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Optical properties and field test results of spectrally-selective solar control window film that enables not increasing downward reflection

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ABSTRACT

Recently high reflective materials such as high reflectance paint for wall and solar control film or Low-E glass for window are utilized as a building façade aiming for reducing the cooling load of the buildings. From a view point of the direction of reflected rays, almost half of the energy goes upward due to diffuse reflection in case of paint, meanwhile most of energy goes down to the ground due to specular reflection by the glass. This leads to deterioration of thermal environment of surrounding buildings, and is one of causes of urban heat island. Retro-reflective façade materials are promising candidates for mitigation of urban heat island. The authors successfully developed a new type of transparent solar control window film Albeedo that selectively reflects near-infrared rays towards the sky. The film has a saw-tooth microstructure with a spectrally-selective reflection layer. This microstructure is able to reflect infra-red rays toward the sky. The upward reflectance of the film is measured by our custom made spectroscope. Firstly, the sample is placed in a large scale integrating sphere. Then, solar energy absorptive materials are arranged under the sample to absorb the transmitted component and positioned where the downward reflection goes to. Finally, a halogen lamp irradiates the sample at an incident angle of 60° as a light source. The result of the upward reflectance of near-infrared is about 33%. We also conducted field test measurements to evaluate the energy savings of the interior of the building and the degree of reflection of the exterior.

1. Introduction

Reduction of greenhouse gases is a pressing challenge for mitigating global warming. It has attracted attention in the architecture sector because it has high reduction potential [1]. Therefore, high reflective paint for walls and solar control film or Low-E glass for windows are utilized as building façade materials aiming at reducing the cooling load of the buildings [2]. In case of paint, almost half of the energy is reflected upward due to diffuse reflection. For glass windows with high solar radiation reflective layer, most of energy goes down to the ground due to the specular reflection of the windows as shown in Fig. 1. This leads to deterioration of thermal environment of surrounding buildings and on the streets, and it is one of the causes of urban heat island [3–6]. In recent years, more and more glass façade buildings are built to meet design or structural requirements. As a result, the deterioration of the thermal environment of pedestrians caused by the reflection of solar radiation on high reflective glass façades becomes more severe.

Retro-reflective façade materials are a promising candidate for reducing the thermal deterioration of pedestrians and the mitigation of urban heat island. It is presented that the state of the art study of local climate change and UHI mitigation techniques, and retro-reflective material is introduced as one of them to reduce UHI effect [7]. Nishioka et al. show the effectiveness of retro-reflective roof that reflects more direct solar radiation within the zenith angle of 22° than diffuse reflector [8]. It is evaluated that the reflective property of retro-reflective materials such as a white tile having corner-cube prism [9] and traffic control sheeting based on ASTM D4956-11a [10–12] as a wall. Although window façade buildings are on the rise, retro-reflective technologies applicable to windows have not been available because no solution has been found to balance retro-reflectivity with transparency. The authors successfully developed a new solar control film Albeedo that is not only transparent but also reflects near-infrared (NIR) rays toward the sky

In the meantime, it has not been possible to measure reflection angular characteristics of retro-reflection because of the spatial

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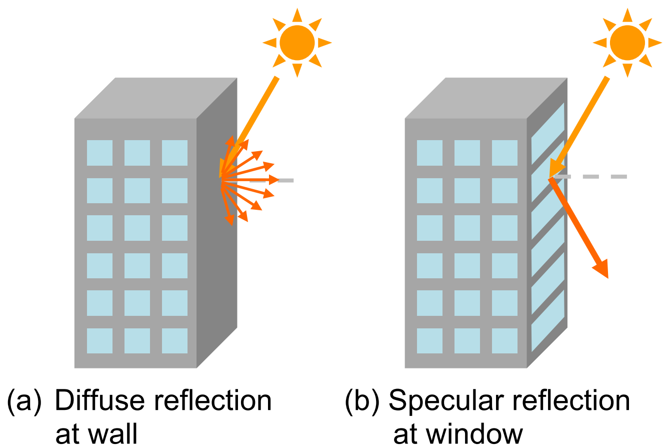

Fig. 1. Schematic image of reflection at building facade.

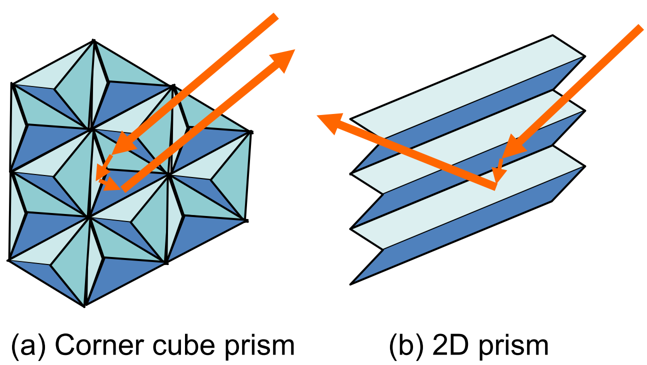

Fig. 2. Microstructure and internal reflection. (a) Corner cube prism, (b) 2D prism.

Fig. 3. Fresnel reflectance at glass surface.

geometry constraint between the detector, light source and reflective material. Additionally, no measurement method exists so far to separate the hemispherical reflectance into upward, and downward, and to quantify them. Aiming for solving these issues, we studied a new measurement method and successfully clarified the angular characteristics of reflection including retro-reflection. Also we developed new evaluation equipment and method, which enabled measurement of upward reflectance at high incident angle. Furthermore, measurement of hemispherical transmittance at high incident angle was made possible as well, which relates to the heat shielding property by simulating the sun's elevation angle.

In this paper the authors present the newly developed transparent window film Albeedo that reflects NIR rays toward the sky, and the quantitative analysis of the reflection and transmission properties through lab and field measurements.

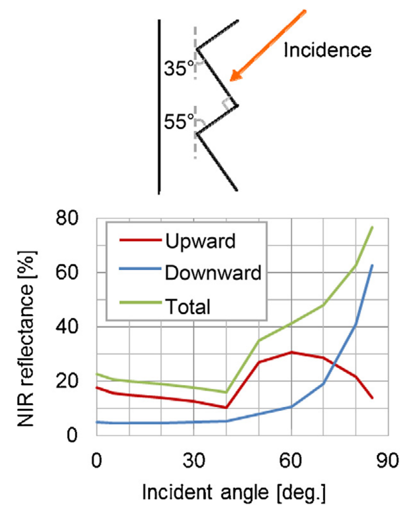

Fig. 4. Microstructure and NIR reflectance.

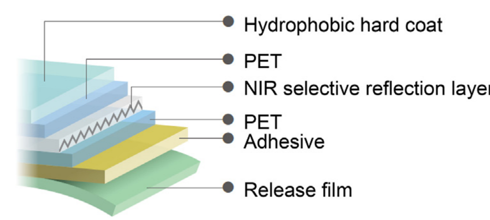

Fig. 5. Structure of NIR upward reflective film Albeedo.

2. Overview of upward reflective solar control film Albeedo

Solar control films can be categorized as absorbing or reflective. Reflective can be further categorized as spectrally-selective or non-selective. Spectrally-selective type, namely that transmits the visible light and reflects or absorbs near infrared (NIR) ray is desirable from the viewpoint of utilizing the daylight for illumination and reducing the cooling load as well. Reflective type is favourable because it reduces the solar energy entering the room, minimizing the absorption by the glass or film and eventual re-emission of it. However attention must be paid to surrounding environments because high reflectivity of visible light or NIR ray may cause unwanted light glare or heat glare to the vicinity. Retro-reflective material is a promising candidate that realizes thermal comfort of both the interior and exterior. Two types of retro-reflectors are compared below. In case of corner cube prism type retro-reflector, incident light is reflected three times, once by each surface, which results in a reversal of direction (Fig. 2(a)). If the reflectance of each surface is assumed to be 80%, the total reflectance is 51% ($0.8 \times 0.8 \times 0.8$) and part of the light is absorbed by each surface as well. On the other hand, 2D prism type reflector reflects the light coming from the above in an upward direction as shown in Fig. 2(b). The number of internal reflections is one or two depending on the shape of prism and incident angle of the light. Thus, by decreasing the number of internal reflections, absorptance can be reduced and reflectance can be increased maintaining the reflection towards the sky. Therefore 2D prism type reflector is covered in this paper. Although, light glare can be neglegible by applying spectrally selective NIR reflection layer, configuration of surrounding buildings should be considered for minimizing heat glare in this case.

Having good upward reflectance at high incident angle of solar radiation is particularly important and useful because the sun's elevation angle is high in hot season or later in the day. Fres-