NMIJ Research Activities relevant to LED Sources for Photometry

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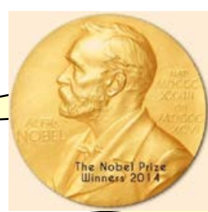
Overview of NMIJ R&D relevant to LED Calibration

Improvement in Luminous Flux and Color Rendering Property

1960
1970
1994
1998

2014

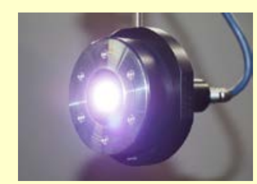


2007:
- Development of Standard LEDs for Low-Power LED Calibration.
- The development is based on a joint research with a Japanese LED manufacture, NICHIA

2013:Luminous Flux Standard LED for High-Power LED Calibration

2014:
- Radiant Flux Standard LED for UV-LED Calibration
- Total Spectral Radiant Flux Standard for 4π geometry

2015:
- Standard LED for Total Spectral Radiant Flux Calibration at 2π geometry

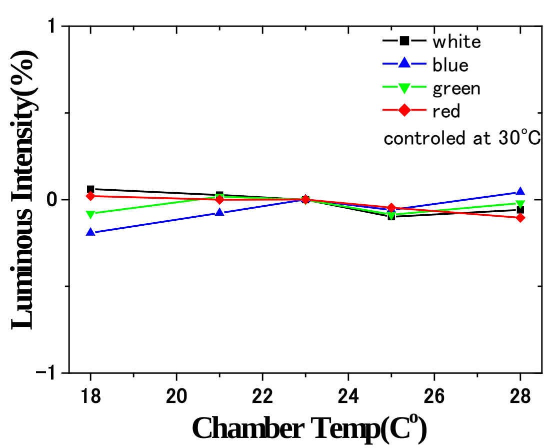


Development of Standard LEDs for Low-Power LED Calibration

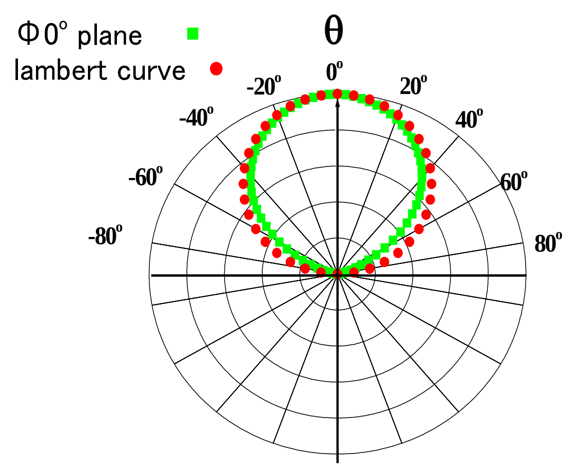
Standard LED for CIE Averaged LED Intensity Calibration (averaged Intensity is about 1.6 cd)

Standard LED for Luminous Flux Calibration (luminous flux is about 1.3 lm)

- NMIJ and NICHIA corporation (Japanese LED manufacturer) jointly developed those standard LEDs.
- The error due to LED alignment is minimized by fixing LED-chip to the body.
- The ambient temperature dependency is minimized by introducing a thermo-module and optimizing the control for stabilizing the LED-chip temperature.
- The luminous intensity distribution is optimized by introducing customized LED tips.
- There are 4 different colors (White, Blue, Green and Red).



The ambient temperature dependency of the standard LED averaged intensity is reduced by the thermo-module.

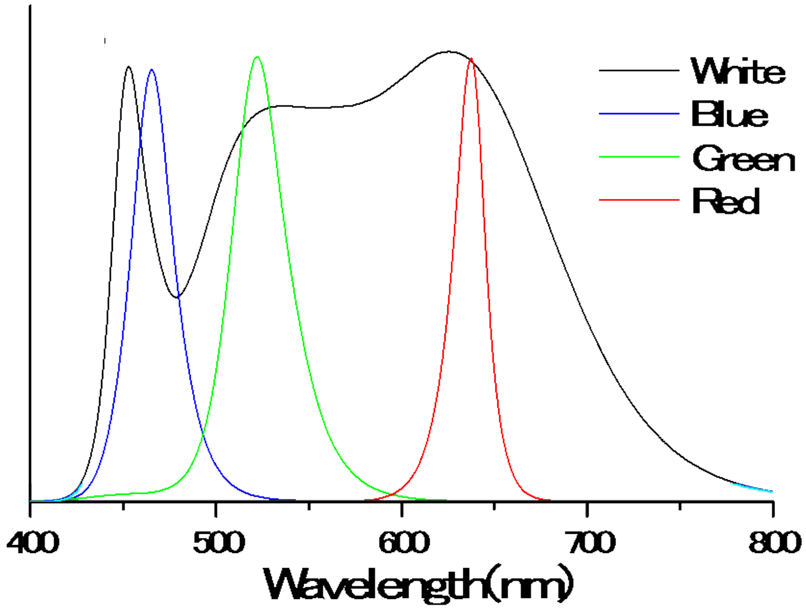


The luminous intensity distribution of the standard LED for luminous flux calibration approximately equal to Lambertian.

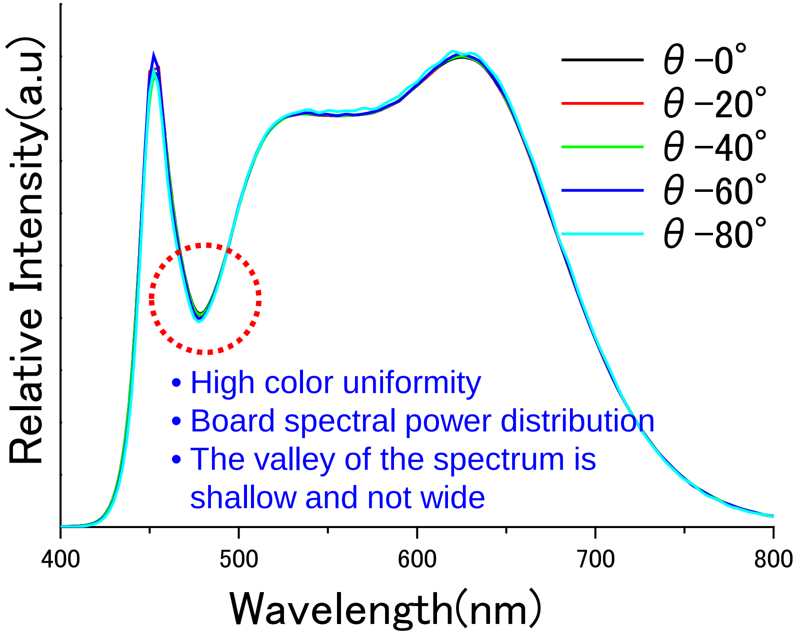
Development of Luminous Flux Standard LEDs for High-Power LED Calibration (1)

Luminous flux standard LED for high-power LED Calibration (luminous flux is about 60 lm)

- NMIJ and NICHIA corporation jointly developed the standard LEDs.
- Luminous intensity distribution and spectral power distribution is optimized by introducing customized LED tips.
- The ambient temperature dependency is minimized by introducing a thermo-module and optimizing the control for stabilizing the LED-chip temperature.
- There are 4 different colors (White, Blue, Green and Red).

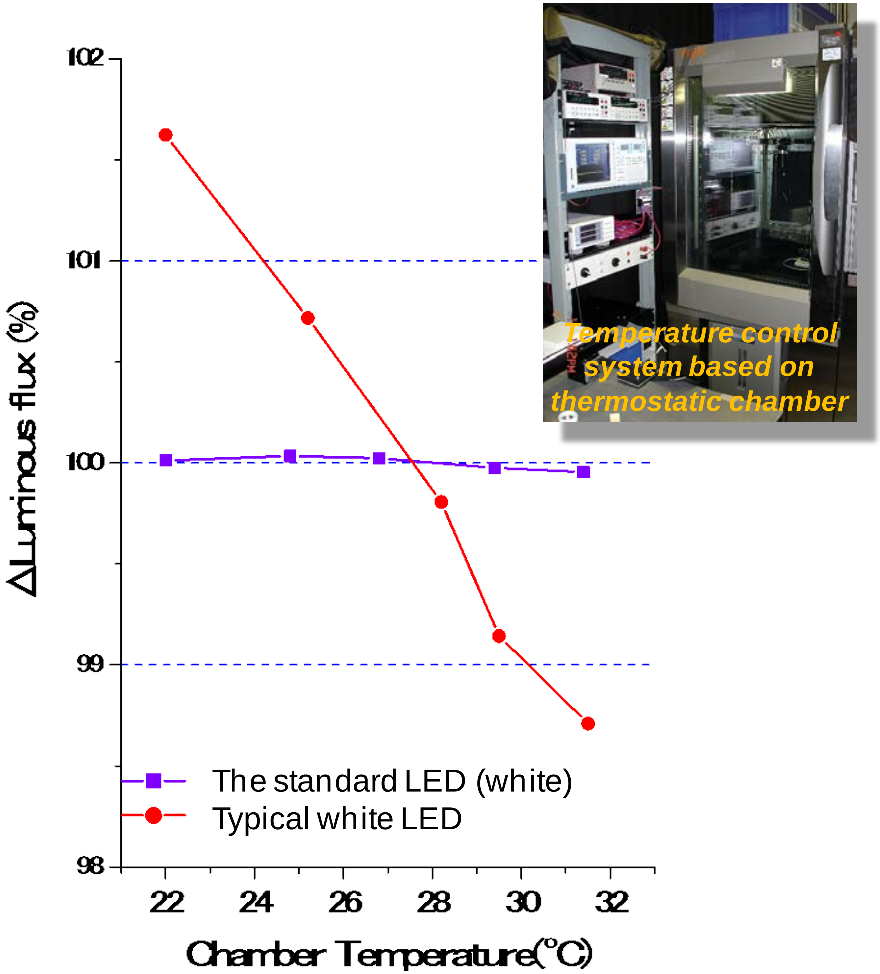


Spectral power distributions of the respective color LEDs

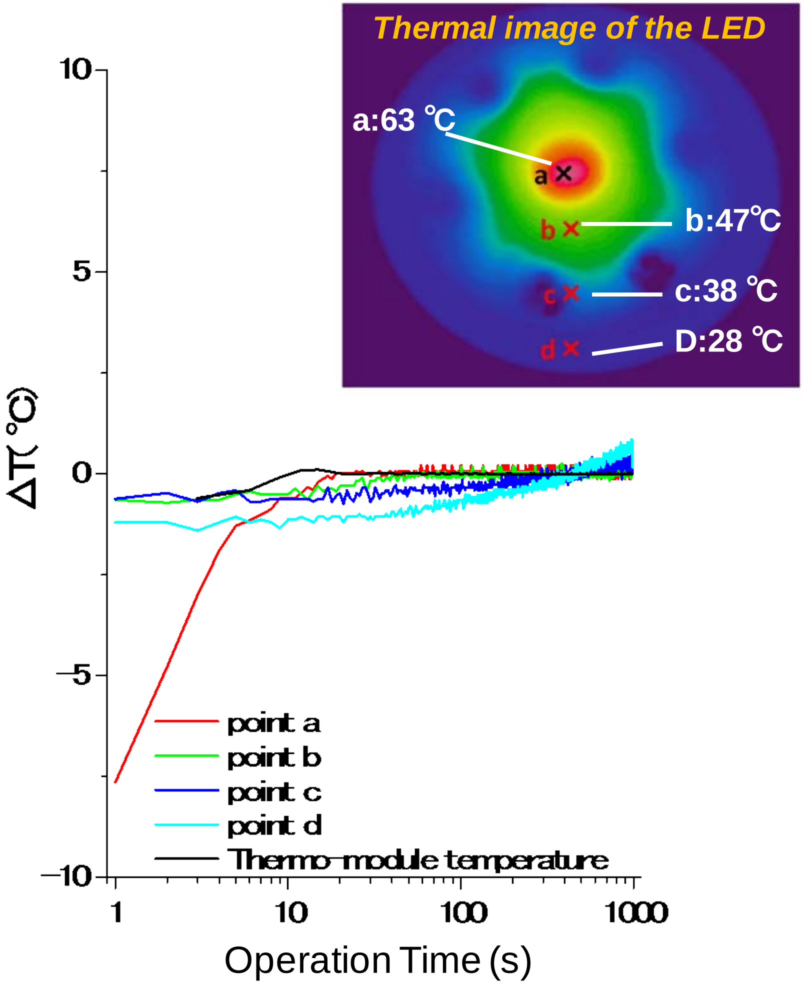


Angular dependence of spectral power distributions

Development of Luminous Flux Standard LEDs for High-Power LED Calibration (2)



The ambient temperature dependency of the standard LED (white) and a typical white LED.

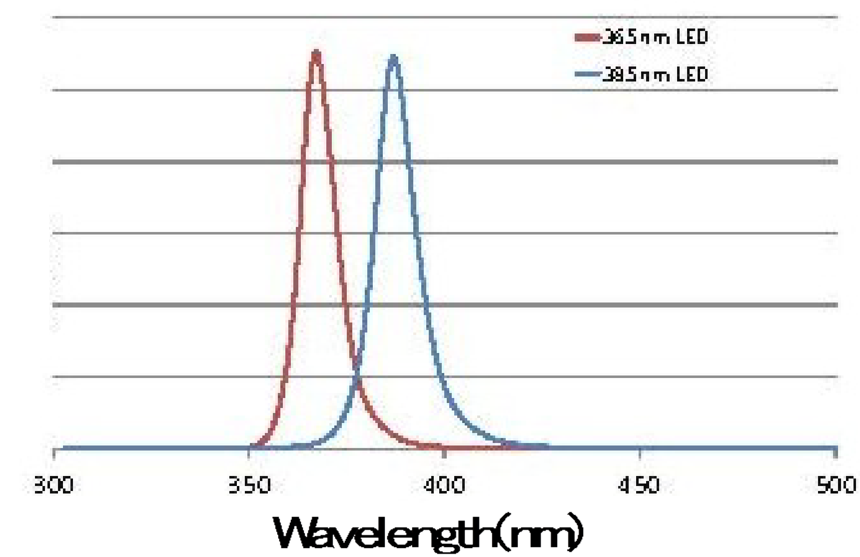


The operation temperature at each measurement point "x" shown in the above thermal image.

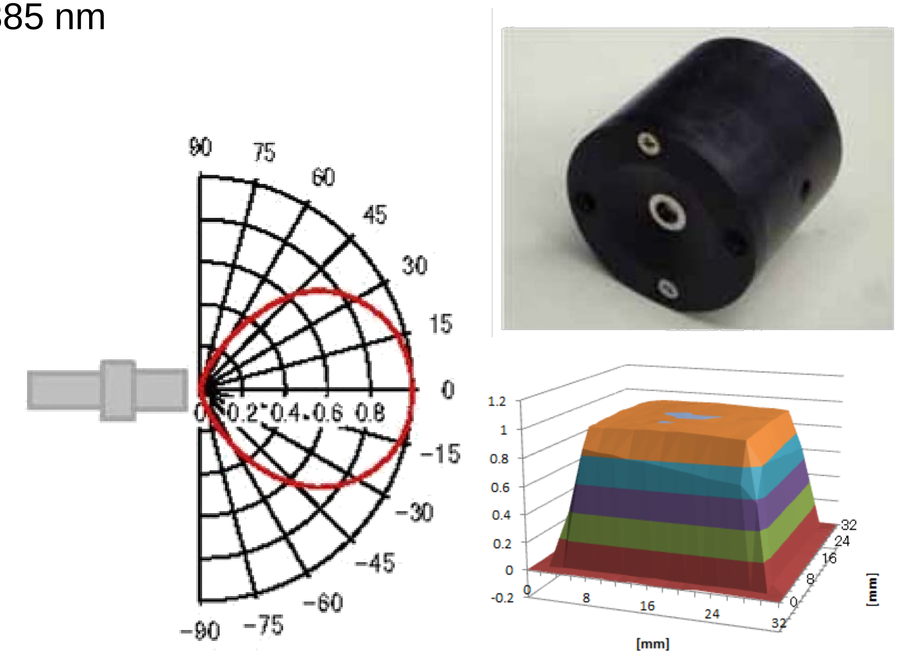
Development of Radiant Flux Standard LEDs for UV-LED Calibration

Radiant Flux Standard LED for UV-LED Calibration (radiant flux is from 0.4 to 0.8 W)

- NMIJ and NICHIA corporation jointly developed the LEDs.
- Radiant intensity distribution is optimized by introducing customized LED tips.
- The ambient temperature dependency is minimized.
- The LEDs are calibrated by using a gonio-spectroradiometer and a standard detector whose spectral irradiance responsivity scale was calibrated.
- The center wavelengths of the transfer standard are 365 nm and 385 nm



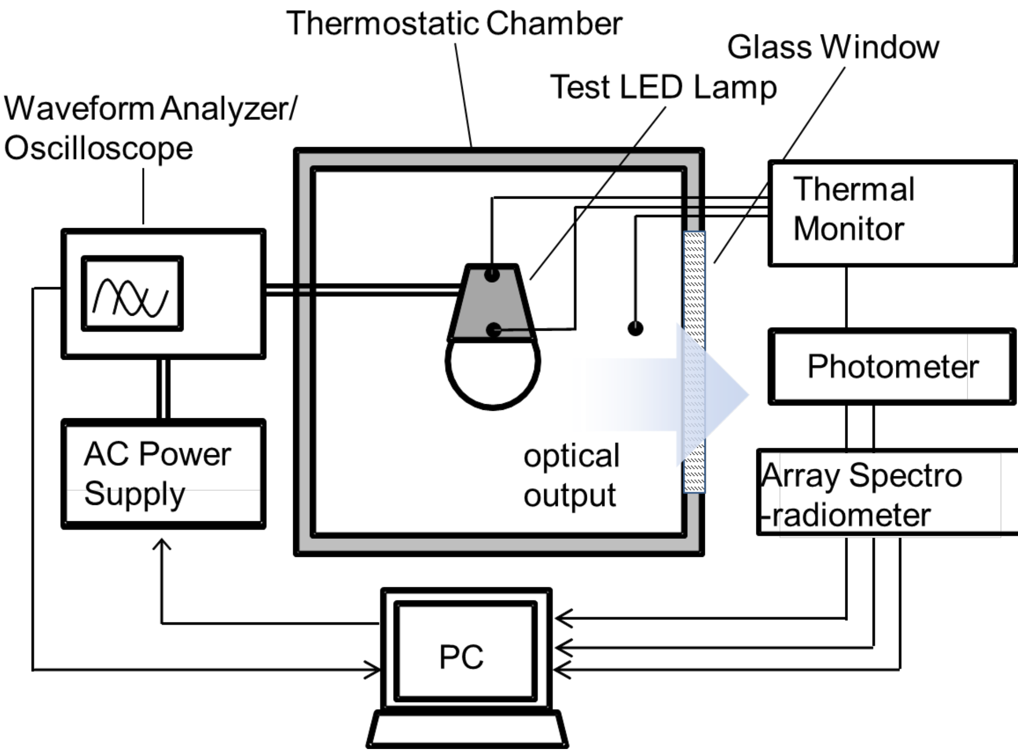
Spectral power distributions of the LEDs



Radiant intensity distribution and the standard detector

Development of Testing System for Light Source Evaluation (1)

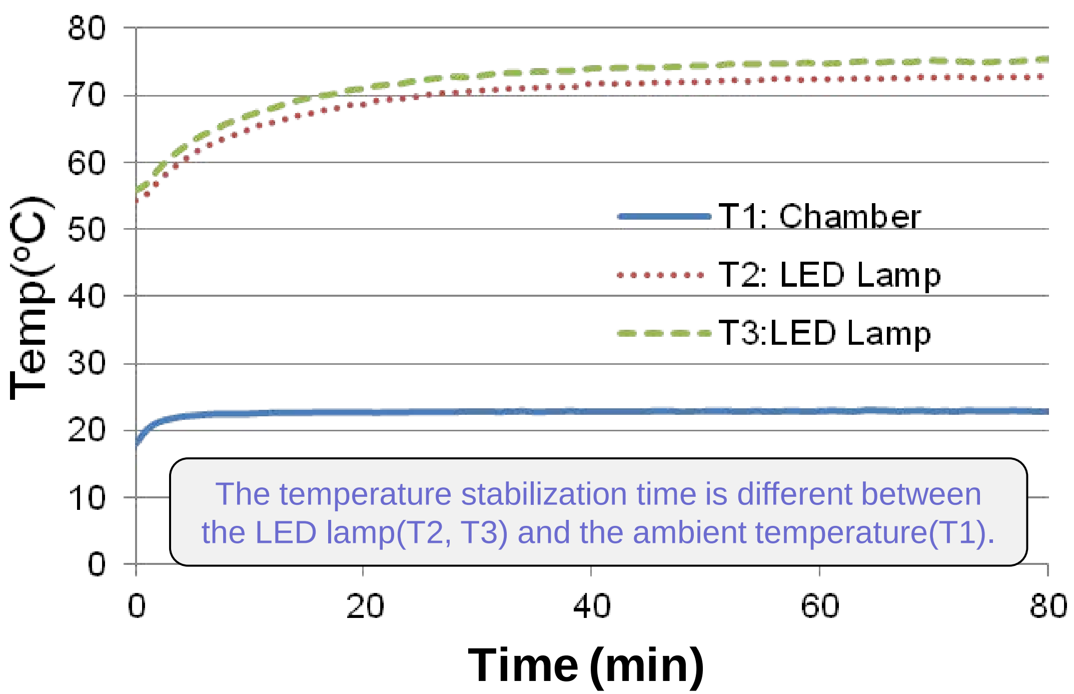
- The testing system consists of a thermostatic chamber, a power supply and monitor instruments.
- Ambient temperature dependency and aging characteristics of light source is evaluated.
- Electrical properties of light source is monitored by waveform analyzer and oscilloscope.
- Photometric and radiometric properties of light source is monitored by photometer and array-spectrometer.
- The testing system is used for evaluating light sources, such as commercial LED lamps, and used for selecting the artifacts which is appropriate for calibration.

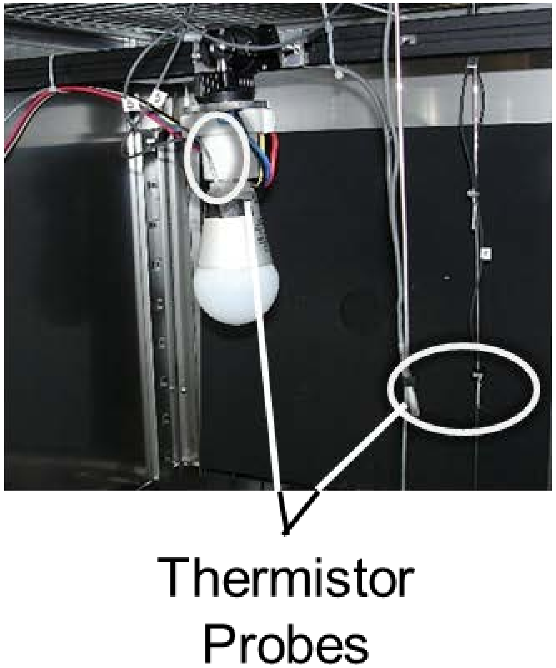


The testing system for light source evaluation.

Development of Testing System for Light Source Evaluation (2)

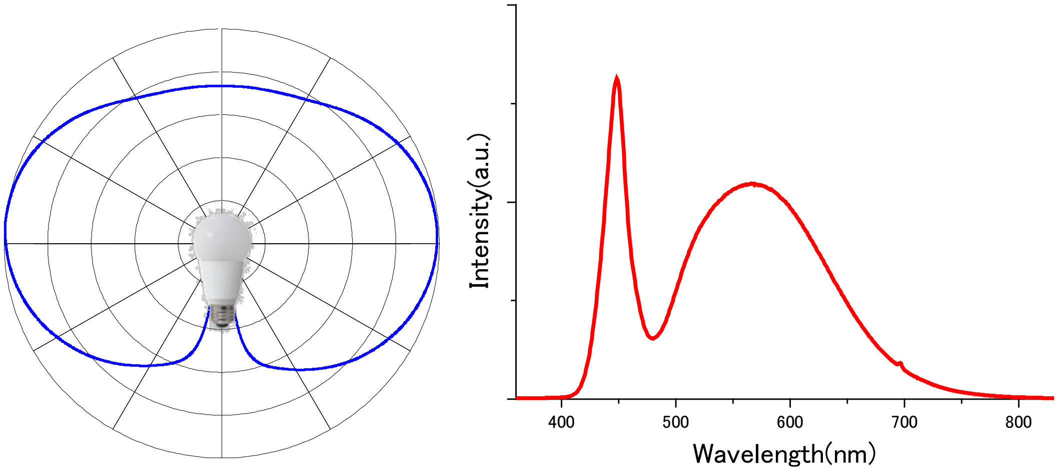
- The thermistor probes in the thermostatic chamber monitors the temperature of light source and the ambient temperature around light source.
- The time required for temperature stabilization is evaluated.
- The temperature difference on light source body is measured and thermal convection effect around the light source is evaluated.
- The light sources, such as commercial LED lamps, are evaluated for selecting the artifacts which is appropriate for calibration.





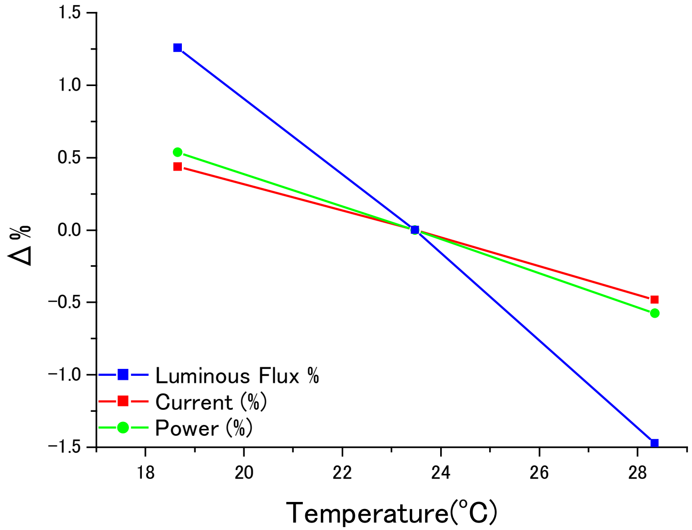
Typical temperature variation properties of LED lamp body and the thermostatic chamber.
The thermistor probes are set on the position shown the picture and the opposite position.

LED Lamp Test Result

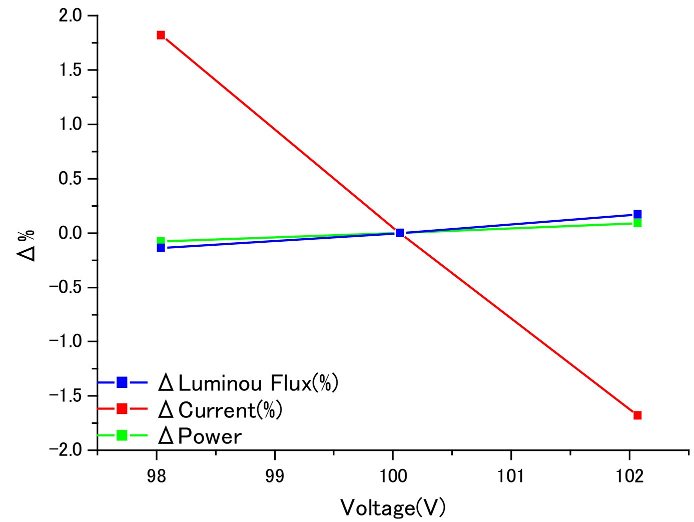


- One of test result of selected commercial LED lamp.
- Luminous flux reproducibility of the selected LED lamps are lower than 1 %.
- Several kind of selected LED lamps were used for IEA 4E SSL Annex Interlaboratory Comparison.
- The results of the comparison was referred to by the proficiency testing of Japanese testing laboratories.

Evaluation results of luminous intensity distribution and spectral distribution of a commercial LED lamp



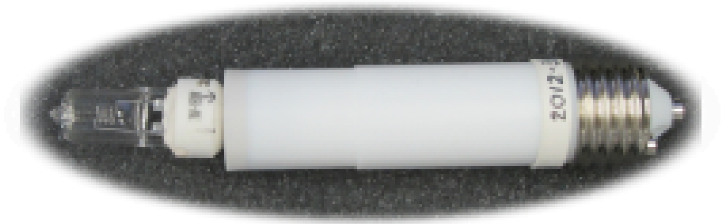
Ambient temperature dependency (Normalized by 23 ^{o}C)



Voltage dependency (Normalized by 100 V)

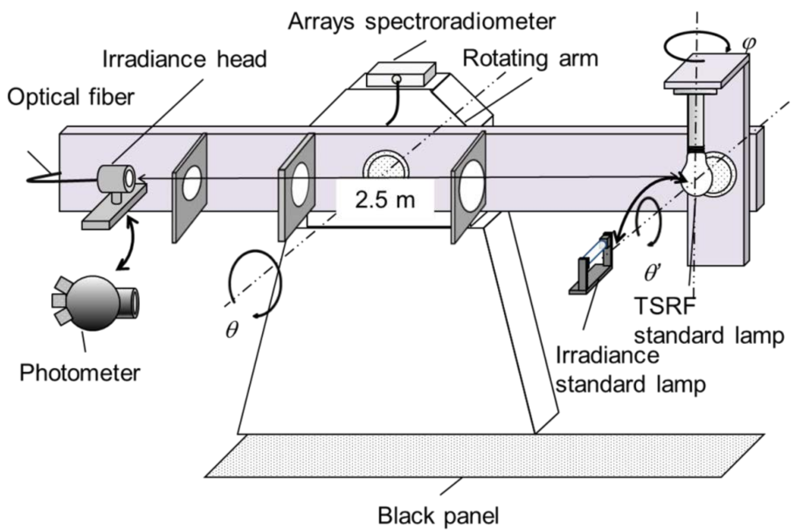
Establishment of Total Spectral Radiant Flux Standard for 4π Geometry

- Total spectral radiant flux (TSRF) standard in visible range (360 nm to 830 nm) was established by using a gonio-photometer and a gonio-spectroradiometer.
- A halogen lamp, which has sufficiently high CCT and stable optical power, was selected as the transfer standard lamp for TSRF calibration.

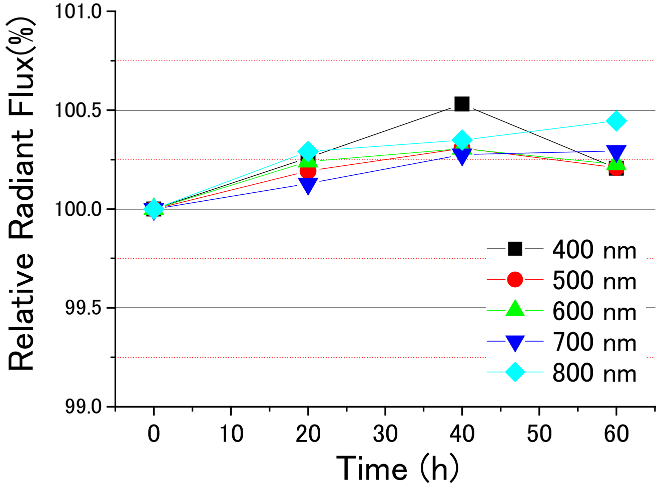


- A 24V-150W QH lamp
- Total luminous flux: approximately 3 000 lm
- CCT: approximately 3 100 K

- Relative Expanded Uncertainty (k=2): 4.0 % to 3.1% (varied with wavelength)



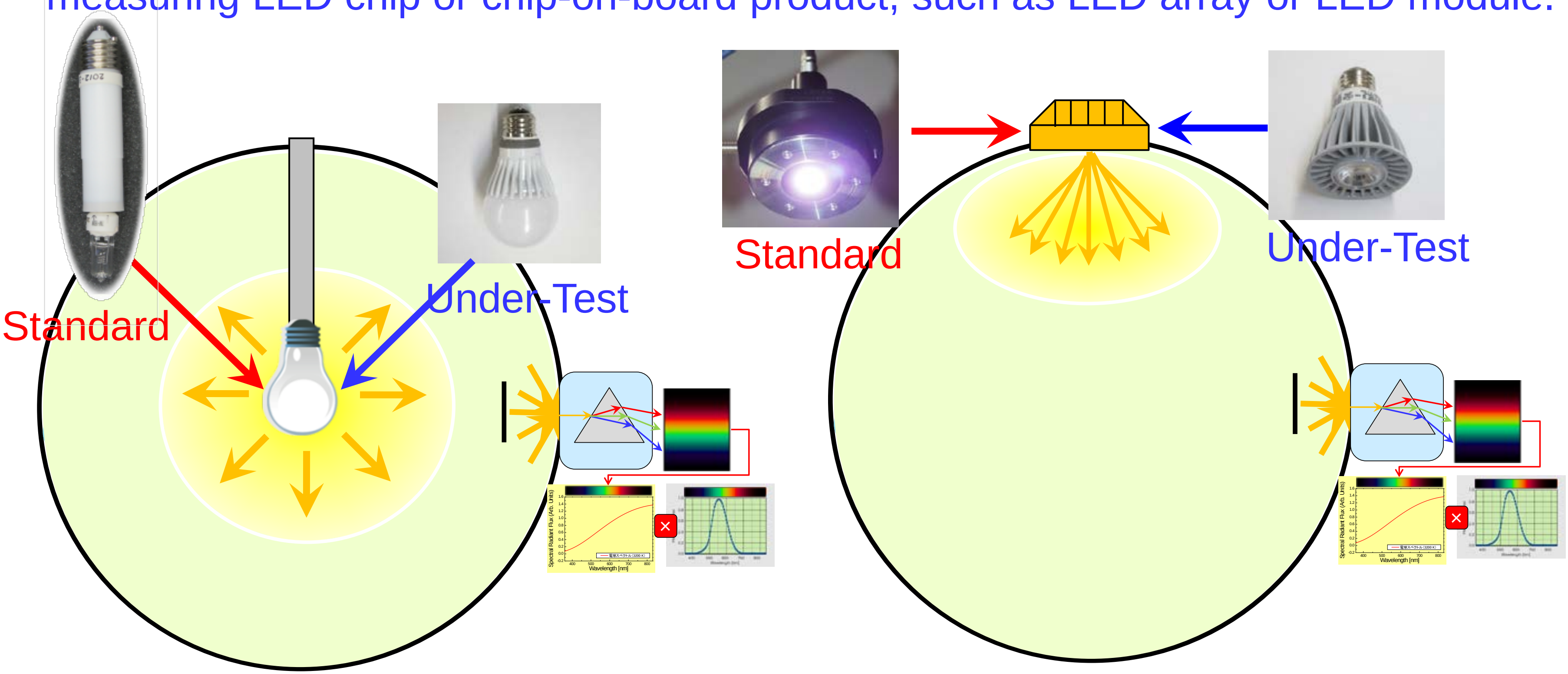
NMIJ gonio-photometer/spectroradiometer



Spectral ageing trend of the TSRF standard lamps after the 100 h pre-seasoning

Two Kinds of Measurement Configurations

- Integrating sphere has two kinds of measurement configurations, such as 4π and 2π, different in light source setting.
- 4π and 2π configurations are appropriate for omni-directional and directional light sources, respectively.
- LED is principally directional light source, so 2π configuration is appropriate for measuring LED chip or chip-on-board product, such as LED array or LED module.

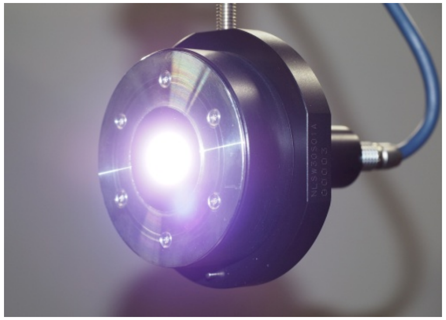


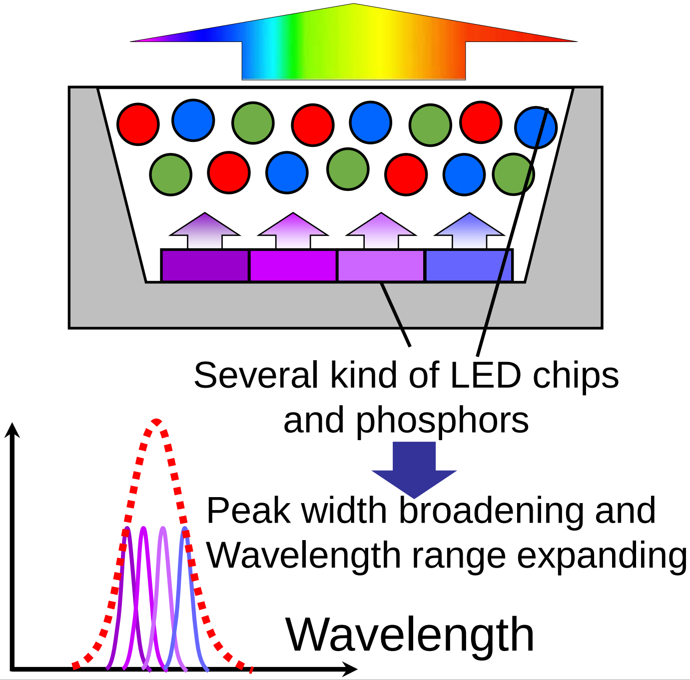
4π configurations

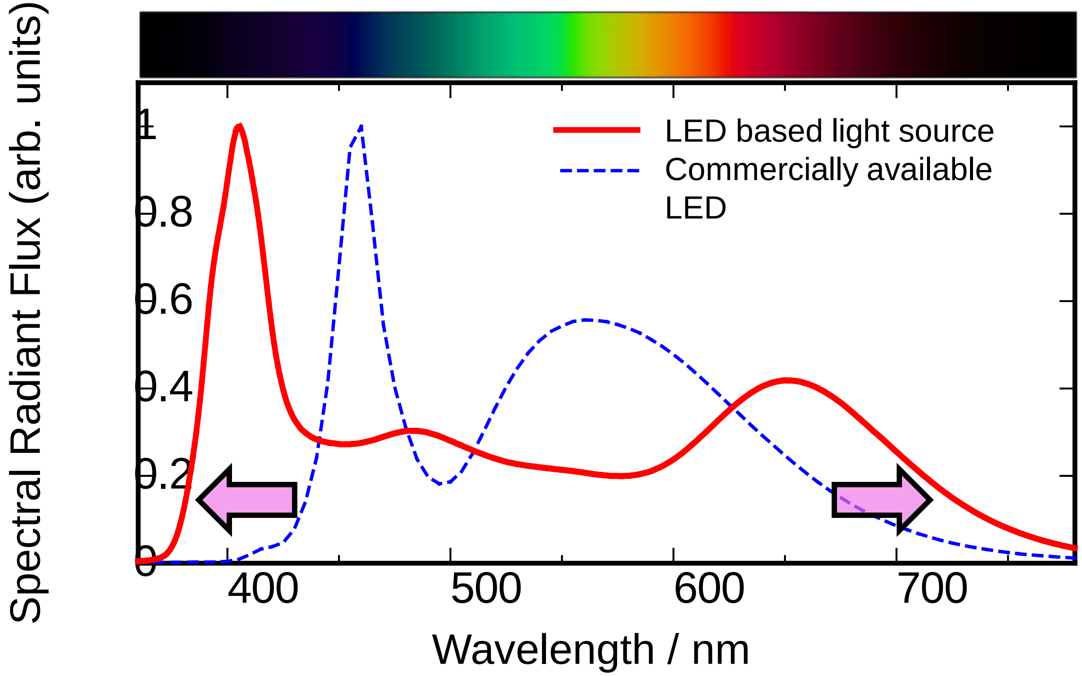
2π configurations

Development of LED based Light Source Appropriate for Total Spectral Radiant Flux Standard for 2π Geometry

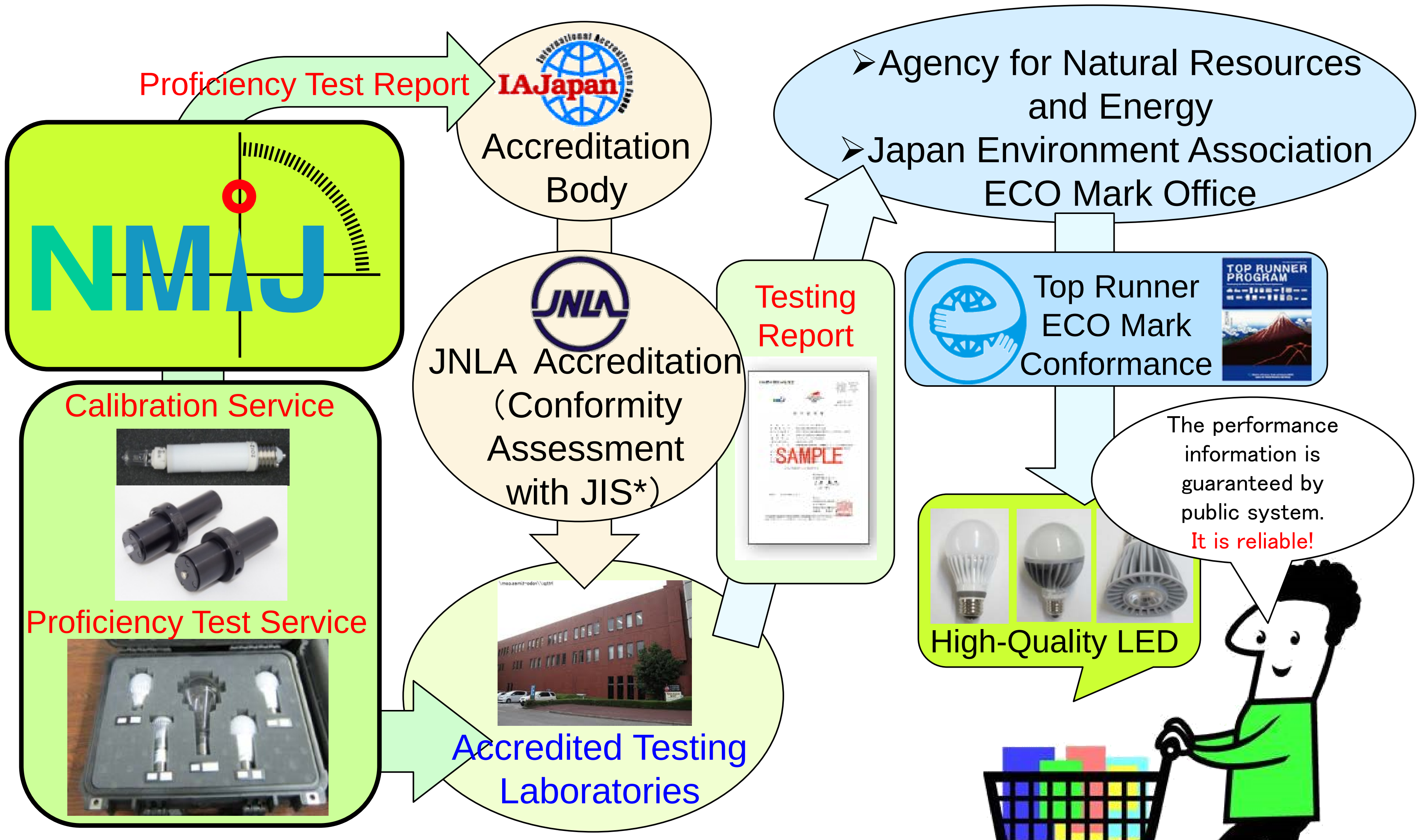
- NMIJ and Nichia Corporation have developed a LED based light source which is appropriate for spectral radiant flux standard for 2π Geometry
- The spectrum of the light source is broader than that of the commercially available LED in wavelength The radiation spectrum covers the wavelength of 380 nm to 780 nm.
- The wavelength range in which spectrum does not have steep peaks or valleys is much wider than that of the commercially available LED.







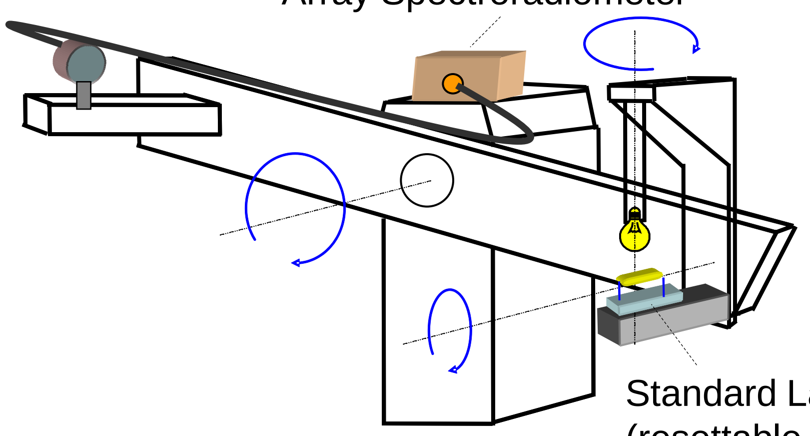
Conducting a Proficiency Testing for LED Based Lighting

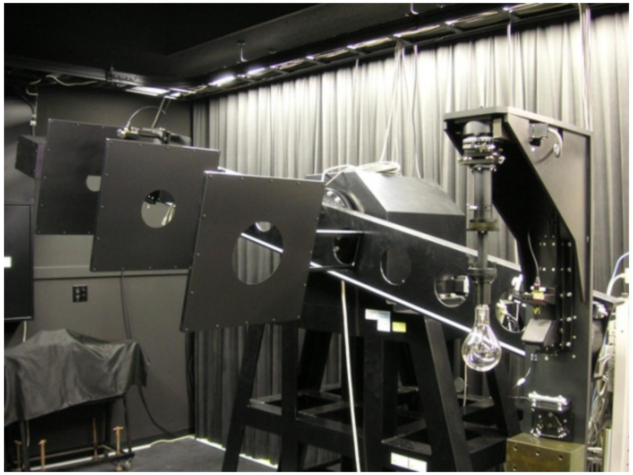


*JIS: Japanese Industrial Standards (Document Standard)

Thank you for your attention

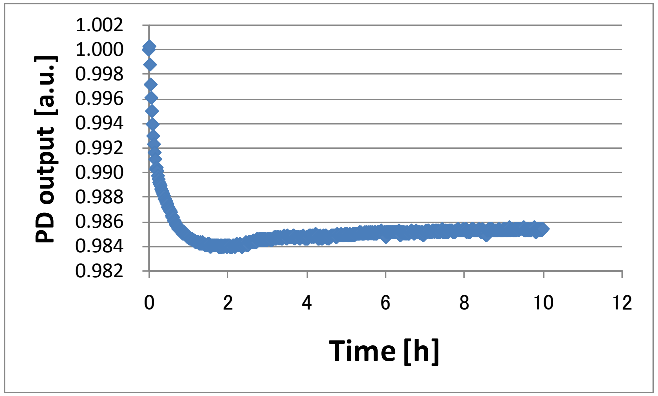
Development of Total Spectral Radiant Flux Standard





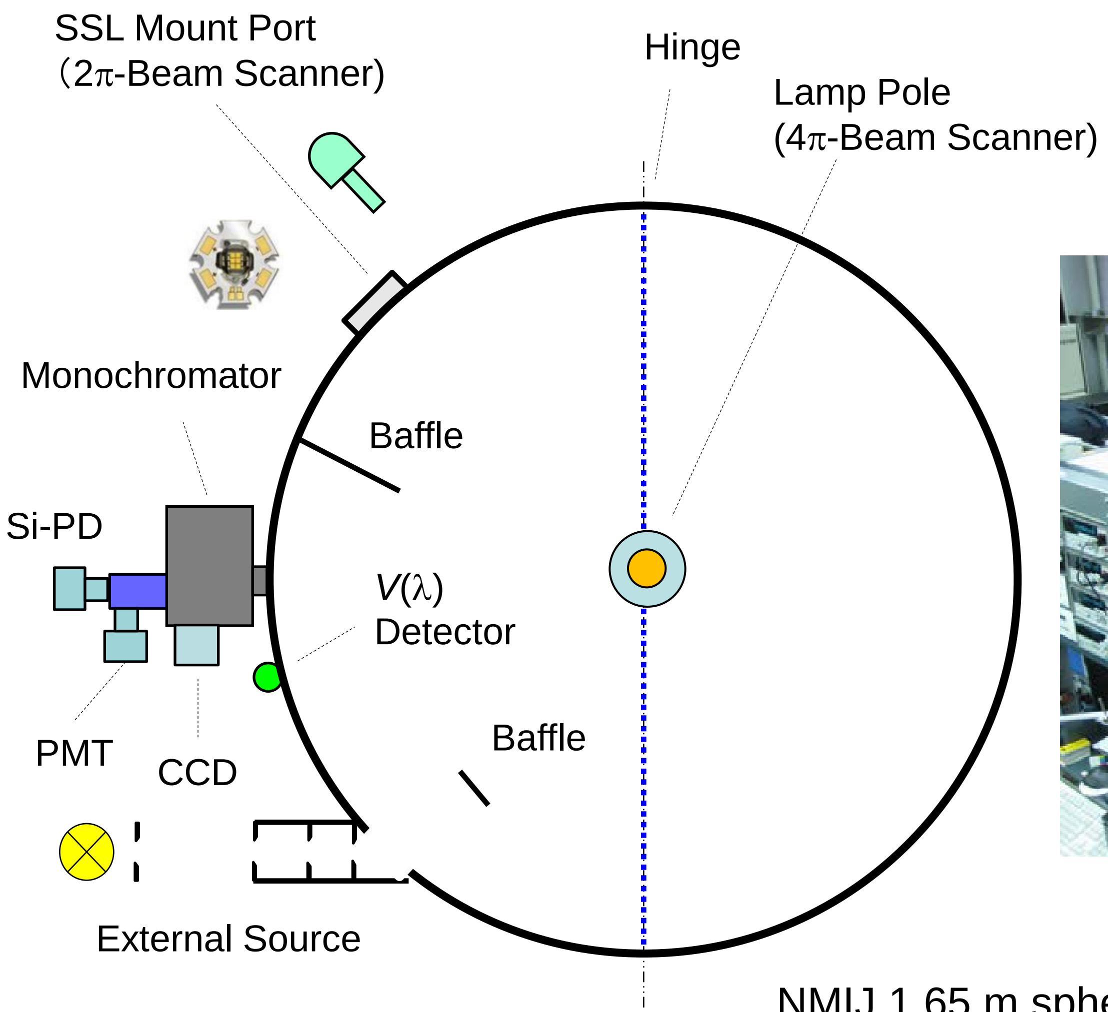
NMIJ gonio-spectroradiometer with photometric distance at 2.7 m

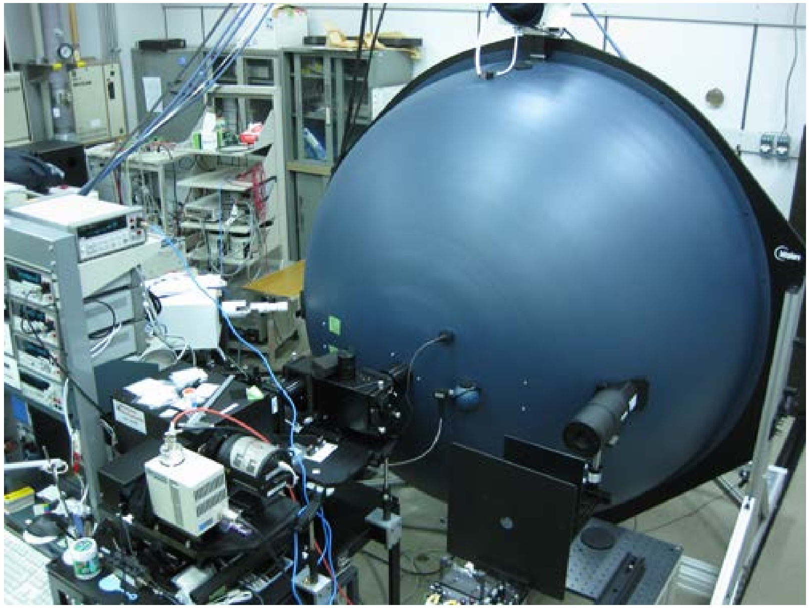
Candidate of transfer standard lamp



Example of a seasoning test

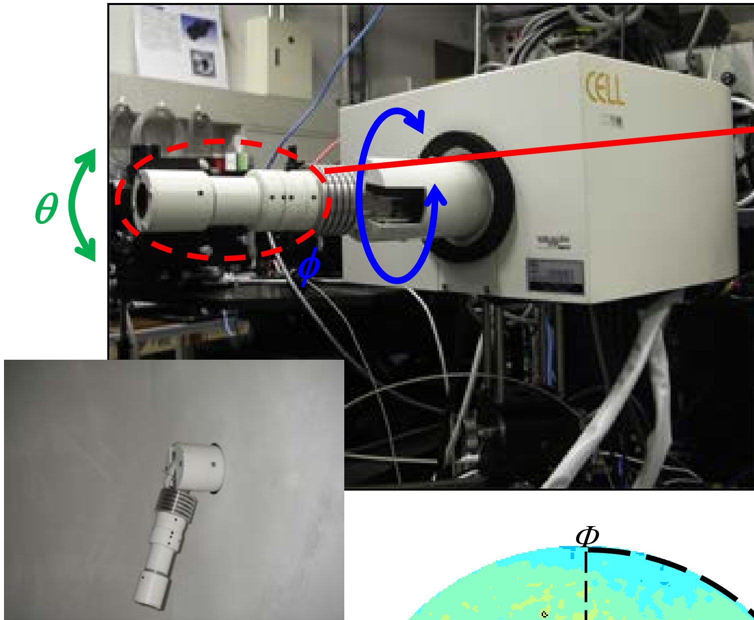
Sphere Spectoradiometer System for Total Spectra Radiant Flux Standard





NMIJ 1.65 m sphere spectroradiometer system

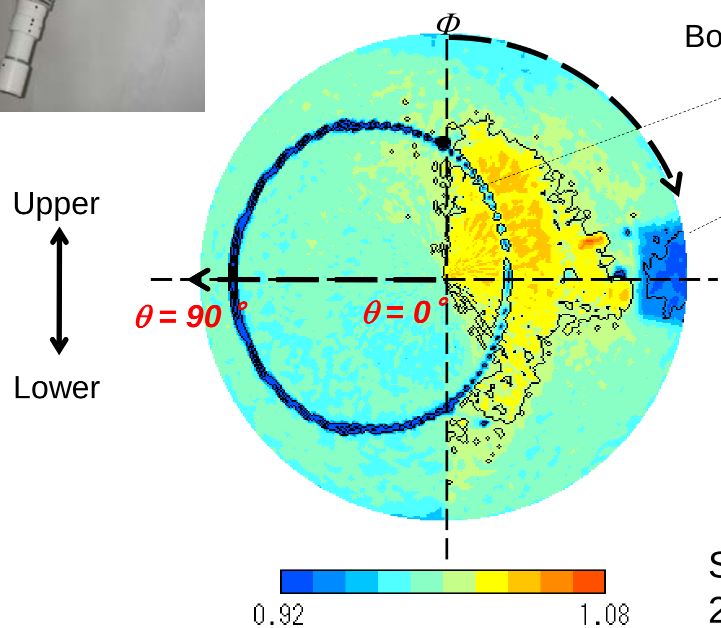
Beam Scanner for 2π Illumination Geometry

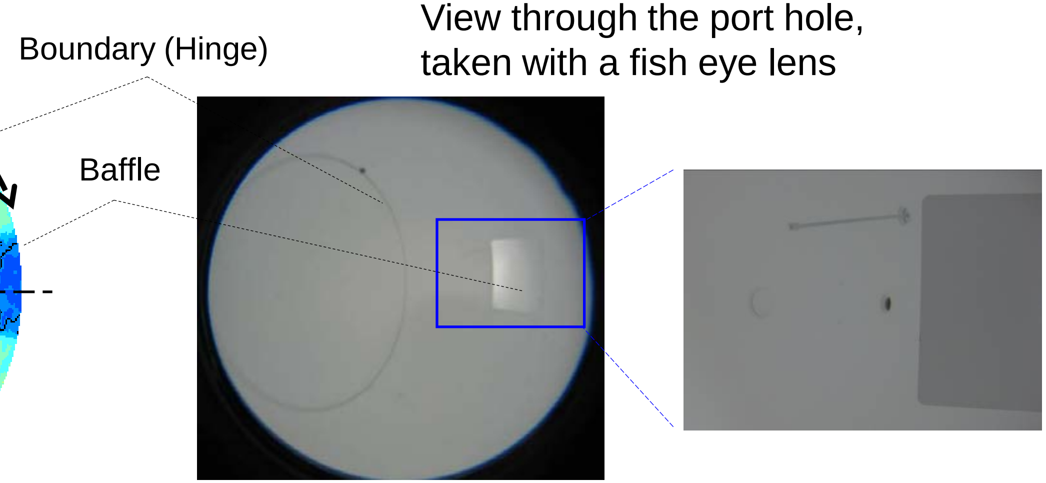


Beam Scanner Head

- Collimate beam by high-power LEDs
- Temperature control for LEDs by thermal-electrical cooler with change of less than 0.1 % over 8 hours

The beam scanner for 2π illumination geometry (left)



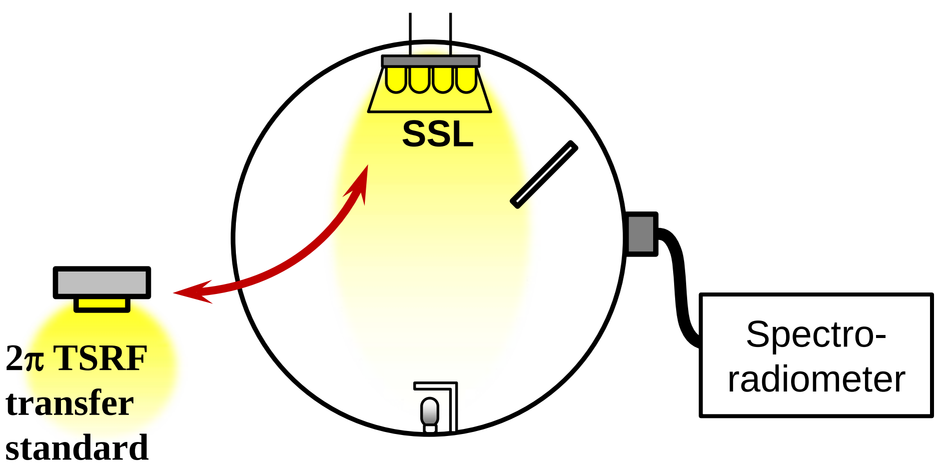


View through the port hole, taken with a fish eye lens

SRDF of NMIJ integrating sphere system under 2π illumination geometry

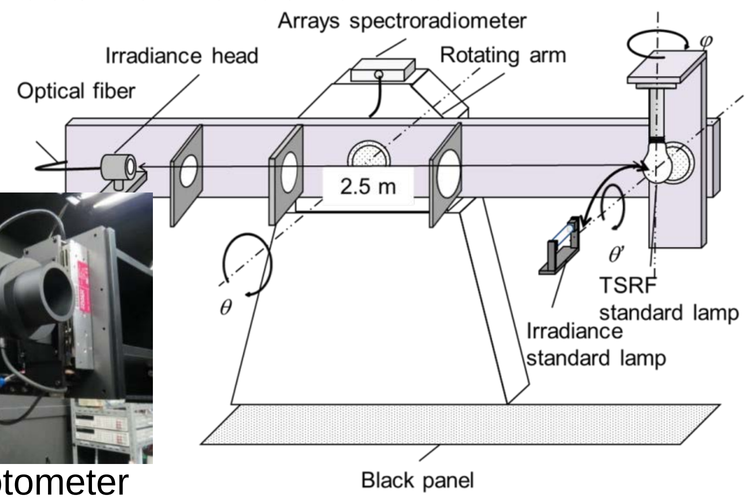
Development of Total Spectral Radiant Flux Standard for 2π sphere geometry

- Strong industrial demand for a standard under 2π geometry in integrating sphere-based measurement
- Suitable for 2π sources such as high-power LEDs or OLEDs, whose radiation only emit within the front hemisphere of them
- Total spectral radiant flux (TSRF) standard under 2π geometry being developed
  - Based on a gonio-photometer/spectroradiometer
  - Installing a new photometer for the realization of the 2π TSRF standard
- Development of a transfer standard suitable for the 2π TSRF standard
  - Luminous intensity distribution being approximated to Lambertian
  - Spectral range: 380 nm to 780 nm, Total luminous flux: around 200 lm



2π sphere geometry


New photometer



NMIJ gonio-photometer/spectroradiometer

Outline of the Interlaboratory Comparison in Japan

・Number of the participant : 12 laboratories
(3: public test laboratories, 9: manufactures)

・Artifacts
We selected 5 types of artifacts for the IC: 4 are LED lamps and one is an incandescent lamp

・Schedule: Nov 2012～Jun 2013
The participant laboratories were divided into 4 groups.
Until end of March, 10 participants finished their measurements.

Fig. IC artifacts

What we did for our Interlaboratory Comparison

✓**April 2012～July 2012: Selection of the artifacts for the IC and Setup the sphere-spectororadiometer system**

- The 4 LED lamps and the incandescent lamp were selected as our artifacts
- The sphere-spectororadiometer system was set up for calibrating the IC artifacts.

✓**July 2012～Sep 2012: Our working standards calibration**

- The working standards were calibrated by our gonio-photometer (Our Total Spectral Radiant Flux standard lamps and additional artifacts' set)
- One artifacts' set was calibrated for the comparison with NIST.

✓**Sep 2012～Nov 2012: Validation of our sphere-spectororadiometer comparison.**

- The correction factor caused by the spatial non-uniformity of our sphere-spectororadiometer were derived.
- Other error factors were evaluated.

✓**Nov 2012～Jun 2013: Calibration and management for Interlaboratory comparison**

- We started our IC artifact's circulation in Japan from middle of November,
- Until end of March 2013,10 participants finished their measurements.

The IC Artifacts in Japan

Identifier	Lamp Type	Manufacture/Model			
		Rated voltage	Rated Power	Power Factor	Nominal CCT
AIST-IAC/IDC	Incandescent	Toshiba Lighting/ Total luminous flux standard lamp			
		100V, AC 50 Hz /100 V DC	200 W	1.0	2800 K
AIST-OD	Omnidirectional	NEC Lighting/ LDA9L-G			
		100V, AC 50 Hz	9.0W	0.91	3000 K
AIST-D	Directional	Mitsubishi Electric Osram/ LDR5L-W-E17			
		100V, AC 50 Hz	5.0 W	0.63	3000 K
AIST-HCCT	High CCT	NEC Lighting /LDA9N-G			
		100V, AC 50 Hz	9.0 W	0.95	5100 K
AIST-LPF	Low power-factor	Hitachi Appliances/ LDA11D-G			
		100V, AC 50 Hz	11.4 W	0.58	6000 K

Artifacts Drift (Difference of go and return measurements in AIST)

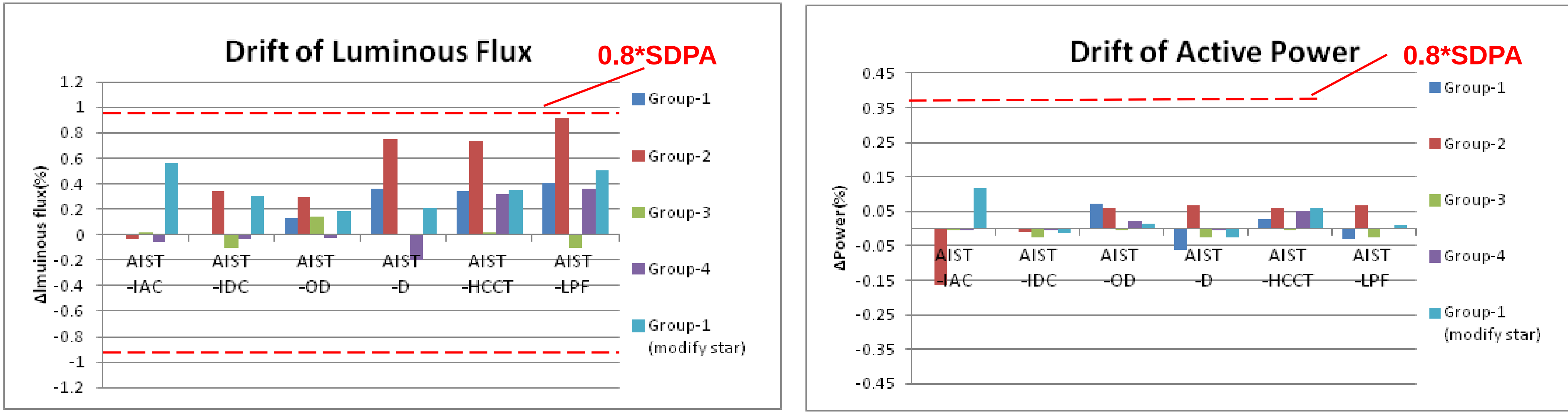


Fig. Drift of luminous flux and active power

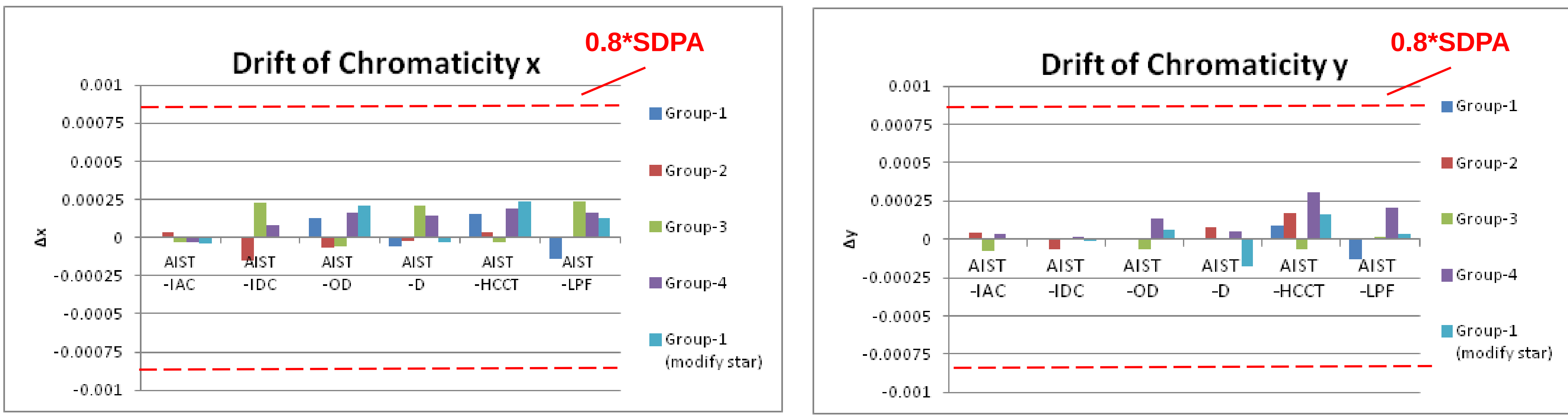


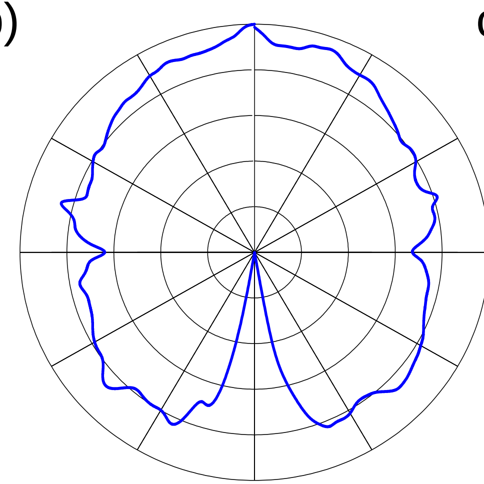
Fig. Drift of chromaticity

We confirmed reliability of our artifacts

AIST-IAC/IDC Incandescent

a)

b)



c)

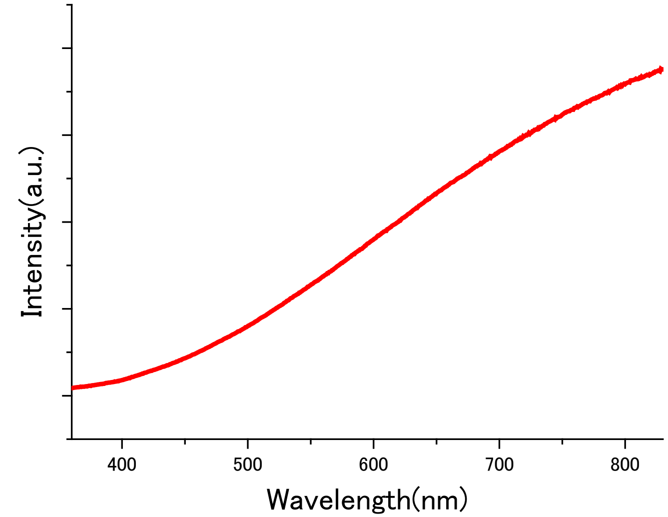


Fig. AIST-IAC/IDC Toshiba Lighting/Total luminous flux standard lamp

a)Picture, b) Angular distribution, c)Spectral distribution

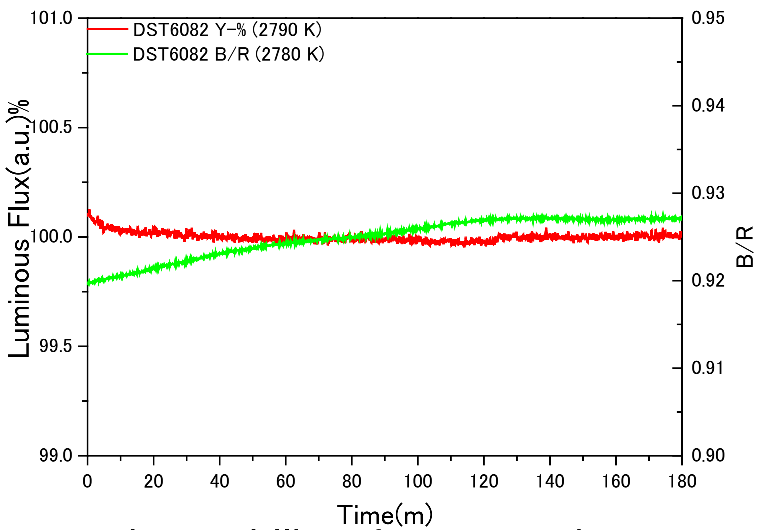


Fig. Stability of AIST-IAC/IDC

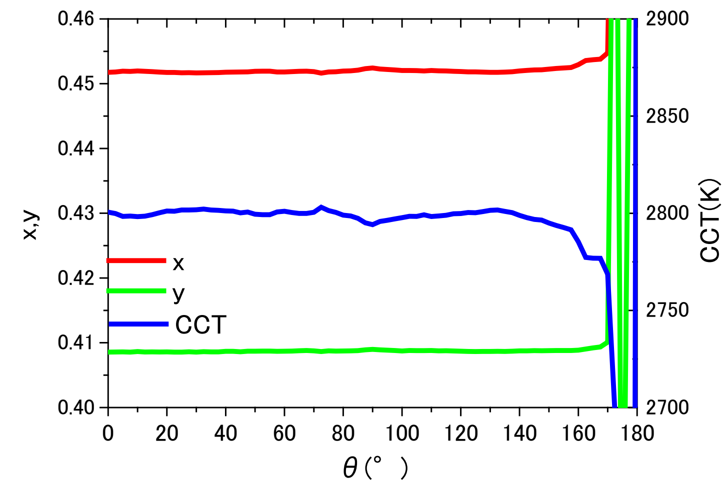


Fig. Angular distributions of color

AIST-OD：Omnidirectional

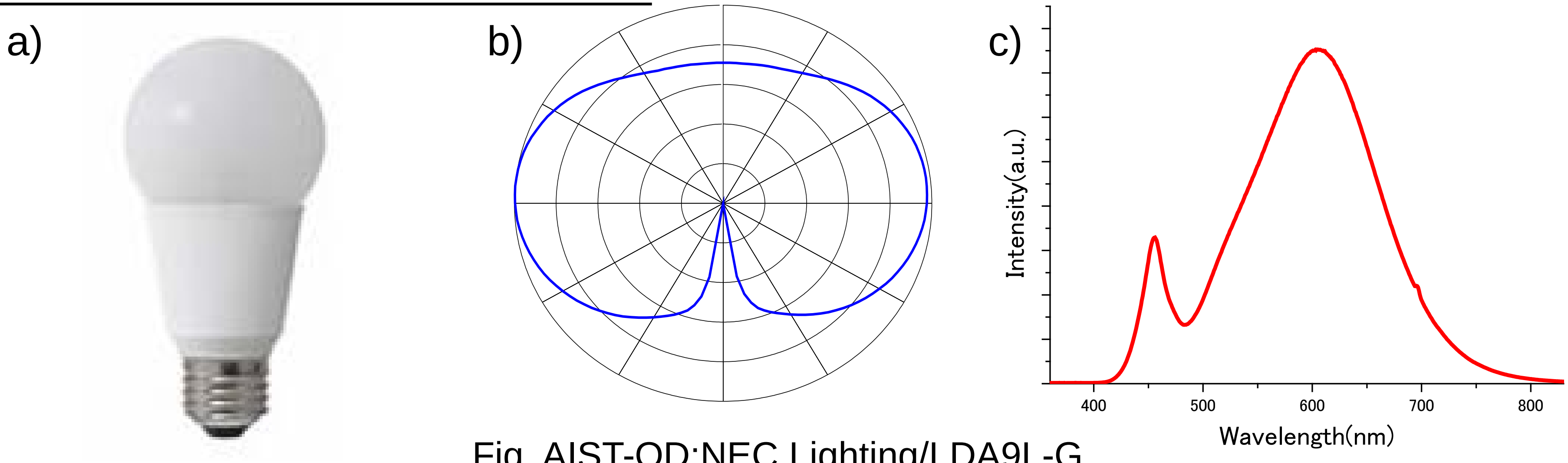


Fig. AIST-OD:NEC Lighting/LDA9L-G
a)Picture, b) Angular distribution, c)Spectral distribution

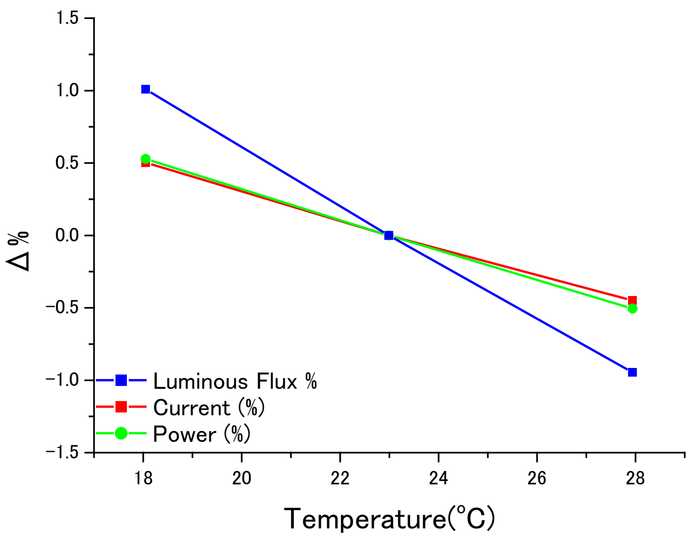


Fig. Temperature dependence (Δ=0.0% @23℃)

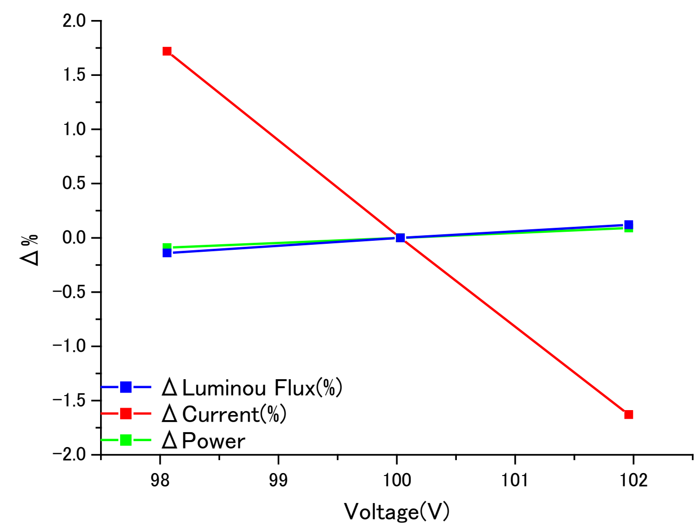


Fig. Voltage dependence (Δ=0.0% @100V)

AIST-D : Directional

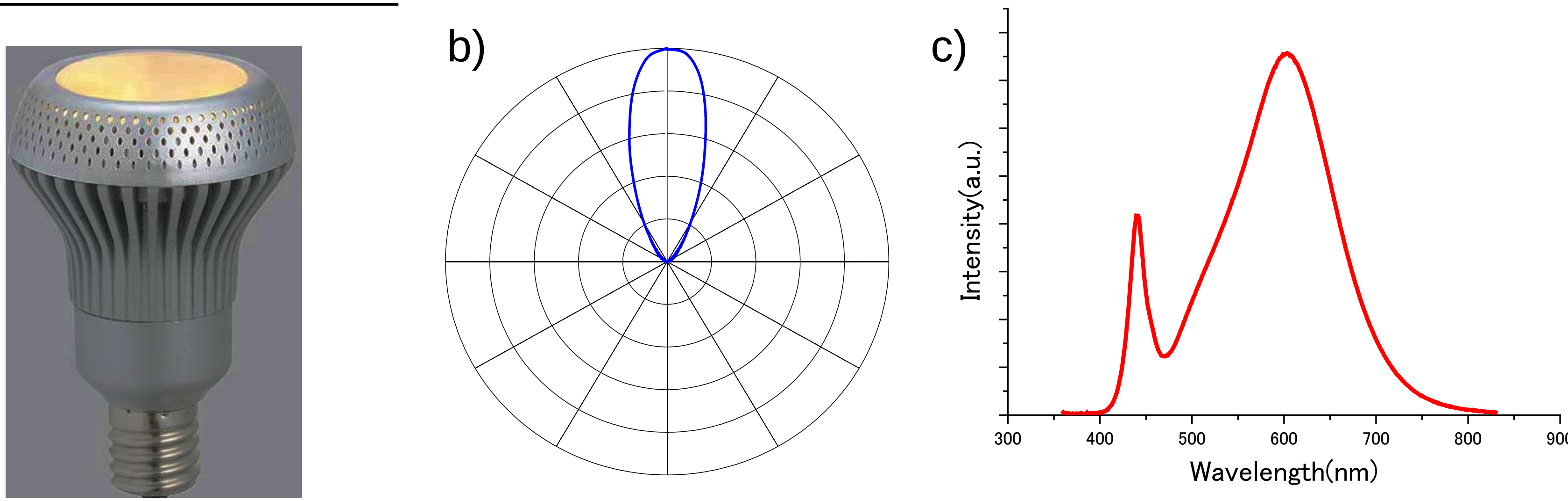


Fig.AIST-D Mitsubishi Electric Osram/LDR5L-W-E17
a)Picture, b) Angular distribution, c)Spectral distribution

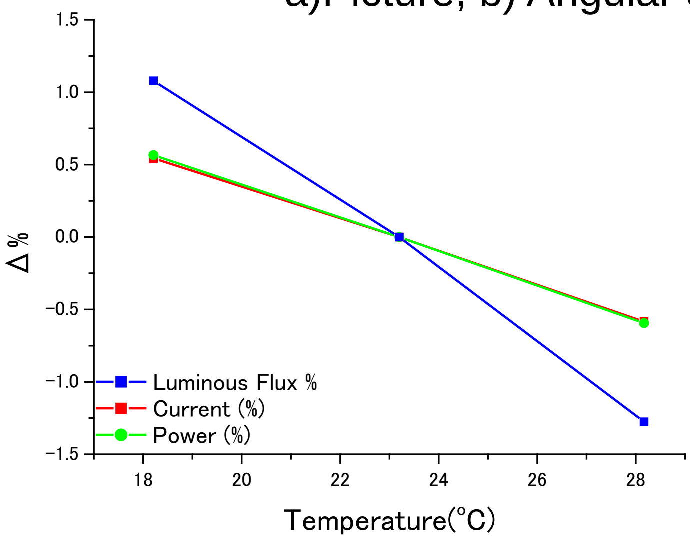


Fig. Temperature dependence (Δ=0.0% @23℃)

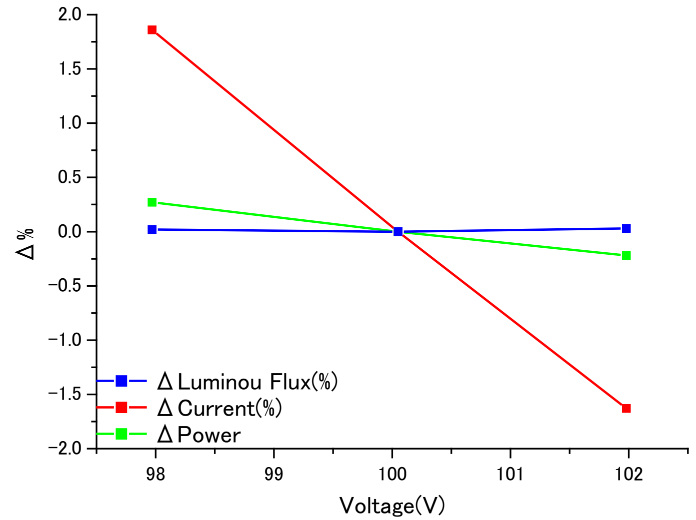
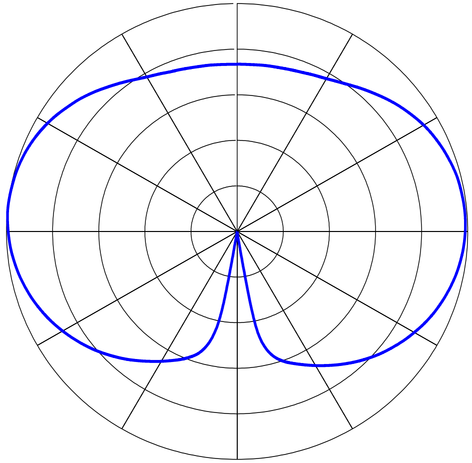


Fig. Voltage dependence (Δ=0.0% @100V)

AIST-HCCT：High CCT

a)

b)



c)

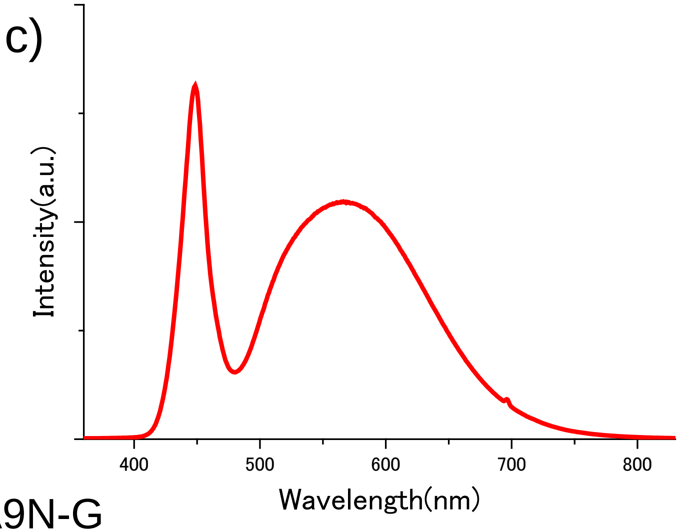


Fig. AIST-HCCT:NEC Lighting/LDA9N-G
a)Picture, b) Angular distribution, c)Spectral distribution

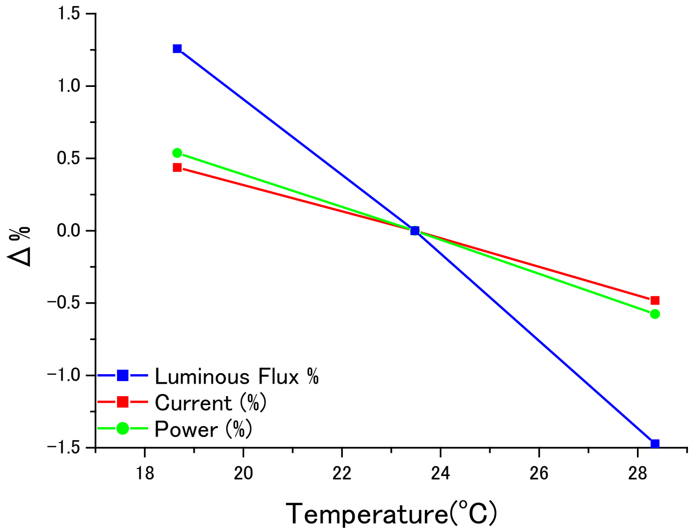


Fig. Temperature dependence (Δ=0.0% @23℃)

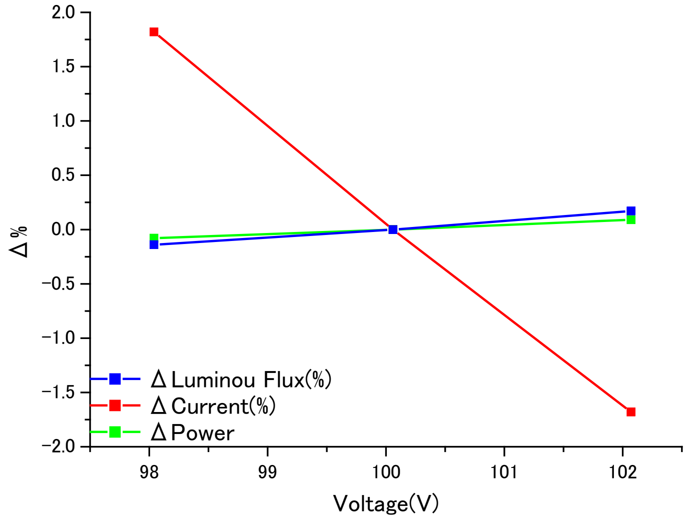


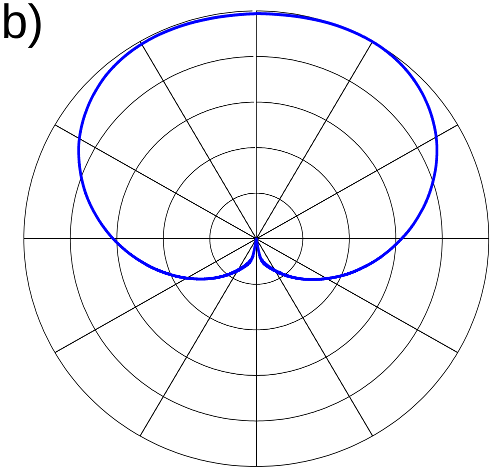
Fig. Voltage dependence (Δ=0.0% @100V)

AIST-LPF：Low power-factor

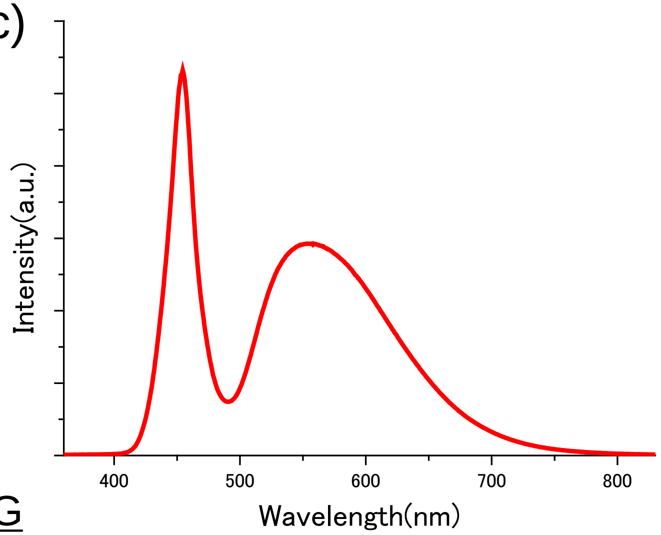
a)

Fig AIST-LPF

b)



c)



Hitachi Appliances/LDA11D-G

a)Picture, b) Angular distribution, c)Spectral distribution

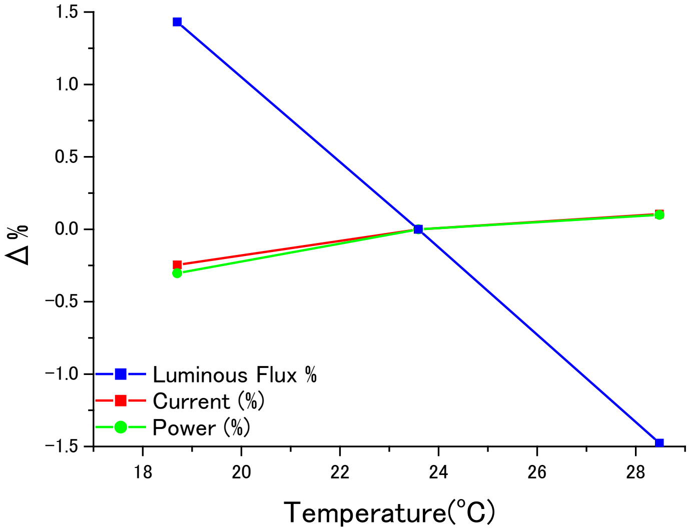


Fig. Temperature dependence (Δ=0.0% @23℃)

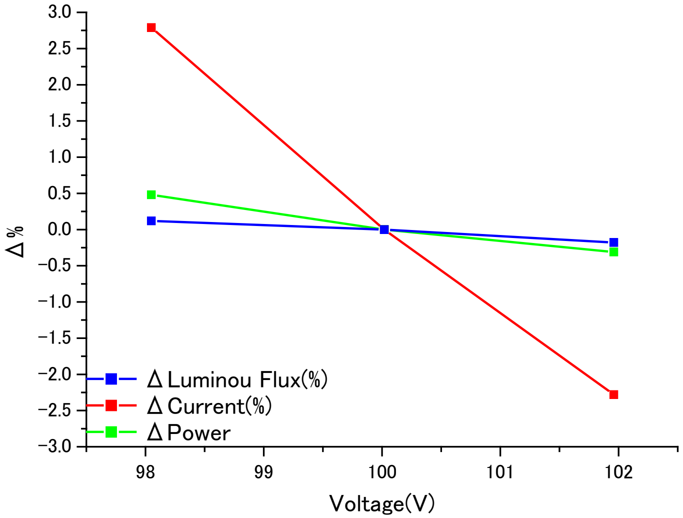
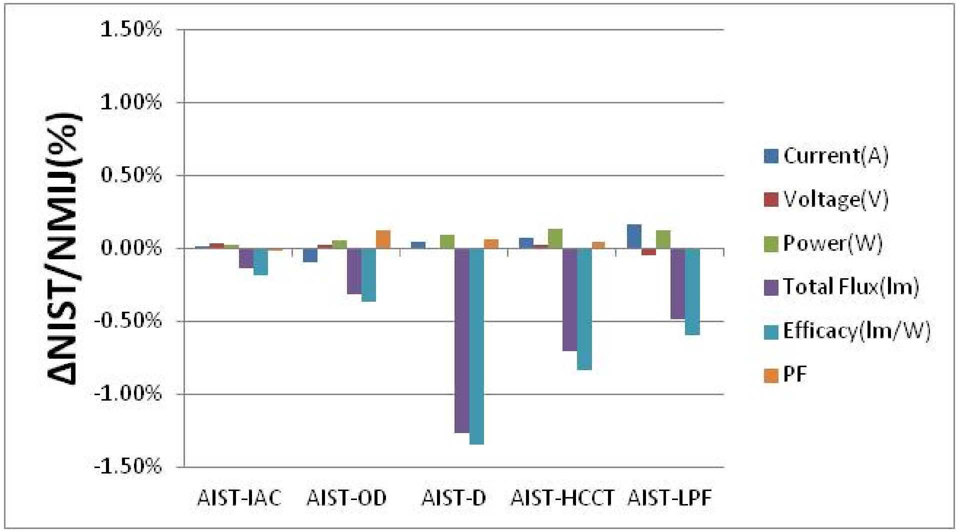


Fig. Voltage dependence (Δ=0.0% @100V)

Comparison results between NIST and NMIJ with Japan IC Artifacts

Last year (Sep/2012～Nov/2012), NMIJ sent IC Artifacts to NIST.



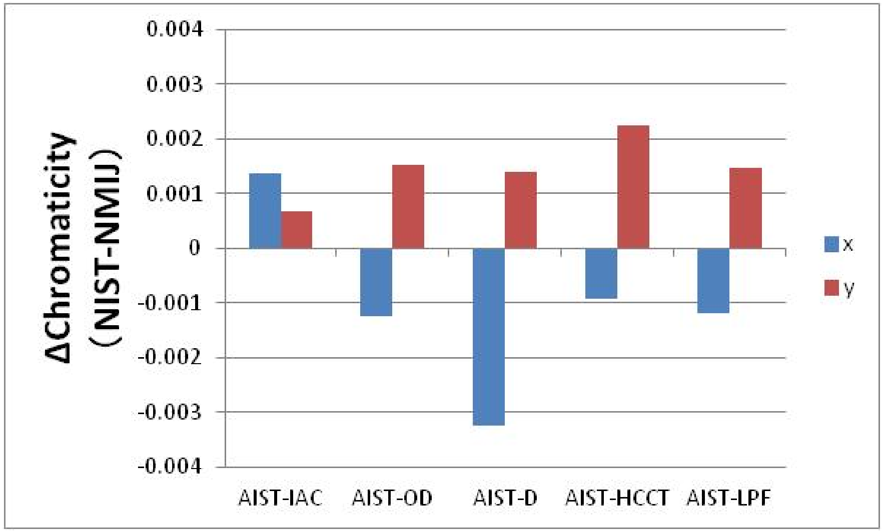
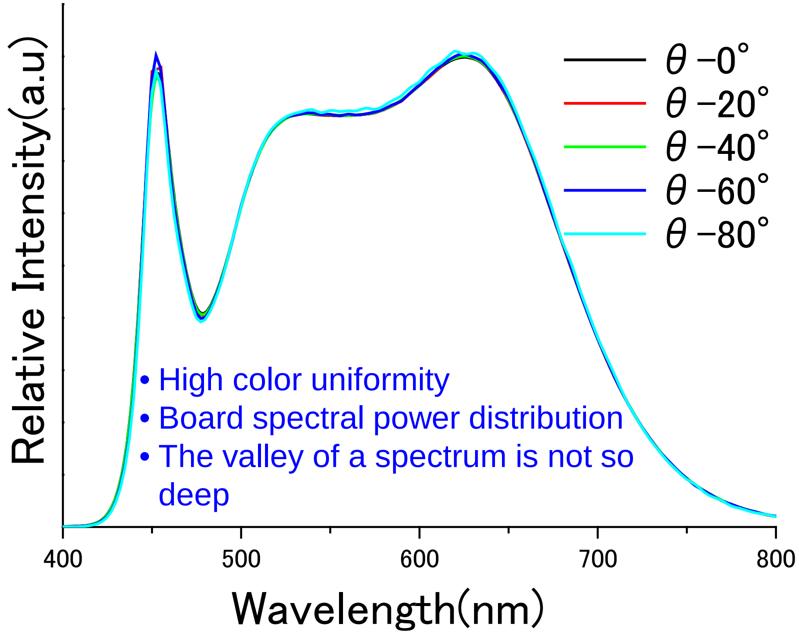


Fig. Comparison results (left fig:luminous flux et.al, right fig:chromaticity)

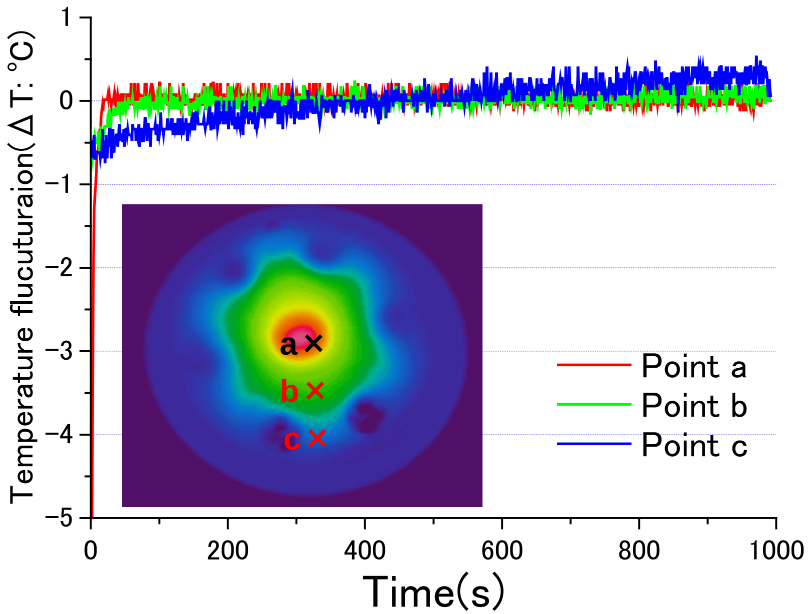
Development of Luminous Flux Standard LEDs for High-Power LED Calibration

Luminous flux standard LED for high-power LED Calibration (rated luminous flux: 68 lm)

- NMIJ and NICHIA corporation jointly developed the standard LEDs.
- Optimizing luminous intensity distribution and spectral power distribution by introducing customized LED tips.
- The temperature dependency is reduced by a thermo-module introduced for stabilizing the LED-chip temperature.
- There are 4 different colors (White, Blue, Green and Red).



Angular dependence of spectral power distributions



Evaluation of LED temperature by thermal image

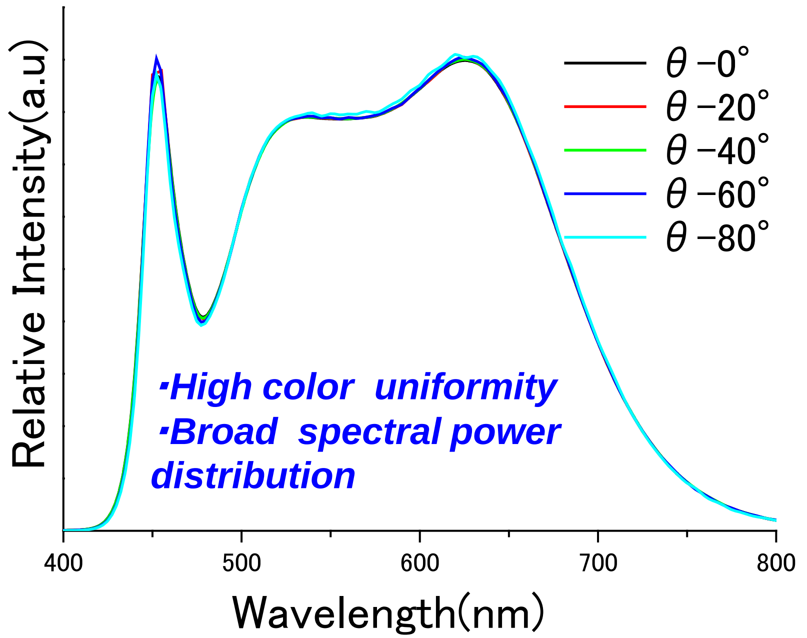
Development of Standard LEDs for Low-Power LED Calibration

Standard LEDs for CIE Averaged LED Intensity Calibration
Standard LEDs for Luminous Flux Calibration

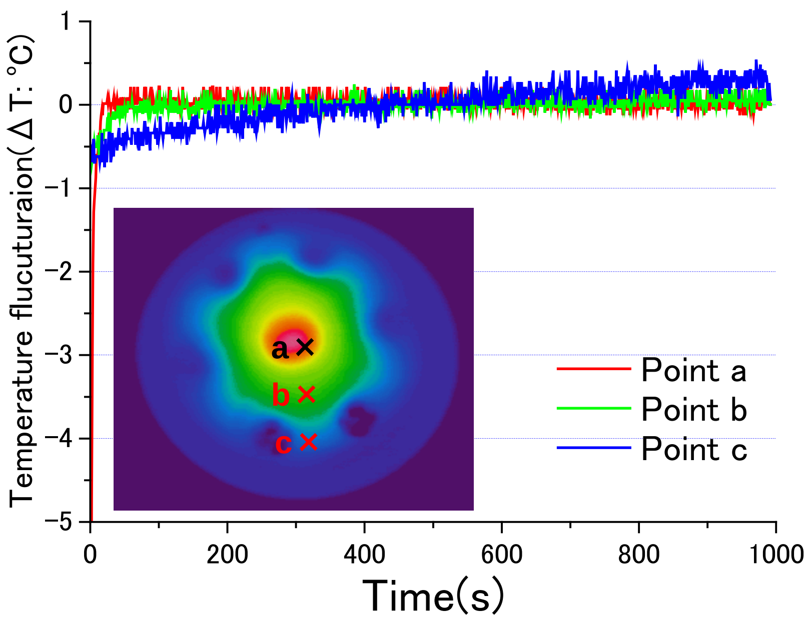
Luminous flux standard LED for high-power LED ※Joint research with NICHIA Corp

-Speciation of the standard LED -

- ✓ **Customized LED tips in terms of angular distribution and spectral power distribution**
- ✓ **High temperature stability**
- ✓ **Luminous flux around 60 lm (for White LED:350 mA)**
- ✓ **Seasoning treatment over 200 h**



Angular dependence of spectral power distributions



Evaluation of LED temperature by thermal image