Absolute irradiance responsivity calibration system using diode lasers for tricolour laser applications

Minoru Tanabe[1] and Kenichi Kinoshita[1]

[1]*National Metrology Institute of Japan, Tsukuba, Japan*
Corresponding e-mail address: tanabe-m@aist.go.jp

An absolute irradiance responsivity calibration system with diode laser light sources at three wavelengths is presented. This system is based on an optical detector with a silicon photodiode and a uniform light source combined with an integrating sphere. The expanded uncertainty of the absolute irradiance responsivity has been analysed to be 0.55‒0.57% (k = 2).

INTRODUCTION

Diode lasers emitting red, green, and blue coloured light are favourable for use as light sources in optical products such as laser- based projectors and displays [1,2] and laser-based lighting [3]. In these laser-based products, an immediate advantage of using these tricolour laser lights for displays and lighting is the wide colour gamut that is available in comparison with light-emitting diode and other light emitting devices. The use of diode lasers also helps us to fabricate energy saving and compact optical products, even though gas lasers and solid-state lasers with a wide range of wavelengths are available. The diode lasers used in these products are occasionally quasi-monochromatic spectrum such as multimode oscillation, asymmetric spectrum, and wavelength width more than several nanometres. Accurate measurements are required to manage such light source and to assure the reliability and safety of these laser-based products.

In the fields of using laser-based projectors, displays, and lighting, not only these absolute optical flux evaluations but also photometric evaluations are required because they relate with vision in humans. Colorimetric evaluation is also required to achieve the desired chromaticity coordinate, which is to measure the lasers' spectral distributions and the intensity ratio of the tricolour laser wavelengths. In photometric and colorimetric evaluations, however, large spectral mismatches of the colour matching functions standardized by the CIE would generate within quasi-monochromatic spectrum of the diode laser. These mismatches would cause a white colour imbalance with red, green, and red colour lasers and deviations from the desired photometric values. Therefore, radiometric evaluation with tricolour laser light sources is an appropriate technique for more accurately evaluating laser-based products with optical detectors. We focus on absolute irradiance responsivity and report on a method to calibrate it using tricolour light source based on diode lasers in order to cover a wide dynamic optical flux range extending over six orders of magnitude. We also discuss the uncertainties of the calibration system.

IRRADIANCE RESPONSIVITY CALIBRATION

A detector-based system with laser diodes was selected for use in calibrating absolute irradiance responsivity values. This calibration system is consisted of a uniform light source combined an integrating sphere with tricolor laser and an optical detector based on a silicon (Si) photodiode (PD) (Hamamatsu S2281) as shown in Figure 1. A knife-edged-aperture was chosen to accurately define the irradiation area of the light source. The standard optical detector was calibrated for the absolute responsivity in units of amperes per watt (A/W) and the linearity of the optical response with respect to the incident flux. The roundness and diameter of the knife-edged-aperture were evaluated.

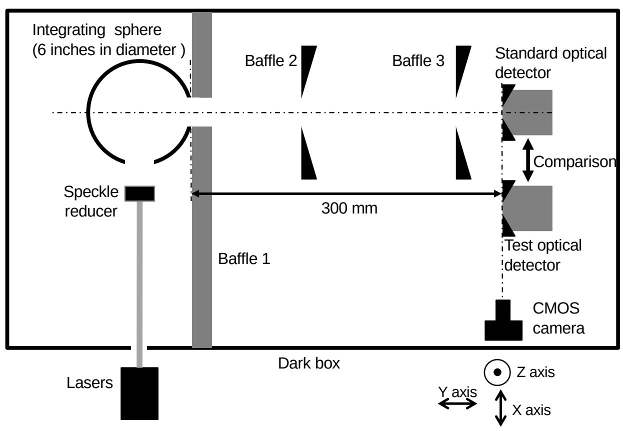

Figure 1. Schematic diagram of irradiance responsivity calibration system with tricolour laser light source.

The light source created with an integrating sphere and tricolor laser is adequate for calibrating the absolute irradiance responsivity of the standard optical detector in terms of its uniformity. The tricolor laser was produced by two Fabry-Perot laser diodes (FPLDs) and a diode-pumped solid state (DPSS) laser. The incident wavelengths were 452 and 665 nm for the FPLDs and 532 nm for the DPSS laser. A speckle reducer was installed in front of the integrating sphere in order to create a spatially uniform light source.

The light source and the standard optical detector were mounted on the perpendicular and horizontal rotation stages and XYZ axis translation stages. These stages were used so that the detector surface and the light source surface radiated from a port of the integrating sphere were parallel. The center of the detector was adjusted to be at the same height as the center of the light source. Three baffles were installed to shield from the stray light caused by the incident laser light to the integrating sphere and the light emitted from a port of the integrating sphere. To validate the feasibility of our absolute calibration system, a test optical detector was also installed. The test optical detector consisted of a commercial Si PD (Hamamatsu S1227-1010) and an accurate knife-edged-aperture. The detection surfaces of the standard and test optical detectors were adjusted to the same position using a CMOS camera that was vertically installed perpendicular to the two detection surfaces.

The following model formula was applied for evaluating the uncertainty factors for the absolute irradiance responsivity in terms of the standard optical detector and for deriving the combined standard uncertainty.

$$R = \frac{S \cdot \pi \cdot r^2}{(1 - C_\theta \cdot \theta)(1 - C_\varphi \cdot \varphi)} \cdot k_{NL} \cdot k_{uni} \cdot k_{dis} \qquad (1)$$

where S is the spectral responsivity of the standard optical detector, r is the radius of the aperture, C_θ and C_φ are the coefficient of the change in irradiance responsivity due to perpendicular and horizontal angular deviations, θ and φ are the perpendicular angular deviation, k_{NL} is the correction of the nonlinearity of the standard optical detector, k_{uni} is the correction due to the non-uniformity of the light source, and k_{dis} is the correction due to the distance difference between the standard and test optical detectors.

Table 1 shows the uncertainty budget for evaluating the irradiance responsivity at 532 nm. A comparison of the irradiance responsivity evaluations conducted on the two optical detectors was performed. The uncertainty of the comparison evaluation was estimated from the standard deviation of the evaluation result. The expanded uncertainty at 532 nm was obtained within 0.55%. In the same manner, the expanded uncertainties at the wavelengths of 452 and 665 nm were obtained within 0.57 and 0.55%, respectively.

Table 1. Uncertainty budget for evaluation of irradiance responsivity at 532 nm.

Uncertainty contribution	Relative uncertainty
Absolute responsivity of the standard optical detector	0.07%
Roundness and diameter of the knife-edged-aperture	0.03%
Linearity of the standard optical detector	0.12%
Uniformity of the light source	0.14%
Horizontal angular deviation of the standard optical detector	0.01%
Perpendicular angular deviation of the standard optical detector	0.02%
Horizontal angular deviation of the light source	0.01%
Perpendicular angular deviation of the light source	0.02%
Distance difference between two detectors	0.19%
Repeated comparison measurement	0.01%
Combined standard uncertainty	0.27%
Expanded uncertainty (k = 2)	0.55%

CONSLUTION

A calibration system of the absolute irradiance responsivity using diode laser emitting at three wavelengths has been developed. This system enables us to evaluate the absolute irradiance at the rage of 10^{-4} W/m^2 to 10^2 W/m^2. The radiometric performance of the system has been thoroughly investigated by considering all sources of uncertainty and their contributions to the uncertainty budget. The expanded uncertainties from 0.55 to 0.57% (k = 2) in irradiance responsivity have been attained. We can conclude that our proposed calibration system of irradiance responsivity based on tricolour laser light was successfully demonstrated. This system is expected to help us to perform radiometric and colorimetric evaluations of the tricolour laser-based products and applications such as displays and lighting.

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