

# Development of environmentally-friendly surface modification technology

— Practical realization of novel oleophobic coatings without relying on perfluorinated compounds and surface texturing —

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Development of non-adhesive and dewetting solid surfaces has attracted much attention in a wide variety of industrial applications, because such surfaces can prevent staining, corrosion and clogging, and also permit control of droplet motion. In this paper, we introduce our strategy for R&D, including classification and analysis of previous work, and establishment of a guiding principle for R&D towards practical and rapid realization of our novel oleophobic coatings. Our R&D strategy successfully reduced the transition period from *Type 1* to *Type 2 Basic Research* and its practical realization. Furthermore, by means of seeds-needs matching between AIST and industrial companies, through PR activities and sample offers, we were able to establish our coating technology on a commercial scale within one year.

**Keywords :** Oleophobic treatment, dynamic dewettability, liquid-like surface, perfluorinated compounds, environmentally friendly

## 1 Introduction

The adherence of liquid droplets (of water or oil) to solid surface can cause corrosion, deterioration, degradation of appearance, or reduction of visibility, thereby significantly damaging the safety or reliability of devices or equipment. Therefore, the development of surface treatments that show excellent performance in removing droplets are being actively pursued. Droplet removal performance was conventionally evaluated only by the magnitude of the angle created by the tangent of a droplet to the solid surface, or the “contact angle” (in cases where water is used as a probe, it is called water droplet contact angle; it is also called the static contact angle, since it is an angle of an almost motionless state). The contact angle only reflects the physical properties of the outermost layer (about 1 nm) of the solid surface, and surfaces with large contact angle values are generally known as hydrophobic or oleophobic surfaces, while those with small values are called hydrophilic or oleophilic surfaces. In most studies up until now, droplet removal performance has been judged by the magnitude of the static contact angle. However, as can be seen in Fig. 1, in some cases the droplet adheres and will not move when the substrate is tilted 90° or more, even if the static contact angle is 150° or greater, depending on the surface conditions. The static contact angle and the droplet removal performance do not necessarily match.

Alternatively, other measurements that indicate droplet

removal performance include the dynamic contact angle (advancing/receding contact angles of the droplet, assuming the droplet can move on the solid surface, and the contact angle hysteresis that is the difference between the advancing/receding contact angles), and the critical angle (sliding angle) where a certain amount of droplet slides off the solid surface. The contact angle hysteresis and sliding angle reflect the droplet removal performance more accurately, and it is actually widely recognized that the droplet removal performance is superior when the contact angle hysteresis or the sliding angle is smaller. These observations suggest that the evaluation of droplet removal performance of solid surfaces should be done using the dynamic contact angle as the index, rather than the conventional static contact angle.

We have defined the droplet removal performance as “oleophobicity,” and have attempted to develop a method to confer excellent oleophobicity on various substrate surfaces. Therefore, we have reviewed past oleophobic treatments, particularly world research trends on oleophobic treatments, and constructed a research strategy by reviewing them from the new perspective of contact angle hysteresis. Although there were a few proposals of methods to control the contact angle hysteresis, they did not step outside the range of *Type 1 Basic Research*. In this paper, our research strategy, that aimed to give excellent and practical oleophobicity to substrate surfaces at low cost, will be discussed. If such surfaces can be put to practical use, the following industrial applications can be expected: prevention of staining;

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improvement of anti-corrosive properties; flow control of MEMS (micro electro mechanical systems), NEMS (nano electro mechanical systems), and other biochips; prevention of ink jet nozzle clogging by residue caking; and others.

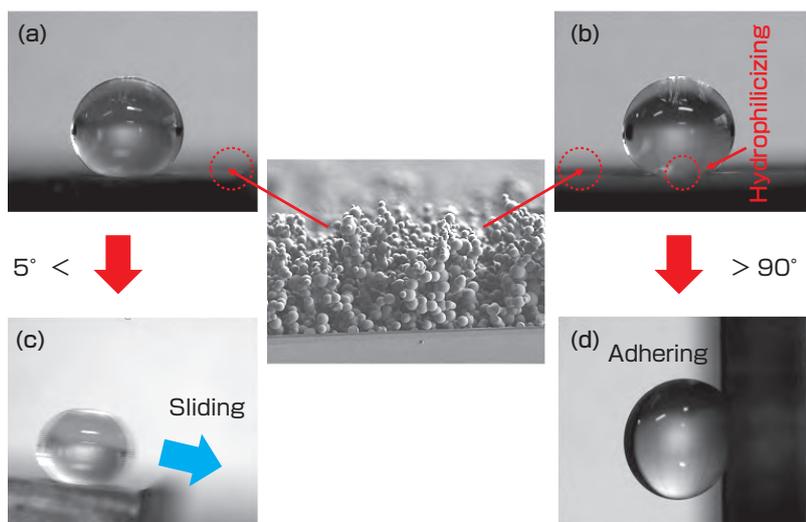
## 2 Issues of the conventional methods: What could be seen from conventional oleophobic treatments

Oleophobic surfaces that have been published so far can be roughly categorized into three groups: (1) smooth surfaces (liquid-like surfaces), (2) rough surfaces, and (3) rough wet surfaces. Figure 2 shows the types of oleophobic surfaces and their processing technologies.<sup>[1]</sup> In this paper, the chronological sequence by which these surfaces were developed is discussed, and they will be referred to as the first-, second-, and third-generation oleophobic surfaces, respectively. Currently, the main subjects of *Type 1 Basic Research* are second- and third-generation oleophobic surfaces. First, the trend of the current oleophobic treatment

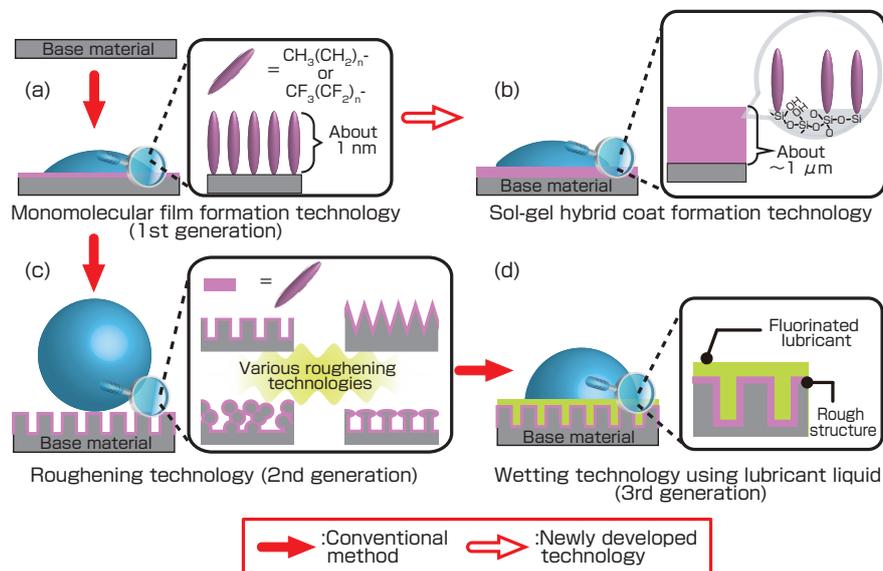
research will be outlined, and then the disadvantages of second- and third-generation surfaces, as well as the reason we returned to first-generation oleophobic surfaces are explained. By accurately understanding the advantages and disadvantages of conventional methods, and formulating the research policy accordingly, we were able to greatly shorten the time needed to shift from *Type 1 Basic Research* to practical realization.

### 2.1 Smooth surface (liquid-like surface) [first generation]

First-generation oleophobic treatments are simple methods, where an organic monomolecular film, terminated by low surface energy functional groups, is coated onto a smooth solid surface (Fig. 2a).<sup>[2]</sup> Conventionally, to increase the magnitude of static contact angle (particularly oil) fluorinated molecules that are effective in decreasing the solid surface energy are used as starting materials. On the other hand, there are some reports of monomolecular film-coated surfaces showing excellent oleophobicity without using fluorinated compounds. For example, it was reported



**Fig. 1**  
 (a) State of static droplet on an ultra-hydrophilicized silicone substrate  
 (b) State of static droplet on a partially hydrophilicized surface (a)  
 (c) When (a) is tilted  
 (d) When (b) is tilted

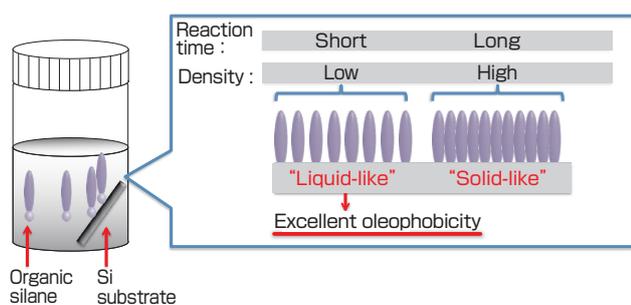


**Fig. 2 Types of oleophobic surfaces and their fabrication methods**  
 (a) Oleophobic technology using a monomolecular film  
 (b) Oleophobic technology developed in this research  
 (c) Oleophobic technology using roughening technology  
 (d) Oleophobic technology using lubricant liquid

in 1946 that a platinum substrate surface coated with a monomolecular film of a long-chain alcohol (20 carbon) showed excellent oleophobicity against *n*-hexadecane, a type of alkane, with a small static contact angle (about 40°).<sup>[3]</sup> Although the principle was not clarified, in the late 1990s McCarthy *et al.* studied the correlation between the molecular density of alkyl group-terminated monomolecular films and oleophobicity, and experimentally demonstrated that the motility of the functional groups on a solid surface had a significant effect on the oleophobicity.<sup>[4]</sup> They measured the changes in contact angle hysteresis of water and *n*-hexadecane as a function of the reaction time, and found that surfaces with an appropriate molecular density showed the best oleophobicity (Fig. 3). At this molecular density, a motile space is generated in the surface-fixed functional groups, and a “liquid-like” surface is formed. They also found excellent oleophobicity on monomolecular film-coated surfaces fabricated using bulky molecules with branched structures (terminated with alkyl groups). Droplets regardless of the type of probe liquids can slide off on such “liquid-like” surfaces.<sup>[4]-[6]</sup> However, since such “liquid-like” surfaces have small contact angles against oil, it did not gain attention around the world as a truly oleophobic surface.

### 2.2 Rough surface [second generation]

For second-generation oleophobic surfaces, the objective is to increase the magnitude of contact angle (normally 150° or more) by simulating the rough, textured structure of a biological surface to reduce the contact area between the droplet and the solid surface. Therefore, (1) surface treatment by low surface energy molecule/film and (2) optimization of the rough structure are essential, and these are major research elements for second-generation oleophobic surface development (Fig. 2c). For example, for (1), it became apparent from first-generation research that surfaces terminated with -CF<sub>3</sub> groups showed the lowest surface energy (about 120° for the static contact angle of water). Therefore, long-chain perfluorinated compounds are used to most efficiently expose the group on the solid surface. For (2), taking inspiration from the microscopic structures of organisms, such as lotus leaves or springtails, the structure is optimized through calculation and simulation, and the



**Fig. 3 Relationship between the surface functional group density and oleophobicity according to reaction time<sup>[4]</sup>**

surface treatment is done using lithography and/or other methods. In 2007, a paper in *Science* by Tuteja and Cohen *et al.* reported a surface from which oil droplets slide off like water droplets from a lotus leaf, made by optimizing the rough structure and by modifying the surface with perfluorinated compounds.<sup>[7]</sup> Since this publication, second-generation research on oleophobic liquid treatments, as well as oleophobicity, has accelerated.<sup>[8]</sup>

### 2.3 Rough wet surface [third generation]

Aizenberg *et al.* reported a new coating method that allowed improvement of oleophobicity without increasing the magnitude of contact angle, as observed in second-generation oleophobic treatments. They reported a surface treatment method with excellent oleophobicity called the slippery liquid-infused porous surfaces (SLIPS) in 2001 in *Nature*.<sup>[9]</sup> There are microscopic grooves in the inner wall of the insect-trapping pitcher of the carnivorous plant *Nepenthes*, which are always covered with aqueous film. The oil on the legs of insects are repelled by this aqueous film, and the insect falls into the digestive fluid in the pitcher.<sup>[10]</sup> The researchers looked at the interior wall of the insect-trapping pitcher and fabricated a surface that simulated the structure. Specifically, similar to the second-generation surface, a solid surface with a fluorine-treated rough structure was fabricated, and was wetted with a fluorine lubricant (Fig. 2d). The liquid film surface obtained did not exhibit a large contact angle, but showed excellent oleophobicity, where a mixture of blood and jam would slide off as well as water or oil. Since it is a liquid film, it also has self-repairing properties, whereby a defect disappears immediately, even if it occurs due to scarring. Currently, the research on SLIPS is gathering the most attention in the field of wettability research.<sup>[11]-[13]</sup>

### 2.4 Disadvantages of the conventional oleophobic surfaces and treatment methods

The second- and third-generation artificial surfaces mentioned above show excellent oleophobicity, and their fabrication methods and optimized surfaces are interesting academically. However, all of these methods depend on rough structures and surface treatments with perfluorinated compounds, which we believed would hinder practical use.<sup>[14]</sup> For example, rough structures have the following disadvantages:<sup>[1]</sup> (1) mass production is difficult, because in many cases special conditions or equipment are needed for processing; (2) rough structures are fragile compared to smooth surfaces and impurities tend to deposit within the structure; (3) it is difficult to maintain transparency since the structures scatter visible light; and (4) droplets with a low surface energy, such as oil, wet and spread on rough surfaces (readily penetrate the interior of structure) and reduce the oleophobicity, or the oleophobicity decreases as the surface energy of the droplet decreases.

Perfluorinated compounds have the following problems: (1)

the price of the fluorite needed for manufacture fluctuates, (2) they are expensive because there are many steps to their synthesis, (3) they produce highly corrosive toxic fumes above a critical temperature, and (4) they tend to persist within the body or environment. Because of such problems, the long-chain perfluorinated compounds perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are regulated in their manufacturing and use, and there is an urgent demand for the development of alternative materials.

### 2.5 Analysis of the current situation

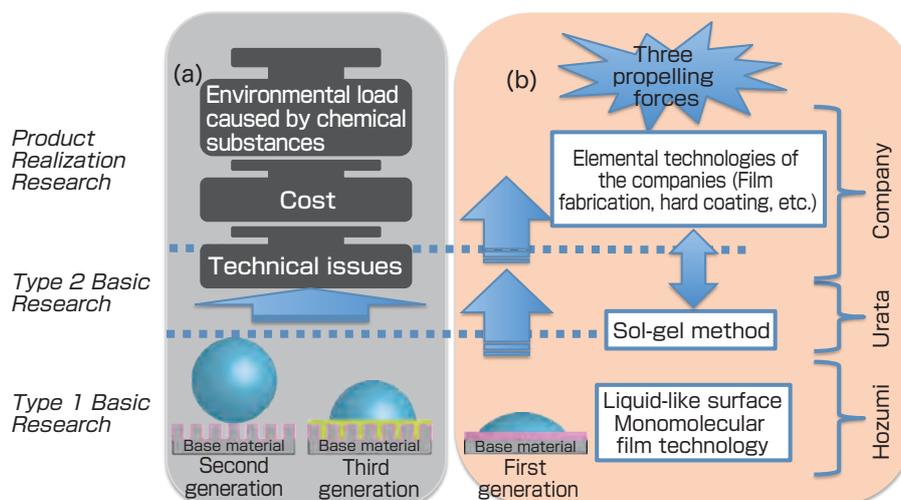
We concluded that because rough structures and perfluorinated compounds are essential for the fabrication of second- and third-generation oleophobic surfaces, they are limited in terms of technology, cost, and environmental impact, which inhibits their practical applications (Fig. 4). Therefore, we looked at first-generation smooth oleophobic surfaces, and focused on “how to realize surfaces where the functional groups behaved like liquid” and started the research. First, we looked at the fluidity and motility of polymers that are liquids at room temperature. Polydimethylsiloxane (PDMS) has a low glass-transition point (about  $-120\text{ }^{\circ}\text{C}$ ) and is a liquid at room temperature. It is also known that PDMS fixed to a surface substrate retains the fluidity of the bulk phase. We surmised that because the glass-transition point decreases as the molecular weight is reduced, low molecular weight PDMS bound to a surface might exhibit “liquid-like” behavior. Therefore, PDMS polymers of different molecular weights were covalently fixed to a silicone substrate surface, and changes in static contact angle were investigated using various probe liquids (water, *n*-hexadecane, *n*-dodecane, and *n*-decane).<sup>[15][16]</sup> It was found that the static contact angle decreased as the surface energy of the probe liquid decreased. Furthermore, it was found that the value of the static contact angle of each probe liquid remained constant, showing no dependence on the molecular weight of PDMS. This is thought to be because each PDMS surface had the same chemical

properties, despite the differences in molecular weight. On the other hand, the oleophobicity was highly dependent on the molecular weight of the PDMS (for the fluidity and motility of polymer chains). It was found that the contact angle hysteresis decreased for all probe liquids as the molecular weight decreased, and showed a corresponding decrease in sliding angle. In cases where the PDMS molecular weight was small, the contact angle hysteresis decreased against the alkanes as well as water. For example, the sliding angle decreased ( $\sim 1^{\circ}$ ) against minute oil droplets ( $3\ \mu\text{L}$  of *n*-decane), showing excellent oleophobicity. This value was much smaller than the sliding angle ( $5.3^{\circ}$ ) of *n*-decane ( $5\ \mu\text{L}$ ) on the oleophobic surface, with a static contact angle of over  $160^{\circ}$ . In addition, since the alkane probe liquids were soluble in PDMS, a so-called “blended liquid-liquid interface” was formed between the oil and the PDMS chains. It is thought that the decreased contact angle hysteresis was caused by the interface acting as a plasticizing agent, causing the movement of the fixed polymer to become smooth due to swelling of the PDMS chains.

It was found that the surface that we created, originally based on the concept of the first-generation surface treatment technology, showed equivalent or better surface properties compared to the second- and third-generation oleophobic surfaces. However, in our experiments the treated solid surfaces were limited to silicone substrates, or metal substrates polished at nano-level, and there was a large technological barrier for applying this technology to practical base materials, such as plastic.

### 3 Research scenario for the realization of oleophobic surface

In order to realize the oleophobic treatment technology nurtured in *Type 1 Basic Research*, it was necessary to develop a surface treatment that satisfied the following four



**Fig. 4** Our research strategy

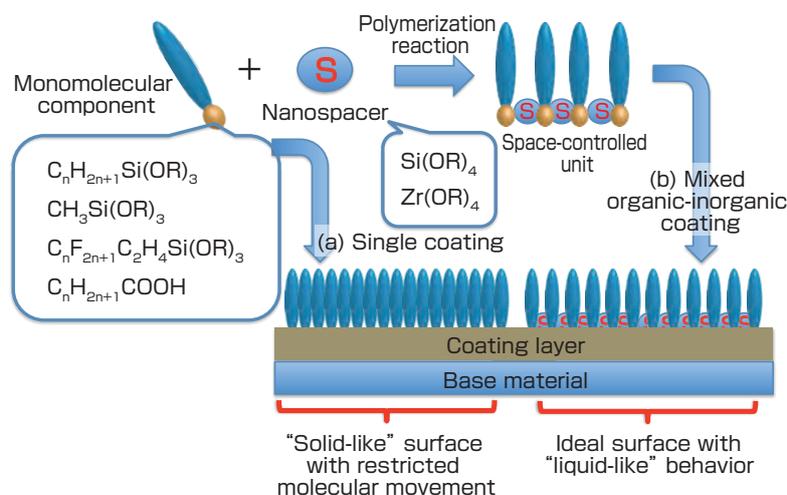
(a) Barriers to practical use if or when the conventional method is used. (b) Advantages of the newly developed method.

criteria: (1) should not depend on rough structure, (2) use as little perfluorinated compound as possible, (3) could be coated onto practical substrates, and (4) that coating could be applied using a simple method, such as painting. For first-generation methods, (3) and (4) were issues, and while we were looking at various surface treatment methods to solve them, Urata, who was involved in the sol-gel method research, joined our research group. The common factor in Hozumi's and Urata's research was a group of molecules called "organosilanes." Hozumi had been engaged in research to fabricate thin and monomolecular films as well as to control wettability using "organosilane" vapour for nearly 20 years.<sup>[17]-[21]</sup> On the other hand, Urata was using "organosilane" to adjust the organic density of organic-inorganic hybrid materials. The sol-gel method is a process for synthesizing transparent inorganic solids via hydrolysis and condensation polymerization of molecules called alkoxy silanes, in liquid. When the organosilanes are added during the reaction mixture, an organic-inorganic hybrid material is formed, in which organic and inorganic phases are homogeneously mixed (Fig. 5b), and the organic concentration can be controlled easily by adjusting the solution composition.<sup>[22]</sup> This method can be used for any base material, and is characterized by the fact that a film layer with excellent adhesion can be fabricated easily using dip or spin coating. After several discussions, we thought that the problems so far could be solved using the sol-gel method, and we decided on the research policy of "improving the motility of surface functional group of the layer obtained by controlling the concentration of organosilane in the reaction solution."

### 3.1 Sol-gel hybrid coating with excellent oleophobicity

We started the research by fabricating a hybrid layer from a mixture of organosilane and tetraalkoxysilane, and studying the relationship between the organosilane concentration and

oleophobicity. First, we used the octadecylsilane that has long alkyl chains and is known as a hydrophobic silane coupling agent. However, although we obtained hydrophobicity, it was found that total wet-spreading occurred for oil that had low surface energies, since the surface of the obtained layers had a rough structure at micrometer scale. Therefore, similar research was continued using molecules with different alkyl chain lengths, and we found that when organosilanes with chains shorter than a certain length were used, a hybrid layer with excellent oleophobicity was obtained, when formed at a certain concentration.<sup>[23]-[25]</sup> This layer had excellent smoothness and transparency, and the surface could make various liquids, such as water, animal/vegetable oil, and alkane, slide without dependence on the surface energy of the droplets. In particular, it was found to have superior oleophobicity to monomolecular films or fluororesin fabricated by organosilane or perfluorinated compound alone (Fig. 6). This hybrid layer hardened at room temperature, and it not only had no limitations of base materials, and achieved relatively good adhesiveness without any special pretreatment, it also had an excellent function whereby fingerprints on the surface could be washed off easily with water. Such fingerprint removal performance is expected to be used in the surface treatments of smart phones and touch panel displays. Since it does not use perfluorinated compounds as raw materials, the environmental load is low and the cost can be greatly reduced. We also found that the lifespan of the reaction solution was about half a year. These were major advantages for practical use. However, more time was needed for determining the optimal solution composition, since for the sol-gel method, many complex factors such as chemical species, composition, and film forming conditions can influence the surface properties of the layer.



**Fig. 5 Development policy for the oleophobic layer using the sol-gel method and variation of the chemical compositions**

(a) Surface condition predicted from the monomolecular component only. (b) Surface condition predicted from the organic-inorganic coating.

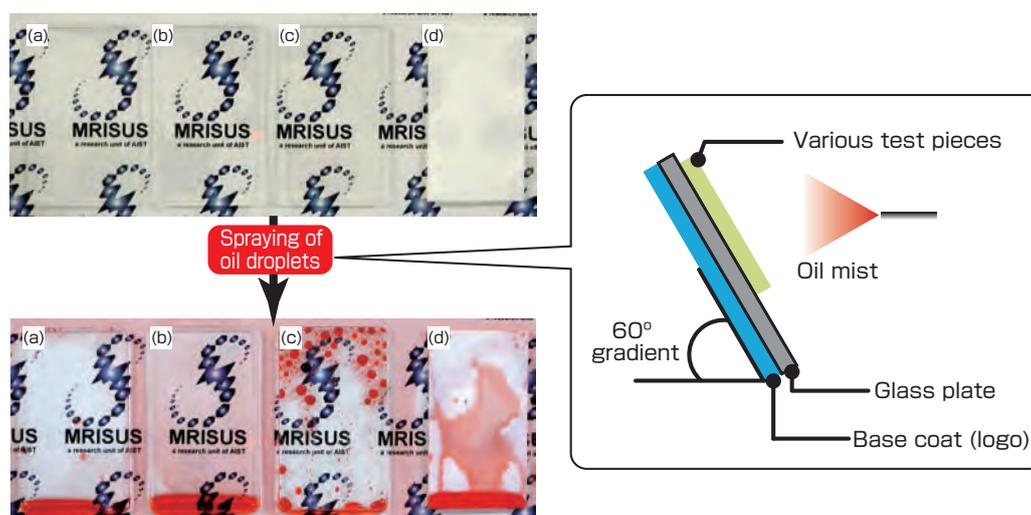
### 3.2 Experimental verification of the hypothesis

Based on the above results, we formed the hypothesis that by controlling the chain length of the organosilane and the concentration of the reaction solution, the density of the alkyl groups that are exposed on the layer surface can be decreased, while their motility increases, which induces “liquid-like” properties on the layer surface, and this ultimately increases the oleophobicity. To verify this hypothesis experimentally, based on the findings obtained so far, we conducted similar research using perfluorinated silanes with perfluoroalkyl groups of different chain lengths ( $C_nF_{2n+1}$ :  $n = 1-8$ ).<sup>[26][27]</sup> Since the static contact angle is dominated by the surface energy, greater static contact angles were shown against water and oil when a long chain perfluorinated silane with an ( $n=8$ ) perfluoroalkyl group was used. In contrast, it was found that the oleophobicity was not dependent on the chain length, and the same surface properties, equivalent to the hybrid layer fabricated using the long-chain perfluorinated silane, was shown even when a short-chain perfluorinated silane ( $n \leq 4$ ) was used. It became clear that the oleophobicity was dominated not by the surface energy but by the motility of the surface functional groups. As mentioned previously, since the manufacture and use of the long-chain perfluorinated compounds will be regulated in the future, researchers around the world are trying to improve oleophobic performance using short-chain perfluorinated compounds ( $n \leq 4$ ), but most research has ended in failure as oleophobic performance decreases as the chain shortens, because a liquid-like structure is not used. We were able to experimentally verify that sufficient oleophobicity could be obtained without using long-chain perfluorinated compounds if our method is used.

### 4 Effort toward practical use

Surface chemistry is a practical science. Surfaces and interfaces exist on all substances from the everyday products around us to industrial instruments. Reactions with other substances always start at the surface, and the surface-interface contributes to some sort of functional expression. Since the surface properties and the required surface properties of individual materials are varied, it can be readily imagined that there is a diverse field of applications and treatment methods.

We utilized the press release effectively to widely publicize our results to society, and surveyed which companies in which industrial fields would show interest in our potential technology. As imagined, we received requests for technical consultation and sample provision from a variety of industrial fields including automobiles, electrical machinery, cosmetics, printing, and foods. We were able to conclude an agreement for know-how provision and licensing with some companies with whom we found a win-win relationship for “seeds and needs (potential and demand).” Our technology withstood the companies’ rigorous screening, and the mass production level coating technology was established in a short period of one year from the first technical consultation. The reason that our developed technology progressed to a stage one step before practical use in such a short time is thought to be because the strategy for practical use was set up before starting the R&D, and that we reconsidered oleophobicity from the aspect of dynamic contact angles without being caught up in the conventional concept of static contact angles. Moreover, it was possible because of the enthusiasm of the researchers, advice from the innovation coordinator, as well as the support of the departments of AIST involved in intellectual property, contracts, public relations, and others, in addition to the film fabrication and hard coating technologies of the



**Fig. 6** Before and after spraying the various substrates with stained *n*-hexadecane

(a) Oleophobic coat developed in this research, (b) organic silane monomolecular film, (c) perfluorinated silane monomolecule, and (d) fluororesin (opaque). The oil droplets slid off the developed coat, while they remained adhered to other substrates.

partner companies. Currently, our industrial partners are working on marketing to commercialize the product.

## 5 Future issues and development

The transparent layer that we developed in this research shows excellent oleophobicity, but from the beginning, we were aware that there are weaknesses, such as insufficient film hardness and heat resistance, because 1) it is not heat treated and 2) there are many organic components. In fact, we received critical evaluations from many companies that the layer lacked durability. Based on the information and demand from the companies and objective self-evaluation of the current layer performance, we were able to determine a future policy for improvements. Currently, we are engaged in research to improve the layer performance.<sup>[28]-[30]</sup> What is the technological development trend in the world, and what is the R&D that fulfills the corporate demand? We were also able to recognize from this R&D that information gathering and being sharp-eyed were important.

As mentioned earlier, it was experimentally verified that excellent oleophobicity was expressed by controlling the functional group density on the surface, but we have not clarified the principle based on scientific analysis. At one glance, the wettability research seems to be research of the surface, but in reality the interface formed by contact of the liquid and solid largely dominates the function. However, there are few analysis methods dedicated to interfaces, and this subject is hardly touched upon in the realm of wettability research. In the future, we hope to clarify the principle of this fascinating interface property by conducting joint research with specialists of analytical chemistry inside and outside AIST.

Also, artificial surfaces, such as the oleophobic layer, lose their function and are permanently impaired when the molecules that layer the surface are detached, the structure breaks down, or impurities deposit through damage, such as friction or wear. This is the definitive difference between artificial surfaces and biological surfaces that have tissue regeneration and self-repairing functions, and it is also the greatest factor inhibiting the practical use of oleophobic materials. In contrast, in the natural world, plant surfaces like the lotus leaf continue to secrete plant wax and maintain their surface functions, such as ultra hydrophobicity and self-cleaning. If it is possible to simulate such maintenance mechanisms and the continuous release of oleophobic molecules, as seen in those organisms, and to incorporate these functions to the layer, dramatic increases in the functional durability can be expected. In the future, we would like to work on the development of a novel functional layer that simulates the function-maintaining mechanism of organisms. Under the philosophy “one that controls the surface controls the material,” we plan to continue our

research toward the development and practical application of functional layers and surfaces through collaboration with the researchers inside and outside AIST, as well as with the administrative departments of AIST.

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## Discussions with Reviewers

### 1 Practical application

#### Question and Comment (Toshimi Shimizu, AIST)

In this paper, various expressions are used for practical application. I understand that practical use technology is nearly established, but sometimes I get the impression that it is already accomplished. Please describe specifically and accurately how actually close the technology is to practical use, using a numerical value of physical properties or other ways.

#### Answer (Chihiro Urata)

As you indicated, this technology has not yet achieved practical use. I have heard from the partner companies of technological transfer, "We have a prospect for mass production, and we have given it a product code," but at this point, they are still working on marketing, and I think a bit more time is needed before commercialization. Therefore, I accurately described the current situation that "we have established the coating technology at mass production level."

### 2 Basic research to this point

#### Question and Comment (Hiroaki Tao, Research Institute for Environment Management Technology, AIST)

Only the papers after 2012 are cited as work by the authors. Was there *Type 1 Basic Research* related to this research or related elemental technology research before 2012? I think the basic research that you have built up made possible the achievement of near-practical use in a short period of one year from the start of the research. If this is the case, I recommend you briefly describe the basic research that was done prior to this research.

#### Answer (Atsushi Hozumi)

As you indicated, I have been engaging in basic research for nearly 20 years, including my student years, for the wettability control technology using thin films and monomolecular films. The findings and failures that I have experienced so far have been useful in the current research. I explained the outline of the past research and added the references to this paper.

### **3 Hydrophobicity/oleophobicity and hydrophilicity/hydrophobicity (oleophilicity)**

#### **Question and Comment (Hiroaki Tao)**

Are you saying that the relationships of hydrophobicity/oleophobicity and hydrophilicity/hydrophobicity (oleophilicity) are different in the static and dynamic situations? I think it will facilitate understanding if you explain the relationships between the hydrophobicity/oleophobicity of the surface and the hydrophilicity/hydrophobicity of the molecules that are coated on the surface from the molecular structure perspective.

#### **Answer (Atsushi Hozumi)**

As you indicated, the situation is totally different in the static and dynamic cases. In the static condition, the contact angle of the alkyl group terminated surface against oil is 40° or less, and judging from the definition of conventional wettability (size of the contact angle), the surface will be oleophilic. However, our film has high alkyl group motility on the surface, and while it looks wet in appearance, dynamically, it is a readily sliding surface. We call such surface “liquid-like” because the molecules are in a mobile condition.

Following your instruction, I newly added Fig. 3 and text to explain the relationships between the hydrophobicity/oleophobicity of the surface and the hydrophilicity/hydrophobicity of the molecules that coat the surface from the molecular structure perspective. The mechanism of the reason for this unique dynamic wetting behavior is becoming clarified by spectrometry. Currently, I am writing a paper on this subject.

### **4 Elemental technologies of the companies and the examples of application**

#### **Question and Comment (Hiroaki Tao)**

In practical application, what elemental technologies of the companies were added to the original technology of AIST? I think the value as a *Synthesiology* paper will increase by showing this point and, as much as you are allowed, the specific applications of this research.

#### **Answer (Atsushi Hozumi)**

The mass production technology was established, with the addition of the surface treatment technology developed by AIST to the film fabrication technology and hard coating technology of the partner companies. I heard that immediately after concluding the licensing agreement, the companies started marketing by distributing the prototypes to the affiliate companies. Personally, I think the technology can be applied to disposable films for automobile side mirrors to maintain visibility, and to coating which prevent fingerprints on touch panel displays.