

UV-LED Based Calibration Method for UV-A Radiometers with a Wide Irradiance Range and Traceability to National Standards

1. Introduction

- ◆ In recent years, UV-LEDs have rapidly replaced conventional mercury lamps. However, the irradiance level of UV-LED varies over a wide range depending on the application, from low levels used in nondestructive testing to high levels required in UV curing.
- ◆ This study presents a practical calibration method for UV-A radiometers that enables accurate and traceable calibration over a wide irradiance range ($5.0 \text{ W/m}^2 - 1.1 \times 10^3 \text{ W/m}^2$) with sufficiently low uncertainty for practical calibration.

This poster is based on the following published work:
『K. Miyasaka, et al., *Measurement*, **276** (2026) 121237』.

2. Two-step calibration method

Step 1: The irradiance of a temperature-stabilized UV-LED (TS UV-LED) is determined using a reference radiometer, and the irradiance responsivity of a working radiometer is calibrated.

$$E_{UV-r} = \frac{i_{r-UV} \int_0^\infty E_{UV-r}(\lambda) d\lambda}{A_r \int_0^\infty E_{UV-r}(\lambda) \cdot s_r(\lambda) d\lambda},$$

where E_{UV-r} : the irradiance of the TS UV-LED ($\text{W}\cdot\text{m}^{-2}$)
 i_{r-UV} : the response of the reference radiometer (A)
 A_r : the area of precision aperture (m^2)
 $E_{UV-r}(\lambda)$: the spectral distribution of the TS UV-LED
 $s_r(\lambda)$: the spectral responsivity of the reference radiometer ($\text{A}\cdot\text{W}^{-1}$).

Step 2: The irradiance of an LED module is determined using a working radiometer, and a test UV-A radiometer is calibrated at high irradiance.

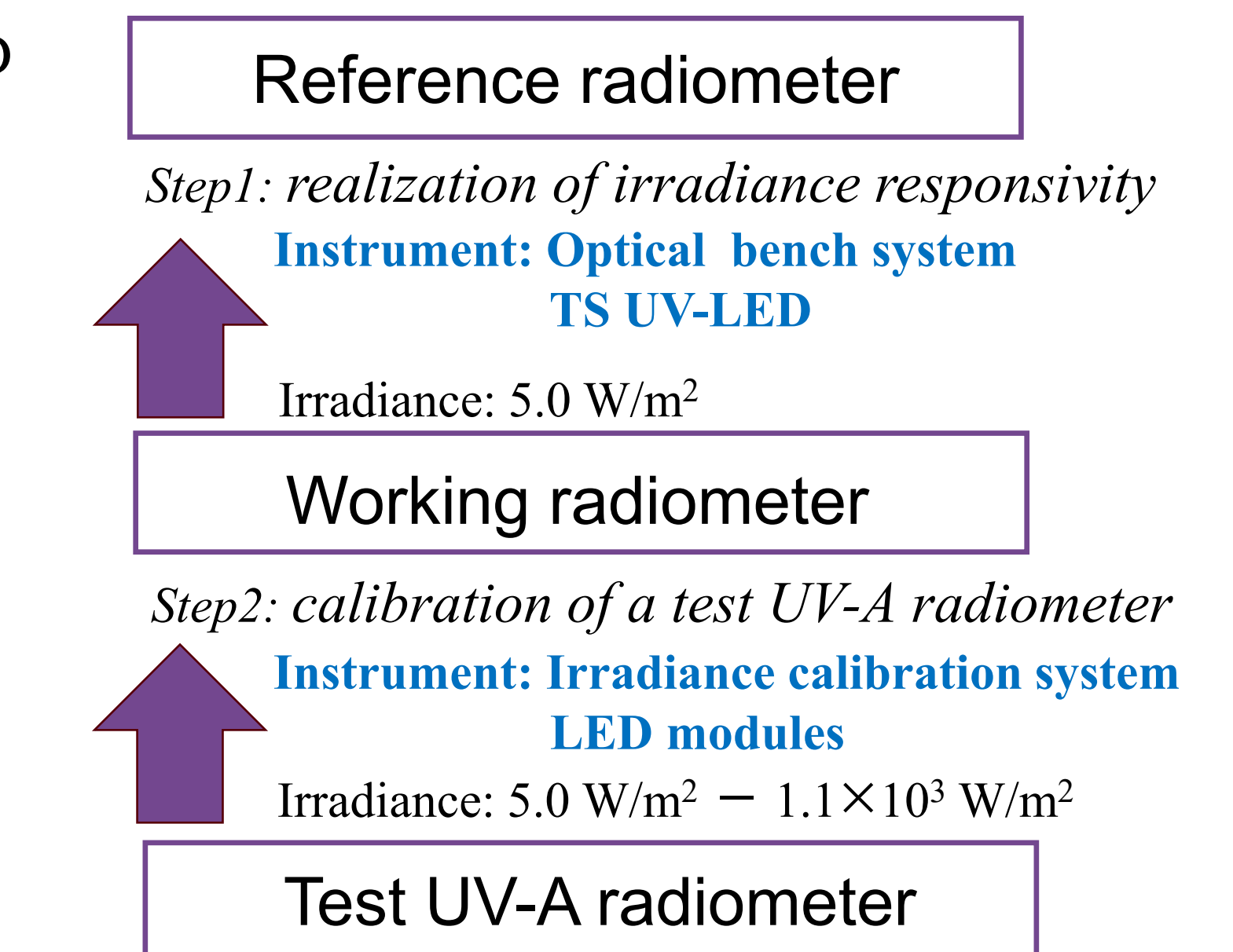


Fig. 1 Traceability chain for UV-A radiometers.

3. Standard radiometer and calibration systems

(a) Standard radiometers

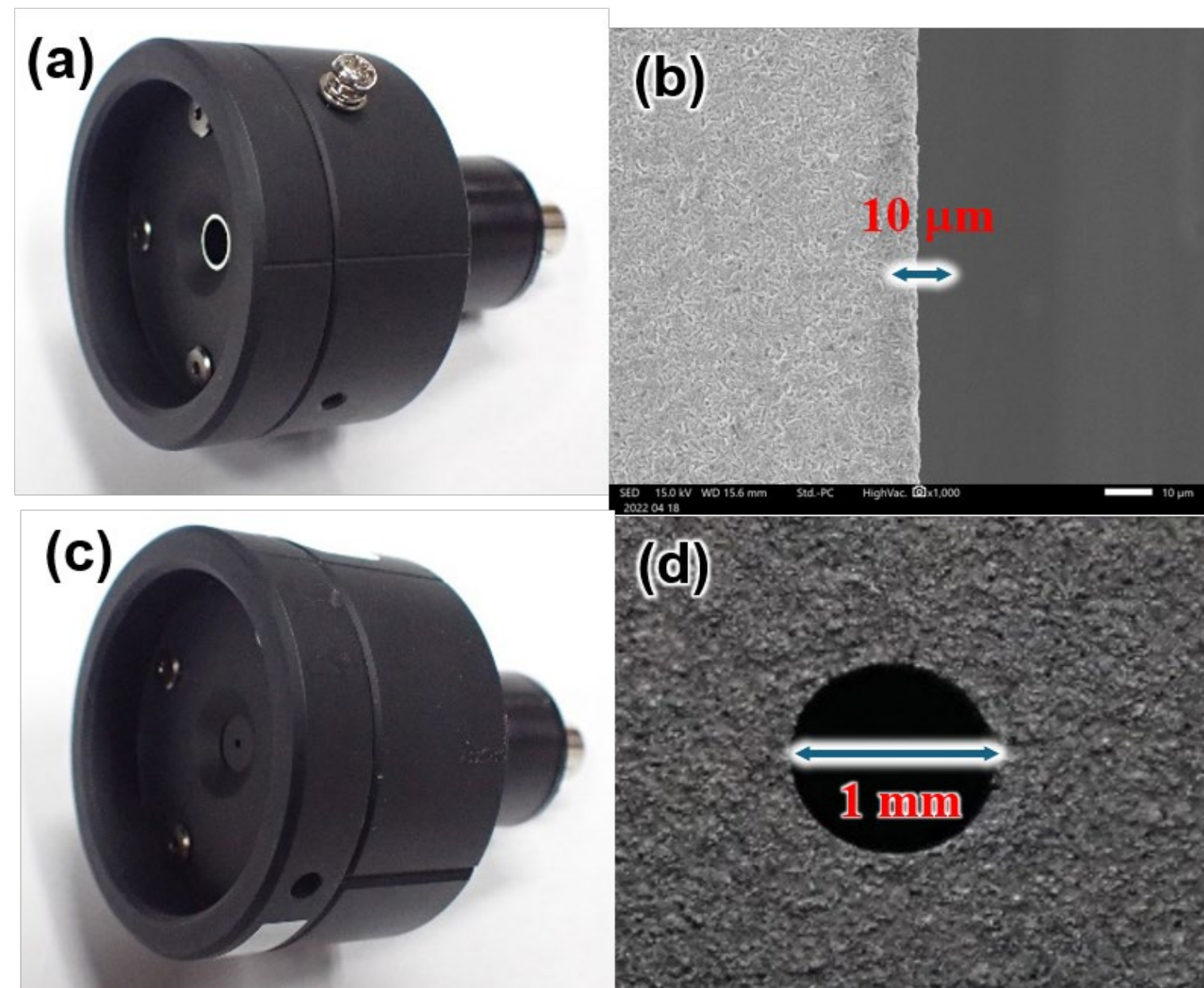


Fig. 2 Standard radiometers:

(a) a reference radiometer, (b) SEM image of a precise aperture, (c) photograph of a working radiometer, and (d) a 1 mm black aperture used in the working radiometer.

- The reference radiometer (Fig. 2(a)) : a 6 mm diameter precision aperture (Fig. 2(b)) and a Hamamatsu S1337 Si-PD
- The working radiometer (Fig. 2(c)) : a 1 mm black aperture (Fig. 2(d)) and a Hamamatsu S1227 Si-PD

(b) Calibration system for scale realization of irradiance responsivity

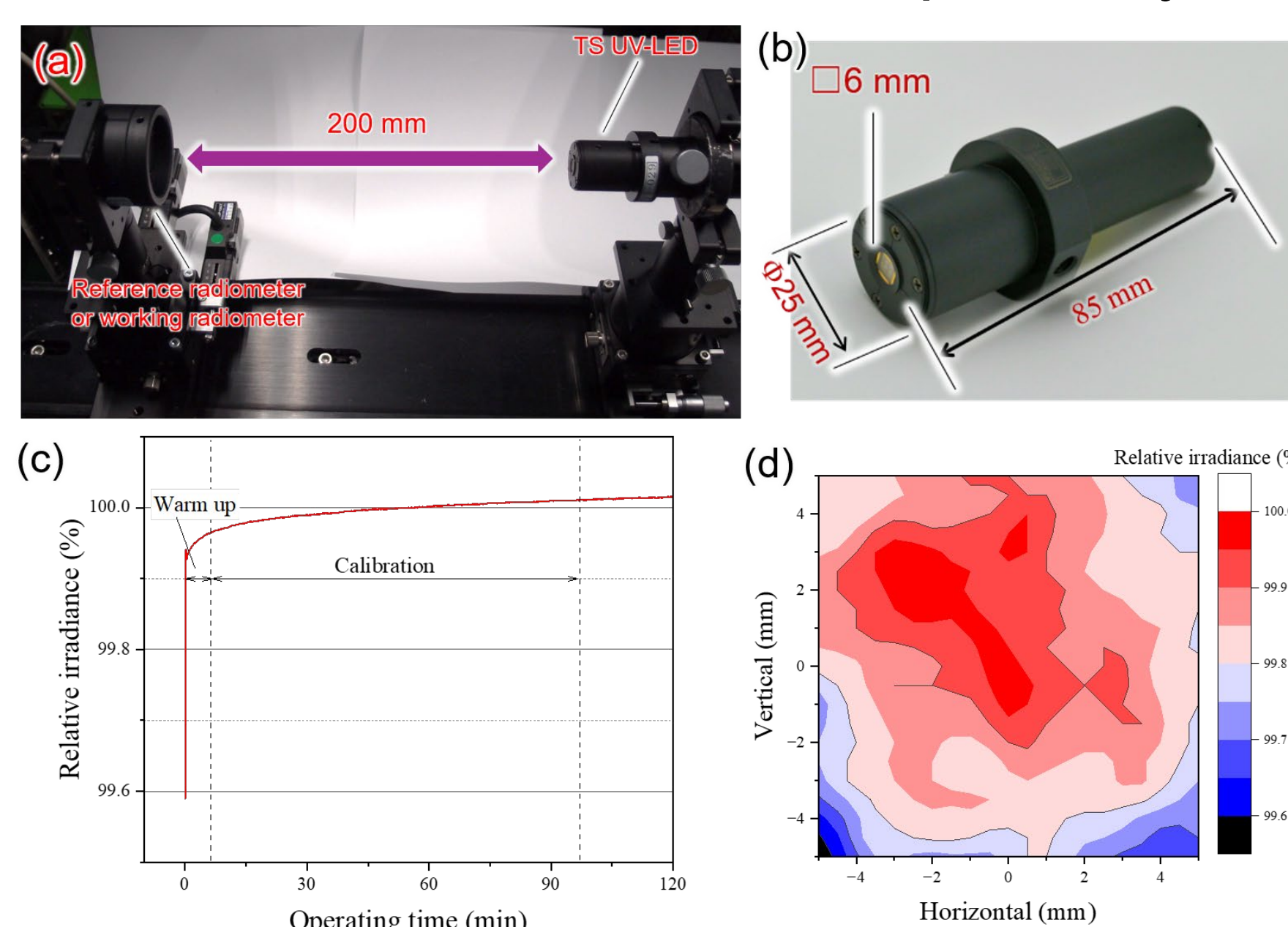


Fig. 3 Optical bench system:

(a) optical bench system, (b) TS UV-LED, (c) optical power stability, and (d) irradiance uniformity.

- The TS UV-LED is a specialized UV-LED that incorporates a thermoelectric element and temperature sensor (Fig. 3(b)).
- The optical power fluctuation remained below **0.1 %** after stabilization (Fig. 3(c)).
- The irradiance uniformity within a 6 mm diameter is **0.03 % (1σ)** (Fig. 3(d)).

(c) Calibration system for calibration of test UV-A radiometers

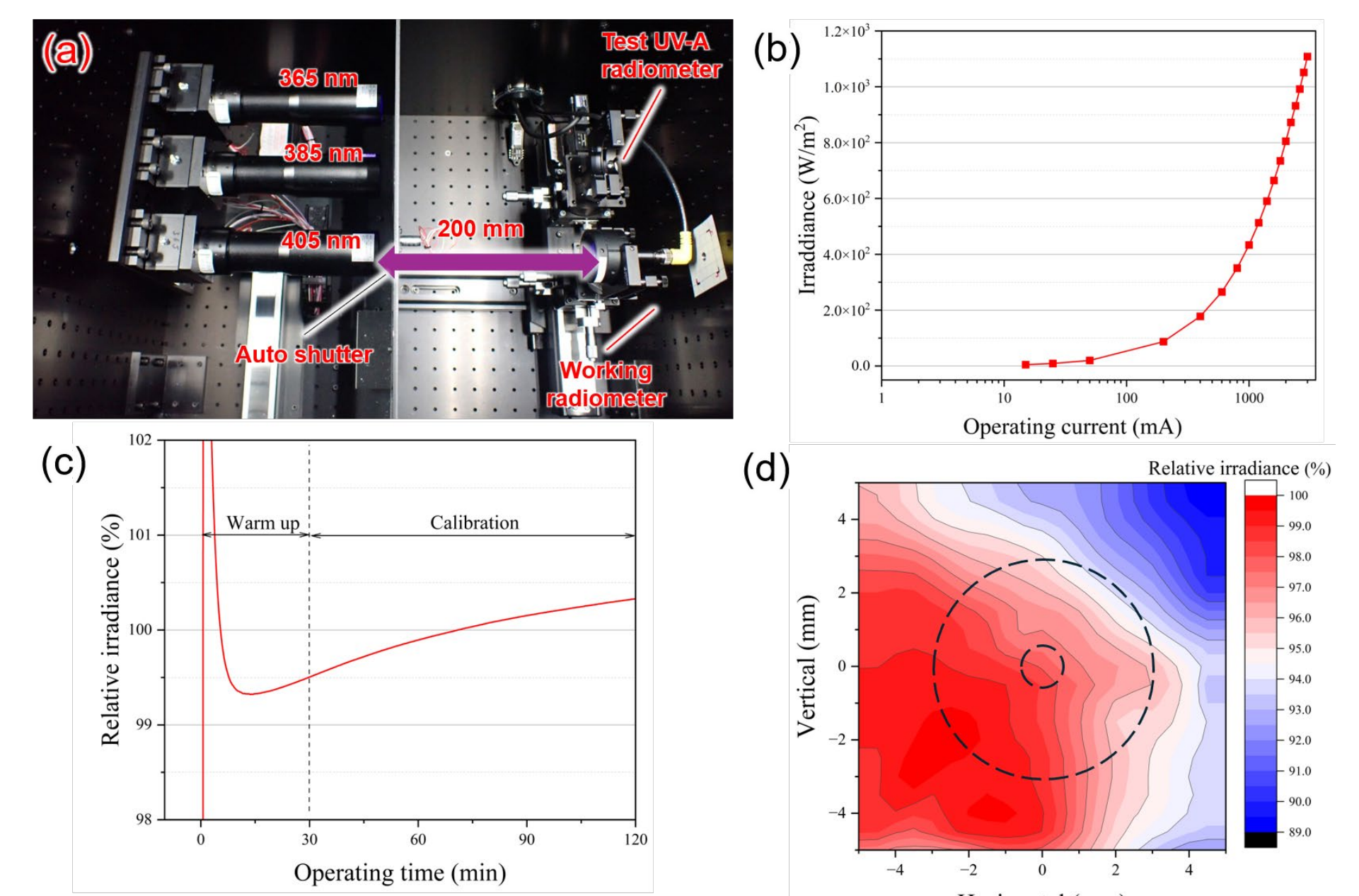


Fig. 4 Semiautomated irradiance calibration system:

(a) irradiance calibration system, (b) operating current vs irradiance, (c) optical power stability, and (d) irradiance uniformity.

- UV-LEDs module comprises a high-power UV-LED combined with a light-pipe homogenizer to achieve a uniform and high irradiance.
- The irradiance range is $5.0 \text{ W/m}^2 - 1.1 \times 10^3 \text{ W/m}^2$
- The optical power fluctuation was **0.18 %** after stabilization (Fig. 4(c)).
- The irradiance uniformity within a 6 mm diameter is **1.5 % (1σ)** (Fig. 4(d)).

4. Calibration Uncertainty

Table. 1 Uncertainty budget for a test UV-A radiometer.

Uncertainty factors	Type	Relative standard uncertainty (%)		
		365 nm	385 nm	405 nm
Irradiance responsivity of working radiometer (scale realization)	B	1.31	0.97	0.93
Linearity of working radiometer	B	<<0.1		
Optical power stability	A	0.18		
Irradiance non-uniformity	B	0.48		
Alignment reproducibility	B	0.69		
Uncertainty of SMCF	B	1.31	0.97	0.93
Aging of working radiometer	B	0.12		
Other factors	B	<<0.1		
Relative standard uncertainty		1.59	1.39	1.31
Expanded uncertainty (k=2)		3.2	2.8	2.6

- The uncertainty described above was evaluated for the test UV-A radiometer shown on the right.
- The linearity of working radiometer was evaluated using the improved distance variation method.
- Uncertainty of the spectral mismatch correction factor (SMCF) was evaluated using the Monte Carlo method.



The test UV-A radiometer

5. Conclusion

- A traceable calibration scheme for UV-A radiometers covering wide irradiance ranges ($5.0 \text{ W/m}^2 - 1.1 \times 10^3 \text{ W/m}^2$) was successfully developed.
- Two types of standard radiometers were developed: a precision reference radiometer and a high-linearity working radiometer.
- The developed optical bench and the semi-automated irradiance calibration system achieved practical irradiance uniformity and optical stability.
- Comprehensive uncertainty analysis demonstrates that the expanded calibration uncertainty of the test UV-A radiometer is **within 3.2 %, 2.8 %, and 2.6 % at 365 nm, 385 nm, and 405 nm, respectively.**

Through technology transfer from AIST/NMIJ, ORC Manufacturing Co., Ltd. became the first organization in Japan to be accredited as a JCSS accredited calibration laboratory for UV radiometers in 2023.

*:JCSS (Japan Calibration Service System)

<https://www.nite.go.jp/en/iajapan/jcss/index.html>