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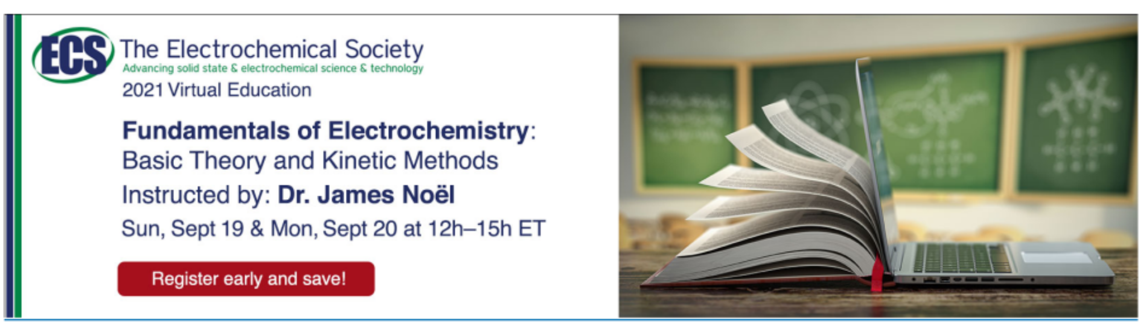

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Experimental study the effect of surface roughness of a material on its hydrophobicity

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Abstract. To investigate the effect of trapped gas and surface roughness, it is necessary to study more deeply the hydrophobic nature of a material which has a different surface roughness value. This research was conducted experimentally, by first preparing materials that have different grain sizes. Then measuring contact angles, mapping surface roughness, and observing droplets when in contact with the material. This study shows that the increase in droplet volume affects the contact angle formed, the greater the droplet volume the droplet surface tension capability is getting weaker. The smaller the grain size, the higher the contact angle formed, this is due to the particle size that supports the droplet surface, when the particle size is small, the surface tension formed is greater so that the droplet has a high contact angle. Micro/nano size bubbles that spread evenly on the surface of hydrophobic material strongly support the occurrence of hydrophobic properties in a material.

Keywords: trapped gas, surface roughness, hydrophobic nature, grain size

1. Introduction

Research on the hydrophobic nature of the material has been widely studied by experts. Hydrophobic animals and plants in nature hold many secrets and uniqueness. The uniqueness of hydrophobic material is very interesting to be studied more deeply [1]. Natural ingredients such as taro leaves (colocasia) have trapped air bubbles that help their superhydrophobicity [2]. Besides being owned by plants, this hydrophobic property is also owned by nano-particles such as a mixture of Alumina (Al_2O_3) and Magnesium (Mg) [3]. By setting the right composition of this layer can create hydrophilic, hydrophobic, and superhydrophobic properties.

Superhydrophobic leaves have a characteristic surface structure and topographic shape. A Topography of a surface is closely related to the texture of surface roughness. The results of the study [4-6] state that surface roughness has a major influence on the wetted surface of a surface. The state of a meta-stable wetting regime on heterogeneous surfaces is an important key to the superhydrophobic nature [7]. When liquid spreads across the surface, the contact line will move continuously until the surface energy reaches a minimum, and balance is reached. In the initial condition the fluid forms the contact angle θ ° moves towards the left, and then move towards the

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right forming the contact angle θº and the fluid fills all the empty spaces in the basin. This event occurs when a large surface gap (macro-scale) forms. A different case occurs when the gap forms at a small size (micro/nanoscale), when the contact fluid creates a space, at the bottom of the basin which is trapped gas. The results of these studies conclude that the occurrence of hydrophobic nature is due to the trapped gas.

Nano-bubbles on the surface caused by chemical reactions or trapped gas are very helpful in determining the hydrophobic nature of a material. Research on nano-bubbles on the surface of Alumina (Al_2O_3) has been carried out by [8]. This research shows that there are different properties on the surface of hydrophobic alumina and hydrophilic alumina. This difference is shown by the appearance of nano-bubble on the surface of hydrophobic Alumina while on the hydrophilic surface it is only found in the grooves and pores. Based on this study it can be concluded that the hydrophobic nature is influenced by the presence of nano-bubbles that appear on the surface of Alumina evenly when in contact with saturated water.

The influence of gas bubbles on the hydrophobic nature then [9] conducted further research on the hydrophobic nature by coating on material. This research was carried out by coating the gases in Diamond nano-crystals. This coating uses Oxygen, Fluorine, and Hydrogen gas. Contact angle test results show coating with Oxygen gas produces hydrophilic properties, whereas in Hydrogen and Fluorine gases produce hydrophobic properties. This shows that the coating with Hydrogen and Fluorine gas has the potential to change the material has hydrophobic properties.
Further research was also carried out by [10] by coating ZnO nanoparticles with hydrophobic gas. This coating uses ultrasound technology (Ultrasound-Assisted Method) by adding Polyvinyl-pyrrolidone (PVP), Polyethylene-glycol (PEG), dodecylamine (DDA), or Hexatetramethylene-tetramine (HMTA). The results of this study show that ZnO nano-particles with ZnO @ DDA2 gas coating can form droplet contact angles up to 141º. This research succeeded in proving a significant change in the hydrophobic nature by coating ZnO @ DDA2 gas. The hydrophobic nature of this coating can survive in 20 days, after which the hydrophobic nature decreases. This shows that the hydrophobic nature of the gas coating results does not apply permanently, but is still influenced by time.

Subsequent research on the effect of gas bubbles on the superhydrophobic nature of Lotus leaves has been carried out [11]. This research succeeded in revealing that trapped gas bubbles are the key influences of superhydrophobic nature. The results of this study concluded that the trapped gas is air due to the influence of the surface roughness of the Lotus leaves. To investigate the effect of trapped gas and surface roughness on hydrophobic materials, it is necessary to study more deeply on other materials that have hydrophobic properties.

2. Methods

2.1 Contact angle measurement

Measurement and picture taking of the contact angle of the droplet is shown as in Figure 1. The volume of the droplet is varied 1-5 ml using an insulin pen (1), dropped on the surface (5): Teflon, grain material 5000, 7000, and 10000. To observe the contact conditions between droplets with a surface (5) used a digital microscope at position (2). To measure the contact angle of the droplet when in contact with the surface using a digital microscope at position (3). Software used to measure the contact angle of a droplet against a surface is used in measurement software.

Digital image microscope specifications (2, 3): Image sensor: 0.3m CMOS, Magnification scale: 0-1000x, focus scale: 10mm, power: 5 Volts, Light: 8 LED lights. Equipped with Measurement software, Operating system used: Windows XP/ Vista / Win 7, 32 bit and 64 bit, Frame Rate: 30 f / s, Digital magnification: 5×.

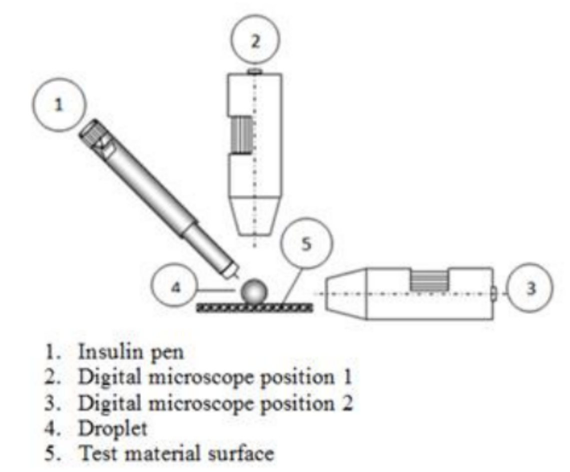

Figure 1. Experimental tool settings for droplet contact angle measurements

2.2 Material used

The materials used in this study are sandpaper with grain sizes of 5000, 7000, 10000, and Teflon are shown in Figure 2. The sandpaper used is a type of wet and dry sandpaper, which has waterproof and good oil resistance properties. Grain material uses high-quality silicon carbide, granular by following per under grain size.

The Polytetrafluoroethylene (PTFE) the compound is better known as the Teflon image (2.d). This compound is a fluoropolymer, also called an ethylene fluorine polymer. PTFE has a low friction coefficient because this material has hydrophobic properties. PTFE is used as a non-stick coating for cooking utensils such as pots, pans, and other cooking utensils. PTFE is very unreactive, so it is often used as a container and pipe for reactive chemicals. The use of Teflon material is used to observe the mechanism of hydrophobic materials when in contact with droplets compared to other materials that have different levels of roughness.

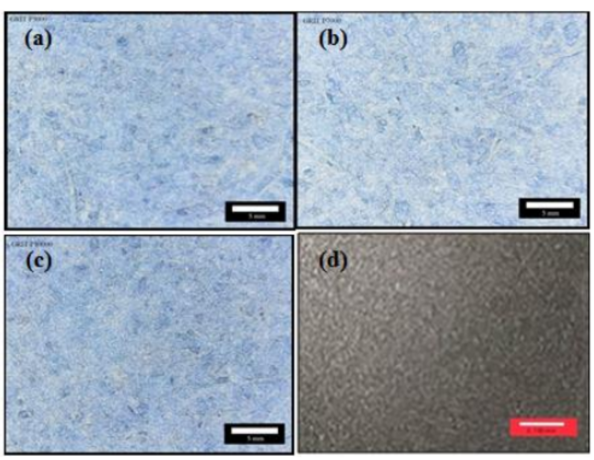

Figure 2. Materials with different levels of roughness: (a). 5000-grain material, (b). Ingredients 7000 grains, (c). The Material of 10000 grain and (d). Teflon

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2.3 Surface roughness measurement
To measure the surface roughness of each material, Gwyddion software is used. This software, used for 2D surface roughness analysis through scanning images from a microscope: Atomic force microscope (AFM), Modified frequency modulation (MFM), Near-field scanning optical microscopy (NSOM). Moreover, it can be used for processing gray images, such as for analysis of profilometric data or thickness spectrophotometric imaging maps. Gwyddion is free software, protected by the GNU General Public License. Gwyddion can be applied to Linux / Unix (including Mac OS X) and Microsoft Windows operating systems.

3. Result and Discussion
Figure 3 shows the graph of the relationship between the droplet volume and the contact angles formed on the surface. These results indicate that the contact angle of the droplet decreases with increasing droplet volume. Increasing the droplet volume affects the contact angle formed, the greater the droplet volume the droplet surface tension capability is getting weaker, so the droplet tends to have a decreasing contact angle. The contact angle of Teflon tends to be higher compared to the others because of the hydrophobic nature of Teflon.

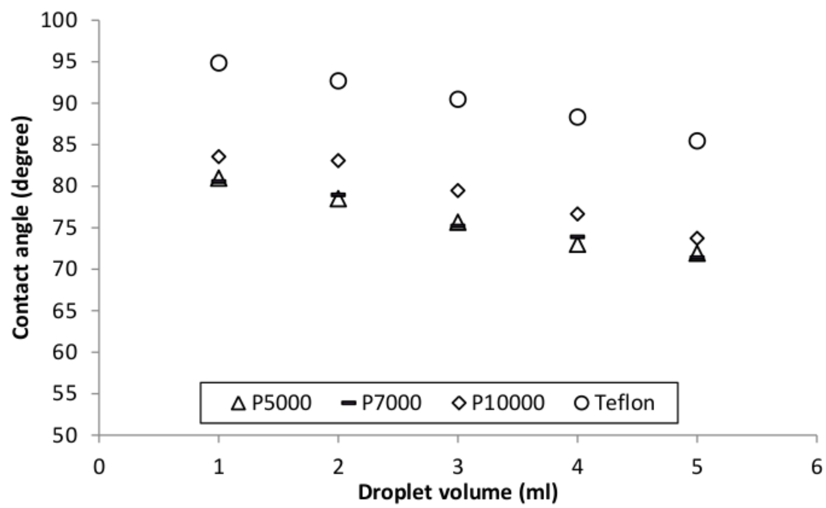

Figure 3. Correlation between droplet volume and contact angles formed

Figure 4 shows the results of measuring the contact angle of the droplet in volume (1-5ml) when in contact with various types of materials, namely: Teflon image 6 (a-e), materials with 5000 grains (f-j), materials with grains 7000 (k-o), and grain materials 10000 (p-q). The results of contact angle measurements are shown in table 1., the highest angle occurs in Teflon with a value (85.45-94.85º) followed by grain material 10000 (73.72-83.55º), grain material 7000 (72.38- 81.56º), and 5000-grain materials (71.92-80.96º). The results of this measurement show that with the smaller grain size, there is an increase in the contact angle as shown in Figure 4 and Table 1.

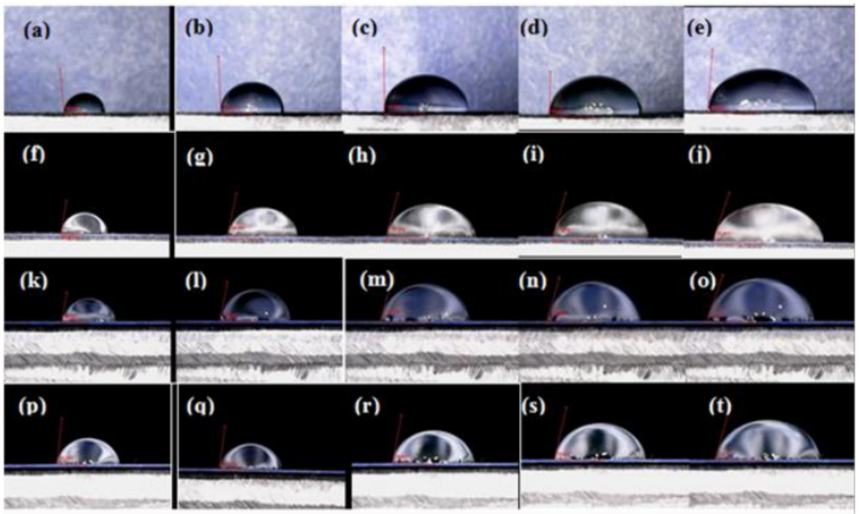

Figure 4. Results of contact angle measurements on various materials: (a-e). Teflon, (f-j). Grain material 5000, (k-o). Grain material 7000 and (p-t). 10000-grain material

Table 1. Results of contact angle measurements of droplets when contacting with various surfaces

Droplet volume (ml)	Material contact angle (degree)			
	Teflon	Grain 5000	Grain 7000	Grain 1000
1	94.85	80.96	81.56	83.55
2	92.69	78.48	79.95	83.07
3	90.46	75.66	76.20	79.46
4	88.33	73.01	74.89	76.64
5	85.45	71.92	72.38	73.72

Figure 5, is the result of 2D surface roughness mapping using Gwyddion software. Roughness analysis on materials with 5000 grains shows figure (7.a), grains 7000 (7.b), grains 10000 (7.c) and the last is on the surface of Teflon (7.d). The measurement results show different levels of surface roughness at the microscale with their respective values: 0.97 μm (grain 5000), 0.93 μm (grain 7000), 0.92 μm (grain 10000), followed by surface roughness on Teflon: 0.59 μm. The roughness measurement results show that the smaller the roughness value of a material, the better its hydrophobic properties. This process can occur when the droplet touches the surface roughness that has a sharp profile (indicated by a circle) then the surface tension increases so that the droplet has a high contact angle. Narrow surface cracks (indicated by a circle) support the occurrence of air trapped on the entire surface, this trapped air is very supportive of the hydrophobic nature as shown in Figure 7.

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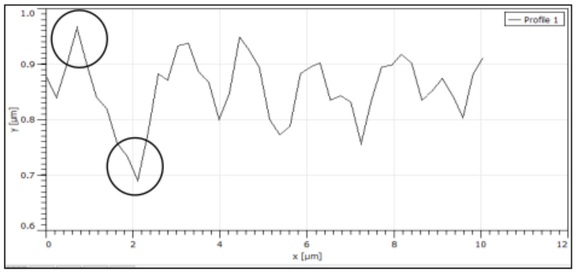
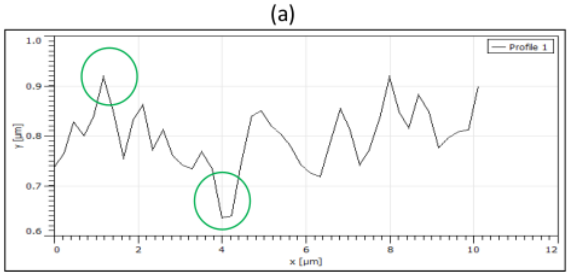


(a)



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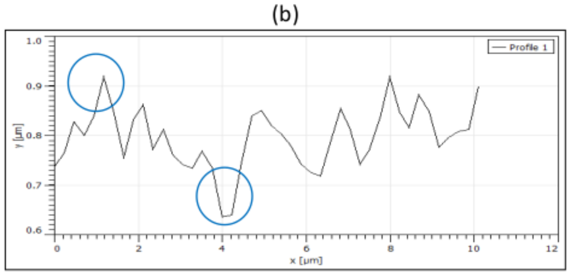

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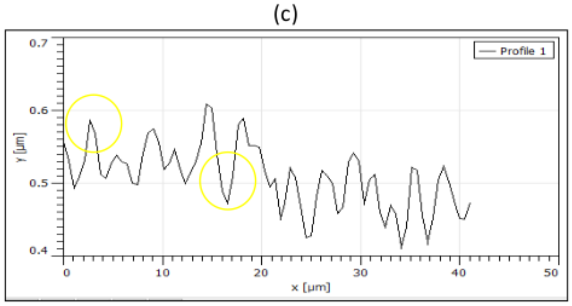

(d)

Figure 5. Results of surface roughness mapping with Gwyddion software in (a). Ingredients 5000 grains, (b). 7000-grain material,

Figure (6.a) is a contact droplet with a Teflon surface, Figure (6.b) is a contact droplet with a 5000-grain surface, Figure (6.c) is a contact droplet with a 7000-grain surface, and Figure (6.d) is a contact droplet with a surface grain of 10000. These results indicate the smaller the size of the grain, the higher the contact angle formed, this is due to the particle size that supports the droplet surface when the particle size is small, the surface tension formed is greater so that the droplet has a high contact angle. The Teflon surface is very smooth compared to the surface of other materials, this supports the gas trapped in a gap that is getting smaller and more evenly, thus creating high surface tension on the droplet. Teflon gas bubbles were found on the surface as shown in figure (6.a), a white circle. The influence of micro or nano-bubbles which help the hydrophobic nature is supported by [2], which has proven the presence of gas bubbles on the leaves of taro (colocasia esculenta). The phenomenon is by with the hydrophobic nature of Teflon where gas bubbles are trapped on the micro/nano surface on the Teflon surface as shown in Figure (6.a), while the yellow circle shows the beam of a lamp on a digital microscope. On surfaces with grains of 5000 (figure 6.b), grains 7000 (figure 6.c), and grains 10000 (figure 6.d), there are no visible gas bubbles, this is consistent with the phenomenon of the measurement results of contact angles of droplets that do not show nature hydrophobic (contact angle <90º).

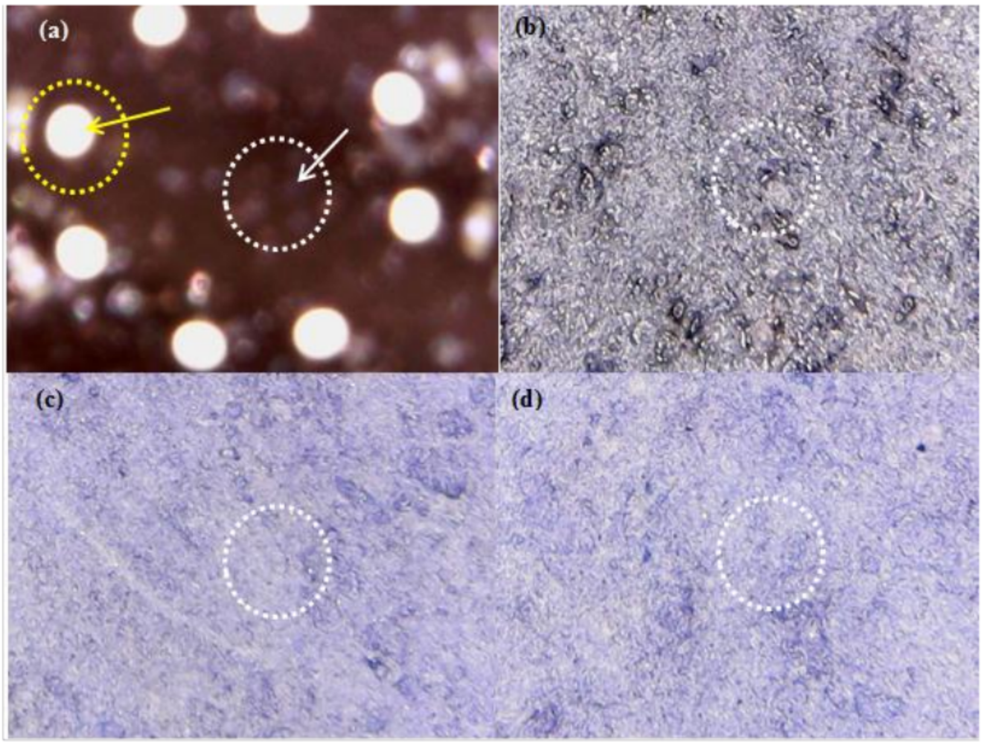

Figure 6. Microscope observations when droplets come in contact with layers: (a). Teflon Surface, (b). Surface Grain-5000, (c). Surface Grain-7000 and (d). Surface Grain-10000

Figure 7 shows the surface of a droplet when in contact with a variety of materials. The results of these observations indicate the formation of gas bubbles that are trapped on the surface. The gas bubbles in Figures 7.a, 7.b and 7.c appear to be irregular in both different shapes and sizes, this is caused by the gas being trapped but unevenly caused by unequal gap sizes. The size of the bubble diameter at the micro-scale causes water to still be able to break through and fill gaps in the surface. Unlike the case with Teflon material has small and very regular bubbles on its surface as shown in Figure 7.d. In taking position 7.d, there is no visible bubble formed due to its very small size, only looks like a layer covering the Teflon surface. This layer is capable of creating hydrophobic properties in Teflon. The layers that appear on the bottom of the droplet are micro/nano size bubbles that spread evenly on the surface of hydrophobic materials such as

Alumina [8], Lotus leaf [11], medical equipment [12], waterproof textile [13,14], hydrophobic membrane [15] and taro leaves [2].

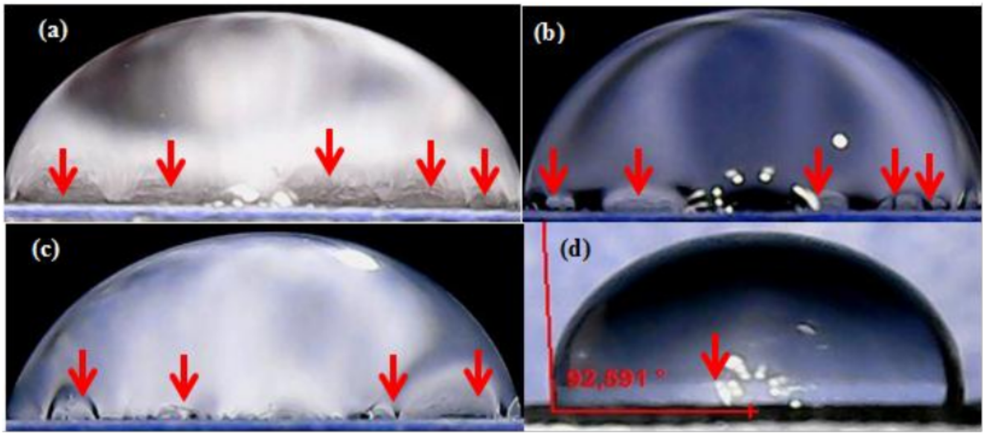

Figure 7. Observation with a microscope when contact droplets on the layer: (a). Surface Grain-5000, (b). Surface Grain-7000 and (c). Surface Grain-10000 and D). Teflon surface

4. Conclusion

The results of this study can be concluded that:

a. Increasing the droplet volume affects the contact angle formed, the greater the droplet volume the ability of the droplet surface tension gets weaker.
b. The smaller the grain size, the higher the contact angle formed, this is due to the particle size that supports the droplet surface, when the particle size is small, the surface tension formed is greater so that the droplet has a high contact angle.
c. The layer at the base of the droplet is a micro/nano size bubble that spreads evenly on the surface of hydrophobic materials such as Teflon.

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