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

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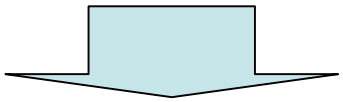
# My Task in our research

- Developing high performance retroreflective paint contained glass beads for anti-heat island
  - Investigation of the controllability of the retroreflective properties by drying process.
  - Optimization of the drying/paint conditions



**To drying process**
- **Low environmental burden**
- **Improve products quality**

**As a first step, ongoing investigation …**

A simple and instantly retroreflenctance measurement method

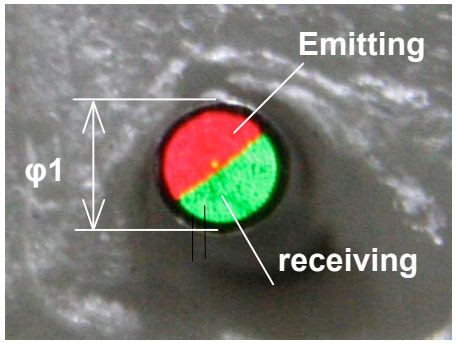
# Motivation and challenges

## Requirements for retroreflectance measurement

- Small size equipment
  (JIS recommend 15m distance from the object to light detector/source)
- Simple and instant measurement
  (on-site, in-situ measurement)
- Angle dependency measurement
  in Visible and Infrared band
  (Anti-heat island materials)

# Background (Measurement)

## Experimental apparatus for **research of drying**




Fiber head

Glass fiber
(packaged emitting and receiving grass fibers)

Emitting-Receiving Optical Fiber

Specular reflection

Light detector
(Phototransistor)

Light source
(LED)

PC

Drying media

Material to be dried
(Coating/polymer membrane/film)

Drying chamber
(Rectangular test section)

Idea of the retroreflectance measurement is form this apparatus.

# Fiber probe

## Measurement for retroreflectance




**Emitting-Receiving Optical Fiber**

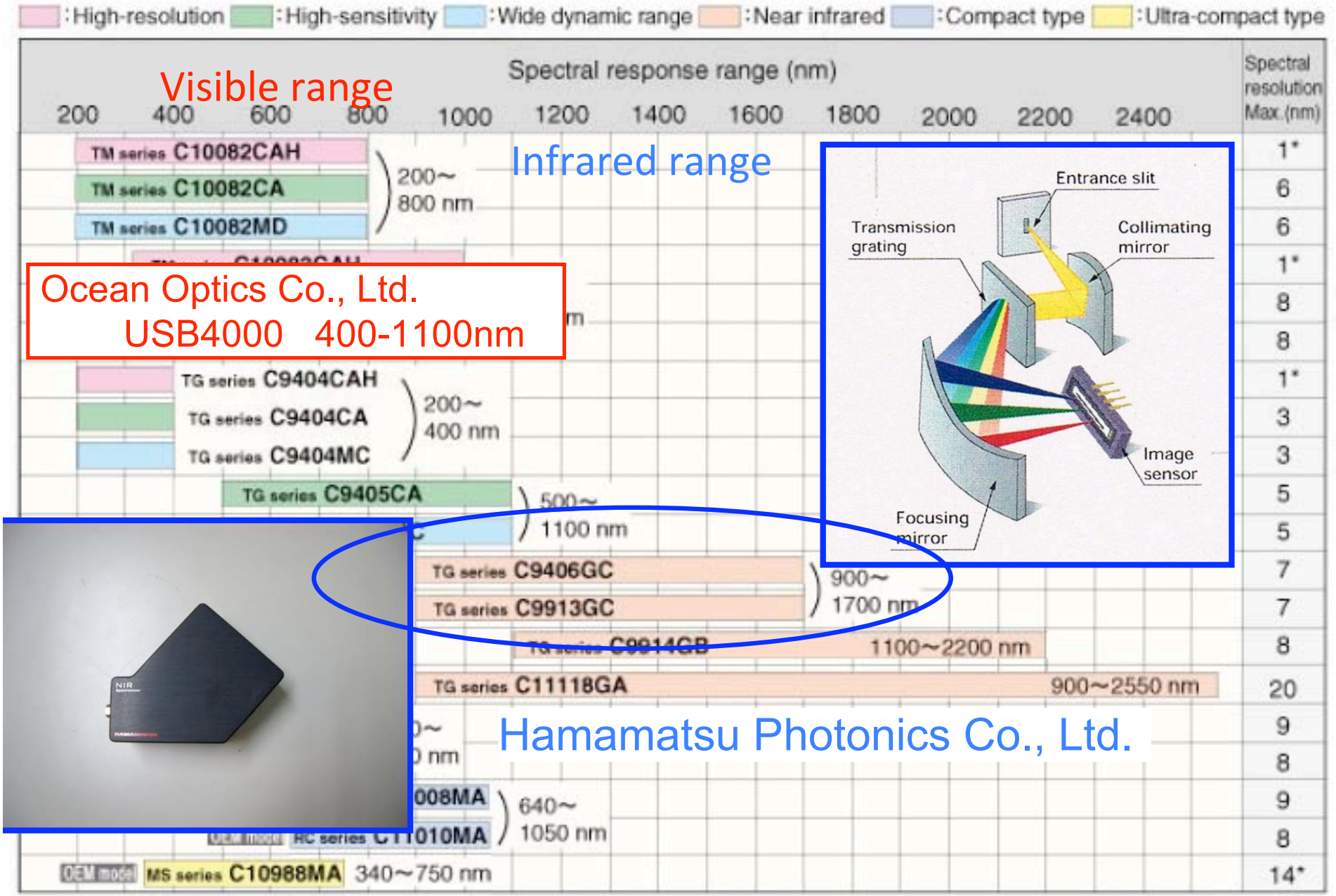
R400-7-VIS/NIR（Ocean Optics Co, Ltd.)

Multi mode, (400 ～ 2,100 nm)

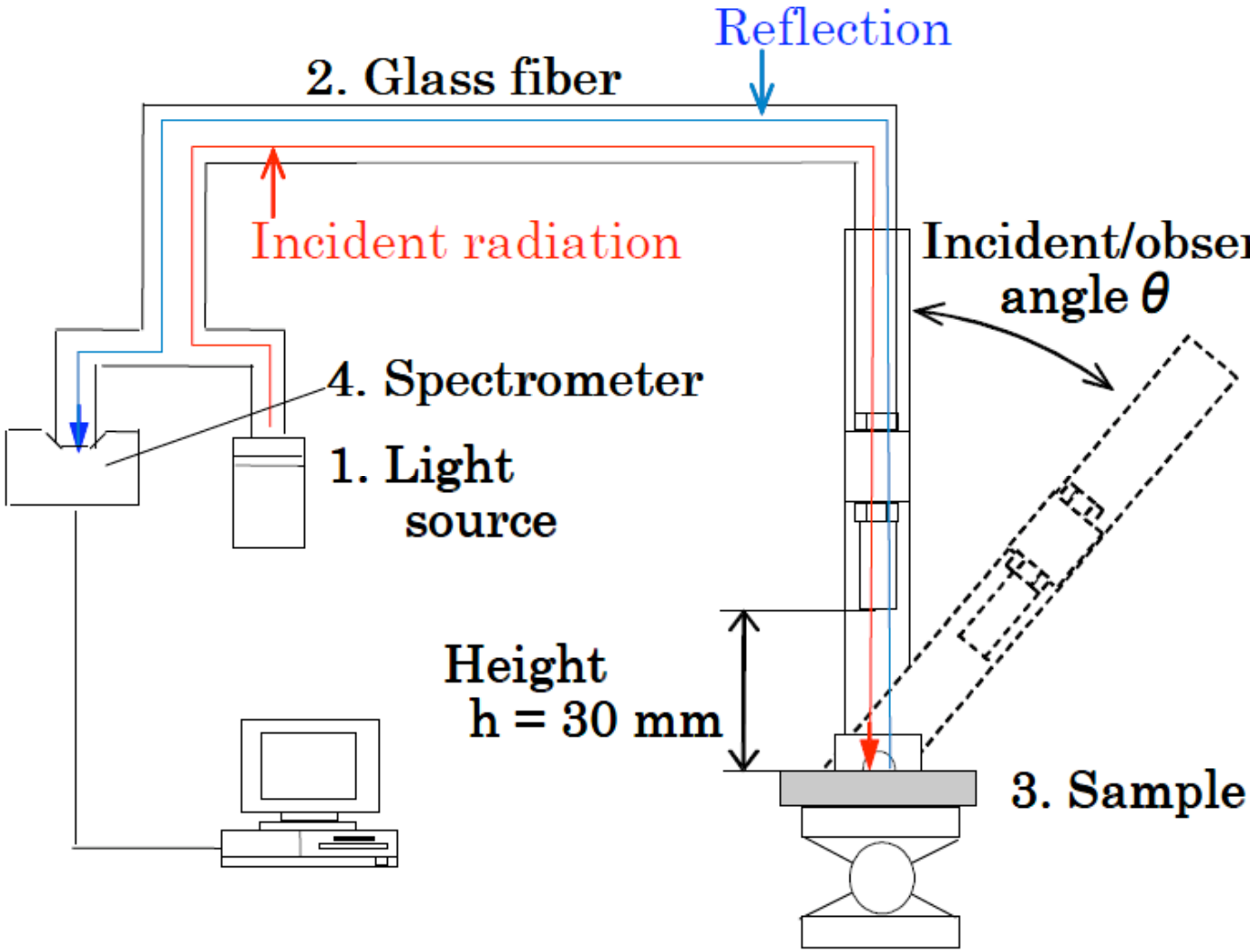
Numerical aperture (NA) = 0.22

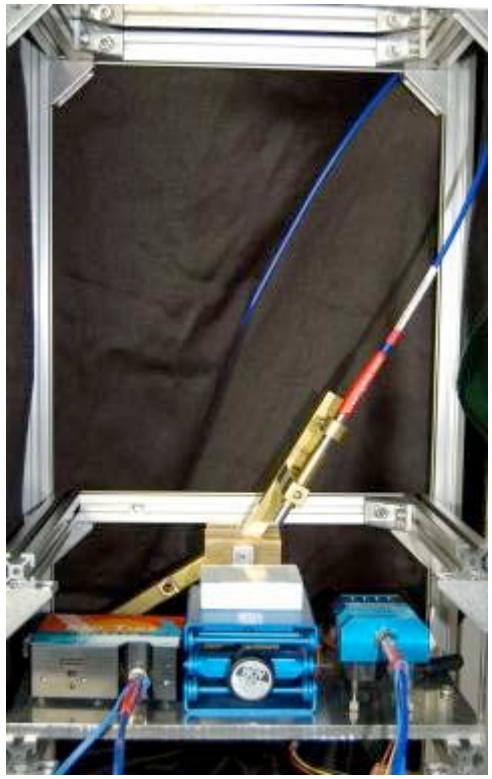
# Mini-spectrometers

Measurement for retroreflectance



# Measurement system

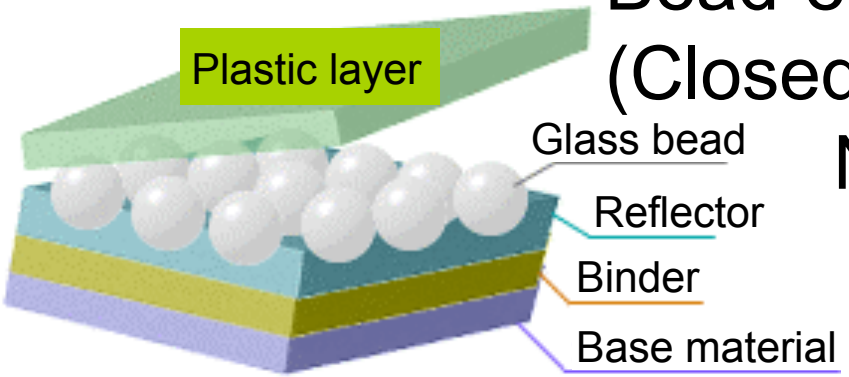


# Retroreflective materials

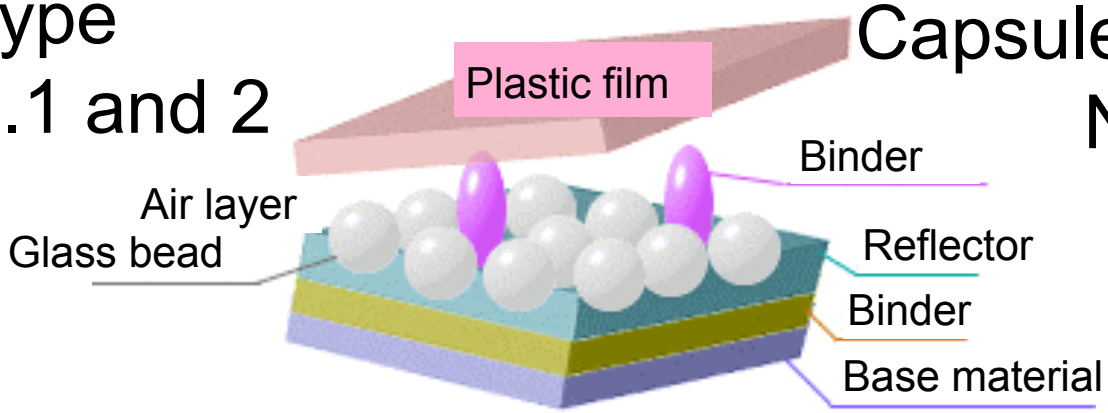
Retroreflective material
- Glass beads type
  - Open type
  - Closed type
  - Capsule lens type
- Prism type
- Paint type

Bead-embedded type (Closed-type) No.4 and 5



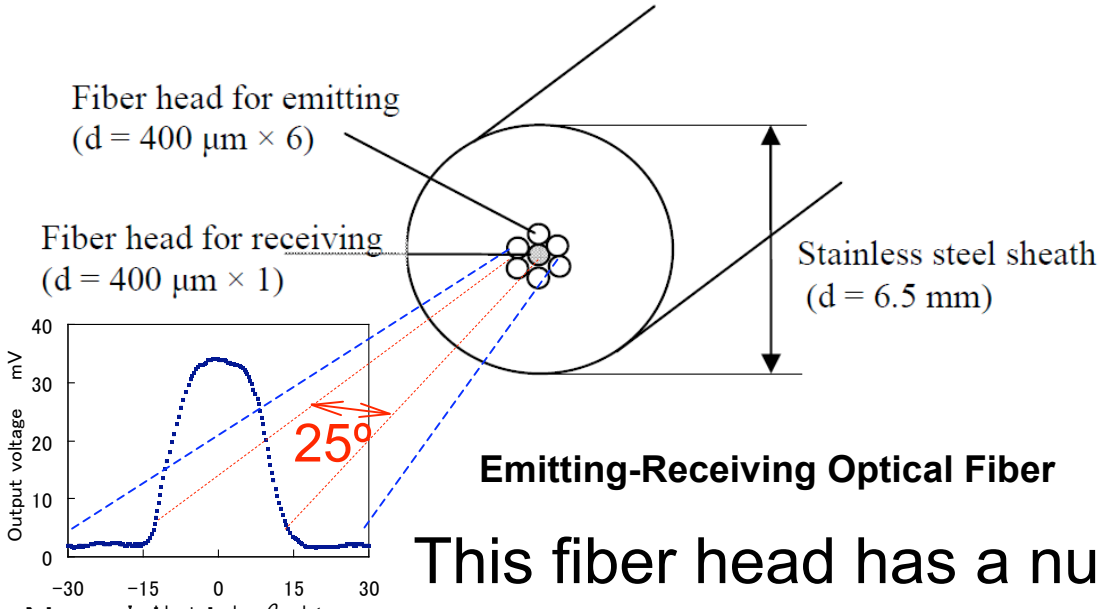

Prism-array type Sample No.1 and 2

Capsule-lens type No.3



# Standardized Method

## Definition of spectral retroreflective strength Rst(λ)




**Emitting-Receiving Optical Fiber**

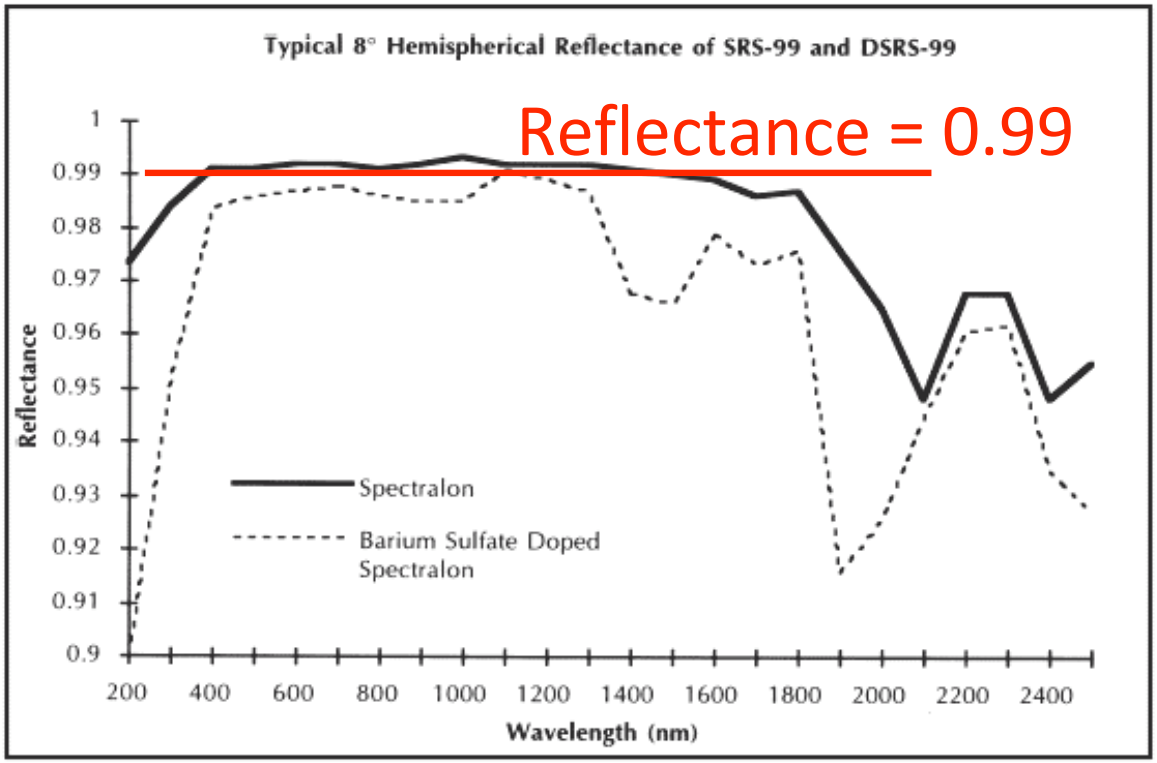
Numerical aperture
NA = 0.22

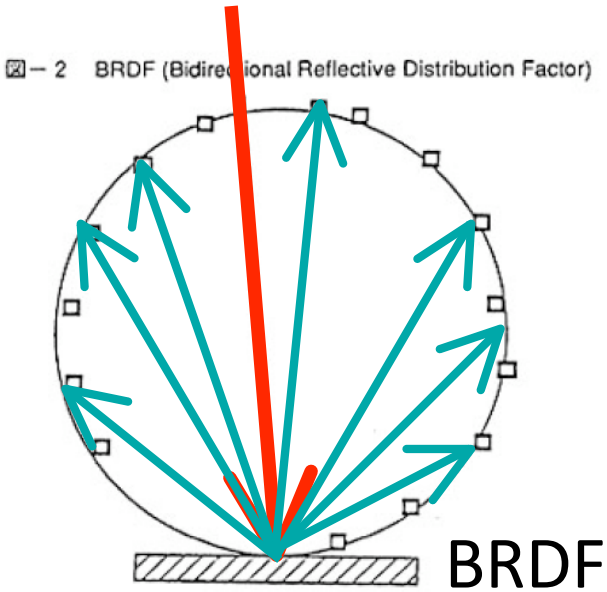
This fiber head has a numerical aperture, and the cross section of fiber has a size

- The light is not parallel, and the receiving position is not exactly the same with emitting point.
- The signal observed by this optical fiber is not only 'ideal retroreflected light'.

# Standardized Method

## Definition of spectral retroreflective strength Rst(λ)




BRDF

$$Rst(\lambda) = \frac{R_{mes\_material}(\lambda)}{R_{mes\_spectralon}(\lambda)/0.99}$$

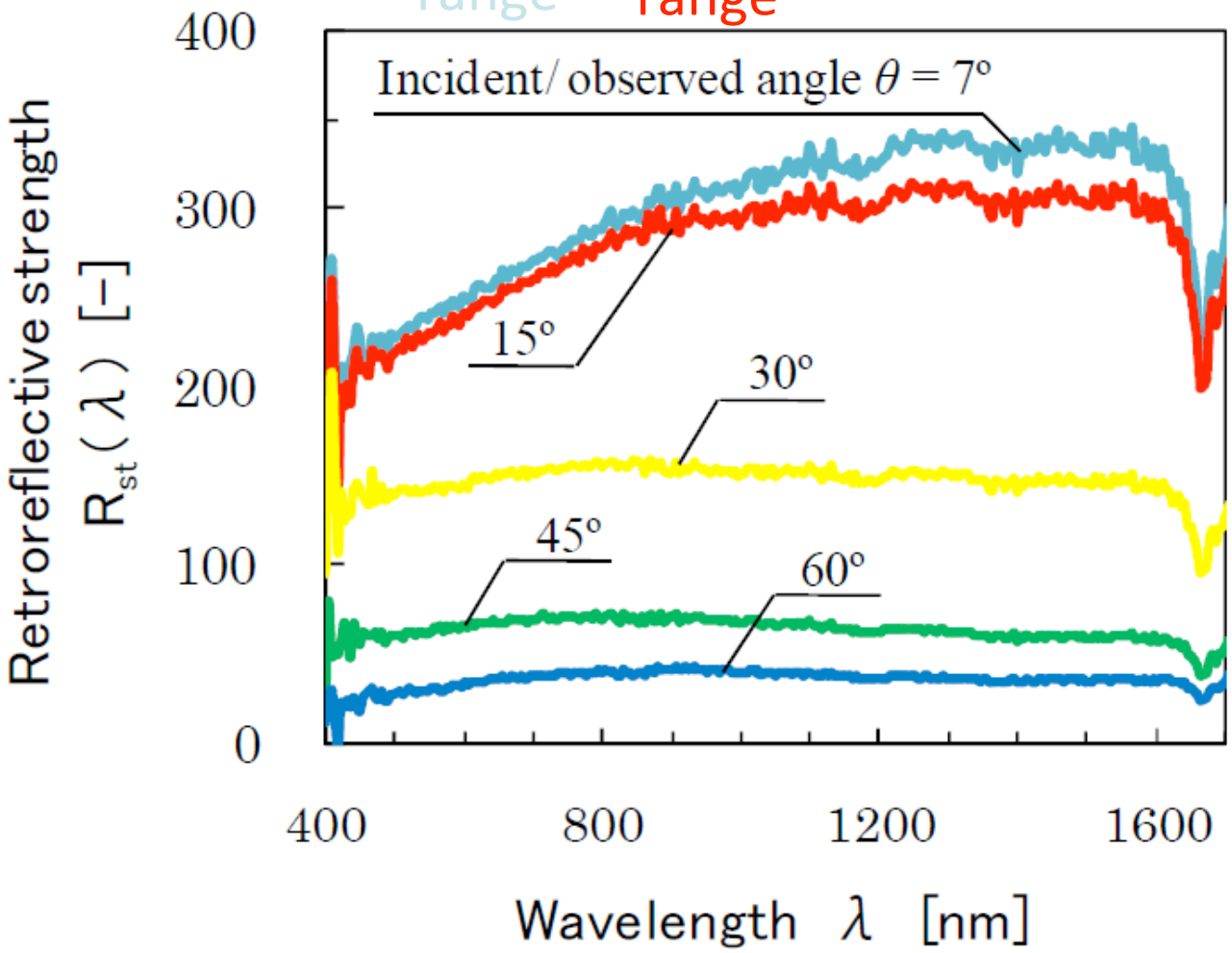

Spectralon

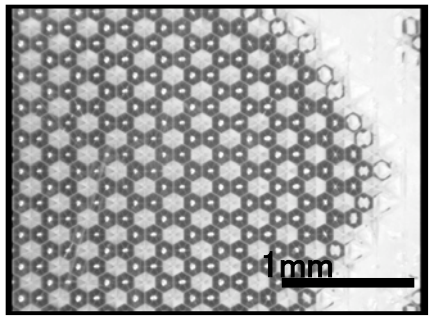
# Results

780nm

Visible range

Infrared range




⑥ N Prism

No.1 (Prism array type)

# Definition of Solar Retroreflective strength Rst

$$Rst = \frac{\sum_{\lambda=400}^{1715} Rst(\lambda)E(\lambda)\Delta\lambda}{\sum_{\lambda=400}^{1715} E(\lambda)\Delta\lambda}$$

E(λ) : spectral direct solar radiation (defined in ISO 9845-1)

The weighted integration of the measured spectral retroreflective strength on between wavelength of 400 and 1715, using spectral direct solar radiation defined in ISO 9845.

# Results (solar retroreflective strength)

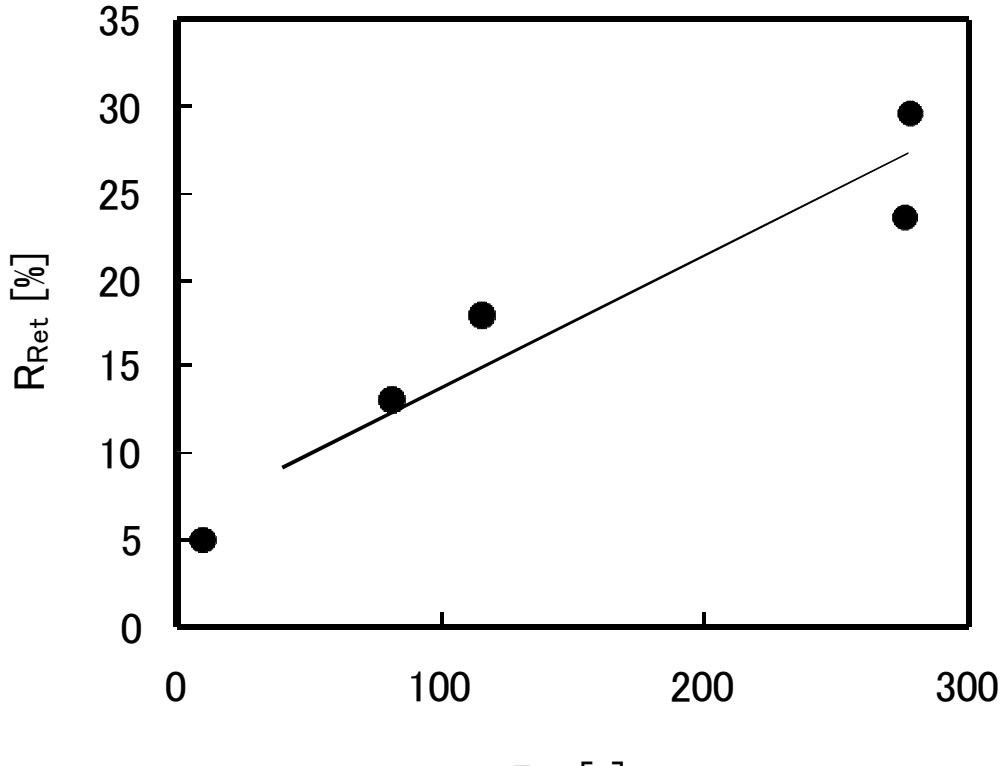
**Table 1 Experimental Result: Angular Dependency of Retroreflective Strength $R_{st}$ of the Sample Sheets Measured by the Emitting-Receiving Optical Fiber System. Retroreflectance $R_{Ret}$ Obtained in the Previous Paper is also Shown for Comparison**

| Sample No. (type) / Incident/observed angle | Retroreflectance $R_{Ret}$ [%] 7° | Retroreflective strength $R_{st}$ [-] 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 |

Optical fiber measurement
(simple and instantly)

Integrating sphere measurement
(accurate and cumbersome)

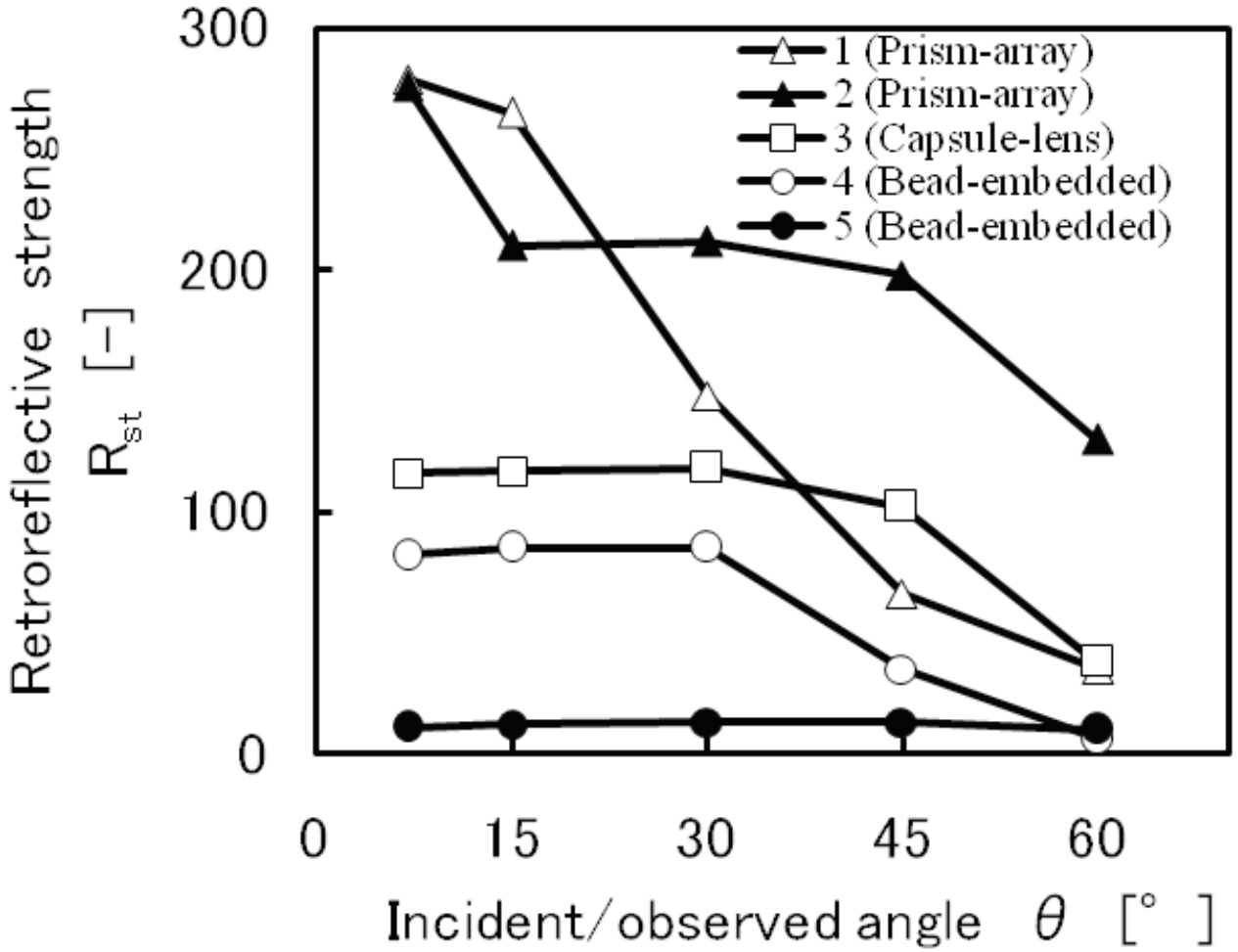
# Relationships between Solar Retroreflectance $R_{Ret}$ and Solar Retroreflective Strength $R_{st}$




$\theta = 7°$

- $R_{st}$ correlate well with $R_{Ret}$
  - The emitting-receiving optical fiber system can be used as a simple solar retroreflectance measuring method.

# Angular dependency of Retroreflective strength $R_{st}$ measured by the Emitting- Receiving Optical Fiber system




▲△Prism has a critical angle for retroreflection, and its reflection mechanism works well only within the critical angle.

➡ Prism-array-type sheets are suitable for preventing heat from sunlight at particular solar positions.

●○▫Ball-shaped lens has no strict critical angle for reflection.

➡ These types are effective at a wide range of solar positions.

# Outlook

1. Make clear the effect of NA value on the observed signals
2. Propose a simple Bidirectional Reflectance Distribution Function (BRDF) or Bidirectional Scattering Surface Reflectance Function (BSSRF) of retroreflective materials for numerical simulation and performance evaluation
3. Optimal drying condition and how to regulate the retroreflective properties of coating contained glass beads
4. Developing simple and automatic measurement system

# 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.