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Imparting Anti-Fingerprint Properties to Moth-Eye Films Using Fingerprint Oils Absorbing Coating Materials

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SUMMARY We have developed novel coating materials capable of absorbing fingerprint oils over time. When touch screens are operated with fingers, these oils adhere to the surface, rendering them visibly dirty. When finger oils adhere to anti-reflective coatings and structures, such as moth-eye films, their anti-reflective efficacy is substantially compromised. Specifically, in moth-eye films, the oils penetrate the grooves of the bell-shaped array and are difficult to remove. In this paper, we discuss our investigation into a technique for developing anti-fingerprint properties using these novel coating materials.
key words: *Coating, Anti-fingerprint, Moth-eye, Touch screens*

1. Introduction

Touch screens, operated either by fingers or stylus pens, have become widely used in various display devices, including smartphones, personal computers, and point-of-sale (POS) systems. Several touch detection methods, such as resistive and capacitive, have been proposed [1]. The outer surface of each of these display devices often includes optical functional layers, such as anti-reflection or anti-glare layers, to reduce external light reflection and enhance visibility [2]-[5]. Moreover, for touch screens operated by fingers, it is important to prevent finger oils (i.e., fingerprints) from adhering to the display because they reduce visibility and lead to contamination [6]-[12].

Two primary approaches for anti-fingerprint coatings have been suggested to mitigate visibility reduction caused by fingerprints. The first approach involves hydrophobic/oleophobic surfaces [13] incorporating a coating layer that includes silicone, fluorine [14]-[15], and nanocomposite materials [16]-[17]; alternatively, the coating layer uses surface shapes inspired by the lotus leaf [18]. The second approach focuses on hydrophilic/lipophilic surfaces [19]. Although hydrophobic/oleophobic coatings make cleaning fingerprints easier, they also repel the oil droplets. This repulsion increases droplet height and scatters light, making fingerprints more very noticeable (Fig. 1). Additionally, biomimicry-based designs present challenges in mechanical strength [20].

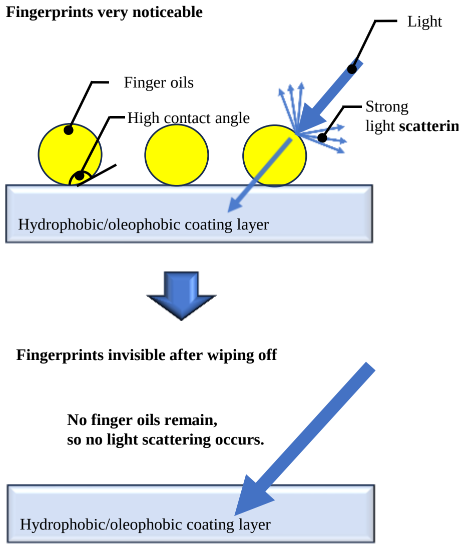

Fig. 1 Schematic illustration showing the features of hydrophobic/oleophobic coating.

A hydrophilic/oleophilic coating layer reduces fingerprint visibility by wetting and spreading oil droplets (Fig. 2). However, this method does not render fingerprints completely invisible, and repeated fingerprint deposits may lead to accumulation and performance degradation. Therefore, the anti-fingerprint technologies proposed thus far are not without flaws [21], and innovative solutions are needed.

The anti-reflection property of moth-eye films is substantially compromised by fingerprints. These films, named after their mimicry of the eye structure of a moth, exhibit a surface covered by a two-dimensional bell-shaped array with dimensions of several hundred nanometers in period and height (Fig. 3) [22]-[24]. Traditional anti-reflection coatings consist of multiple layers with various refractive indices that reduce reflection by cancelling out reflected light through interference at each interface [25]-[27] (Fig. 4a).

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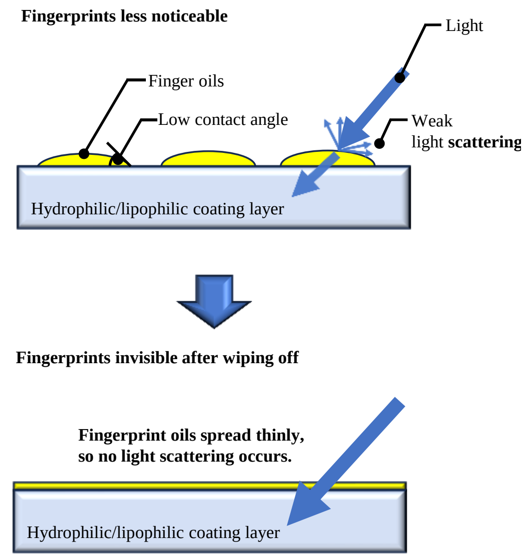


Fig. 2 Schematic illustration showing the features of hydrophilic/lipophilic coating.

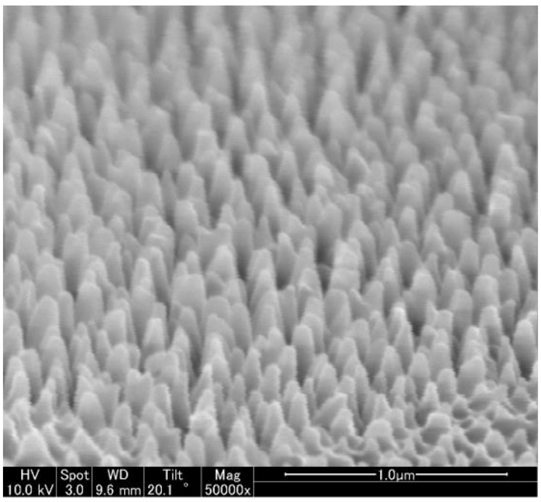


Fig. 3 SEM image of conventional Moth-eye patterns.

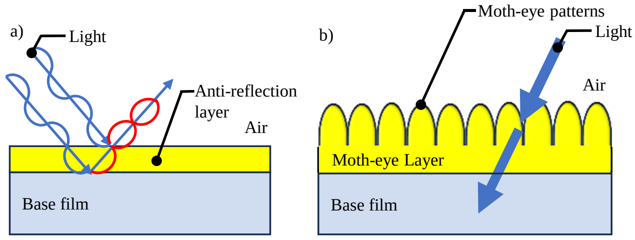


Fig. 4 Schematic illustration of low reflection in (a) conventional film and (b) moth-eye film.

On the other hand, the cross-sectional area of the bell-shaped arrays in moth-eye films increases from top to bottom, creating a gradual change in refractive index. This design lacks a distinct refractive index interface, allowing incident light on the bell-shaped structure to be transmitted without reflection. It also can minimize light reflection across a broad wavelength range, from ultraviolet to near-infrared, even at broad incident angles.

However, in moth-eye films, fingerprints penetrate the grooves of the bell-shaped array and are difficult to remove [29]. We recognized the need for a new approach to develop anti-fingerprint technology and sought to create a novel coating material that gradually absorbs fingerprints. A coating material that can effectively absorb fingerprints would represent a breakthrough in anti-fingerprint technology, improving surface smoothness and transparency for anti-fingerprint films. Moreover, its application to moth-eye films could address the challenge of imparting anti-fingerprint properties and expand their application. This paper presents recent findings regarding the effectiveness of anti-fingerprint properties when fingerprint-absorbing coating materials are applied to anti-fingerprint films and moth-eye films.

2. Clear anti-fingerprint film application

A novel coating material, designed based on an entirely new material design concept that confers anti-fingerprint properties by absorbing oils on the surface, was initially tested on a smooth coating layer. For touch screen applications, it is essential that finger slip properties are required. Considering that hydrophilic/lipophilic coating materials typically exhibit poor finger slip characteristics, we engineered a hydrophilic/oleophobic coating formulation, primarily comprising polyurethane resin and an isocyanate curing agent, to possess fingerprint absorbency.

The coating material was diluted with toluene to adjust its viscosity for the coating process. This mixture was applied to a 125-µm-thick PET film using a Meyer bar. The coated film was subjected to drying and curing in an oven at 100°C for 3 min. Subsequently, the coated film was laminated with a release film containing a silicone-coated 38-µm-thick PET film, and allowed to cure for 3 days at room temperature. The final thickness of the coated layer was 10 µm. After the curing period, the release film was removed, and the anti-fingerprint film was prepared. Fig. 5 outlines the preparation process for the anti-fingerprint film.

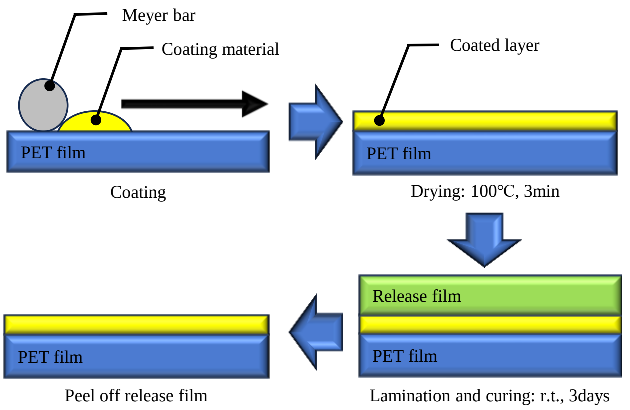


Fig. 5 Schematic illustration of outlines the preparation process for the anti-fingerprint film.

Furthermore, this film was compared with a conventional film, which had been coated with a hydrophilic/lipophilic layer (mainly comprising UV-curable urethane acrylate) on a 125-μm-thick PET film. To evaluate the anti-fingerprint properties of both films, the author adhered their fingerprint to the films. Changes in haze value over time, before and after fingerprints had been adhered, were measured using a spectroscopic haze meter (Nippon Denshoku Industries Co., Ltd., SH-7000). The haze value, indicative of cloudiness, reflects the percentage of light passing through the film that is scattered by the film.

The results are presented in Fig. 6. To facilitate the assessment of haze changes solely attributable to fingerprint absorption, the vertical axis illustrates the difference in haze values before and after fingerprints were applied. The haze value of the conventional hydrophilic/oleophilic anti-fingerprint film increased by about 0.9 pt. when fingerprints were adhered. Because this film does not absorb fingerprints, its haze value remained unchanged over time. Conversely, the haze value of the novel anti-fingerprint film, having fingerprint absorption capabilities, initially increased by about 0.8 pt. due to the fingerprints. However, after 1 h, the haze value returned to its original level.

Fig. 7 presents photographs showing the degree to which fingerprints become less visible on the films. Samples were prepared by laminating each film onto a black polymethylmethacrylate (PMMA) plate using pressure-sensitive adhesive; they were evaluated immediately after fingerprint adherence and again 24 h later. The conventional anti-fingerprint film showed slight fingerprint visibility after 24 h, whereas the novel anti-fingerprint film rendered fingerprints virtually invisible through absorption.

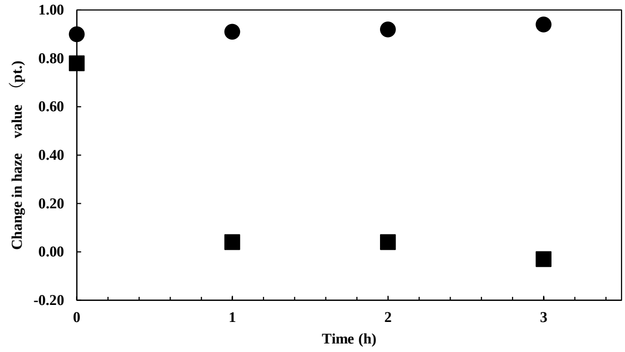


Fig. 6 Change in haze value after fingerprinting.
● : Conventional anti-fingerprint film, ■ : Novel coating film

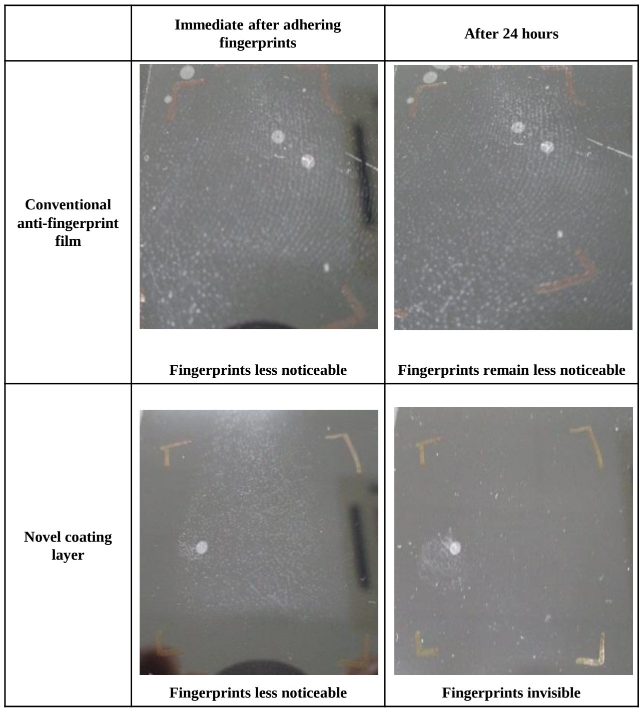


Fig. 7 Photographs of fingerprints absorption effect comparison test.

The mechanism underlying the novel anti-fingerprint film's ability to absorb fingerprints was investigated by measuring the contact angles of water and oleic acid on each film using a contact angle meter (Kyowa Interface Science Co., Ltd., DM-SA). Oleic acid was selected for evaluation based on its presence in fingerprint oils [3]. The conventional anti-fingerprint film demonstrated a water contact angle of 87° and an oleic acid contact angle of 23°, indicating a hydrophilic/lipophilic surface. This surface characteristic allows fingerprints to become less noticeable as they wet and spread, but it does not significantly change over time. In contrast, the novel anti-fingerprint film exhibited a water contact angle of 103° and an oleic acid contact angle of 66° , representing a hydrophobic/oleophobic surface. Despite its hydrophobic/oleophobic nature, fingerprints adhered to the developed anti-fingerprint film immediately became scarcely noticeable and eventually became invisible; these results suggested that the fingerprints were rapidly absorbed into the coating film, reducing and eventually eliminating their visibility. The model image in Fig. 8 shows the immediate absorption behavior of fingerprints upon contact and 24 h later.

The durability of this fingerprint-absorbing performance was also tested by adhering and absorbing fingerprints 50 times while monitoring the change in haze value, which increased by only 0.17 pt. This result confirmed that absorption performance remains consistent even after the film has been subjected to repeated fingerprinting ≥ 50 times. Therefore, the developed film can absorb more oil than is present in 50 fingerprints. Future studies will focus on determining the oil capacity saturation point and assessing whether the film's function can be restored by alcohol-based cleaning methods.

Table 1 summarizes the practical characteristics of the novel anti-fingerprint film, highlighting its remarkable transparency that is suitable for touch screen applications. The coating surface on the film provides excellent finger slip properties, thereby enabling smooth operation on touch screens. The high contact angles of water and oleic acid on the coating surface also allow easy cleaning of fingerprint oils. Durability tests under various environmental conditions confirmed that the change of haze value after exposure is within 0.5 pt., so the appearance of the film remained consistent after exposure.

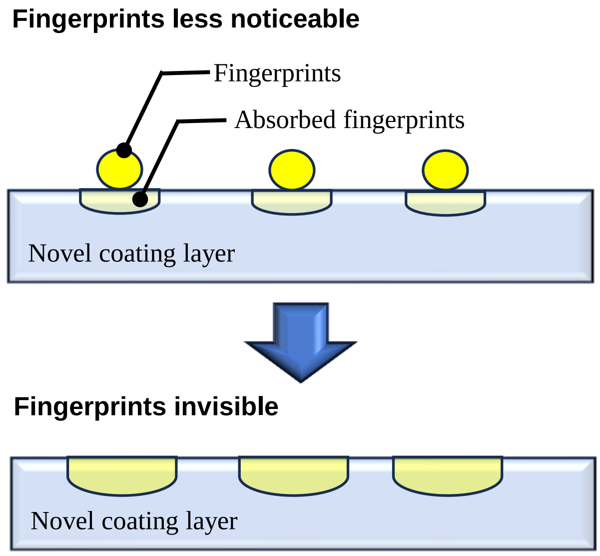


Fig. 8 Schematic illustration of principle of estimating the fingerprints absorption properties of novel coating material over time.

Table 1 Practical characteristics of novel anti-fingerprint film

Items	Novel anti-fingerprint film	Method
Haze (%)	1.1	JIS K 7361
Total Transmittance (%)	91.4	JIS K 7136
Adhesion (-)	100/100	JIS K 5600
Scratch Resistance (number of scratches)	5	Steel wool (#0000), 125 g/cm^2,10 round trips
Finger slip properties (-)	Very Smooth	Sensory evaluation
Fingerprint wipe ability (-)	Very Good	Wipe with tissue
High Temperature	ΔHaze ≦0.5pt.	Condition: +85 °C, 1000 hours
Low Temperature	ΔHaze ≦0.5pt.	Condition: -40 °C, 1000 hours
High Temp/Humidity	ΔHaze ≦0.5pt.	Condition: +65 °C/90 %RH, 1000 hours
UV	ΔHaze ≦0.5pt.	Condition: Fade meter, 100 hours

3. Moth-eye film application

After successfully achieving a smooth coating surface that absorbs fingerprint oil, we proceeded to apply this technology to moth-eye film. This film exhibits a nanoscale convex-concave surface structure that requires the strongest anti-fingerprint properties. The moth-eye film was fabricated using the widely accepted method of ultraviolet nanoimprint lithography [30]-[32]. In this process, a moth-eye plate is pressed onto a coating layer before curing to imprint the moth-eye structure; then, UV curing is performed. The coating materials selected primarily were UV-curable prepolymers (multifunctional urethane acrylate) and photopolymerization initiators (1-hydroxycyclohexyl phenyl ketone).

The coating material was thinned with propylene glycol monomethyl ether to fine-tune the viscosity for coating. This mixture was applied to a 125-μm-thick PET film using a Meyer bar. The coating layer was then dried in an oven at 70°C for 1 min, resulting in a final thickness of 5 μm. The coating layer was pressed against the moth-eye plate and cured by UV light irradiation through the coating film (300 mJ/cm2 from an Hg-lamp). After curing, the moth-eye plate was removed, yielding the moth-eye film. Fig. 9 shows the moth-eye film preparation process as outlined above. A conventional moth-eye film without the fingerprint absorption property was also prepared for a comparative analysis of anti-fingerprint performance.

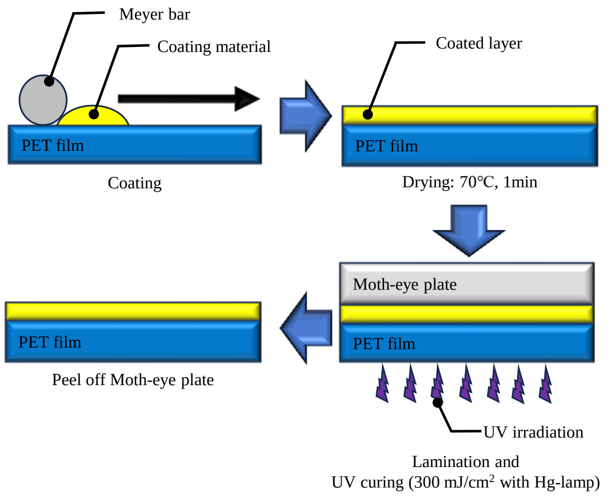


Fig. 9 Schematic illustration of outlines the preparation process for the Moth-eye film.

The surface morphology of the moth-eye film was examined using a scanning electron microscope (SEM, FEI Company Japan Ltd., Quanta 200FEG) at 50,000× magnification. Fig. 10 illustrates a comparison with the conventional moth-eye film, confirming that the newly prepared moth-eye film possessed nanoscale bell-shaped surface structures similar to the conventional variant.

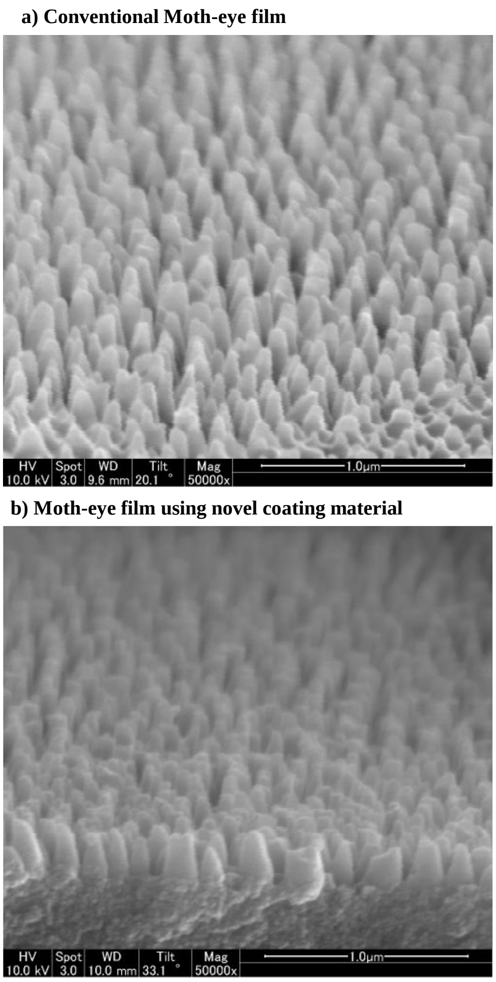


Fig. 10 SEM images of Moth-eye films.

The anti-fingerprint properties of the moth-eye film were assessed by measuring its reflectance before and after fingerprint application. Reflectance measurements were conducted with a spectrophotometer (Shimadzu Corporation, UV-3600) at specific time intervals while the sample was maintained at room temperature. For these measurements, the moth-eye film was laminated onto black PMMA plates using a clear pressure-sensitive adhesive.

Reflectance spectra were compared to assess the performances of conventional and novel moth-eye films (Fig.

11). The reflectance of the conventional moth-eye film increased after fingerprints had been adhered and remained elevated even after 24 h (Fig. 11a). Conversely, the reflectance of the novel moth-eye film initially increased upon fingerprint adherence but returned to the original level after 24 h. This restoration of reflectance was attributed to the coating material forming the moth-eye structure, which gradually absorbs the oils and fats that adhere to its fine structure.

To visually illustrate the fingerprint absorption effect, Fig. 12 shows photographs of each film before and 24 h after fingerprint adherence. These photographs reveal that whereas fingerprints on the conventional moth-eye film remained visible after 24 h, fingerprints on the novel moth-eye film were significantly less noticeable.

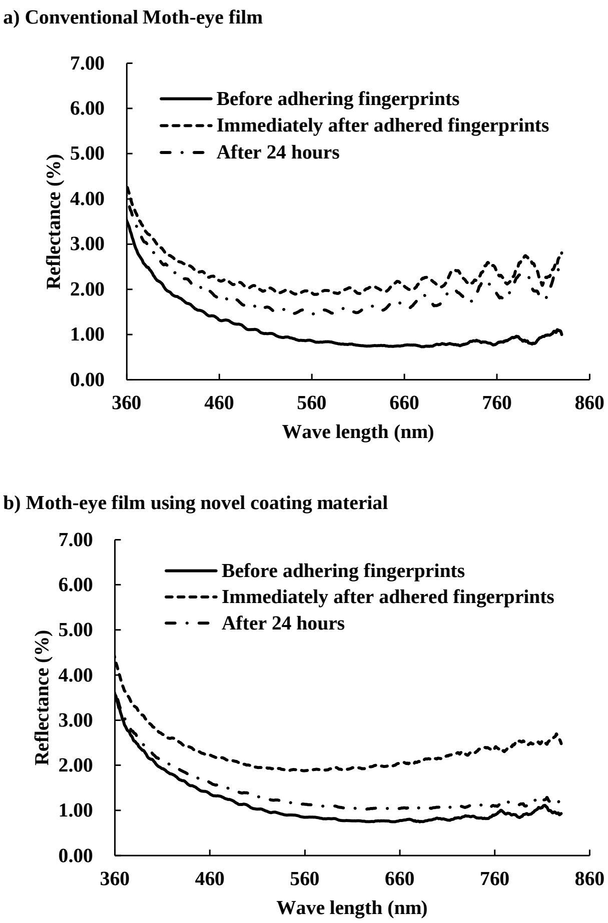


Fig.11 Change behavior of the reflectance before and after adhering fingerprints.

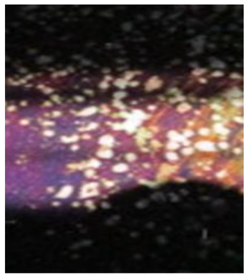
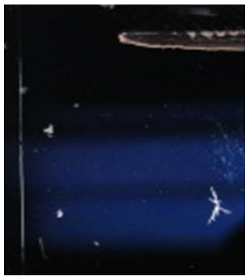
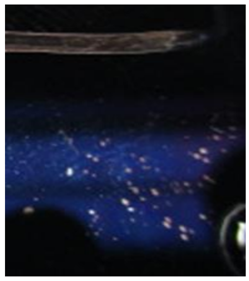
	Initial	After 24 hours after fingerprints
Conventional Moth-eye film	 High anti-reflection performance	 Anti-reflection performance deteriorated
Novel Moth-eye film	 High anti-reflection performance	 Remain high anti-reflection performance

Fig. 12 Photographs of fingerprints absorption effect comparison test.

4. Conclusion

This paper has described the application of newly developed coating materials, designed to absorb fingerprints, to both smooth surface anti-fingerprint coatings and moth-eye films. After optimization of the anti-fingerprint coating film composition, fingerprints on such films became invisible over time. The novel clear anti-fingerprint film, with distinct hydrophobic/oleophobic properties, allows for easy removal of fingerprints. This technology holds promise for application on touch screen surfaces, as well as the coatings of various device housings and furniture.

The moth-eye film was also developed and evaluated, based on an optimized UV-curable coating material composition. Reflectance measurements, conducted before and after fingerprint application, confirmed that the reflectance recovery was related to the gradual absorption of oils by the coating material forming the moth-eye structure. These findings are expected to significantly contribute to the field of anti-reflective films by improving anti-fingerprint properties and facilitating the broader adoption of moth-eye films.

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