Controlling the direction and amount of a splash with textured surface

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Because splashing is such a violent process, one might naively expect that neither the direction of droplet emission nor the amount of ejected material can be controlled with any precision. Even though it is observed countless times in the course of a day, drop splashing is highly non-intuitive[1]: for example, it is surprising that the surrounding air pressure determines whether a drop will splash when hitting a smooth surface[2]. Here we describe a discovery with significant practical ramifications: the direction, as well as the number, of the ejected droplets can be controlled by the texture of a surface.

Splashing of a liquid drop after hitting a solid surface is crucial in many industrial applications such as inkjet printing[3], surface coating[4], combustion of liquid fuel[5] and spray drying[6]. Precise manipulation of the direction in which ejected droplets emerge from the point of impact as well as of the number and total volume of the ejecta is highly desirable. We find that all of these parameters can be controlled by using a substrate with a well-defined texture.

Using UV-lithography techniques, we create a substrate consisting of a square lattice of square pillars as shown in Fig. 1a. The three parameters, (i) vertical pillar height, \( h \), (ii) lateral pillar side, \( l \), and (iii) spacing between pillars, \( s \), can be varied independently. Fig.1b shows bottom-view photographs of a 3.4mm diameter drop after colliding with this substrate at 4.3m/s in a low-pressure environment of 13kPa. The liquid is a mixture of ethanol with ink so that the splash is clearly visible. There is a striking feature: the splashes have 4-fold-symmetry. They emerge predominantly in the diagonal directions of the underlying lattice where the distance between pillars is the largest. This is consistent with data showing that in this regime of pillar dimensions, splashing is suppressed by a higher pillar density.

FIG. 1: Splash on a textured surface. (a), Textured surface manufactured by UV-lithography. The left cartoon shows the lithography process. The photograph at right is a top view of the textured surface. Each square is a pillar with height \( h = 18\mu m \); the lateral pillar size, \( l \), is the same as the pillar spacing, \( s: l = s = 60\mu m \). (b), A splash at low pressure, 13kPa. There is a clear 4-fold-symmetry, predominantly in diagonal directions of the lattice. (c), A splash at atmospheric pressure, 100kPa. The amount of splash increases with air pressure, but the 4-fold-symmetry is preserved.

There are two distinct components to a splash: the corona splash caused by air[2] and the prompt splash caused by surface roughness[8]. By working at low pressure, as in Fig. 1b, air effects are minimized so that there is no corona splash. In this case only the surface-roughness induced prompt splash remains. Fig. 1c shows another series of photographs of drop splashing with the same initial conditions as in Fig. 1b except that the background air is at atmospheric pressure, 100kPa. Here both the air and the surface roughness contribute to producing a splash. We see a larger splash but with the same 4-fold-symmetry seen in Fig. 1b. This indicates that even though air is present, the splash directions are still controlled by the substrate texture.

The surface texture not only controls the direction of the droplets ejected by a splash, but it also affects the splash magnitude. To show this effect, we did a series of experiments at atmospheric pressure with fixed lateral pillar dimensions: \( l = s = 60\mu m \), while varying the pillar height, \( h \). The impact velocity was kept at \( V_0 = 4.3m/s \). Fig. 2a shows a symmetric corona splash on a smooth surface (\( h = 0\mu m \)). The photographs in Fig. 2b show that for small \( h \) (\( h = 5\mu m \)), there is a large splash. This splash is not as symmetric as the smooth case. Fig. 2c shows that as we increase the height to \( h = 54\mu m \) (a value close to \( l \) and \( s \)), the splash amount is greatly reduced. Finally, Fig. 2d shows that further increasing the height
FIG. 2: Splashing on surfaces with different pillar heights under atmospheric air pressure. In all images, the lateral pillar dimensions were fixed at \( l = s = 60 \mu m \).

(a) A symmetric corona splash on a smooth surface \((h = 0 \mu m)\). (b) When \( h = 5 \mu m \), the splash is a mixture of a corona and a prompt component. The ejected droplets are not as symmetrically distributed as in (a). (c) As we increase \( h \) to about the same size as \( l \) and \( s \), \( h = 54 \mu m \), there is a dramatic decrease in the magnitude of the splash. (d) When \( h \) is further increased to \( h = 125 \mu m \), the splash is completely suppressed.

Why do tall pillars suppress splashing? Tall pillars can form channels through which air can easily escape without interfering with the liquid motion. This can minimize the effects of air that would otherwise create a corona splash. However, it is much less clear why tall pillars would also reduce the contributions from the prompt component of the splash. This result suggests that the drop feels little disturbance during its expansion on top of the tall pillar surfaces. This could resemble the drops floating on top of the super-hydrophobic surfaces studied by Quéré et al \cite{9,10}.

Thus texture can control both the direction and magnitude of a splash. Since splashing is involved in many industrial processes, these discoveries should have important applications.

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