Modification of Surface Topography and Wetting Properties of Oxygen-Plasma Treated Polydimethylsiloxane (PDMS)

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Abstract

In this work, we address the issue of controlled modification of the surface topography of polydimethylsiloxane (PDMS) when subjected to oxygen-based plasma treatments, and we investigate the resulting enhanced surface area as a means of controlling the surface wetting properties. We fabricate wavy structures of controllable nanoscale amplitude and periodicity in the range 50–300 nm, spontaneously formed on PDMS surfaces, by means of appropriate plasma processing conditions and radiation pretreatment. Such structures are desirable for applications in sensor microdevices, the development of biocompatible materials, and micro- and nanosystems in general. Ordered structures fabricated on polydimethylsiloxane of relatively high amplitude and small periodicity are chosen as appropriate surfaces for the enhancement of the surface wetting properties, which can be tuned from highly hydrophilic to hydrophobic when combined with a hydrophobic coating applied on the rich surface nanotexture. This fact underlines the potential application of the proposed technique in the field of microfluidics, where polydimethylsiloxane is gaining popularity as structural material for microfluidic devices.

Surface topography modification and surface analysis

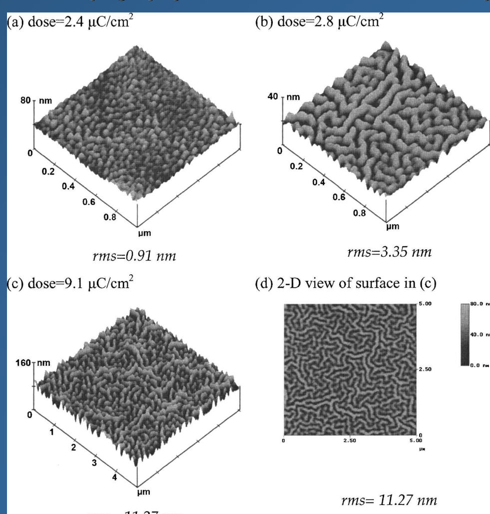

Figure 1: Shows AFM images of PDMS surfaces after treatment in O_2 plasmas. Images in (a)–(d) correspond to samples treated for 1 min in a RIE reactor after being exposed to variable radiation dose. It is obvious from these images that O_2 plasma-treated PDMS surfaces acquire topography of increasing roughness with increasing exposure dose. The top-down image of the surface in Fig. 1(d) indicates strongly a periodic surface roughness of random orientation. Periodic roughness is found also on the surfaces shown in Figs. 1(a) and 1(b), however of smaller magnitude and periodicity. In fact, comparison of the images in Fig. 1 indicates an increase of roughness and periodicity with exposure dose.

Effect of topography modification on surface wettability

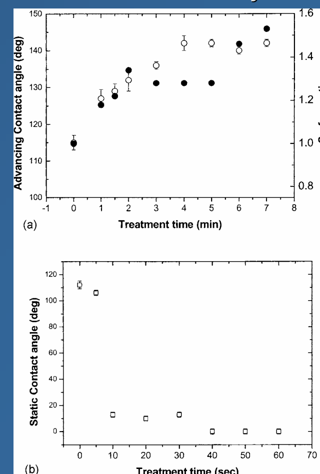

Figure 2: Effect of plasma treatment on the PDMS surface wetting properties. a Increase of the advancing water contact angle open circles of a Teflon-like thin film 10 nm coated on an O_2 RIE plasma-modified PDMS surface, and the corresponding increase of the effective surface area filled circles, estimated by means of AFM measurements, with plasma treatment time. b Decrease of the static water contact angle of an O_2 plasma treated PDMS surface with treatment time. Plasma treatment conditions: 10 mTorr pressure, 400 W plasma power.

Conclusion

We have shown that the surface morphology and wettability of PDMS (an example of Si-containing polymers) can be tailored on demand. In specific, the surface topography can acquire the desired magnitude of surface roughness (w) and periodicity (λ) in the nanometer- and subhalf- micrometer-scale, respectively. This is possible since, on the one hand, periodicity is solely affected by the thickness of the silica-like layer grown on plasma-treated PDMS surfaces, and on the other hand, the magnitude of roughness is determined by the difference between plasma processing and ambient temperature (for a polymer of certain history before plasma treatment). In addition, both magnitudes are affected simultaneously by varying the Young modulus of the polymer. Therefore, plasma processing parameters can be appropriately adjusted to control and yield desirable surface topography with formation of periodic structures of nanometer size. Such controlled modification of the surface of a widely used polymer such as PDMS can find numerous potential applications in the fabrication of sensor and microfluidic devices, as on the one hand it allows easy fabrication of nanometer-scale structures and on the other it affects significant surface properties, such as the effective surface area and the wettability.

Materials and Methods

Commercial PDMS material from Aldrich (pure PDMS of M_n=60000 and M_w=120000) and from UCT (94.5% PDMS, copolymer 5% diphenyl siloxane, copolymer 0.5% methyl-vinyl-siloxane, of M_n=450000 and M_w=990000) were used. The former material is easily crosslinked with e-beam exposures, while the latter is photosensitive and crosslinkable with deep ultraviolet (UV) radiation (in the range 200–250 nm). Thin films were prepared by spincoating a solution of PDMS in methyl-isobutyl ketone (MIBK), to form a 80-nm-thick film on top of 360 nm hardbaked novolac resist (AZ5214 of Clariant), coated on a Si wafer. Subsequently, the samples were exposed to crosslink radiation and developed in MIBK to remove non-crosslinked areas. The samples were then treated in oxygen plasmas generated either in a reactive ion etcher (RIE) from Nextral (NE 330) or in an inductively coupled (ICP) plasma reactor from Alcatel (Micromachining Etching Tool MET). In the case of the ICP plasma reactor, the temperature of the electrode was well controlled, and a good thermal contact of the samples with the electrode was provided by means of He flowing on the back side of the samples to thermally equilibrate the samples to the electrode temperature. In the RIE reactor, on the contrary, samples are placed on a thick quartz plate, preventing efficient heat conduction from the samples, and thus the temperature of a treated surface can easily exceed 100 °C within 1 min after plasma ignition.
Scanning electron microscopy (SEM) and atomic force microscopy (AFM) are used to generate surface images and to quantify roughness, while statistical analysis is performed on the resulting images to yield the scaling behavior of surface roughness (SR).
The effect of the topography modification on the wettability of the surface was examined by water contact angle measurements.

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