UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-

REPORT OF CALIBRATION

Special Test for CIE Color Quantities of Submitted LEDs (37100S)

for

Two white LEDs with designations of X1 and W3

Submitted by:

Cree, Incorporated
Attn.: Mr. Ralph C. Tuttle
4425 Silicon Drive
Building 10
Durham, NC 27703

(See your Purchase Order No. 3825, dated September 14, 2006)

1. Calibration Item

Two surface mount white LEDs (Cree XLamp 7090 power LEDs) were calibrated for CIE color quantities in 4π geometry. The designations of the two LEDs are X1 and W3 that are marked on their circuit boards. Both LEDs are mounted on their heat sinks. A photograph of the two test LEDs is shown in Figure 1. The red pigtail wire is the LED anode and black pigtail wire is the LED cathode.

2. Description of the Calibration

This color calibration is based on the NIST spectral irradiance scale using the source-based method as described in reference 1. The principle of the method is depicted in Figure 2. The test LED was calibrated in the NIST 2.5 m integrating sphere (4π geometry) for spectral power distribution to calculate the CIE color quantities. A CCD-array spectroradiometer was used for the calibration which has approximately 3 nm (FWHM) bandpass with spectral range from 200 nm to 790 nm. The measurement system (the integrating sphere and the spectroradiometer) was calibrated immediately after the measurements of the test LEDs against two spectral irradiance standard FEL lamps for spectral irradiance responsivity. The spectral irradiance standard FEL lamp was periodically calibrated in the direction of its optical axis for spectral irradiance at 0.5 m distance in the NIST Facility for Automated Spectroradiometric Calibrations (FASCAL) [2] [3]. A heat-absorbing optical filter (Schott KG-5) was inserted between the opal glass diffuser and the optical fiber bundle to prevent the unwanted infrared radiation of the

standard FEL lamps from entering into the spectroradiometer for reducing spectral stray light inside the spectroradiometer.

The test LED was mounted at the center of the sphere that directly illuminated a part of the sphere wall on the equator. The error due to the spatial nonuniformity of the integrating sphere has been analyzed and included in the uncertainty budget. The test LED was operated on DC power at a constant current specified by the customer using the four-wire connection. The operating current of the LED was measured with a digital multimeter through a calibrated shunt resistor, and the LED voltage was measured across the two pigtail wires. The measurements took place after the LED had stabilized (approximately 5 minutes after it was powered on as specified by the customer). The 4π-geometry LED color measurements were made for two lightings of each test LED and the mean value of the two measurements is reported. The variation of the results in the two lightings is included in the uncertainty budget of the calibration. Corrections were applied for the dark signal, the fluorescence of the sphere system, and the spectral stray light [4] and signal nonlinearities of the spectroradiometer.

The sphere temperature was 24 °C. The room temperature was 24 °C and relative humidity was 39 % at the time of calibration.

3. Results of Calibration

The results and the expanded uncertainties (coverage factor k=2) of this calibration are shown in Table 1. The relative spectral power distribution of the test LED X1 is shown in Figure 3 (for reference only). The uncertainty budget is shown in Table 2. The NIST policy on uncertainty statements is described in reference 5.

Table 1. Results of calibration

Measurement quantity		LED Designation		Expanded Uncertainty (coverage factor k=2)
		X1	W3	
LED Current (A)		0.3500	0.3500	
LED Voltage (V)*		3.173	3.192	
CIE 1931 chromaticity coordinates	x	0.3195	0.3220	0.0007
	y	0.3364	0.3388	0.0012
CIE 1976 chromaticity coordinates	u'	0.1998	0.2006	0.0003
	v'	0.4732	0.4748	0.0007
Correlated Color Temperature (CCT) (K)		6110	5979	38
Color Rendering Index (CRI) (CIE 13.3 $-R_a$)		77.9	78.0	0.2

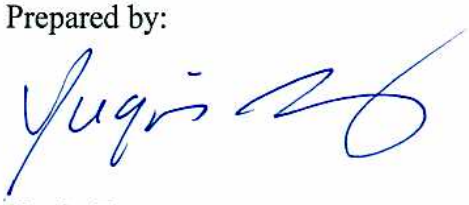
* The LED voltage is for reference only.

4. General Information

The LEDs shall be operated on DC power at the reported current. Colorimetric measurements should be made after the LED has stabilized (approximately 5 minutes after it is powered on).

The color characteristics of a LED may change slightly with the ambient temperature. Additional uncertainties should be taken into account by the customer if these LEDs are operated at ambient temperatures other than that reported in this calibration.

Prepared by:



Yuqin Zong
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(301) 975-2332

Approved by:

Yoshihiro Ohno
For the Director,
National Institute of Standards and Technology
(301) 975-2321

References:

[1] Y. Zong, C. C. Miller, K. R. Lykke, Y. Ohno, Measurement of Total Radiant Flux of UV LEDs, Proceeding of the CIE Expert Symposium on LED Light Sources, June 2004, Tokyo.

[2] J. H. Walker, R. D. Saunders, J. K. Jackson, and D. A. McSparron, Spectral Irradiance Calibrations, NBS Special Publication 250-20 (1987).

[3] H. W. Yoon, C. E. Gibson, and P. Y. Barnes, Realization of the National Institute of Standards and Technology detector-based spectral irradiance scale, Appl. Opt. 41, 5879-5890 (2002).

[4] Yuqin Zong, Steven W. Brown, B. Carol Johnson, Keith R. Lykke, and Yoshi Ohno, Simple spectral stray light correction method for array spectroradiometers, Applied Optics, Vol. 45, Issue 6, pp. 1111-1119 (February 2006).

[5] B. N. Taylor, and C. E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297 (1993).

Table 2. Uncertainty budget for the calibration

Component	Type	Standard uncertainty					
		u(x)	u(y)	u(u')	u(v')	u(CCT) (K)	u(R_a)
NIST spectral irradiance standards (FEL)	B	0.00014	0.00023	0.00008	0.00014	7.8	0.06
Instrument wavelength (0.2 nm)	B	0.00028	0.00053	0.00006	0.00032	16.7	0.06
Uncorrected instrument spectral stray light	B	0.00005	0.00005	0.00004	0.00003	2.1	0.02
Calibration of instrument with spectral irradiance standards	B	0.00002	0.00003	0.00001	0.00002	1.2	0.01
Sphere nonuniformity	B	0.00005	0.00005	0.00004	0.00003	2.1	0.02
Repeatability of measurement of test LED	A	0.00010	0.00010	0.00008	0.00005	4.2	0.03
Combined standard uncertainty		0.00034	0.00059	0.00014	0.00036	19.2	0.09
Expanded uncertainty (k=2)		**0.0007**	**0.0012**	**0.0003**	**0.0007**	**38**	**0.2**

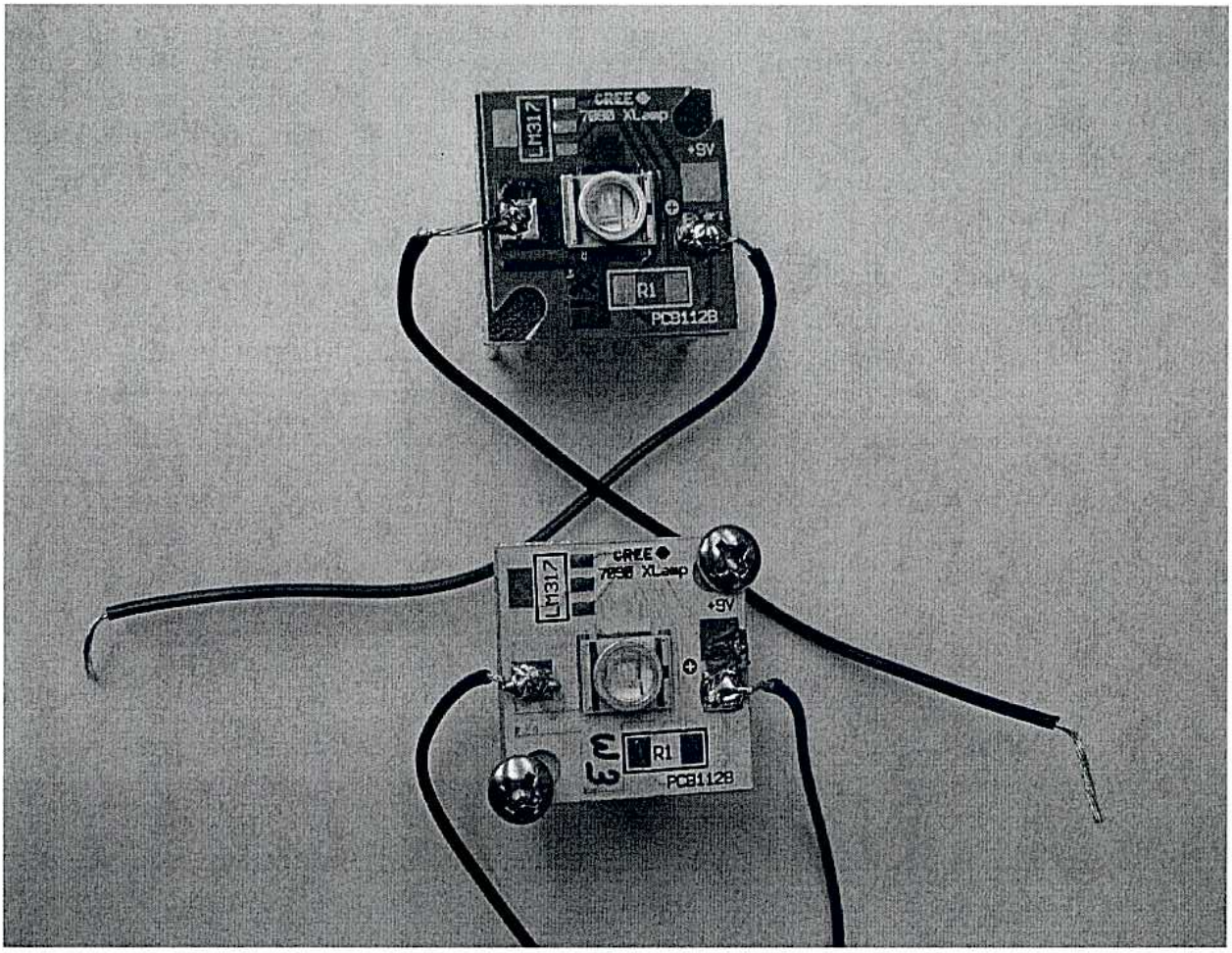

Figure 1. Photograph of the two test LEDs

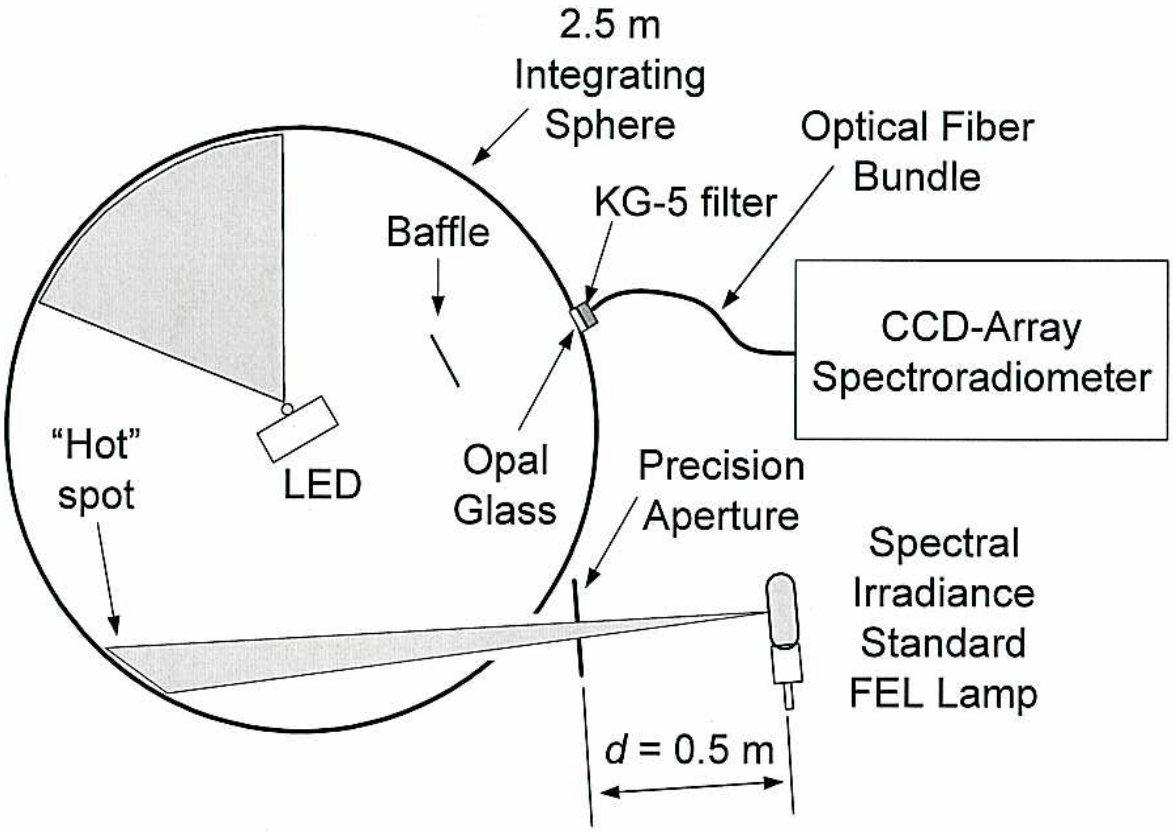

Figure 2. System setup for the LED color calibration

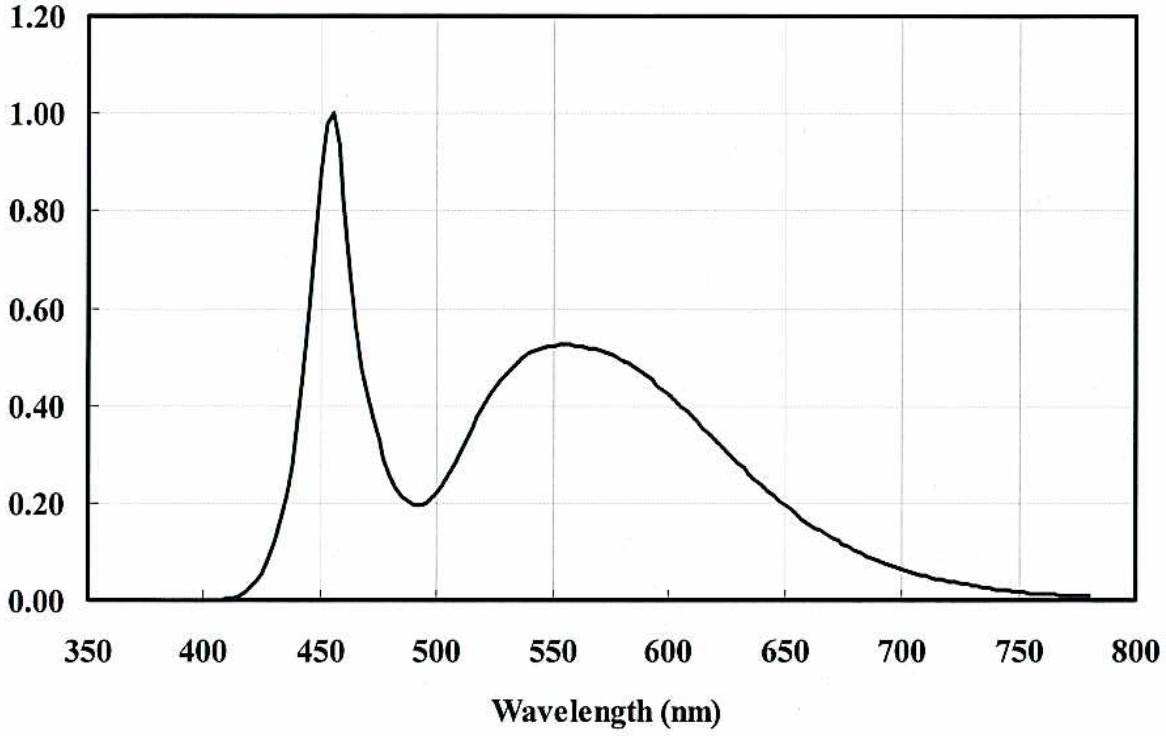

Figure 3. The relative spectral power distribution of the test LED: X1

UNITED STATES DEPARTMENT OF COMMERCE
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REPORT OF CALIBRATION

Special Test for Total Luminous Flux of LEDs (37130S)

for

Two white LEDs with designations of X1 and W3

Submitted by:

Cree, Incorporated
Attn.: Mr. Ralph C. Tuttle
4425 Silicon Drive
Building 10
Durham, NC 27703

(See your Purchase Order No. 3825, dated September 14, 2006)

1. Calibration Item

Two surface mount white LEDs (Cree XLamp 7090 power LEDs) were calibrated for total luminous flux (unit: lumen). The designations of the two LEDs are X1 and W3 that are marked on their circuit boards. Both LEDs are mounted on their heat sinks. A photograph of the two test LEDs is shown in Figure 1. The red pigtail wire is the LED anode and black pigtail wire is the LED cathode.

2. Description of the Calibration

This total luminous flux measurement is based on the NIST luminous flux scale realized in 2006 which has been derived from the NIST detector-based candela scale realized in 2006 and, therefore, based on the international definition of candela in effect since 1979 [1].

The test LEDs were calibrated in the NIST 2.5 m integrating sphere using the detector-based measurement procedures as described in reference 2. The test LED was mounted at the center of the sphere that directly illuminates a part of the sphere wall on the equator. The error due to the spatial nonuniformity of the integrating sphere has been analyzed and included in the uncertainty budget. The details of the measurement facility and calibration procedures are described in reference 3.

Calibration Date: October 3, 2006
NIST Test No.: 844/274060-06/2

The test LED was operated on DC power at a constant current specified by the customer using a four-wire connection. The operating current of the LED was measured using a digital multimeter through a calibrated shunt resistor, and the LED voltage was measured across the two pigtail wires. Readings were taken after the LED had stabilized (5 minutes after the LED was powered on as specified by the customer). The total luminous flux measurements were made for two lightings of each test LED. The sphere photometer output signals were recorded together with the electrical quantities and the data on the environmental conditions. The spectral power distribution of the test LED used for the spectral mismatch correction was also measured in the 2.5 m integrating sphere using a spectroradiometer. Corrections were applied for the dark reading, the self-absorption effect (automatically corrected), and the spectral mismatch factor, to calculate the total luminous flux of the test LED. See Section 5.4 of reference 1 and Section 4 of reference 2. The mean value of each test LED from the two lightings is reported. The variation of total luminous flux values is included in the uncertainty budget of the calibration.

The sphere temperature was 24 °C. The room temperature was 24 °C and relative humidity was 39 % at the time of calibration.

3. Results of Calibration

The results of the calibration are shown in Table 1. The relative expanded uncertainties (coverage factor k=2) are 0.76 % for total luminous flux (lm) and 0.77 % for luminous efficacy (lm/W). The uncertainty budget for this calibration is shown in Table 2. The NIST policy on uncertainty statements is described in reference 4.

Table 1. Results of Calibration

LED Designation	LED Current (A)	LED Voltage* (V)	Total Luminous Flux (lm)	Luminous Efficacy (lm/W)
X1	0.3500	3.173	84.04	75.7
W3	0.3500	3.192	83.95	75.1

* The LED voltages are for reference only

4. General Information

The LED shall be operated on DC power at the reported current. Photometric measurements should be made after the LED has stabilized (5 minutes after it is powered on). The luminous flux of a LED is generally sensitive to ambient temperature. An additional uncertainty should be

taken into account by the customer if the LED is operated at ambient temperatures other than that reported in this calibration.

The uncertainty due to aging of the LED should be taken into account by the customer, depending on the calibration cycle of the LED.

The Calibration Report shall not be reproduced except in full, without the written approval of NIST.

Prepared by:

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Approved by:

Yoshihiro Ohno
For the Director,
National Institute of Standards and Technology
(301) 975-2321

References:

[1] Y. Ohno, NIST Special Publication 250-37 Photometric Calibrations (1997).

[2] Y. Ohno and Y. Zong, Detector-Based Integrating Sphere Photometry, CIE Proceedings, 24 Session – Warsaw, pp. 155-160, 1999.

[3] C. C. Miller, and Y. Ohno, Luminous Flux Calibration of LEDs at NIST, CIE Proceedings, 2nd CIE Expert Symposium on LED Measurement, pp. 45, 2001.

[4] B. N. Taylor and C. E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297 (1993).

Table 2. Uncertainty budget for the luminous flux calibration of the test LEDs

Uncertainty component	Type	Relative standard uncertainty (%)
Determination of the external beam flux	B	0.23
Spatial non-uniformity correction for external beam	B	0.05
Long-term drift of spatial non-uniformity of the sphere	B	0.05
Incident angle correction for external beam	B	0.03
Near-field absorption	B	0.10
Uncorrected spectral mismatch of the photometer	B	0.10
Sphere fluorescence	B	0.10
Uncorrected spatial non-uniformity errors due to LED intensity distributions	B	0.15
Stability/repeatability of LED	A	0.13
Ambient temperature	A	0.13
Relative combined uncertainty of total luminous flux (%)		0.38
Relative expanded uncertainty of total luminous flux (k=2) (%)		**0.76**
LED electrical power	A	0.05
Relative combined uncertainty of luminous efficacy (%)		0.38
Relative expanded uncertainty of luminous efficacy (k=2) (%)		**0.77**

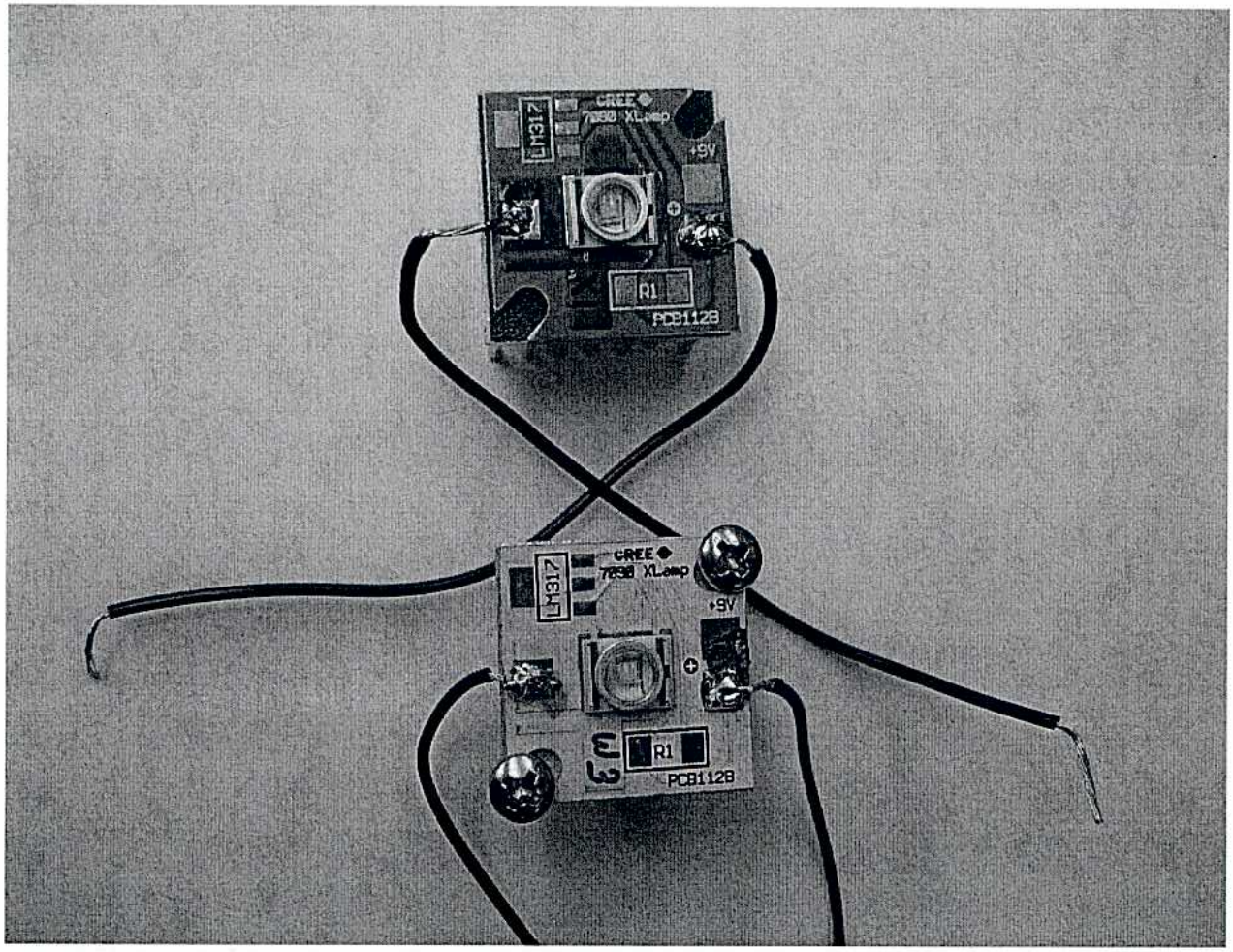

Figure 1. Photograph of the two test LEDs

UNITED STATES DEPARTMENT OF COMMERCE
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In reply refer to: 844/274060-06

October 18, 2006

Mr. Ralph C. Tuttle
Cree, Incorporated
4425 Silicon Drive
Building 10
Durham, NC 27703

Purchase Order No.: 3825 dated September 14, 2006

Dear Mr. Tuttle:

Enclosed are the results of the NIST measurement services and associated documentation that you requested. Please refer to the above file numbers in any later communication concerning these tests.

Sincerely,

Albert Parr

Albert C. Parr, Chief
Optical Technology Division
Physics Laboratory

Enclosures: Two Reports of Calibration

NIST Service ID Numbers:
2 each 37100S Special Photometric Tests
2 each 37130S Special Tests for Luminous Intensity and Luminous Flux of LEDs

ACP/issc

NIST