Temperature Dependence Measurement of Color Speckle for Projected Fiber-out White Laser Beam from RGB Laser Module

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ABSTRACT

Temperature dependence of color speckle of the projected image of a fiber-out white laser beam from a laser module with red, green, blue laser diodes was measured. Larger temperature dependence of the red laser diode was found to greatly affect the performance of the white beam and color-speckle.

1 INTRODUCTION

Laser modules with red, green, and blue (RGB) laser diodes emitting a white laser beam as a fiber output combining the monochromatic R, G, B laser outputs are applied for wide-gamut projectors. Raster-scan laser mobile projectors use a small-form factor RGB laser module with a single-mode fiber (SMF) output.

The temperature dependence of the fundamental optical characteristics of the fiber-out white laser beam is important for thermal and optical designs of laser projectors. Speckle-related behaviors must be measured particularly for designing speckle reducing devices. Monochromatic and color speckle metrics [1], [2] must be measured statistically on the uniform background. However, the fiber-out beam projected on a screen has a far field pattern (FFP) affected by the fiber transverse modes. The speckle patterns are superposed on this non-uniform FFP. Therefore, we must convert the non-uniform FFP background into the uniform one when the speckle metrics are measured [3], [4]. The temperature dependence of the performance of laser diodes is distinctively different depending on the diode material systems and their bandgap. For example, the temperature dependence of AlInGaP/GaAs laser diodes (red) is much larger than that of InGaN/GaN laser diodes (green, blue). As a result, the chromaticity of the white beam created by RGB color addition is greatly affected by the temperature dependence differences of the performance among the RGB laser diodes.

This work presents the measured results and discussion of temperature dependence of the fundamental optical characteristics and the monochromatic and color speckle metrics of the fiber-out white laser beam from the RGB laser module.

2 EXPERIMENT

2.1 Measurement Setup

The measurement setup of the temperature dependence of the fundamental optical characteristics of the fiber-out white laser beam is shown in Fig.1. A small-form-factor RGB laser module with a SMF provided by Shimadzu Corporation was employed. The module has a similar structure shown in [5]. The SMF is PM (Polarization Maintaining) type with a cladding diameter of 125 microns. The module was fixed on the cool/hot plate (SCP-125, AS ONE Corporation) to keep the ambient temperature T_a constant. The case temperature T_c was determined as the highest temperature on the top surface of the module, using the thermal imager (PI-230, Optris GmbH). All the white laser beam power was received by the aperture of the RGB meter, TM6104 provided by HIOKI E.E. CORPORATION. The RGB meter is particularly designed for measuring narrow spectral linewidth [6].

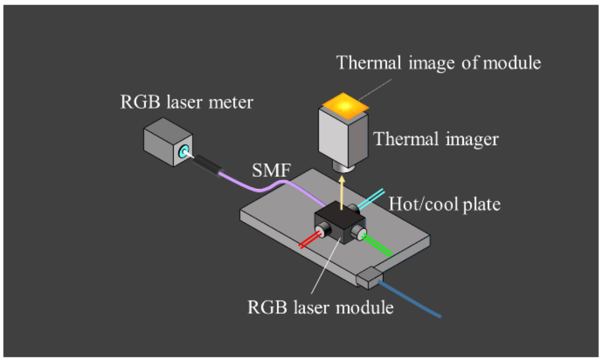

Fig. 1 Setup for measuring the temperature dependence of the fundamental optical characteristics

The R, G, B monochromatic and color speckles on the FFP background were measured using the setup shown in Fig.2. The diffuse reflectance target (SRT-99-120, Labsphere Inc.) was used as the standard screen. The diffusive reflectance values are more than 99% over the wavelength range of 400 to 1500nm. It is an ideal Lambertian diffusion screen covering the RGB wavelengths. Speckle measurement equipment

(SM01VS11, Oxide Corporation) capable of measuring color speckle was employed [7]. The iris diameter of 1.2mm is employed for simulating the MTF of human eye optics [8].

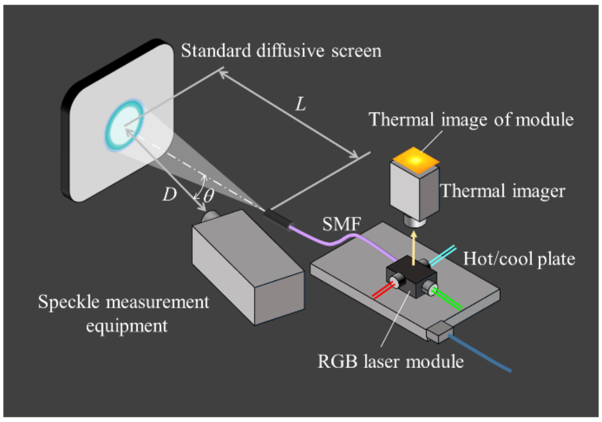

Fig. 2 Setup for measuring the temperature dependence of monochromatic and color speckles on the FFP background

2.2 Measurement Method

The 2D (512×512) data of R, G, B monochromatic speckles can be measured by switching the RGB optical filters. The 2D (512×512) color speckle data can be also calculated by additive color mixing of the 2D R, G, B data using the RGB wavelengths and the RGB power ratio, which had been already measured by the RGB laser meter as shown in Fig.1. To convert the FFP background into the uniform background, the method opening the iris was employed [4]. The 2D monochromatic data obtained by opening the iris are considered as the background FFP data unaffected by speckle grains. The speckle data on the uniform background can be calculated by means of dividing the 2D speckle data by the corresponding 2D un-speckled data.

The measurements were carried out for T_a =25°C, 30°C and 35°C.

The measurement methods of the monochromatic and color speckles are basically compliant with the two IEC standards, IEC 62906-5-2: 2016, Laser display devices - Part 5-2: Optical measuring methods of speckle contrast, and IEC 62906-5-4: 2018, Laser display devices - Part 5-4: Optical measuring methods of colour speckle.

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3 RESULTS

3.1 Fundamental optical characteristics

The measured results of the temperature dependence of the R, G, B wavelengths are summarized in Table 1 and plotted as the graphs in Fig.3.

The measured results of the temperature dependence of the white chromaticity and the R, G, B optical output powers are summarized in Table 2 and plotted as the graphs in Fig.4.

The laser wavelengths shift towards longer and the output powers decrease as temperature increases. It is obvious that the temperature dependence of the red wavelength and the red power is much larger than those of green and blue.

Table 1 Temperature dependence of R, G, B wavelengths

T_a (°C)	T_c (°C)	Wavelength (nm)		
		R	G	B
25	29.2	636.94	520.34	455.67
30	32.8	637.90	520.39	455.92
35	36.6	638.58	520.42	456.15

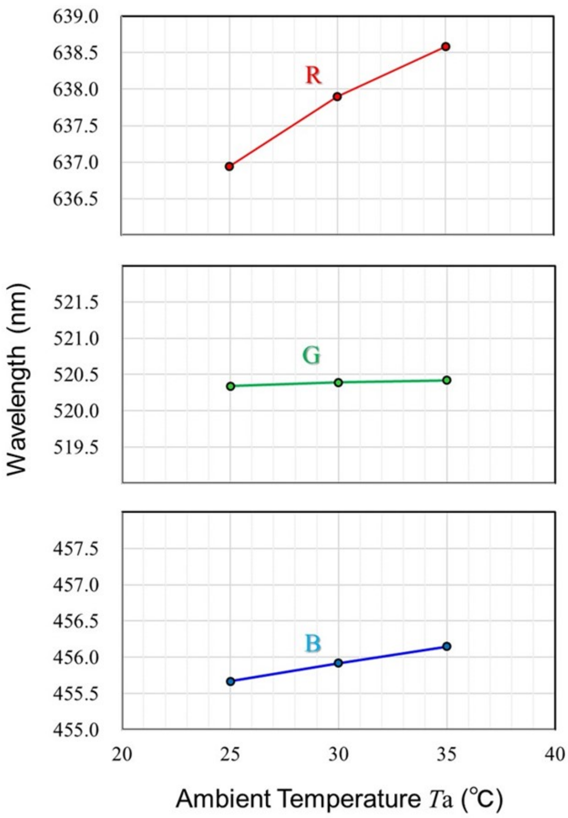

Fig. 3 Temperature dependence of R, G, B wavelengths

Table 2 Temperature dependence of white chromaticity and R, G, B output powers

T_a (°C)	T_c (°C)	Chromaticity		Power (mW)		
		x	y	R	G	B
25	29.2	0.3003	0.2740	2.63	1.58	1.48
30	32.8	0.2710	0.2602	1.68	1.18	1.23
35	36.6	0.1811	0.2300	0.36	0.74	0.92

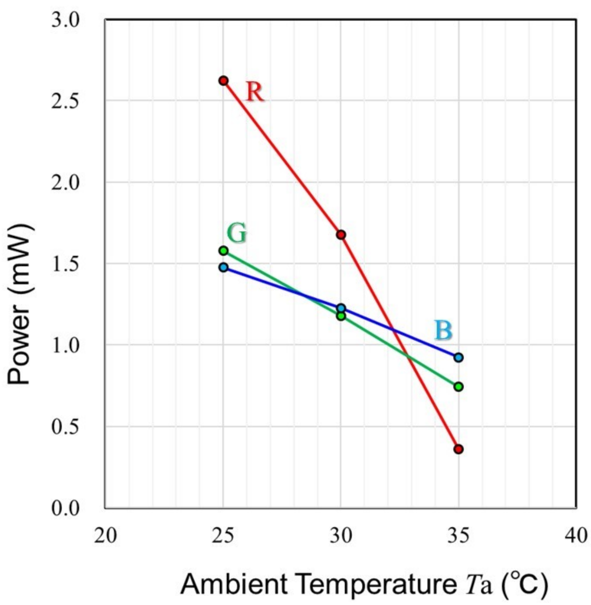

Fig. 4 Temperature dependence of R, G, B powers

3.2 Speckle behavior

The measured results of the temperature dependence of the R, G, B monochromatic speckle contrasts (C_s) are summarized in Table 3. The measured results for photometric speckle contrast (C_{ps}), variance and covariance of color speckle distributions in CIE 1931 chromaticity diagram are summarized in Table 4. The theoretically calculated C_{ps}, variance and covariance of color speckle distributions are also summarized in Table 5. The calculations were carried out assuming the RGB speckle contrast values shown in Table 3, the RGB wavelengths in Table 1 and the RGB power ratios in Table 2.

Table 3 Temperature dependence of the R, G, B monochromatic speckle contrasts (C_s)

T_a (°C)	T_c (°C)	Speckle contrast (monochromatic)		
		C_{sR}	C_{sG}	C_{sB}
25	29.2	0.229	0.224	0.247
30	32.8	0.256	0.237	0.240
35	36.6	0.447	0.228	0.236

Table 4 Temperature dependence of measured photometric speckle contrast (C_{ps}), variance and covariance of color speckle distributions

T_a (°C)	T_c (°C)	C_{ps}	Variance/covariance		
			Var-x	Var-y	Cov-xy
25	29.2	0.173	1.05e-3	1.54e-3	3.46e-4
30	32.8	0.186	0.93e-3	1.66e-3	2.87e-4
35	36.6	0.200	0.05e-3	1.83e-3	0.95e-4

Table 5 Temperature dependence of calculated photometric speckle contrast (C_{ps}), variance and covariance of color speckle distributions

T_a (°C)	T_c (°C)	C_{ps}	Variance/covariance		
			Var-x	Var-y	Cov-xy
25	29.2	0.168	1.28e-3	1.52e-3	1.92e-4
30	32.8	0.176	1.00e-3	1.80e-3	2.08e-4
35	36.6	0.193	0.05e-3	2.07e-3	0.32e-4

The 2D (512×512) data of R, G, B monochromatic speckle and the 2D color speckle data obtained by additive color mixing are shown in Fig.5 for T_a=25°C, 30°C and 35°C.

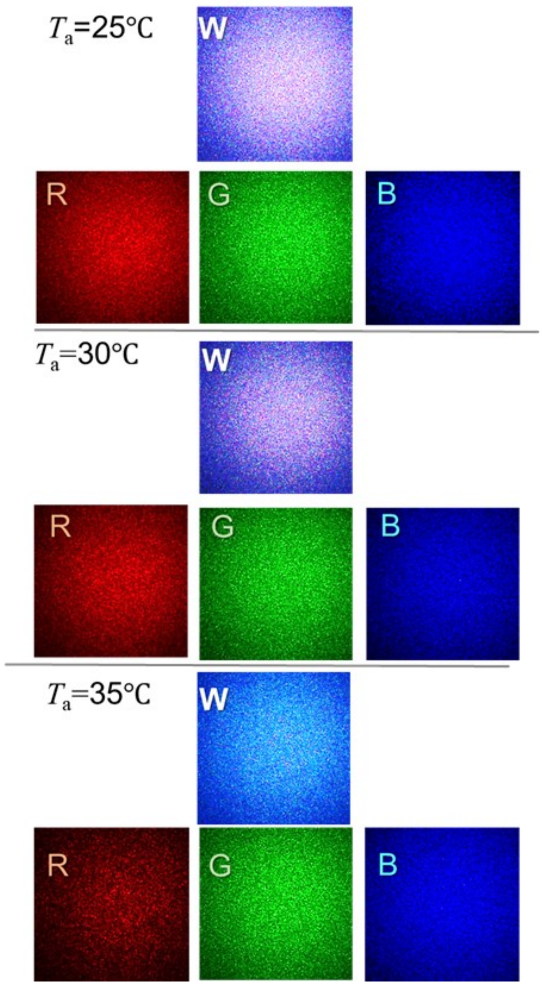

Fig. 5 Temperature dependence of 2D data of monochromatic speckles (RGB) and color speckles (white)

The measured color speckle distributions in CIE 1931 chromaticity diagram are shown on the left side of Fig.6, and the theoretically calculated distributions are shown on the right side of Fig.6, respectively, for T_a=25°C, 30°C and 35°C.

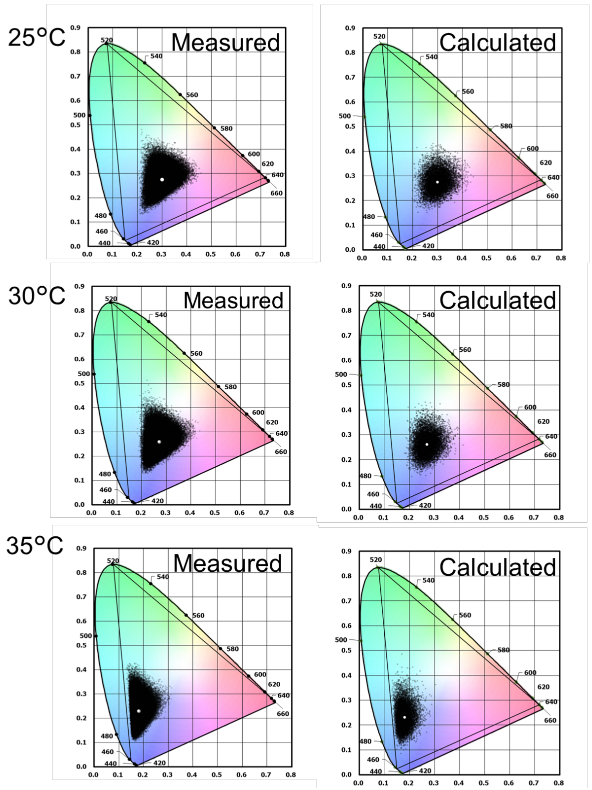

Fig. 6 Temperature dependence of color speckle distribution in CIE 1931 chromaticity diagram (Measured: left side, Calculated: right side)

4 DISCUSSION

As in Table 2, Fig.5 and Fig.6, the average chromaticity of the white beam obviously changes from white to pale blue as Ta increases. It is not white anymore at Ta=35°C. This is because the red laser power decreases much more rapidly with Ta-increase than the rest of the colors.

The red speckle contrast C_{sR}=0.447 at Ta=35°C is much higher than the other colors, as in Table 3. The coherence is usually much higher at currents just above the threshold. In fact, the optical power of the red laser diode approaches the threshold level at Ta=35°C.

The measured color speckle distributions on the left side of Fig.6 appear more triangular than the calculated distributions on the right side. Compared with Table 4 and Table 5, the measured Cps values are slightly larger than the calculated values. The measured variance values along x and y directions are slightly smaller than the calculated values although the measured distributions appear more widely spread. In the calculations, the Cs values for R, G, B colors are obtained assuming the Cs values to be uniform as the average of the whole 2D data. In fact, the measured Cs values of the laser beams projected on a screen have angular dependence [3]. Therefore, the triangular distributions of the measured data should be caused by non-uniform angular dependence of the Cs values

5 CONCLUSIONS

The temperature dependence of RGB wavelengths, RGB optical output powers, white chromaticity, and RGB monochromatic and color speckle metrics for the fiber-out white laser beam from an RGB laser module was measured for the first time.

The temperature dependence is different among the R, G, B laser diodes. Particularly, the wavelength and the power variations of the red laser diode are distinctively larger, greatly affecting the white chromaticity and the color speckle metrics.

It is necessary for stabilizing the chromaticity and color speckle to cool the module or the lasers. The cooling mechanism is particularly necessary for the R-laser diode.

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