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Surface wettability control of nanopillar array structures fabricated by bio-template ultimate top-down processes

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Artificial intelligence (AI) and the Internet of Things (IoT) are seen a pathways to realizing smart societies. In particular, IoT sensors need to be installed everywhere within such a society in order to collect weather, temperature, traffic information, etc. The surfaces of the sensors, especially mm-wave radars and cameras, should be kept clean and free from water droplets. Here, controlling the surface wettability of transmittance materials such as wettability control on the transmittance material such as have been widely studied as means of controlling wettability; their characteristics can be explained using the Wenzel and Cassie-Baxter equations.

The Wenzel model indicates that roughness on a hydrophilic (hydrophobic) surface leads to more hydrophilicity (hydrophobicity). The Cassie-Baxter model shows that narrowing and widening lead to more hydrophobicity. On the other hand, in the case of a hydrophilic material, the Cassie-Baxter model does not hold because of capillarity. As a result, for realizing a transparent hydrophobic structure, organic polymer is usually coated on a transparent material such as quartz. Organic polymer is used mainly because it is very difficult to fashion a hydrophobic and water-repellent surface made of uncoated quartz, which is hydrophilic. Despite this, molecular dynamics (MD) simulations have predicted that hydrophobicity due to molecular level surface tension can be created with nanostructures on a hydrophilic surface. Water capillarity does not occur completely because significantly narrow gaps prevent water from filling them. On the other hand, microscale or a combination of microscale and nanoscale structures on a surface decrease the transmittance of quartz because they increase the surface roughness, which leads to more light being scattered. A structure less than 1/10th the visible optical wavelength is necessary for maintaining transparent characteristics. This means that well-controlled structures on the scale of a few nanometers can achieve a hydrophobic and transparent quartz surface. We supposed that a nanopillar (NP) structure could be fabricated of the surface by using a precisely controlled method. Our fabrication technique using a bio-template and neutral-beam (NB) etching is capable of making high-precision, defect-free NP structures. (Fig.1) [1].

In this study, we fabricated hydrophobic and transparent quartz NP structures to investigate the effect of varying a contact angle (CA) by using 10-nm-order gaps and 10-nm-diameter NPs, as shown in Fig.2. Gaps from 15 to 30 nm led to CAs of more than 100°, showing hydrophobicity, to a maximum of 105°. The mechanism of repelling water on quartz could be explained by the Cassie-Baxter model with a filling factor (Fig.3). A gap of more than 30 nm fills with water due to capillarity, but a gap of less than 30 nm causes water to be repelled by air. We were able to repeatedly fabricate a quartz NP structure with a controllable gap by using a combination of a bio-template and neutral-beam etching and found this structure to be highly water-repellent. The structure has high durability and optical transparency. As a result, we conclude that it can be used in sensors and lenses on various devices such as cameras and radars.

[1] Seiji Samukawa, ECS Journal of Solid State Science and Technology, 4 (6) (2015) N5089(6pp).

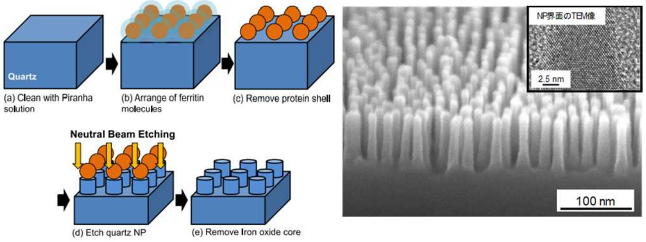


Fig.1 Our fabrication technique using a bio-template and neutral-beam (NB) etching is capable of making high-precision, defect-free NP structures.

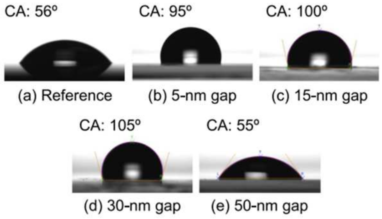
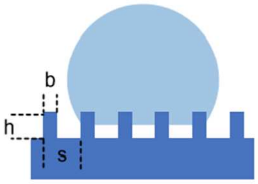


Fig.2 Hydrophobic and transparent quartz NP structures to investigate the effect of varying CA by using 10-nm-order gaps and 10-nm-diameter NPs



$$\cos\theta_r = \Phi_S \cos\theta + \Phi_V \cos 180^\circ$$

$$\Phi_S = \frac{b + (s - b + 2h)\, f_W}{s},$$

$$\Phi_V = \frac{b + (s - b + 2h)(1 - f_W)}{s}$$

Fig.3 Schematic diagram of Cassie-Baxter with filling factor mode. θr is CA on the structure, θ is CA of the material, Φ_S is the part of the water in contact with the material, Φ_V is the part of the air contacting the material, and f_W is the filling factor.