Optical properties of Al_2O_3 and $Al_2O_3/BaSO_4$ reflecting diffusers processed with plasma powder spraying

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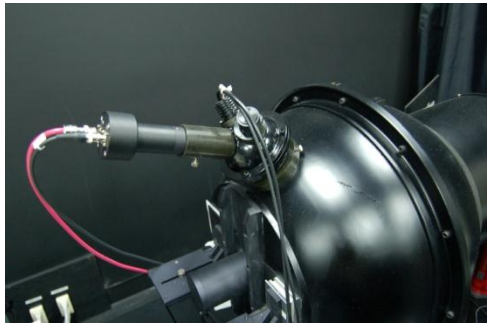
Integrating spheres, diffusers

- Integrating spheres
  - Total luminous flux measurements
  - Reflectance/Transmittance measurements
  - Components of photo-detectors
- Reflecting diffusers
  - Radiance/Luminance standards
  - Reflectance standard (diffuse, reflectance factor, BRDF)
  - Installation in optical systems to uniform radiation



Consideration for industrial use

Integrating spheres and reflecting diffusers used for...

- **Products inspection (high-speed testing)**
- **Field measurements**

have problems such as …

- **Damage (mechanical vibration, frequent attachment/detachment of products etc.)**
- **Deterioration (due to environmental factor etc.)**
- **High-cost**

They need to have …

- Optical properties similar to those used in laboratories
- High durability against mechanical shocks etc.
- Cost effectiveness (material, preparation process)

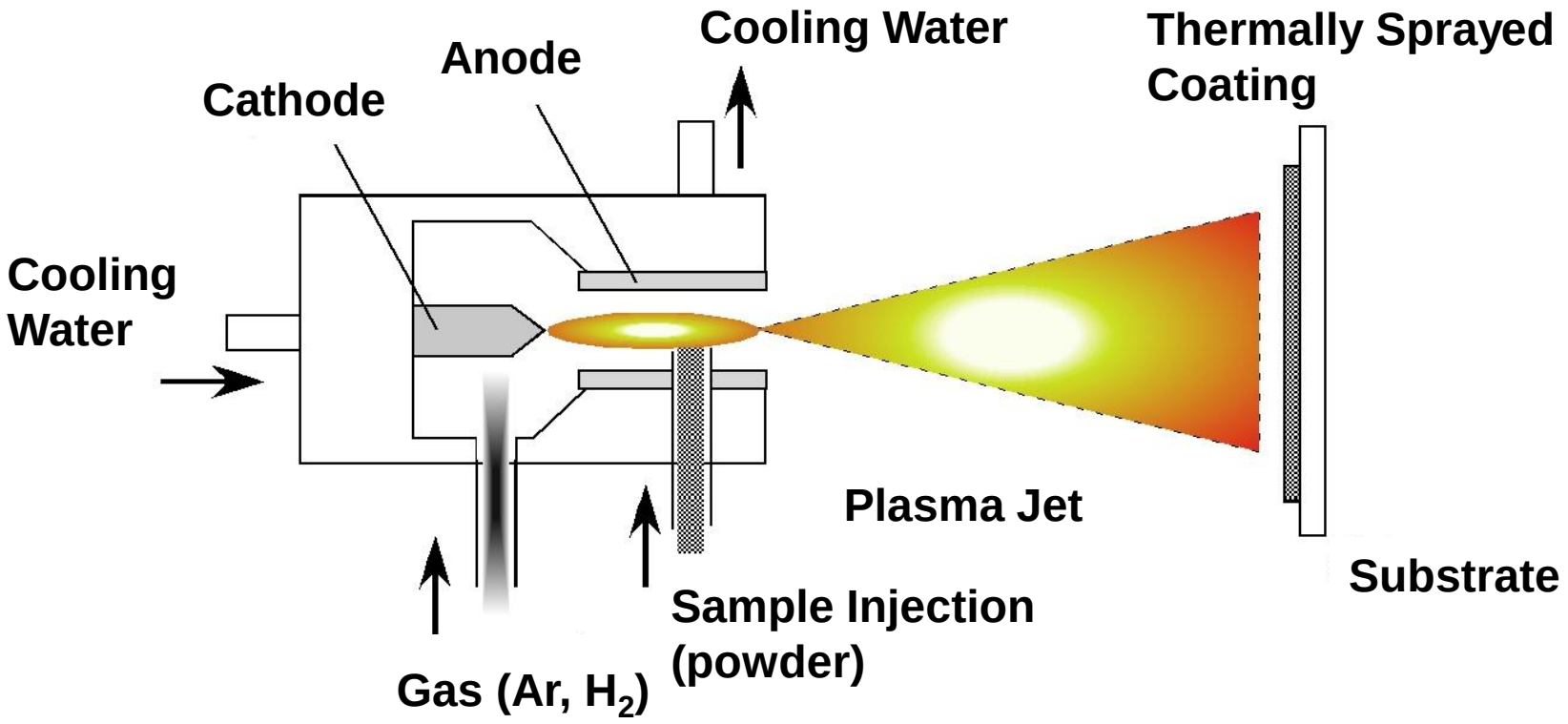
Major Reflecting Diffusers

- Major process to prepare reflecting diffusers (or integrating spheres)
  - Painting : $BaSO_4$
  - Pressing : $BaSO_4$, PTFE etc.
  - Sintering : Ceramic tiles (Al_2O_3 etc.)
  - Resin : PTFE
  - Smoking : MgO

Reflecting diffusers prepared by	Mechanical strength	Reproduci-bility	Optical Properties	Applicability to sphere	Cost
Painting	X	X	O	O	O
Pressing	X	X	O	O	O
Sintering	O	O	O	X	X
Resin	X	O	O	O	X
Smoking	X	X	X	O	O

Plasma powder spraying

Electrically generated plasma flame + Powdered material → Heating, Melting and accelerating → Impact on substrate and rapid cooling → Deposition over the substrate



Coating with high mechanical strength using various types of materials

Objectives

- Investigation on **basic optical properties** of Al_2O_3 based reflecting diffusers processed with plasma powder spraying technique

- Approaches **to improve reflection properties** (reflectance, spectral flatness) by means of ...
  - Containing $BaSO_4$ as compound
  - Another (new) thermal spraying technique

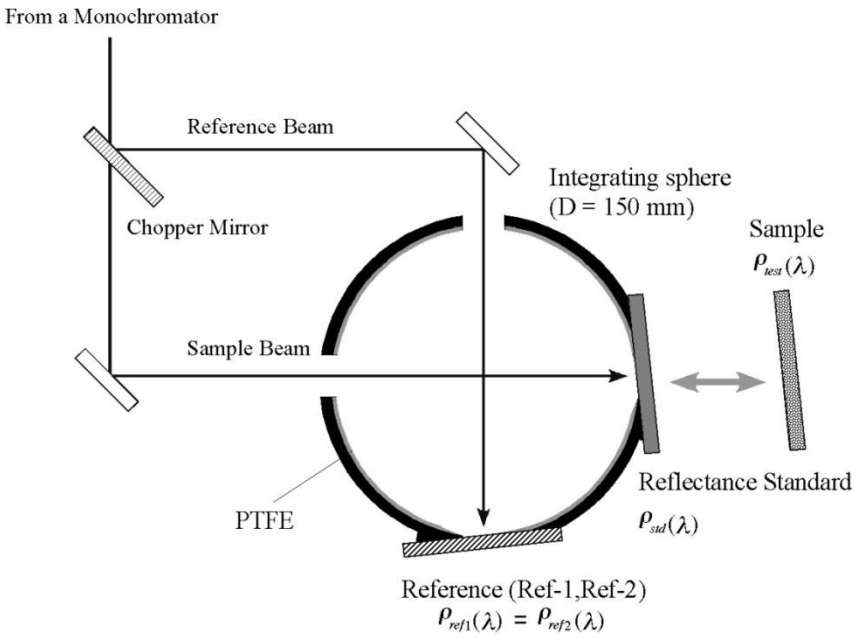
Experimental setup

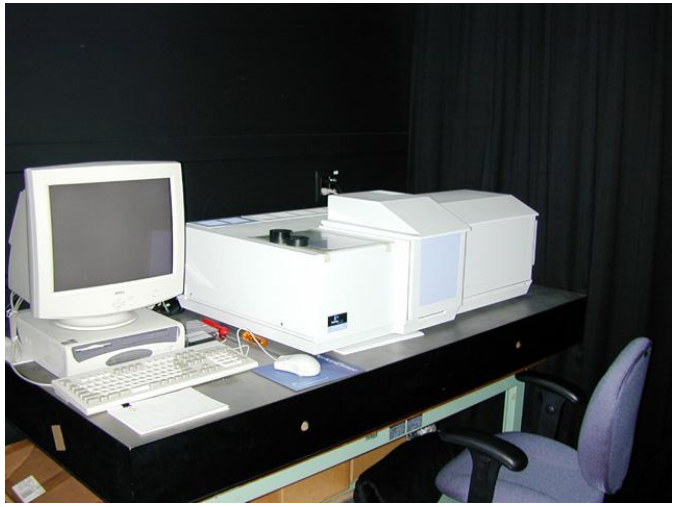
- Reflecting diffusers based on plasma powder spraying
  - Targeted material: Al_2O_3
    - *Thickness: 0.2 mm, 0.4 mm, 0.6 mm
    - *Substrate: Aluminum (50 x 50 x 3) mm
- Basic Optical Properties
  - •Reflectance
  - •Spatial distribution
  - •Ageing
  - •Exposure to UV radiation
- Containing $BaSO_4$ as compound
  - $Al_2O_3/BaSO_4$ (3:1) and $Al_2O_3/BaSO_4$ (7:1)
- New thermal spraying process
  - Suspension thermal spraying

Methods for Evaluation (1)

1) Spectral Diffuse Reflectance

- Instrument: Calibrated spectrophotometer (PerkinElmer, Lambda-900)
- Range: 250 nm to 900 nm (5 nm interval)
- Bandwidth: about 3 nm
- Geometry: 8º:*di*（SCI）



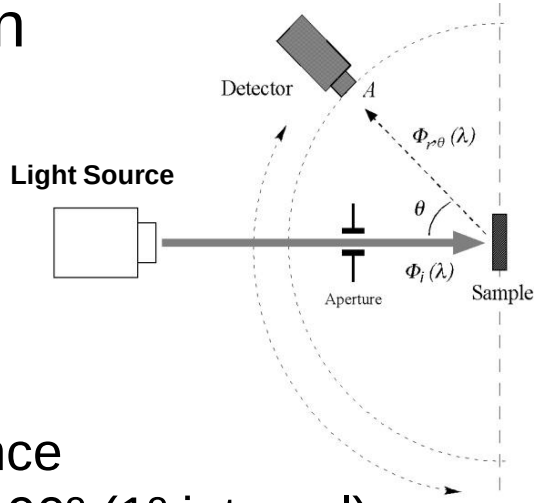


$$\rho_{test}(\lambda) = \frac{R_{ref1}(\lambda)}{R_{std}(\lambda)} \cdot \frac{R_{test}(\lambda)}{R_{ref2}(\lambda)} \cdot \rho_{std}(\lambda)$$

Methods for Evaluation (2)

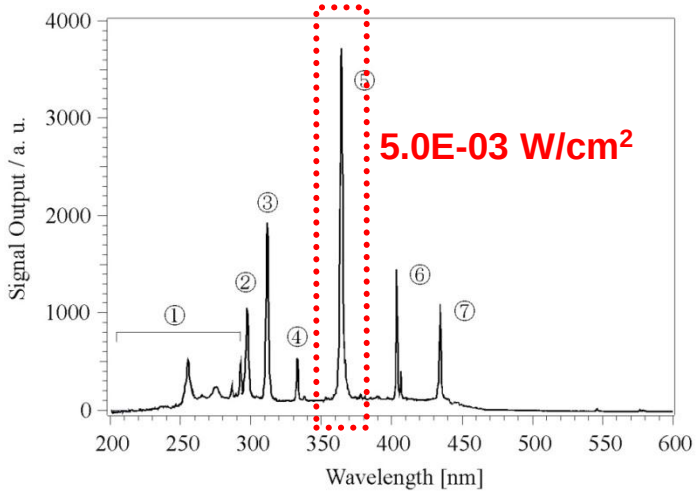
2) Spatial Distribution of Reflected Radiation

- Instrument: Gonio-Reflectometer (Murakami, GP-200)
- Range: 400 nm to 700 nm (16 interference filters)
- Bandwidth: ~10 nm
- Geometry: Incident Angle: 0º incidence
  Receiving Angle: -45º to 90º (1º interval)



3) UV radiation exposure

- Source: Hg/Xe lamp
- Irradiation area: 100 mm x 100 mm
- Uniformity: < 2.5 % (for surface reforming)
- Dose: 50 J/cm^2, 100 J/cm^2, 150 J/cm^2 (at 365 nm)



Mechanical Strength

- Vickers Hardness (Load: 0.5 N)

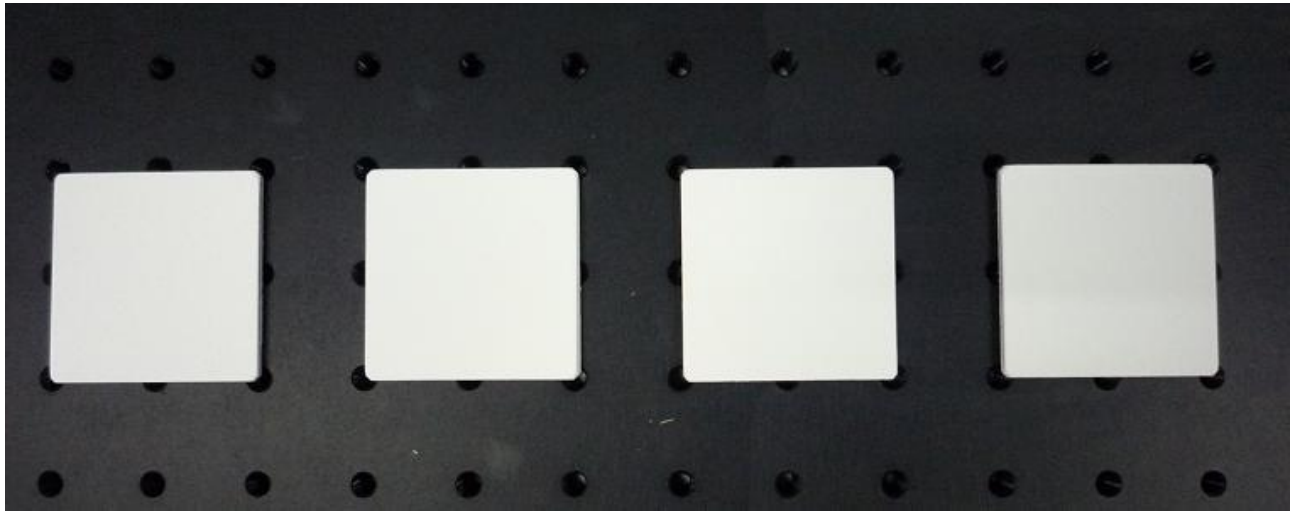
  Al_2O_3 thermal spraying: **~500 HV**

  $Al_2O_3/BaSO_4$ (3:1) thermal spraying: **~ 400 HV**

  cf.) $BaSO_4$ sprayed with PVA-aq: **N/A**

- Strength test

  No damage after strength test with intense vibration and scratch using a metal spatula.



Reflectance vs. Thickness

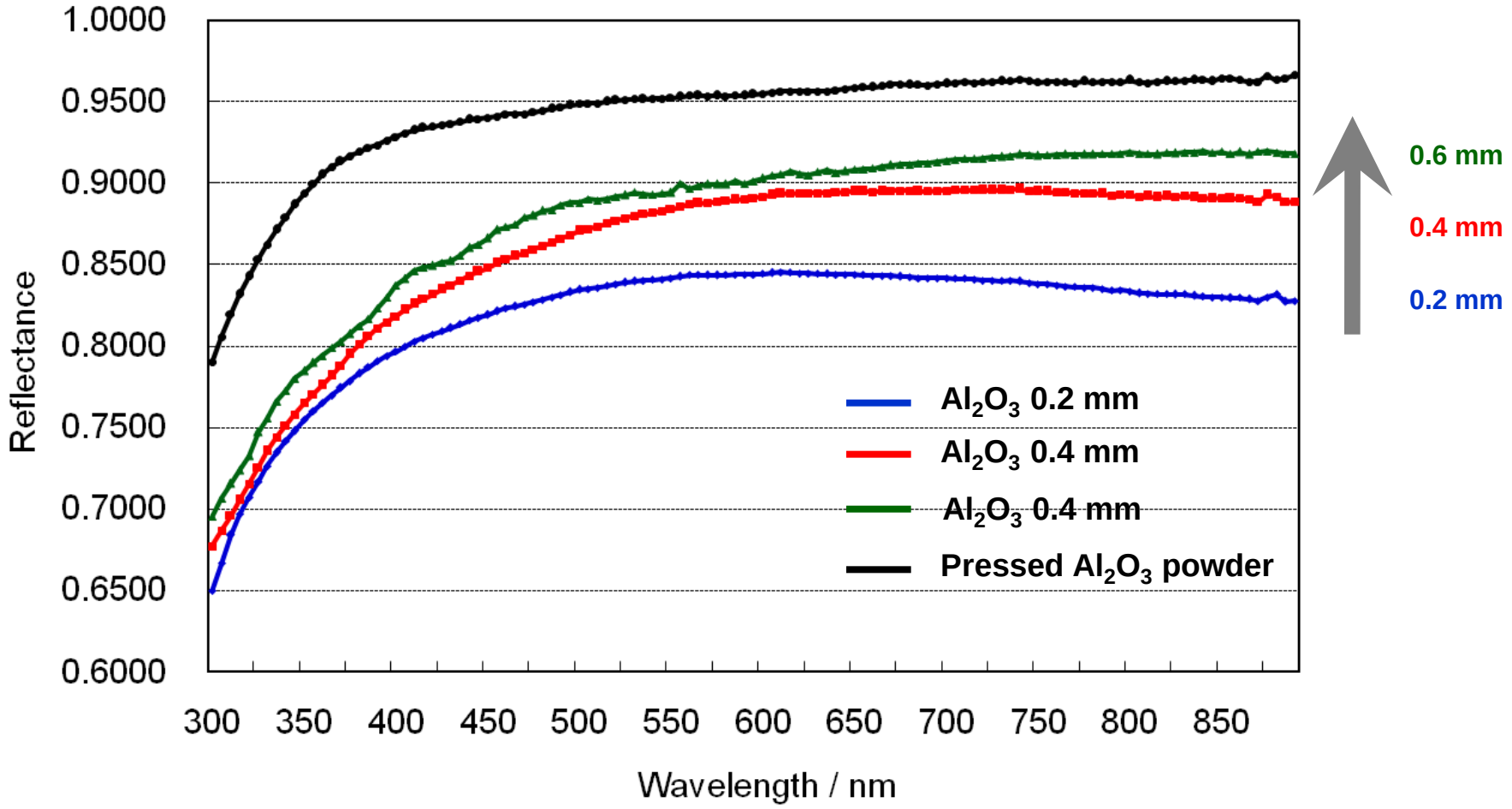


Fig. Spectral diffuse reflectance of Al_2O_3 plasma powder spraying samples with different thickness

Effect on Containing $BaSO_4$

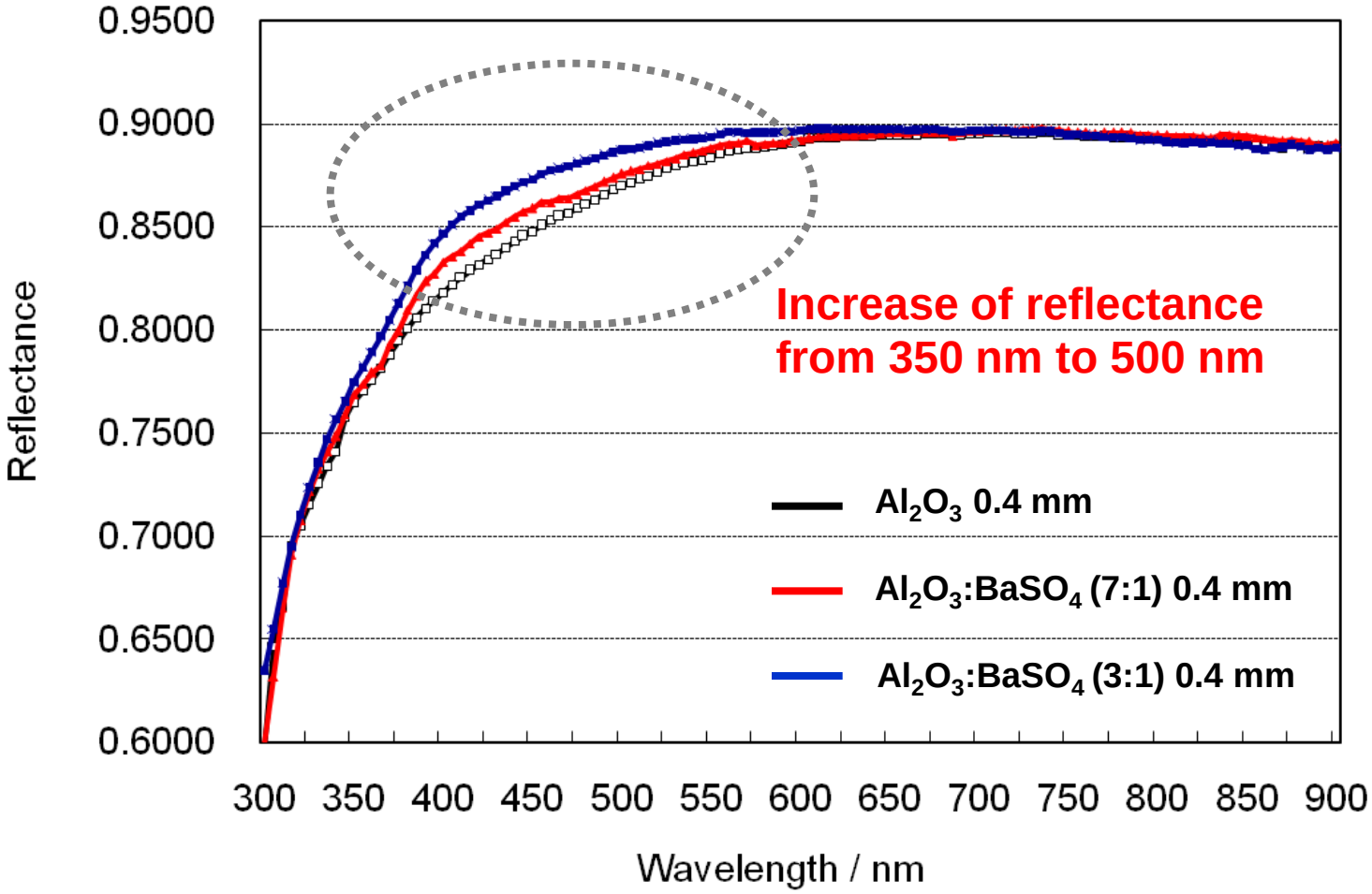


Fig. Spectral diffuse reflectance of Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples processed with plasma powder spraying

Reflectance Uniformity

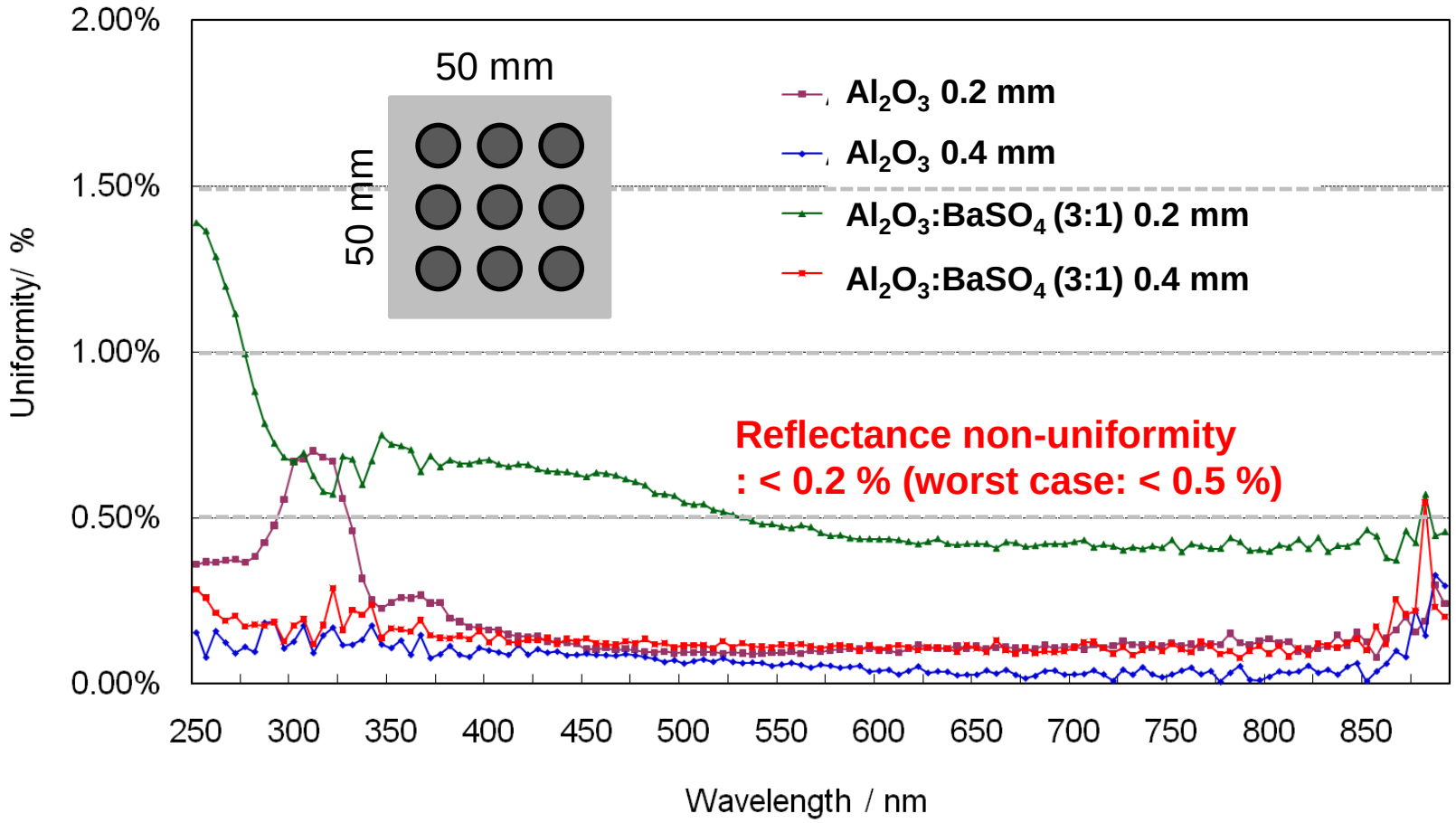


Fig. Reflectance non-uniformity of Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples processed with plasma powder spraying samples

Spatial Distribution (1)

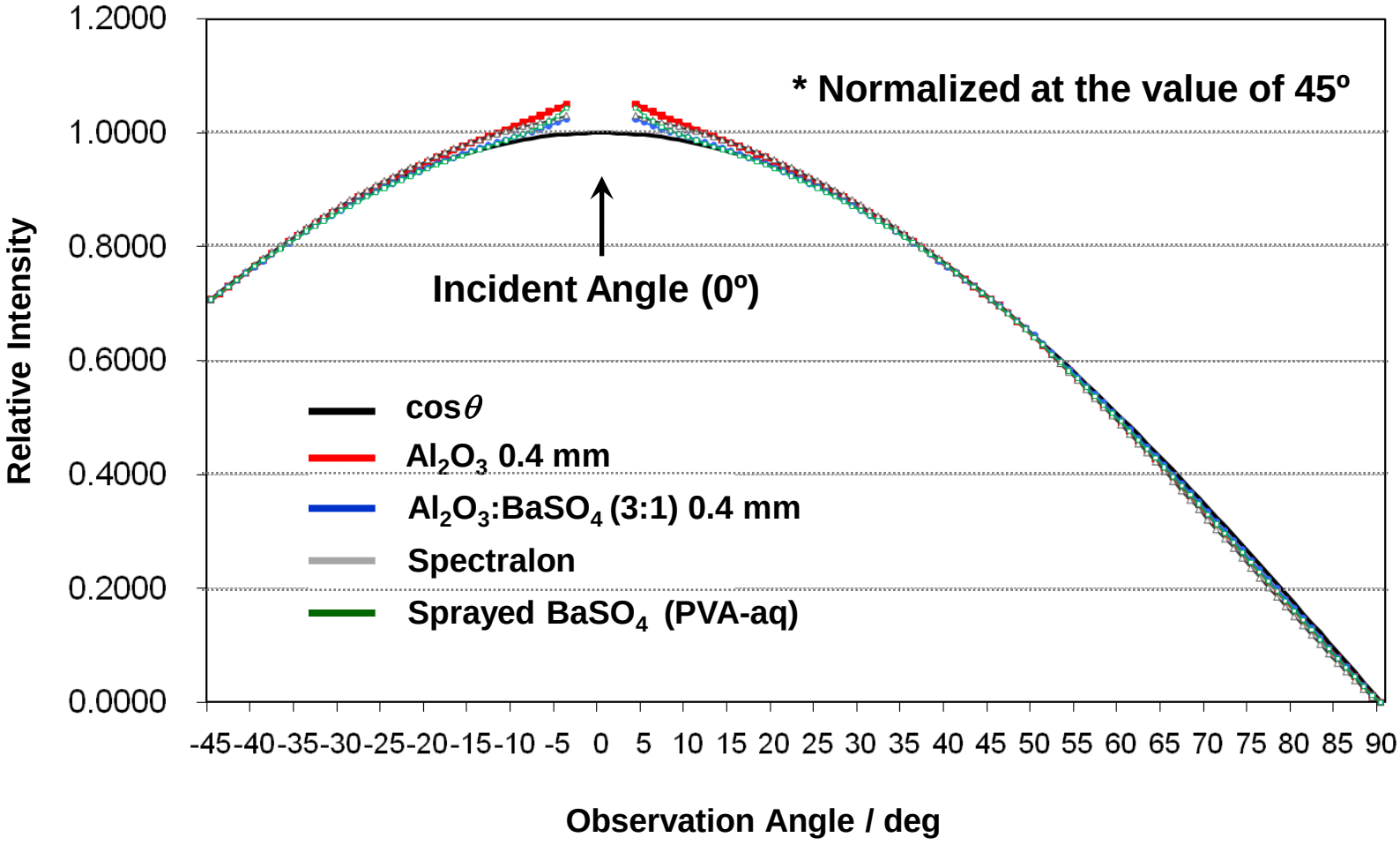


Fig. Spatial distribution of reflected radiation from Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples processed with plasma powder spraying

Spatial Distribution (2)

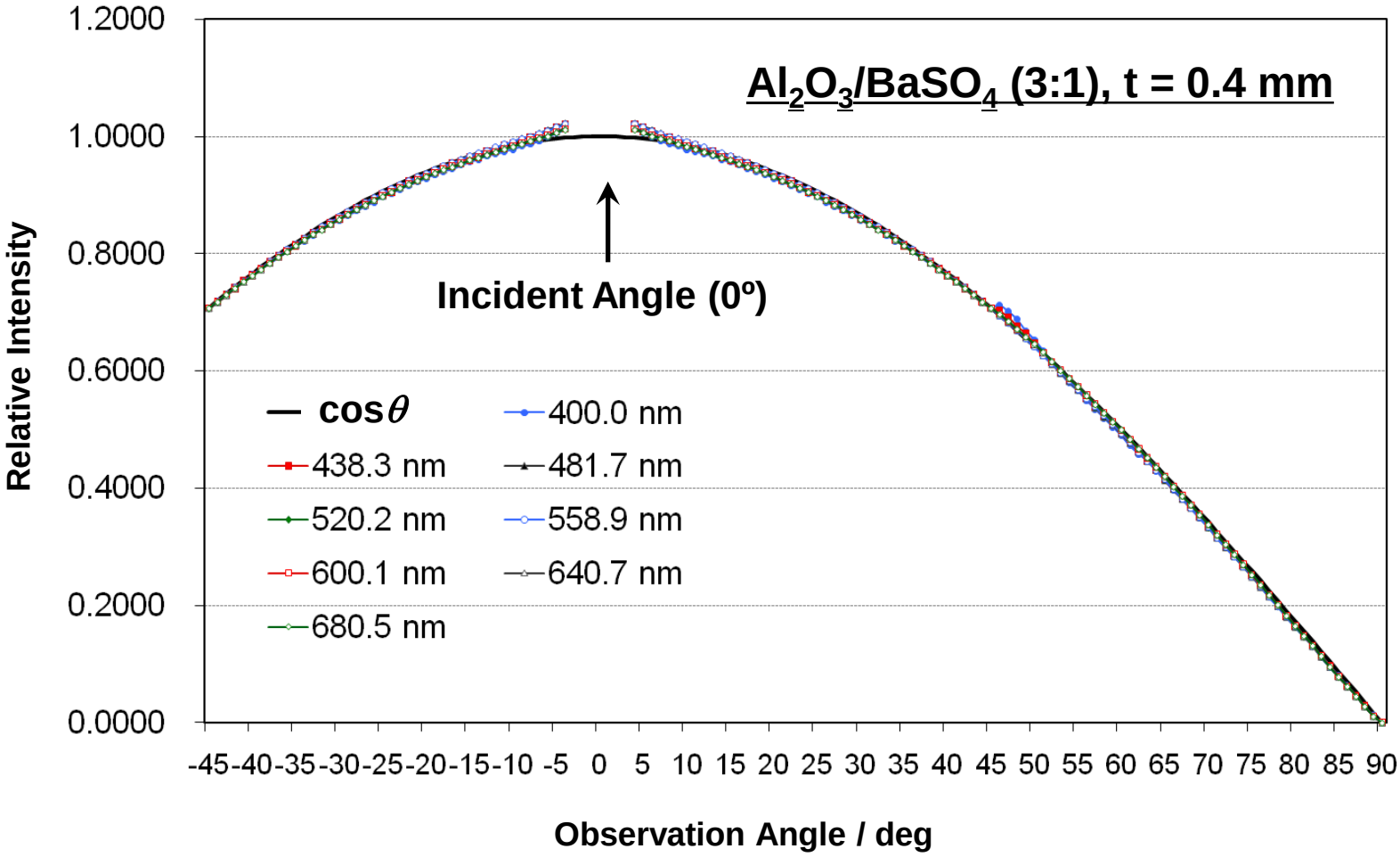


Fig. Spatial distribution of reflected radiation from Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples processed with plasma powder spraying

Ageing Characteristics (1)

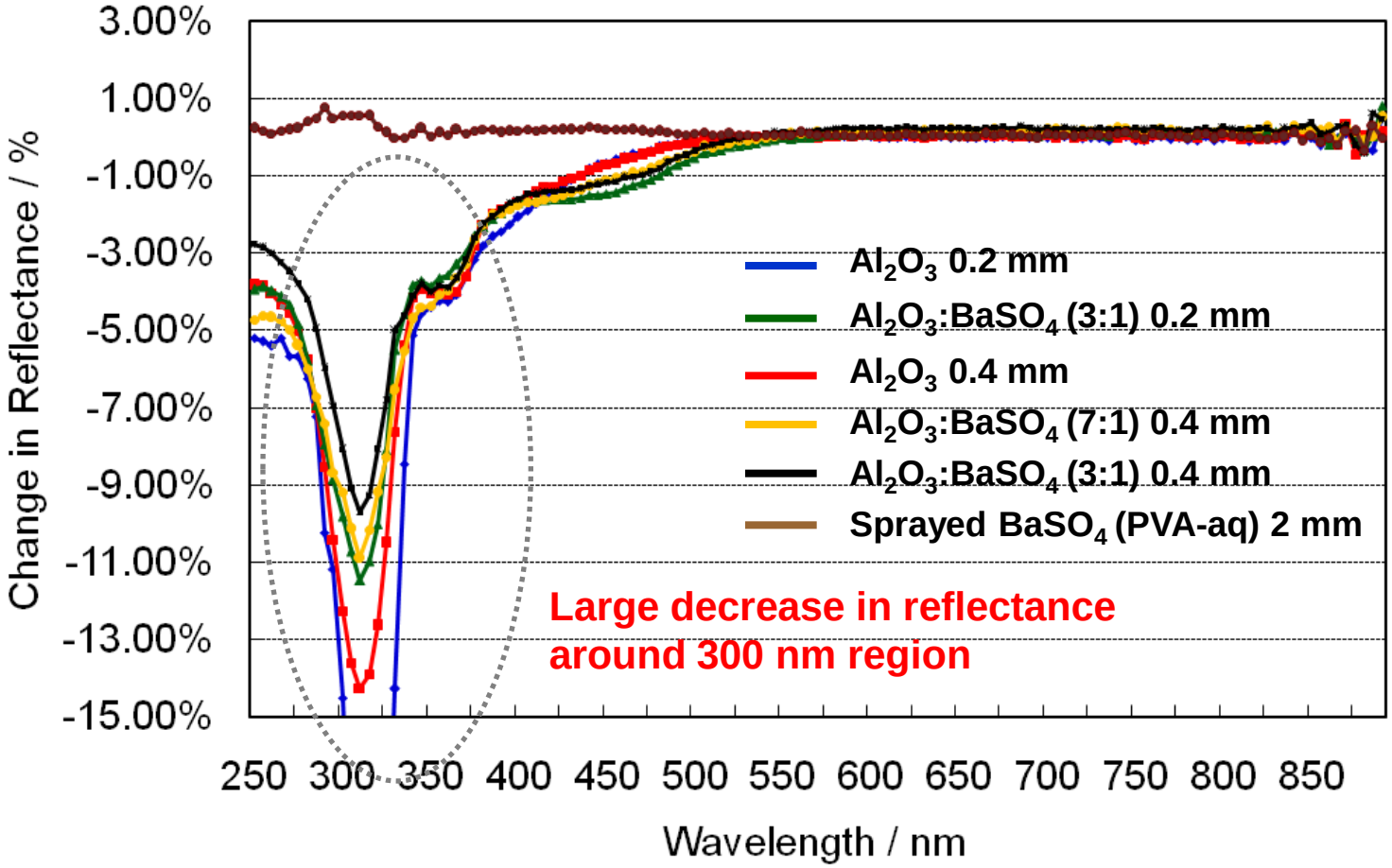


Fig. Change of spectral diffuse reflectance after a half-year storage for Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples

Ageing Characteristics (2)

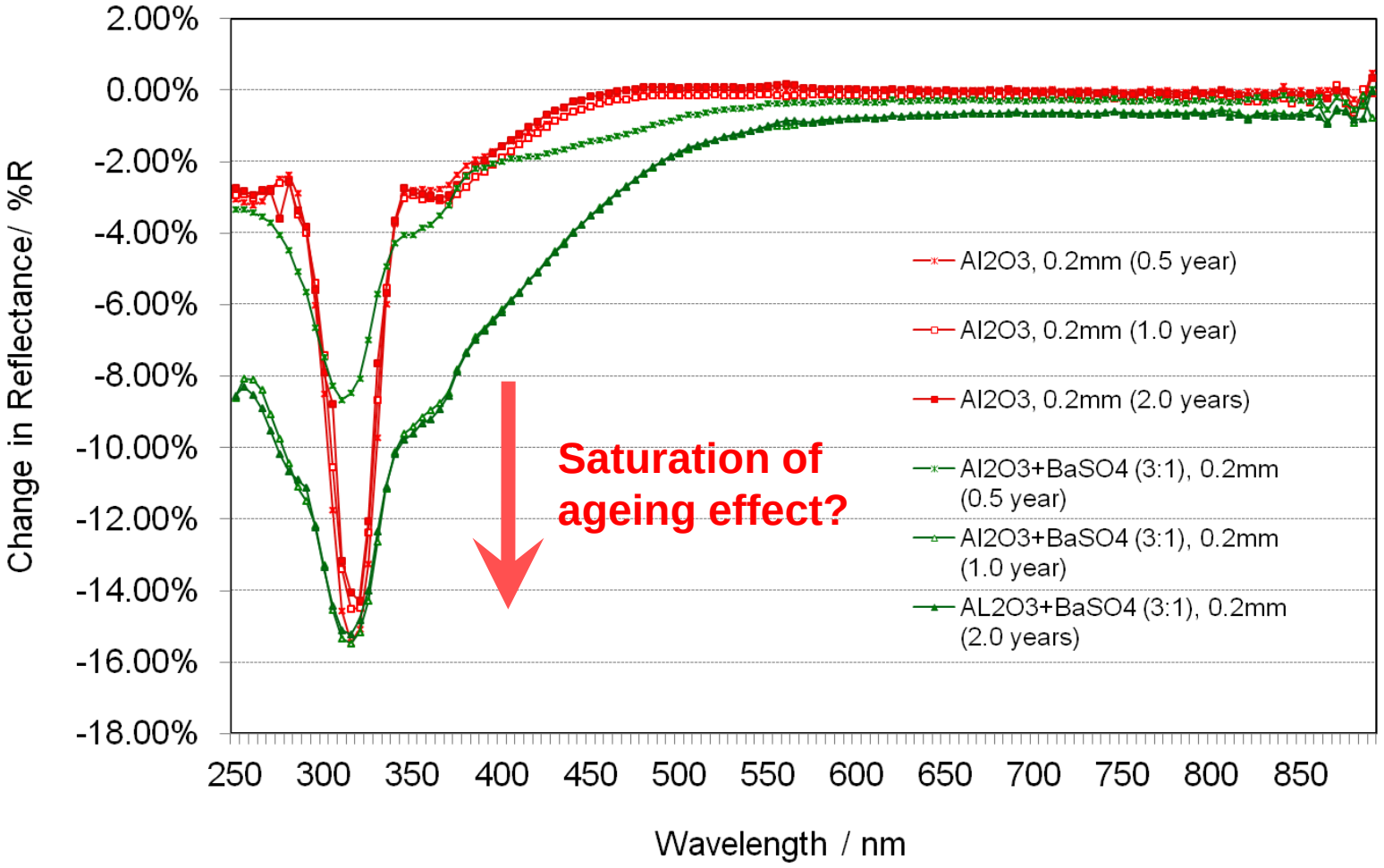


Fig. Change of spectral diffuse reflectance after a half-year, a one year and two years storage for Al_2O_3 and Al_2O_3+$BaSO_4$ (3:1) samples

Exposure to UV Radiation

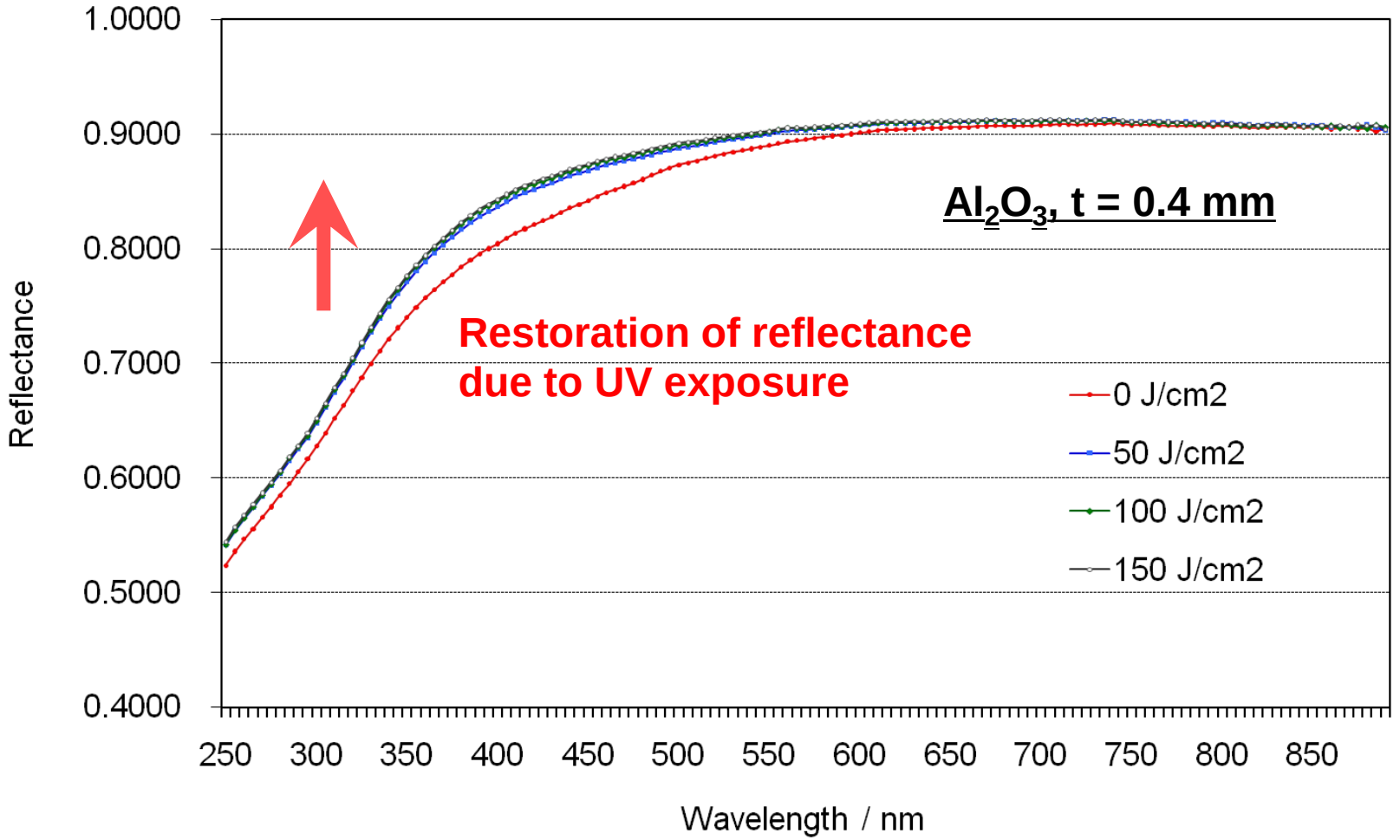
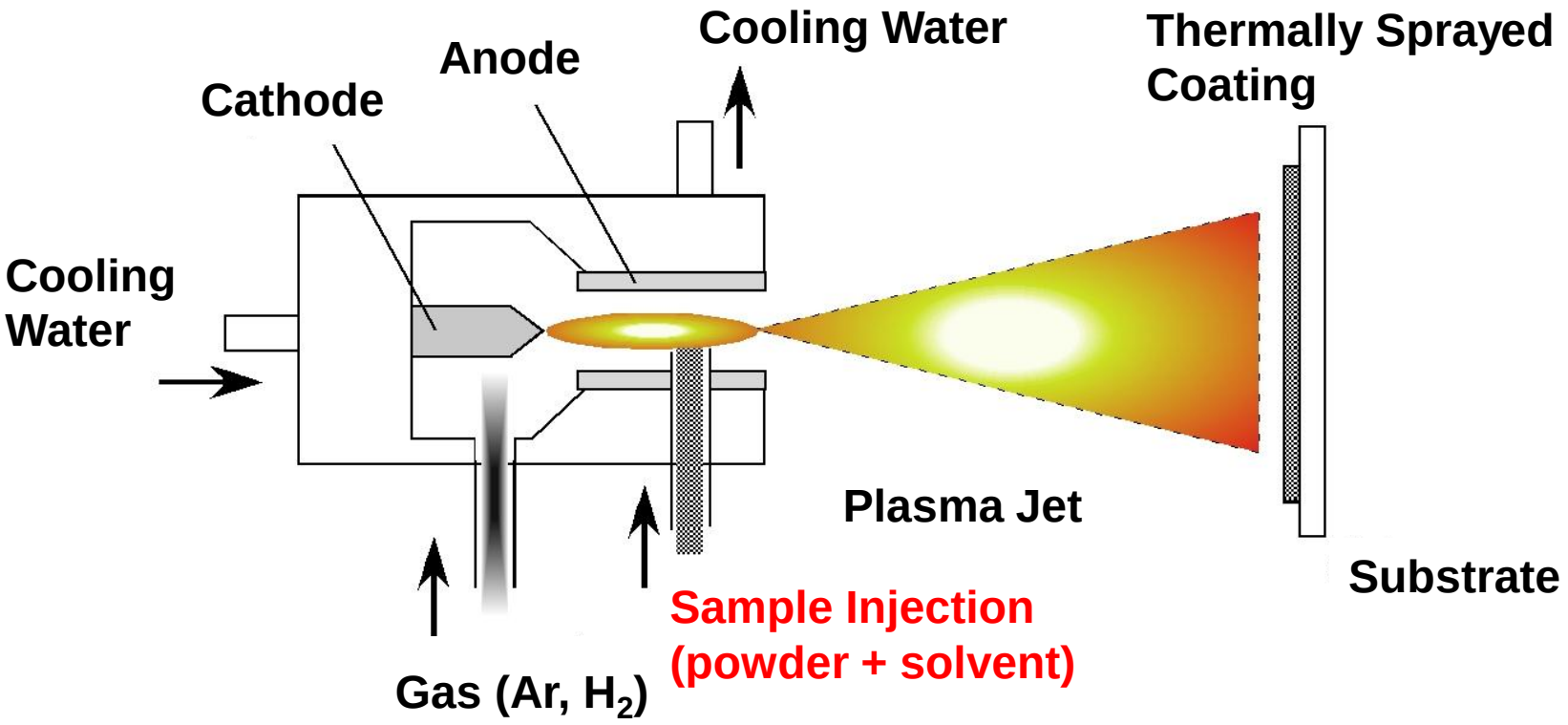


Fig. Reflectance change of an Al_2O_3 sample processed with plasma powder spraying due to UV exposure

Suspension thermal spraying

Supplying the sample by means of suspension (aqueous solution)
--- nano-structured coatings



1) Suspension HVOF spraying
2) Suspension Plasma spraying → **Al_2O_3 samples**

Suspension thermal Spraying

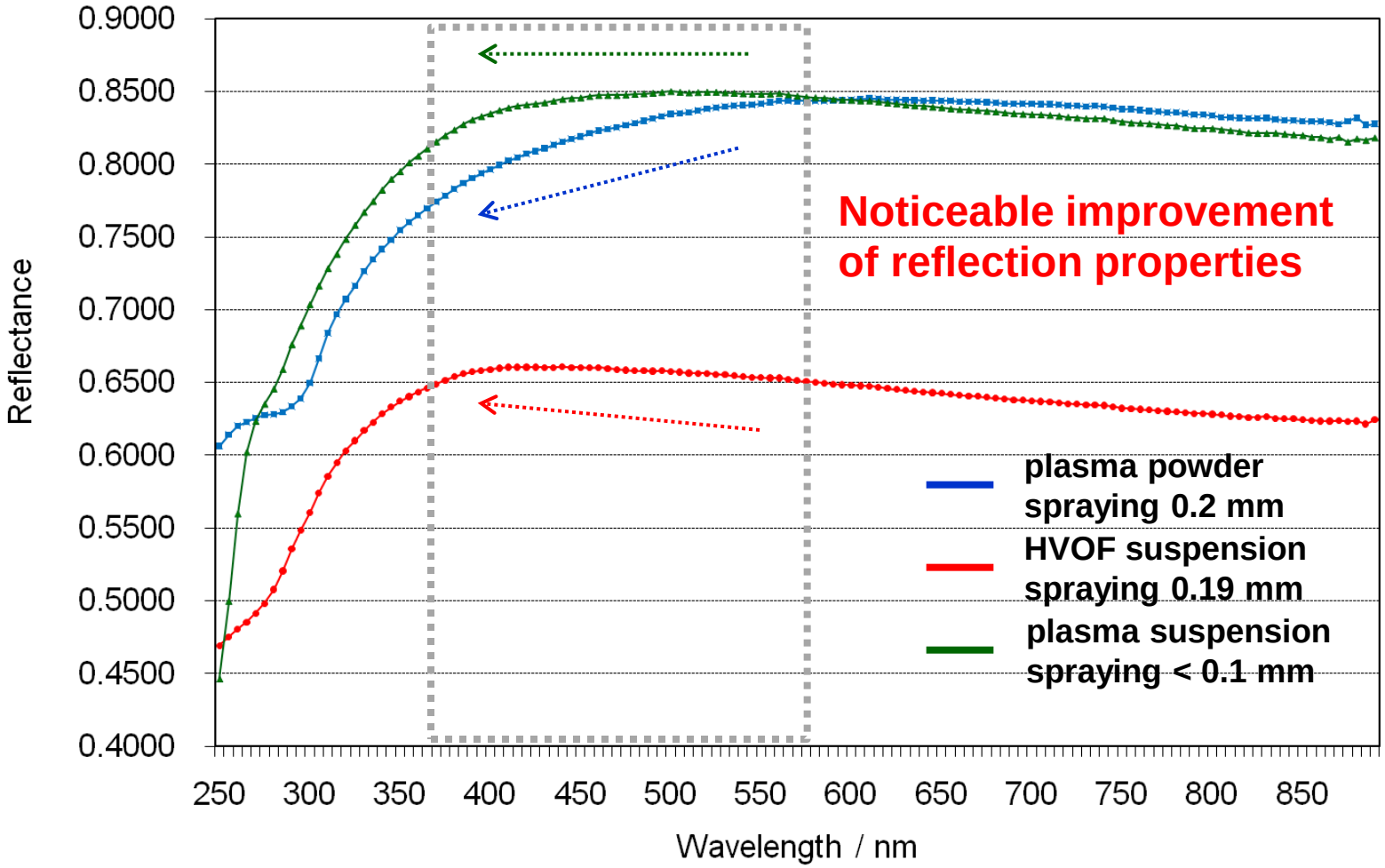


Fig. Spectral diffuse reflectance of Al_2O_3 samples based on (1) plasma powder spraying, (2) HVOF suspension spraying, and (3) plasma suspension spraying

Summary

- Al_2O_3 and $Al_2O_3/BaSO_4$ (3:1) reflecting diffusers processed with plasma powder spraying technique
- Realization of reflecting diffusers with high mechanical strength
- Investigation of the basic optical properties
  - Reflectance of approximately 0.85 to 0.90 in the visible range
  - Improvement of reflectance from 350 nm to 500 by Adding $BaSO_4$
  - Reflectance uniformity $< 0.5\ \% (1\sigma)$
  - Spatial distribution of reflected radiation: approximate to lambertian
  - Ageing properties
    - decrease of reflectance around 300 nm to 400 nm
    - saturation effect
    - restoration of reflectance due to UV exposure
  - Needs for further investigation, especially to clarify the mechanism
- Potential of suspension thermal spraying