

# Method for Measuring Solar Reflectance of Retroreflective Materials Using Emitting-Receiving Optical Fiber

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## ABSTRACT

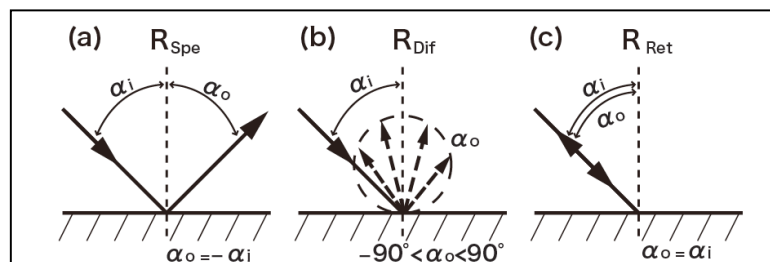
The heat generated by reflected sunlight from buildings to surrounding structures or pedestrians can be reduced by using retroreflective materials as building exteriors. However, it is very difficult to evaluate the solar reflective performance of retroreflective materials because retroreflective light cannot be determined directly using the integrating sphere measurement. To solve this difficulty, we proposed a simple method for retroreflectance measurement that can be used practically. A prototype of a special apparatus was manufactured; this apparatus contains an emitting-receiving optical fiber and spectrometers for both the visible and the infrared bands. The retroreflectances of several types of retroreflective materials are measured using this apparatus. The measured values correlate well with the retroreflectances obtained by an accurate (but tedious) measurement. The characteristics of several types of retroreflective sheets are investigated.

## Introduction

Among the various reflective characteristics, retroreflective materials as shown in Fig.1(c) have been widely used in road signs or work clothes to improve night-time visibility. Retroreflection was given by some mechanisms: prisms, glass beads, and so on. The reflective performance has been evaluated from the viewpoint of these usages only.

On the other hand, we have shown that retroreflective materials reduce the heat generated by reflected sunlight (Sakai, in submission). The use of such materials on building exteriors may help reduce the urban heat island effect. However, it is difficult to evaluate the solar reflective performance of retroreflective materials because retroreflectance cannot be determined using

**Figure 1. (a) Specular Reflection, (b) Diffuse Reflection, and (c) Retroreflection**



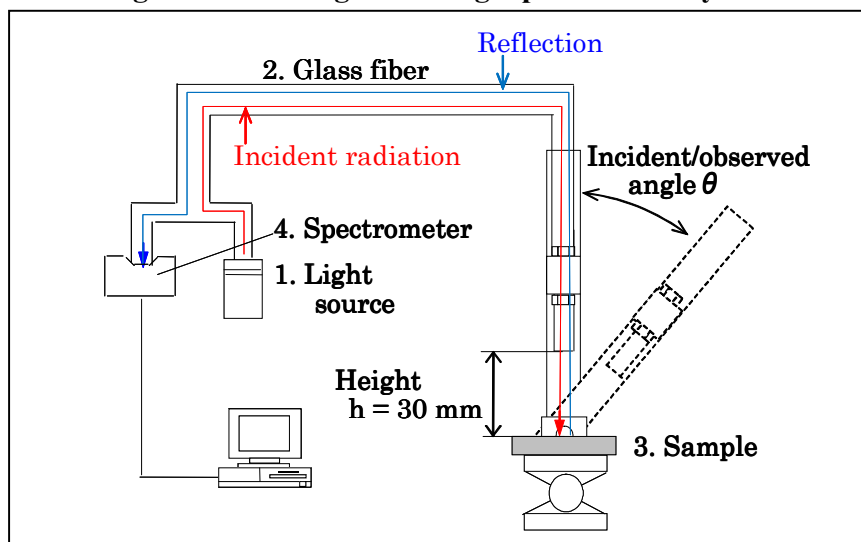
the integrating sphere measurement.

In this study, we propose a simple method for measuring retroreflectance that can be used practically. A special apparatus containing an emitting-receiving optical fiber and spectrometers for both the visible and the infrared band was developed. The retroreflectance and angular dependency of several commercial sheet-type retroreflective materials were measured using this apparatus.

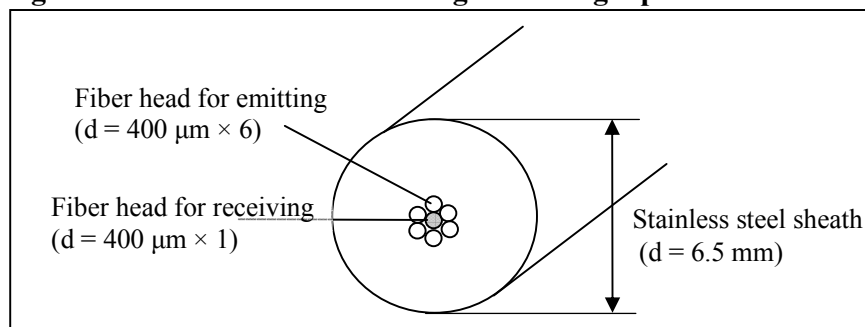
## Materials and Method

We designed an apparatus (Fig.2) consisting of a halogen light source, spectrometers for both the visible and the infrared bands (Ocean Optics Co. Ltd., USB4000, for 400–1100 nm; Hamamatsu Photonics Co, Ltd., C9606GC, for 1000–1715 nm, respectively), an emitting-receiving optical fiber probe (Ocean Optics Co. Ltd., R400-7-VIS/NIR), a rotation mechanism for varying the incident/observed angle  $\theta$  (7, 15, 30, 45, and 60°), and a sample stage for adjusting the sample surface height. A detailed view of the fiber head is shown in Fig.3. This fiber probe has seven multimode glass fibers having a diameter of 400  $\mu\text{m}$  and a numerical aperture of 0.22. Six fibers are used for emitting light to the sample surface while the remaining one is located at the center for receiving the reflected light from the sample surface.

**Figure 2. Emitting-Receiving Optical Fiber System**



**Figure 3. Detailed view of Emitting-Receiving Optical Fiber Head**



This system detects a part of the retroreflective light. The measured value is also affected by the numerical aperture of the fiber end. Thus, the measured value using this apparatus is relative, and not absolute. In this study, we used a calibrated white diffuser, Spectralon (Labsphere Co., Ltd.), having 99% reflectance to standardize the output of the system. Then, we defined the retroreflective strength,  $R_{st}$ , that is derived from the weighted integration of the measured spectral retroreflection using spectral direct solar radiation defined in ISO 9845-1(ISO, 1992).

To test the performance of this system, five types of retroreflective sheets (Nos. 1 and 2: Prism-array type, No. 3: Capsule-lens type, Nos. 4 and 5: Bead-embedded type) were used as the samples.

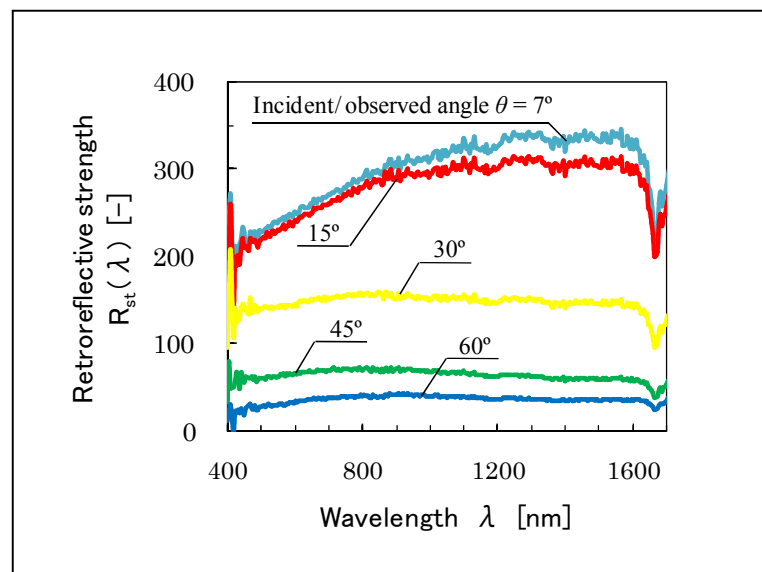
## Results and Discussions

As an example of data measured using the emitting-receiving optical fiber measurement system, Fig.4 shows the spectral retroreflectance  $R_{st}(\lambda)$  of the prism-array sheet (sample 1). The sample sheets used are mainly designed for traffic signs in the wavelength of visible light. However, the results indicate that they have obvious retroreflective properties for wavelengths of 400–1715 nm, i.e., both visible and near-infrared light.

The retroreflective strengths  $R_{st}$  of all samples at incident angles ranging from  $7^\circ$  to  $60^\circ$  are shown in Table 1. The retroreflectance  $R_{Ret}$  at  $7^\circ$ , which was reported in a previous paper (Sakai, in submission), is shown in the second column of Table 1.

Figure 5 shows the relationship between the retroreflectance  $R_{Ret}$  and the retroreflective strength  $R_{st}$  measured at an incident/observed angle of  $7^\circ$ . The figure indicates that the measured values ( $R_{st}$ ) correlate well with results ( $R_{Ret}$ ) obtained by an accurate measurement, and they have a proportional relation. Therefore, the emitting-receiving optical fiber system can be used as a simple method for measuring the retroreflectance.

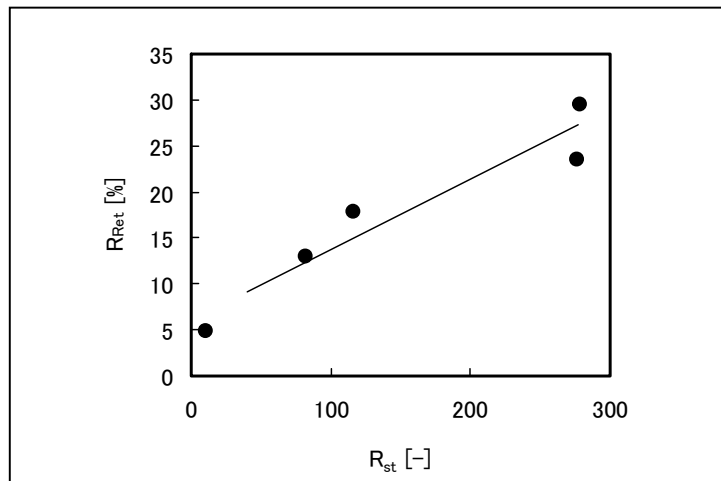
**Figure 4. Angular Dependency of Spectra of Retroreflective Strength  $R_{st}(\lambda)$  Measured by the Emitting-Receiving Optical Fiber System (Sample No. 1: Prism-array type)**



**Table 1 Experimental Result: Angular Dependency of Retroreflective Strength  $R_{st}$  of the Sample Sheets Measured by the Emitting-Receiving Optical Fiber System. Retroreflectance  $R_{Ret}$  Obtained in the Previous Paper is also Shown for Comparison**

Sample No. (type)	Retroreflectance	Retroreflective strength				
	$R_{Ret}$ [%] 7°	7°	15°	30°	45°	60°
1 (Prism-array)	29.5	279	265	148	66	35
2 (Prism-array)	23.5	276	210	212	198	130
3 (Capsule-lens)	17.8	116	117	118	102	38
4 (Bead-embedded)	12.9	82	85	85	35	6
5 (Bead-embedded)	4.9	11	12	13	13	10

**Figure 5. Relationships between Retroreflectance  $R_{Ret}$  Obtained in the Previous Paper and Retroreflective Strength  $R_{st}$  Measured by the Emitting-Receiving Optical Fiber System**



**Figure 6. Angular Dependency of Retroreflectance  $R_{st}$  Measured by the Emitting-Receiving Optical Fiber System**

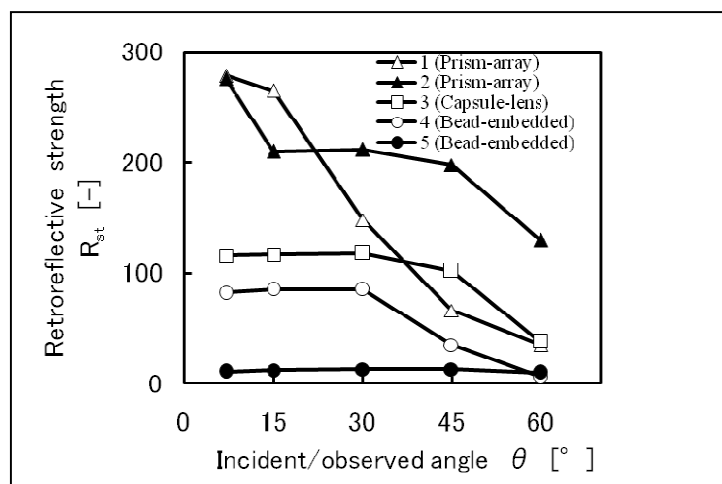


Figure 6 shows the angular dependency of the retroreflective strength  $R_{st}$  of all the abovementioned samples. The characteristics of retroreflectance for each sample type were summarized as follows.

#### Prism-array type (Nos. 1 and 2)

The retroreflectance of the prism-array type is generally higher than that of other types of retroreflective sheets. At an incident/observing angle of  $7^\circ$ , its retroreflective strength was found to be more than twice that of the other types. However, its angular dependence was larger than those of the others types. The retroreflective strength decreased sharply at large angles. This is because a prism has a critical angle for retroreflection, and its reflection mechanism works well only within the critical angle. Therefore, prism-array-type sheets are suitable for preventing heat due to reflected sunlight at particular solar positions.

#### Capsule-lens type (No. 3) and bead-embedded type (Nos. 4 and 5)

The retroreflectances of the capsule-lens type and bead-embedded type are less than half those of the prism-array type at small incident/observing angles. However, their angular dependences are small and their retroreflective strengths are almost constant at angles between  $7^\circ$  and  $45^\circ$ . This is because the ball-shaped lens used in the capsule-lens or bead-embedded-type retroreflective sheet has no strict critical angle for reflection. Therefore, these sheets of these types are effective at a wide range of solar positions.

## **Conclusions**

The following results have been obtained in the present study.

- 1) A simple method was proposed for measuring the retroreflective performance using an emitting-receiving optical fiber system. The values measured using this method correlate well with the retroreflections obtained by an accurate measurement.
- 2) The retroreflectances of prism-array retroreflective materials are generally high. However, their angular dependence is large, and the retroreflective strength decreases sharply at large angles.
- 3) The retroreflectances of capsule-lens and bead-embedded retroreflective materials are less than half those of the prism-array type at small incident/observing angles. However, their angular dependences are small.

## **Acknowledgment**

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