Fabrication and Demonstration of Anti-dust Nanostructured Surfaces

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Passive mitigation of dust adhesion is recognized as one of the main challenges to a sustained presence where the energy source is limited [1]. Passive mitigation approaches aim to reduce the surface energy, thereby mitigating the likelihood of particle contamination without additional energy consumption [2]. The key challenge in dust mitigation technology is to overcome the forces involved in the adhesive interactions such as Van der Waals and capillary forces [3]. Particulate adhesion to a surface is largely dependent on the surface chemistry and contact area of the surface materials. The contact radius between the nanostructures and dust particles can be reduced by minimizing the structure feature. This work demonstrates that nanostructures can be engineered to mitigate the adhesion of micrometer size particles.

In this work, the anti-dust nanostructured surfaces on polycarbonate substrates were fabricated using a highly scalable nanocoining and thermal nanoimprint process [4]. The fabricated structures with 3, 2, 1, and 0.5 µm periods as shown in Figure 1. In addition to reducing the contact area, the work of adhesion between the surface and particulates can be minimized using surface treatment. This is accomplished by cleaning the substrates with oxygen plasma etching to activate the hydroxyl groups and treating the surface via vapor phase deposition of trichloro(octyl)silane. The adhesion tests were performed on smooth and nanostructured polycarbonate samples with 3, 1, and 0.5 µm period to examine the scaling effect of period on particle removal from the surface. The top-view confocal microscope images of the samples before and after applying calibrated force are shown in Figure 2. Here it can be observed that the nanostructures can greatly reduce the particle adhesion on the substrate.

The size distributions of the particles remaining on the smooth and nanostructured samples before and after spinning are extracted by analyzing the confocal images, as illustrated in Figure 3. The particle size distribution on the smooth sample confirms that most of the particles still remain on the surface even after spinning, with a total count of 27 particles in the >10 µm and 1908 particles in the <10 µm range. The effect of the structure topography on dust adhesion is most dramatic when the feature size is reduced to 500 nm. The particle size distribution verifies that the particle counts before and after spinning on 500 nm nanostructure sample are very similar, and the peak is around 25 counts.

In this work, we demonstrated anti-dust surfaces by precise engineering of surface nanostructures with both topographical features and surface chemistry. Comparing the 500 nm period sample to a smooth surface, the particle coverage area was reduced from 35% to 2.4%, indicating over a 93.1% reduction in dust adhesion. The demonstrated fabrication process is also highly scalable and compatible with R2R manufacturing, enabling the demonstrated anti-dust nanostructures to be implemented in broad applications such as space exploration, solar panels, and wind turbines.

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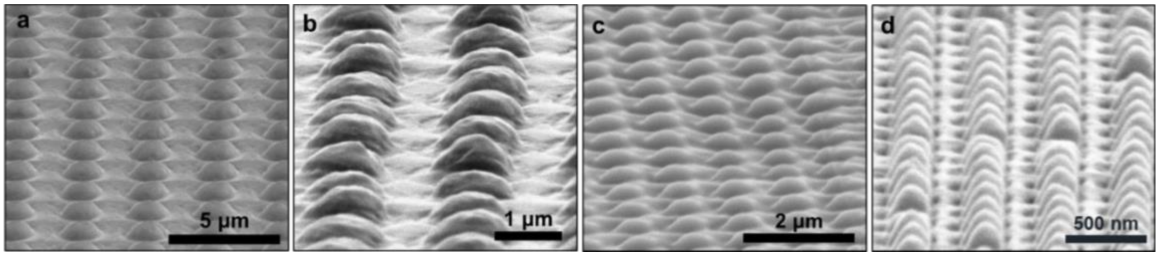

Figure 1. SEM images of the nanostructured surfaces. (a) 3 µm period. (b) 2 µm period. (c) 1 µm period. (d) 500 nm period.

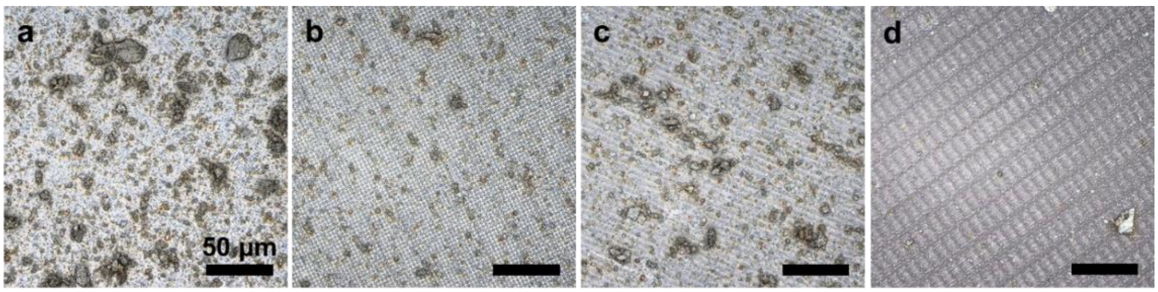

Figure 2. Top view confocal microscope images of the surface-treated polycarbonate samples after tilting vertically. (a) Untextured. (b) 3 µm period. (c) 1 µm period. (d) 500 nm period.

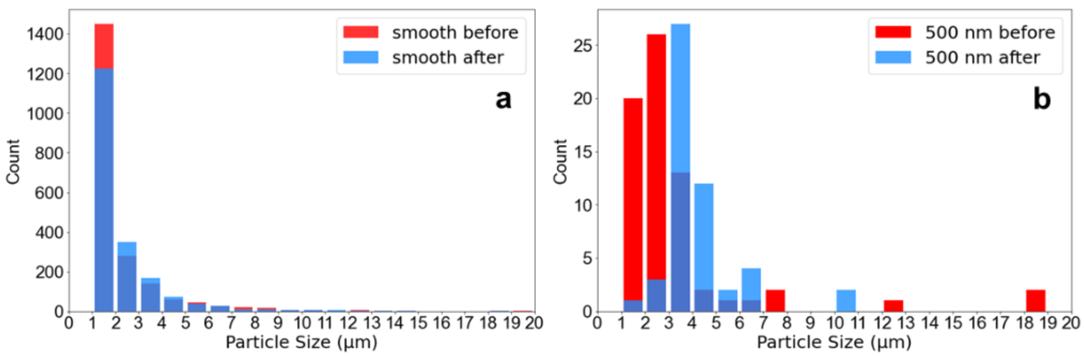

Figure 3. Particle size distribution of (a) smooth and (b) 500 nm nanostructured samples

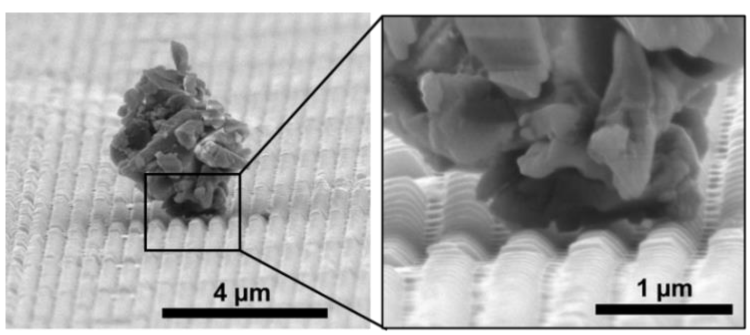

Figure 4. SEM images of a clump of dust particles on top of the 500 nm period textured surface.

References:

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