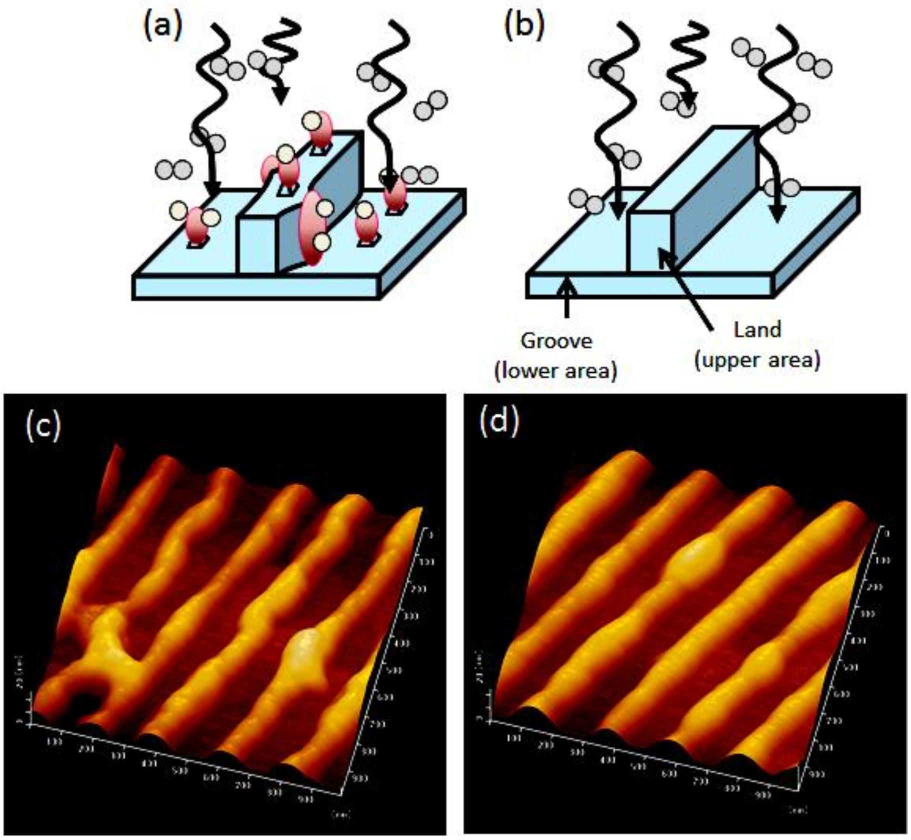

Fig. 3 – (a and b) Schematic of DPP etching on three dimensional structure. AFM images: (c) before and (d) after DPP etching

3. CONCLUSION

We reviewed recent developement of DPP etching. DPP etching is based on photo-chemical reaction, it can be applicable to other materials, including semiconductor, metal, plastic, and so on.

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