Ref. LEDtech-GROW #10412 - 03/12/2025

Report on the LEDs performance
WP2 (D2.2)

LEDtech-GROW

LED TECHNOLOGY BASED ON BISMUTH-SENSITIZED Eu^{3+} LUMINESCENCE FOR COST-EFFECTIVE INDOOR PLANT GROWTH

PROGRAM-PROMIS-2024-2025

Grant Agreement: 10412

Deliverable 2.2
Report on the LEDs performance
Contractual Date Delivery: 03/12/2025

This project is supported by the Science Fund of the Republic of Serbia, Grant No. 10412,
LED technology based on bismuth-sensitized Eu^{3+} luminescence for cost-effective indoor plant growth – LEDtech-GROW

Project Deliverable Information Sheet

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	Principal investigator: Dr. BOJANA MILIĆEVIĆ
	Abstract: The report includes a description of the LEDs' performance for plant growth applications that combine UV and near-UV semiconductor chips and (*i*) triple-wavelength emitting single-component phosphors based on Bi^{3+} and Eu^{3+} activators, or (*ii*) double-wavelength emitting single-component phosphors based on Eu^{3+} activators. This report is a result of Subactivity 2.3 - Testing LED Performance.

Document Control Sheet

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	Contributed by Ljubica Đačanin Far
	Approved by Bojana Milićević

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Executive Summary

This document constitutes Deliverable D2.2 – Report on the LEDs' Performance within the LEDtech-GROW project. The deliverable is a public document prepared under Work Package 2 (WP2) – Design, Fabrication, and LEDs' Performance, specifically addressing Subactivity 2.3 – Testing LED Performance during months 15 to 24 of the project.

The report provides a comprehensive overview and evaluation of the performance characteristics of light-emitting diodes (LEDs) developed and used for plant growth applications. This deliverable aims to support knowledge dissemination and ensure transparency of the results achieved among LEDtech-GROW team members and toward the wider scientific and professional community.

To ensure the reliability and comparability of the results, all LED samples were systematically measured and characterized in two independent research units in Serbia and China. Parallel testing of identical samples under comparable experimental conditions enabled cross-validation of the measurement data and provided a solid basis for benchmarking the performance of the developed LEDs. This comparative approach further strengthens the credibility of the reported results and allows identification of potential variations arising from measurement setups, environmental conditions, or instrumentation.

Overall, Deliverable D2.2 contributes to a deeper understanding of LED performance in plant growth applications and represents an important step toward optimizing LED-based lighting solutions within the LEDtech-GROW project. The findings presented herein support subsequent research activities and provide a validated foundation for further development.

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Abbreviations and Acronyms

	Explanation
[CIE]	Commission Internationale de l'Eclairage
[ET]	Energy transfer
[LED]	Light-emitting diode
[LEDtech-GROW]	Acronym of the Project Titled "*LED technology based on bismuth-sensitized Eu^{3+} luminescence for cost-effective indoor plant growth*"
[PAR]	Photosynthetically Active Radiation
[PL]	Photoluminescence emission spectra
[SGF]	Sr_2GdF_7
[SLF]	Sr_2LaF_7
[near-UV]	near-ultraviolet
[WP]	Work package

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1. The list of fabricated LEDs for testing

A novel LED fabrication strategy for plant growth applications combines near-UV or UV semiconductor chips with representative single-component phosphors that emit in three wavelengths, based on Bi^{3+} and Eu^{3+} activators and their efficient energy transfer (ET). This strategy provides broadband blue emission that may sensitize various cryptochrome and phototropin photoreceptors (pterin (380), flavin (447 nm), Phytotropin, and Zeitlupes, LOV (390, 457, and 480 nm)). In addition, an LED fabrication strategy integrating near-UV or UV semiconductor chips with representative single-component phosphors that emit in two wavelengths, activated by Eu^{3+}, was also implemented. Four selected Eu^{3+}-based phosphors, used as layers on the LED chips, are as follows:

- SrF_2: Bi^{3+}, Eu^{3+}
- $SrGdF_7$: Eu^{3+}
- $SrLaF_7$: Eu^{3+}
- RbY_3F_{10}:Eu^{3+}

Converting UV light into blue and red light using inorganic phosphors in LEDs is crucial for enhancing photosynthesis in greenhouse-grown plants. Red light, for instance, supports flowering and fruiting in crops such as tomatoes, peppers, and orchids, and also improves fruit production in strawberries and cucumbers. Meanwhile, blue light encourages healthy leaf development in leafy greens like lettuce, spinach, and kale, and strengthens early seedling growth by fostering robust leaves and stems. The tunable red/blue light properties of the synthesized phosphors could ensure plants receive the optimal light spectrum at each stage of their growth cycle.

2. LED performance: LED based on a UV chip and SrF_2:Bi^{3+}, Eu^{3+} phosphor

LED fabrication- methodology 1

The SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor was mixed separately with a high-temperature inorganic binder, Aremco-CeramabindTM 643-2, before being deposited onto (i) 278 nm and (ii) 395 nm LED chips (LED accessories purchased on the market). The resulting resin, containing Ceramabind and SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor, was deposited on top of the LED chip using the doctor blade (tape casting) technique, then dried for 48 hours. Photographs of the fabricated LED device, presented in Figure 1a, show a strong pink-violet light when the power supply is on. The PL spectrum of the fabricated LED, composed of a 278 nm chip and SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor, reveals strong emissions in the blue, orange/red, and far-red regions (see Figure 1b). Figure 1b (right) shows the emission of the 278 nm LED chip before the red phosphor was applied. Owing to its intense blue, orange/red, and far-red emissions, this LED holds great promise for indoor horticultural applications.

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Figure 1c shows the PL spectrum of the fabricated LED, composed of a 395 nm chip and SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor exhibits strong emissions in the near-UV, orange/red, and far-red regions. Figure 1c (right) shows the emission of the 395 nm LED chip before the red phosphor was applied. A noticeable dip at 391 nm confirms UV absorption by Eu^{3+} ions.

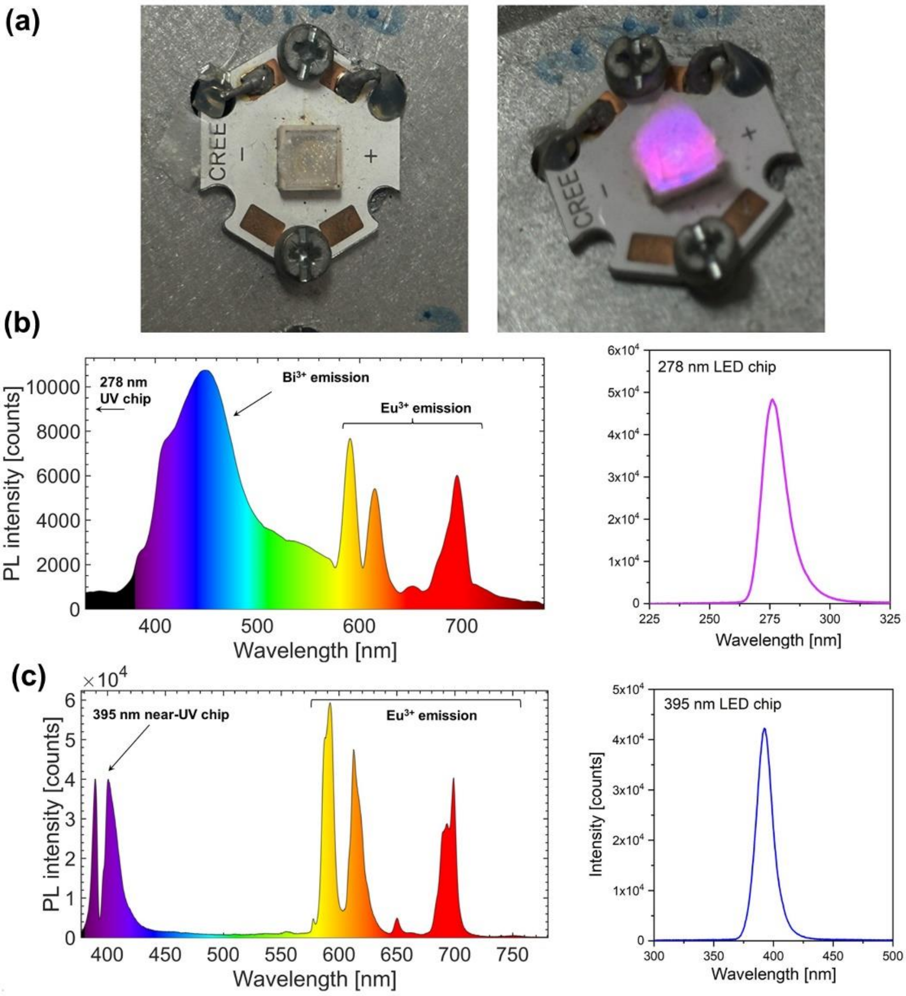

Figure 1. *(a) Photograph of the fabricated LED device emitting pinkish-violet light, using a 278 nm LED chip combined with* SrF_2*:10%*Eu^{3+}*,20%*Bi^{3+} *phosphor; (b) PL spectrum of the LED based on 278 nm chip, with the emission of the bare chip (without phosphor) shown on the right for comparison; (c) PL spectrum of the LED based on 395 nm chip, with the corresponding emission from the bare chip (without phosphor) shown on the right.*

<u>*LED fabrication- methodology 2*</u>

The SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor was separately mixed with UV curing adhesive (LEAFTOP, SHENZHENSHI TEGU NEW MATERIALS CO., LTD) before being deposited on the 395 nm and 365 nm UV chips (LED accessories purchased on the market) for a comparative study. All samples were coated on the semiconductor chip with phosphor-adhesive layers of varying thicknesses to optimize PL efficacy. The LEDs' performance operating at around 3.0 V at various driving currents was monitored, and the following were determined: (i) PL spectrum of fabricated LEDs; (ii) Commission Internationale de l'Eclairage (CIE) spectrum of fabricated LEDs; (iii) Correlated Color Temperature; (iv) Color Rendering Index; (v) Luminous Flux; and (vi) Luminous Efficacy of fabricated LEDs. The photoelectric & colorimetric properties of the fabricated LEDs were measured by an Auto-Temperatured LED Opto-Electronic Analyzer (ATA-500). Photographs of the fabricated LED device under daylight and 365 nm

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UV illumination are shown in Figure 2. The photoluminescence (PL) spectrum of the LED fabricated with a 365 nm chip and SrF_2:10%Eu^{3+}, 20%Bi^{3+} phosphor, the LED exhibits intense UV emission, along with orange/red and far-red emissions (Figure 2). The absence of blue emission indicates that this LED configuration does not meet the spectral requirements for indoor plant cultivation. Consequently, an alternative LED design was developed by combining the same phosphor with a 395 nm UV chip, as shown in Figure 3.

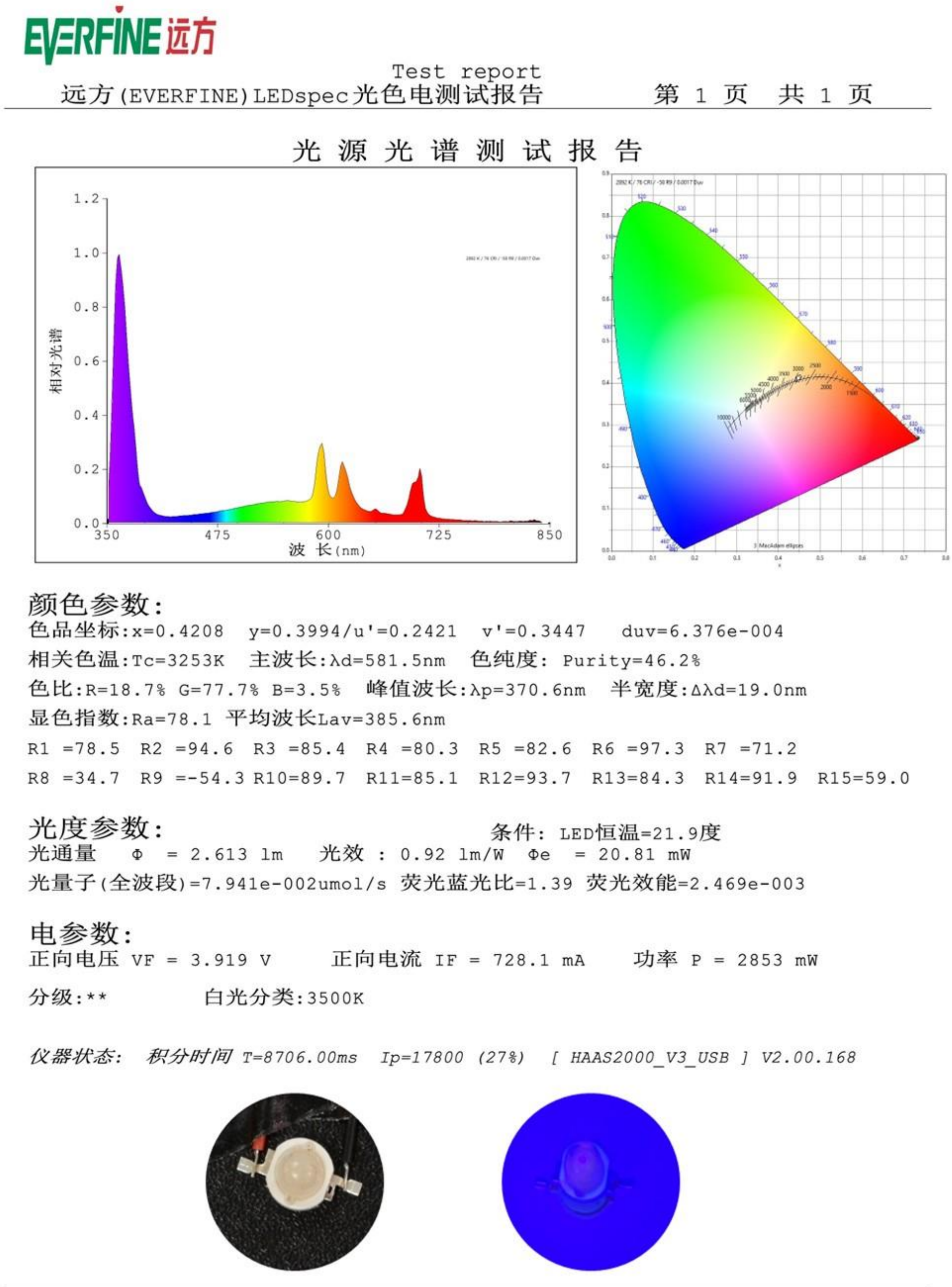

***Figure 2**. Photoluminescence (PL) spectrum of the LED fabricated using a 365 nm chip and SrF_2:10%Eu^{3+}, 20%Bi^{3+} phosphor (driving current: 1000 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

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The performance of the LED based on SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor and a 365 nm chip, operating at around 3.0 V with a driving current of 50 mA, is summarized as follows: (i) the PL spectrum of the fabricated LED shows good overlap with the photosynthetically active radiation (PAR) range of plant photoreceptors, with pronounced blue and red emission components; (ii) CIE chromaticity coordinates of x = 0.3759 and y = 0.2743, corresponding to a pinkish emission; (iii) a correlated color temperature (CCT) of 2858 K; (iv) a color rendering index (CRI, Ra) of 67.4; (v) a luminous flux (Φ) of 0.7146 lm; and (vi) a luminous efficacy of 4.72 lm/W.

The PL spectrum further reveals intense emission in the UV–blue region, followed by orange/red and far-red emissions. Collectively, these results indicate that the fabricated LED is a promising candidate for indoor horticultural applications.

EVERFINE 远方

Test report

远方(EVERFINE)LEDspec光色电测试报告　　第 1 页　共 1 页

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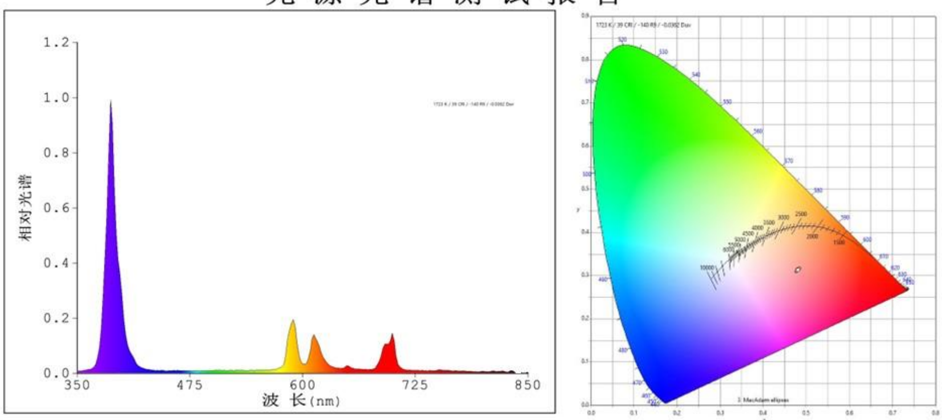

颜色参数:

色品坐标:x=0.3759　y=0.2695/u'=0.2743　v'=0.2949　duv=-5.758e-002

相关色温:Tc=2858K　主波长:λd=-513.0nm　色纯度: Purity=13.9%

色比:R=22.5% G=73.7% B=3.8%　峰值波长:λp=396.5nm　半宽度:Δλd=10.8nm

显色指数:Ra=67.4　平均波长Lav=399.6nm

R1 =77.8　R2 =89.3　R3 =64.1　R4 =70.9　R5 =87.3　R6 =76.0　R7 =51.1

R8 =22.7　R9 =-62.8　R10=79.9　R11=82.9　R12=19.1　R13=82.8　R14=80.1　R15=63.1

光度参数:　条件: LED恒温=22.0度

光通量　Φ　= 0.7146 lm　光效 : 4.72 lm/W　Φe　= 11.92 mW

光量子(全波段)=4.364e-002umol/s　荧光蓝光比=0.219　荧光效能=1.400e-002

电参数:

正向电压 VF = 3.028 V　正向电流 IF = 50.0 mA　功率 P = 151.4 mW

分级:**　白光分类:OUT

仪器状态:　积分时间 T=10528.00ms　Ip=37634 (57%)　[HAAS2000_V3_USB] V2.00.168

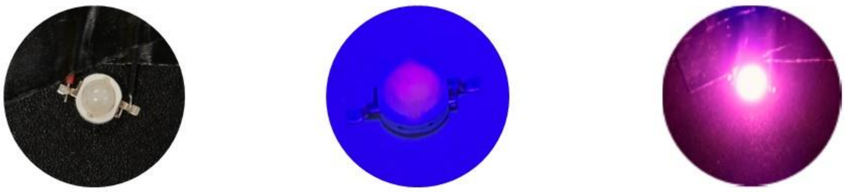

***Figure 3**. PL spectrum of the LED fabricated using a 395 nm chip and SrF_2:10%Eu^{3+}, 20%Bi^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

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3. LED performance: LED based on a UV chip and $Sr_2GdF_7:Eu^{3+}$ phosphor

LED fabrication - methodology 1

The Sr2GdF7:80%Eu3+ nanophosphor was mixed separately with a high-temperature inorganic binder, Aremco-CeramabindTM 643-2, before being deposited onto a 365 nm LED chip. The resin mixture was deposited on top of the LED chip using the doctor blade (tape casting) technique, then dried for 48 hours. Photographs of the fabricated LED device, shown in Figure 4a, show strong red light when the power supply is on. The PL spectrum of the fabricated LED, composed of a 365 nm chip and SGF:80Eu nanophosphor, shows strong emissions in the red and far-red regions, with a noticeably weaker near-UV LED component (see Figure 4b).

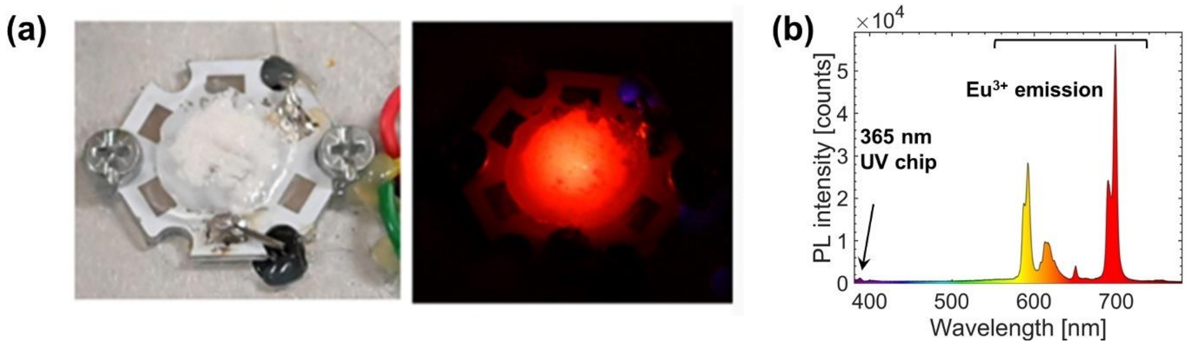

***Figure 4**. (a) A fabricated LED device comprising a 365 nm semiconductor chip and SGF_80Eu nanopowders displays a red light when the electrical power supply is on; and (b) PL spectrum of the fabricated 365nm-chip-based LED.*

LED fabrication- methodology 2

The Sr_2GdF_7:80%Eu^{3+} phosphor was mixed separately with UV-curing adhesive (LEAFTOP, SHENZHENSHI TEGU NEW MATERIALS CO., LTD) and then deposited onto 395 nm and 365 nm near-UV chips (LED accessories purchased on the market) for a comparative study. LED performance was evaluated at an operating voltage of approximately 3.0 V under driving currents of 20 and 50 mA. The following parameters were determined: (i) the PL spectra of the fabricated LEDs and their correspondence with the photosynthetically active radiation (PAR) range of plant photoreceptors; (ii) CIE chromaticity coordinates; (iii) correlated color temperature (CCT); (iv) color rendering index (CRI); (v) luminous flux; and (vi) luminous efficacy. The photoelectric and colorimetric properties of the fabricated LEDs were measured using an auto-temperature-controlled LED optoelectronic analyzer (ATA-500).

Photographs of the fabricated LED device under daylight, 365 nm UV illumination, and electrical operation are shown in Figure 5. Under a driving current of 50 mA, the PL spectrum of the LED fabricated using a 365 nm chip and Sr_2GdF_7:80%Eu^{3+} phosphor shows strong UV emission, along with orange/red and far-red emission bands (Figure 5). Because blue emission is absent, the resulting PL output appears reddish and does not meet the spectral requirements for indoor plant cultivation. Consequently, an alternative LED configuration was developed by combining the same phosphor with a 395 nm UV chip and operating it at various driving currents, as presented in Figures 6 and 7.

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Test report
远方(EVERFINE)LEDspec光色电测试报告 第 1 页 共 1 页

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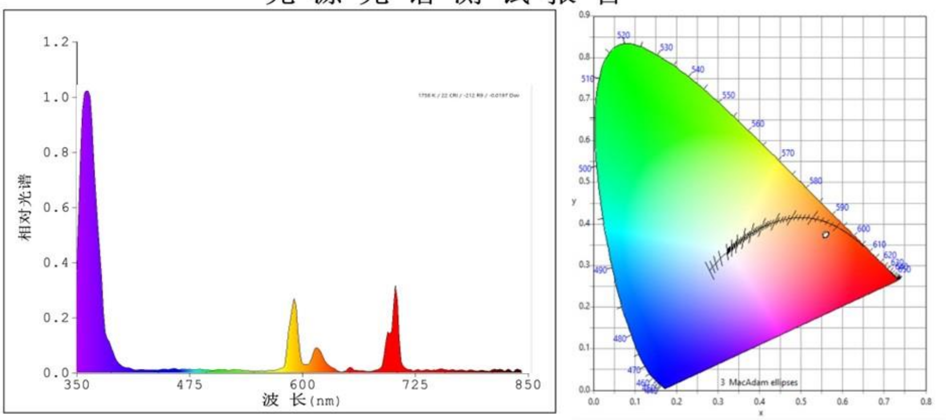

颜色参数:
色品坐标:x=0.4543 y=0.3477/u'=0.2901 v'=0.3331 duv=-2.403e-002
相关色温:Tc=2257K 主波长:λd=600.8nm 色纯度: Purity=40.7%
色比:R=18.8% G=78.1% B=3.1% 峰值波长:λp=372.1nm 半宽度:Δλd=20.4nm
显色指数:Ra=45.8 平均波长Lav=378.0nm
R1 =48.9 R2 =94.4 R3 =39.5 R4 =40.2 R5 =61.3 R6 =83.4 R7 =28.3
R8 =-29.5 R9 =-157.7R10=90.5 R11=52.8 R12=57.4 R13=66.1 R14=63.4 R15=20.7

光度参数: 条件: LED恒温=22.0度
光通量 Φ = 0.1624 lm 光效 : 0.98 lm/W Φe = 4.692 mW
光量子(全波段)=1.599e-002umol/s 荧光蓝光比=0.373 荧光效能=3.267e-003

电参数:
正向电压 VF = 3.328 V 正向电流 IF = 50.0 mA 功率 P = 166.4 mW
分级:** 白光分类:OUT

仪器状态: 积分时间 T=12386.00ms Ip=15074 (23%) [HAAS2000_V3_USB] V2.00.168

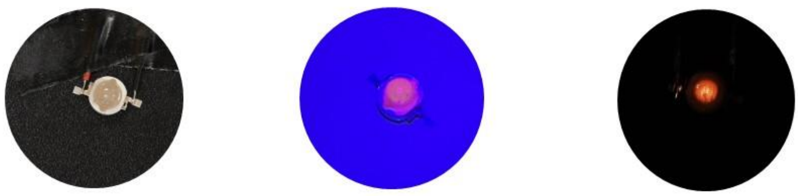

***Figure 5**. PL spectrum of the LED fabricated using a 365 nm chip and SGF_80Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

The performance characteristics of the LED fabricated using SGF:80%Eu phosphor with a 395 nm chip (Figure 6), operated at approximately 3.0 V and a driving current of 20 mA, are summarized as follows: (i) the PL spectrum of the fabricated LED shows good agreement with the photosynthetically active radiation (PAR) range of plant photoreceptors, featuring strong near-UV/blue, orange/red, and deep-red emissions; (ii) CIE chromaticity coordinates of x = 0.4165 and y = 0.2643, corresponding to a pinkish emission; (iii) a correlated color temperature (CCT) of 1977 K; (iv) a color rendering index (CRI, Ra) of 29.3; (v) a luminous flux (Φ) of 0.2295 lm; and (vi) a luminous efficacy of 3.89 lm/W.

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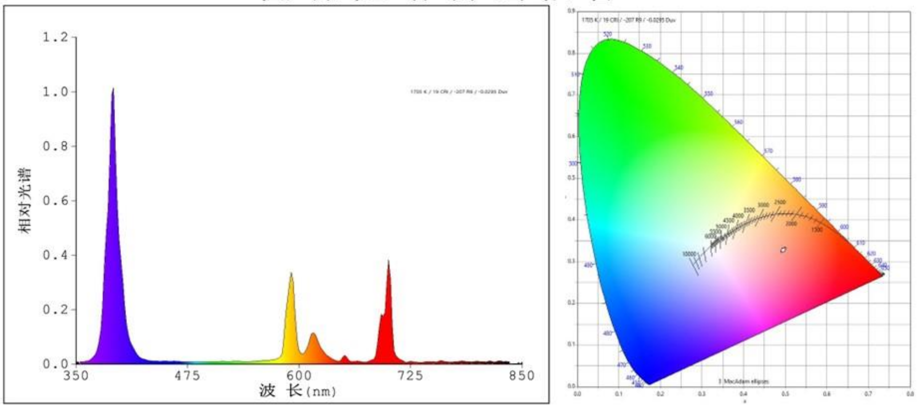

颜色参数：
色品坐标:x=0.4165 y=0.2643/u'=0.3121 v'=0.2971 duv=-6.237e-002
相关色温:Tc=1977K 主波长:λd=-502.8nm 色纯度: Purity=25.3%
色比:R=21.1% G=76.7% B=2.2% 峰值波长:λp=396.5nm 半宽度:Δλd=8.5nm
显色指数:Ra=29.3 平均波长Lav=399.5nm
R1 =25.2 R2 =88.2 R3 =26.9 R4 =3.1 R5 =34.4 R6 =92.4 R7 =13.7
R8 =-49.0 R9 =-187.9R10=91.7 R11=7.4 R12=59.5 R13=46.9 R14=54.8 R15=8.2

光度参数： 条件: LED恒温=22.0度
光通量 Φ = 0.2295 lm 光效 : 3.89 lm/W Φe = 4.377 mW
光量子(全波段)=1.617e-002umol/s 荧光蓝光比=0.23 荧光效能=1.365e-002

电参数：
正向电压 VF = 2.949 V 正向电流 IF = 20.0 mA 功率 P = 59.04 mW
分级:** 白光分类:OUT

仪器状态: 积分时间 T=33353.00ms Ip=51492 (79%) [HAAS2000_V3_USB] V2.00.168

***Figure 6**. PL spectrum of the LED fabricated using a 395 nm chip and SGF_80Eu^{3+} phosphor (driving current: 20 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

The performance of LEDs based on SGF:80%Eu phosphor and a 395 nm chip (see Figure 7), operating at around 3.0 V with a driving current of 50 mA, is as follows: (i) The PL spectrum of the fabricated LEDs matches the PAR spectrum of plant photoreceptors, with the most intense near-UV-blue, orange/red, and deep red emissions; (ii) CIE chromaticity coordinates x=0.4100, y=0.2531, showing pinkish LED emission; (iii) Correlated Color Temperature CCT=1951K; (iv) Color Rendering Index Ra=26.0; (v) Luminous Flux ϕ=0.6623 lm; and (vi) Luminous Efficacy of the fabricated LEDs 4.41 lm/W. The PL spectrum reveals strong emissions in the UV-blue, followed by orange/red and far-red regions. All findings suggest that this LED holds great promise for indoor horticultural applications.

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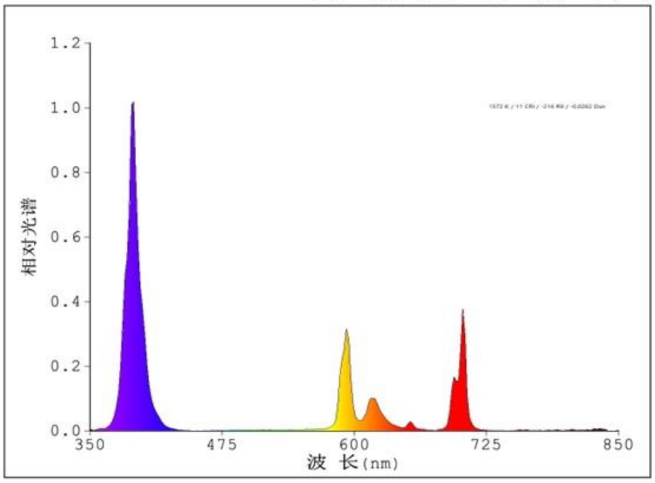

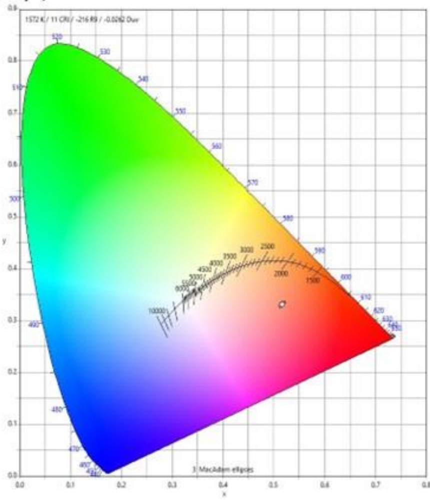

颜色参数:

色品坐标:x=0.4100 y=0.2531/u'=0.3144 v'=0.2911 duv=-6.853e-002

相关色温:Tc=1951K 主波长:λd=-506.1nm 色纯度: Purity=23.3%

色比:R=21.4% G=76.3% B=2.3% 峰值波长:λp=396.6nm 半宽度:Δλd=8.6nm

显色指数:Ra=26.0 平均波长Lav=399.4nm

R1 =22.1 R2 =88.8 R3 =20.6 R4 =-3.6 R5 =31.6 R6 =91.9 R7 =9.5

R8 =-53.2 R9 =-193.0R10=92.9 R11=-0.2 R12=59.1 R13=45.1 R14=50.9 R15=6.6

光度参数: 条件: LED恒温=22.0度

光通量 Φ = 0.6623 lm 光效 : 4.41 lm/W Φe = 13.64 mW

光量子(全波段)=5.004e-002umol/s 荧光蓝光比=0.212 荧光效能=1.564e-002

电参数:

正向电压 VF = 3.004 V 正向电流 IF = 50.0 mA 功率 P = 150.2 mW

分级:** 白光分类:OUT

仪器状态: 积分时间 T=8338.00ms Ip=34498 (53%) [HAAS2000_V3_USB] V2.00.168

Figure 7*. PL spectrum of the LED fabricated using a 395 nm chip and SGF_80Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; and key performance characteristics of the LED.*

4. LED performance: LED based on a UV chip and $Sr_2LaF_7:Eu^{3+}$ phosphor

LED fabrication - methodology 1

The $Sr_2LaF_7:50Eu^{3+}$ nanophosphor was mixed separately with a high-temperature inorganic binder, Aremco-CeramabindTM 643-2, before being deposited on the 395 nm LED chip. The resulting resin, containing Ceramabind and SLF:50Eu phosphor, was deposited on the LED chip using the doctor

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blade (tape casting) technique, then dried for 48 hours. Photographs of the fabricated LED device, shown in Figure 8a, show strong red light when the power supply is on. The PL spectrum of the fabricated LED, composed of a 395 nm chip and SLF:50Eu phosphor, shows strong emissions in the near-UV, orange/red, and far-red regions. Figure 8b (right) shows the emission of the 395 nm LED chip before the red phosphor was applied. A noticeable dip at 391 nm confirms absorption of UV light by Eu^{3+} ions. Consequently, this LED demonstrates strong potential for application in indoor horticultural systems.

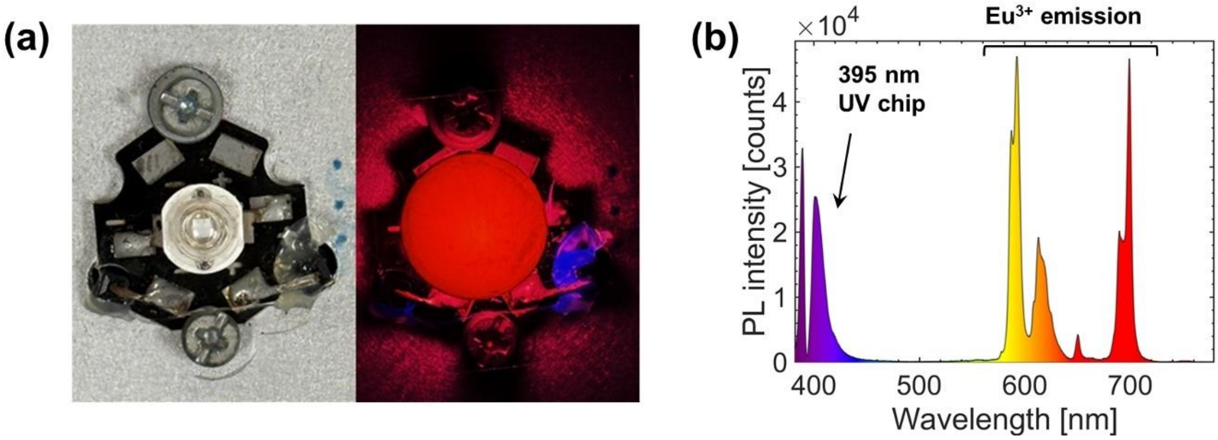

Figure 8. *A fabricated LED device comprising a semiconductor chip and Sr_2LaF_7:50mol%Eu^{3+} nanopowders displays a red light when the electrical power supply is on; PL spectrum of the fabricated 395nm-chip-based LED.*

The Sr_2LaF_7:50%Eu^{3+} phosphor was mixed separately with UV curing adhesive (LEAFTOP, SHENZHENSHI TEGU NEW MATERIALS CO., LTD) and then deposited onto a 395 nm LED chip (LED accessories purchased on the market). LED performance was evaluated at an operating voltage of approximately 3.0 V and a driving current of 50 mA (Figure 9). The results show that: (*i*) the PL spectrum of the fabricated LED exhibits near-UV/blue, orange/red, and deep-red emissions that align well with the PAR spectrum of plant photoreceptors; (*ii*) the CIE chromaticity coordinates are x = 0.3993 and y = 0.3108, corresponding to a pinkish emission; (*iii*) the correlated color temperature (CCT) is 2011 K; (*iv*) the color rendering index (CRI, Ra) is 29.3; (*v*) the luminous flux (Φ) is 0.9040 lm; and (*vi*) the luminous efficacy is 6.02 lm/W.

Photographs of the fabricated LED device based on a 395 nm UV chip, taken under daylight, under 365 nm UV illumination, and during electrical operation, are also shown in Figure 9. When powered on, the device emits an intense pinkish-violet light. Owing to its strong blue, orange/red, and far-red emission components, this LED demonstrates significant potential for indoor horticultural applications.

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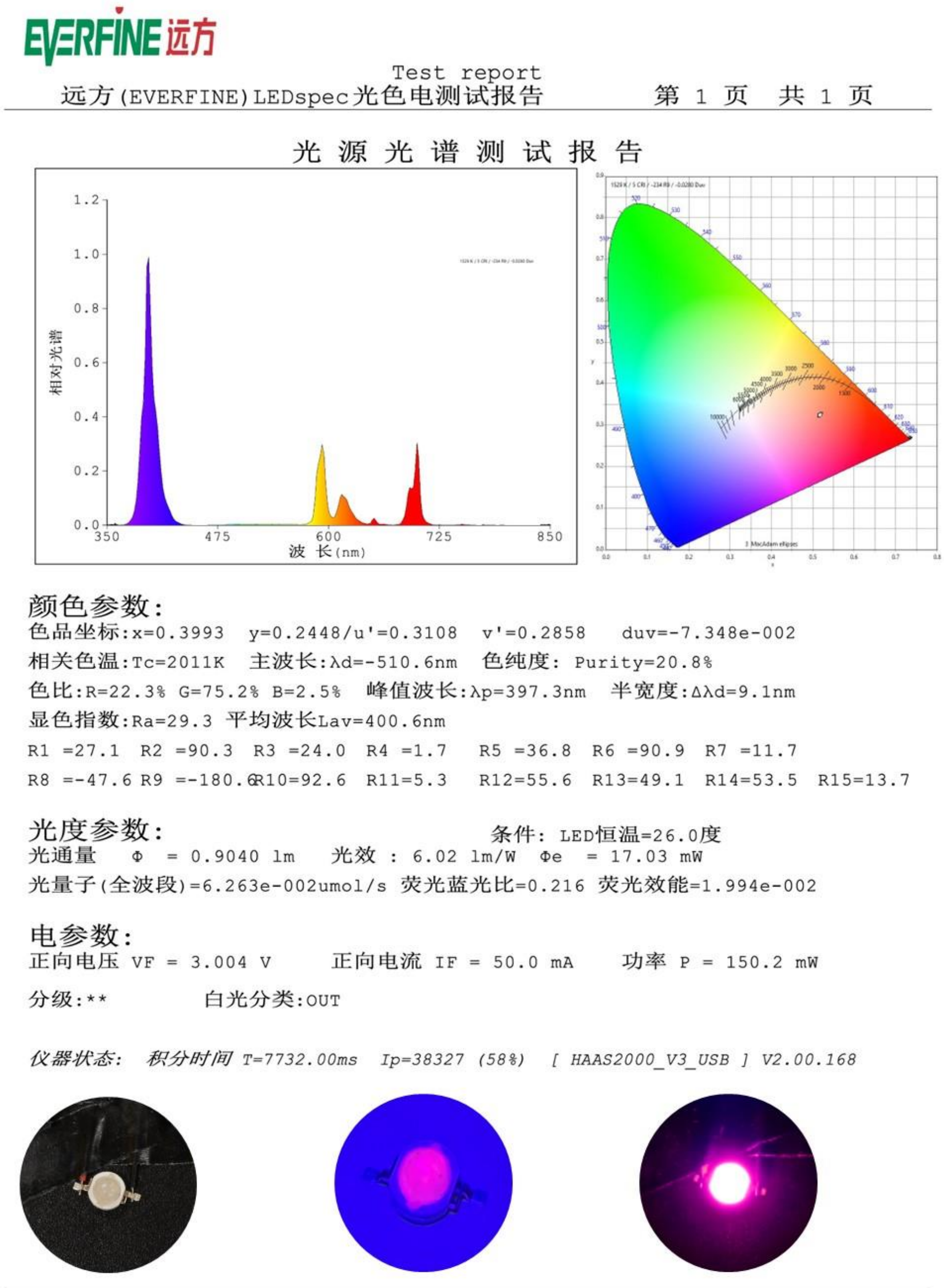
Test report
远方(EVERFINE)LEDspec光色电测试报告 第 1 页 共 1 页

光 源 光 谱 测 试 报 告

颜色参数:
色品坐标:x=0.3993 y=0.2448/u'=0.3108 v'=0.2858 duv=-7.348e-002
相关色温:Tc=2011K 主波长:λd=-510.6nm 色纯度: Purity=20.8%
色比:R=22.3% G=75.2% B=2.5% 峰值波长:λp=397.3nm 半宽度:Δλd=9.1nm
显色指数:Ra=29.3 平均波长Lav=400.6nm
R1 =27.1 R2 =90.3 R3 =24.0 R4 =1.7 R5 =36.8 R6 =90.9 R7 =11.7
R8 =-47.6 R9 =-180.6R10=92.6 R11=5.3 R12=55.6 R13=49.1 R14=53.5 R15=13.7

光度参数: 条件: LED恒温=26.0度
光通量 Φ = 0.9040 lm 光效 : 6.02 lm/W Φe = 17.03 mW
光量子(全波段)=6.263e-002umol/s 荧光蓝光比=0.216 荧光效能=1.994e-002

电参数:
正向电压 VF = 3.004 V 正向电流 IF = 50.0 mA 功率 P = 150.2 mW
分级:** 白光分类:OUT

仪器状态: 积分时间 T=7732.00ms Ip=38327 (58%) [HAAS2000_V3_USB] V2.00.168

Figure 9. *PL spectrum of the LED fabricated using a 395 nm chip and Sr_2LaF_7:50mol%Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

5. LED performance: LED based on a UV chip and RbY_3F_{10}: Eu^{3+} phosphor

<u>*LED fabrication - methodology 1*</u>

The RbY_3F_{10}:50Eu^{3+} nanophosphor was mixed separately with a high-temperature inorganic binder, Aremco-CeramabindTM 643-2, before being deposited onto the 395 nm LED chip. The

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resulting resin, containing Ceramabind and RbY_3F_{10}:50Eu^{3+} phosphor, was deposited on the LED chip using the doctor blade (tape casting) technique, then dried for 48 hours. Photographs of the fabricated LED device, shown in Figure 10a, display a strong violet/pinkish light when the power supply is on. The PL spectrum of the fabricated LED, comprising a 395 nm chip and RbY_3F_{10}:50Eu^{3+} phosphor, exhibits strong emissions in the near-UV, orange/red, and far-red regions (see Figure 10b). A minor dip at 391 nm indicates low absorption of near-UV light by Eu^{3+} ions. The insufficient intensity of red and far-red emissions makes this LED unsuitable for effective indoor horticultural use. Our upcoming research will focus on the improvement of red and far-red light components.

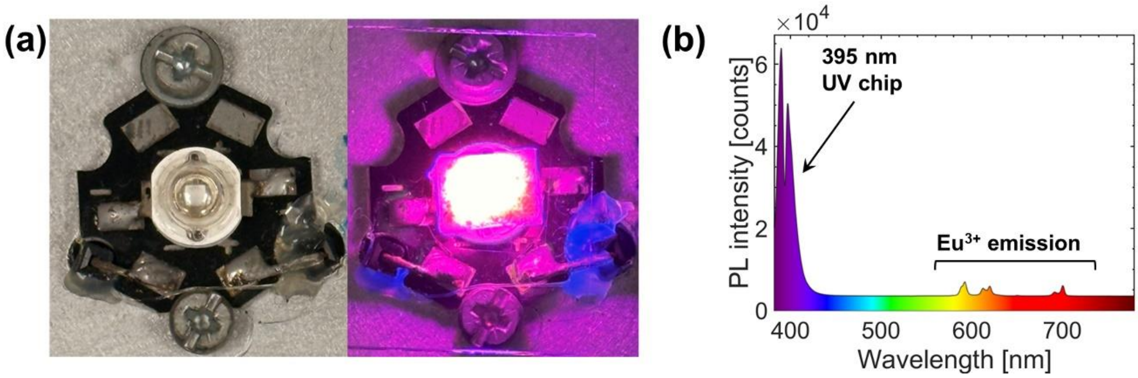

Figure 10. *A fabricated LED device comprising a semiconductor chip and RbY_3F_{10}:50mol%Eu^{3+} nanopowders displays a violet/pinkish light when the electrical power supply is on; and (b) PL spectrum of the fabricated 395nm-chip-based LED.*

<u>*LED fabrication - methodology 2*</u>

The RbY_3F_{10}:50Eu^{3+} phosphor was mixed separately with UV-curing adhesive (LEAFTOP, SHENZHENSHI TEGU NEW MATERIALS CO., LTD) and then deposited onto the 395 nm near-UV chip (LED accessories purchased on the market). The LED performance was evaluated at an operating voltage of approximately 3.0 V and a driving current of 50 mA (Figure 11). The analysis indicates that: (i) the PL spectrum of the fabricated LED exhibits near-UV/blue, orange/red, and deep-red emissions that closely match the photosynthetically active radiation (PAR) range of plant photoreceptors; (ii) the CIE chromaticity coordinates are x = 0.3895 and y = 0.2188, corresponding to a pinkish emission; (iii) the correlated color temperature (CCT) is 1867 K; (iv) the color rendering index (CRI, Ra) is 38.3; (v) the luminous flux (Φ) is 0.8361 lm; and (vi) the luminous efficacy is 5.58 lm/W.

Photographs of the fabricated LED device based on a 395 nm UV chip, recorded under daylight, 365 nm UV illumination, and electrical operation, are shown in Figure 11. When powered on, the device emits intense pinkish-violet light. Owing to its strong blue, orange/red, and far-red emission components, this LED shows considerable potential for indoor horticultural applications. Additionally, a distinct dip at 391 nm confirms the absorption of UV radiation by Eu^{3+} ions.

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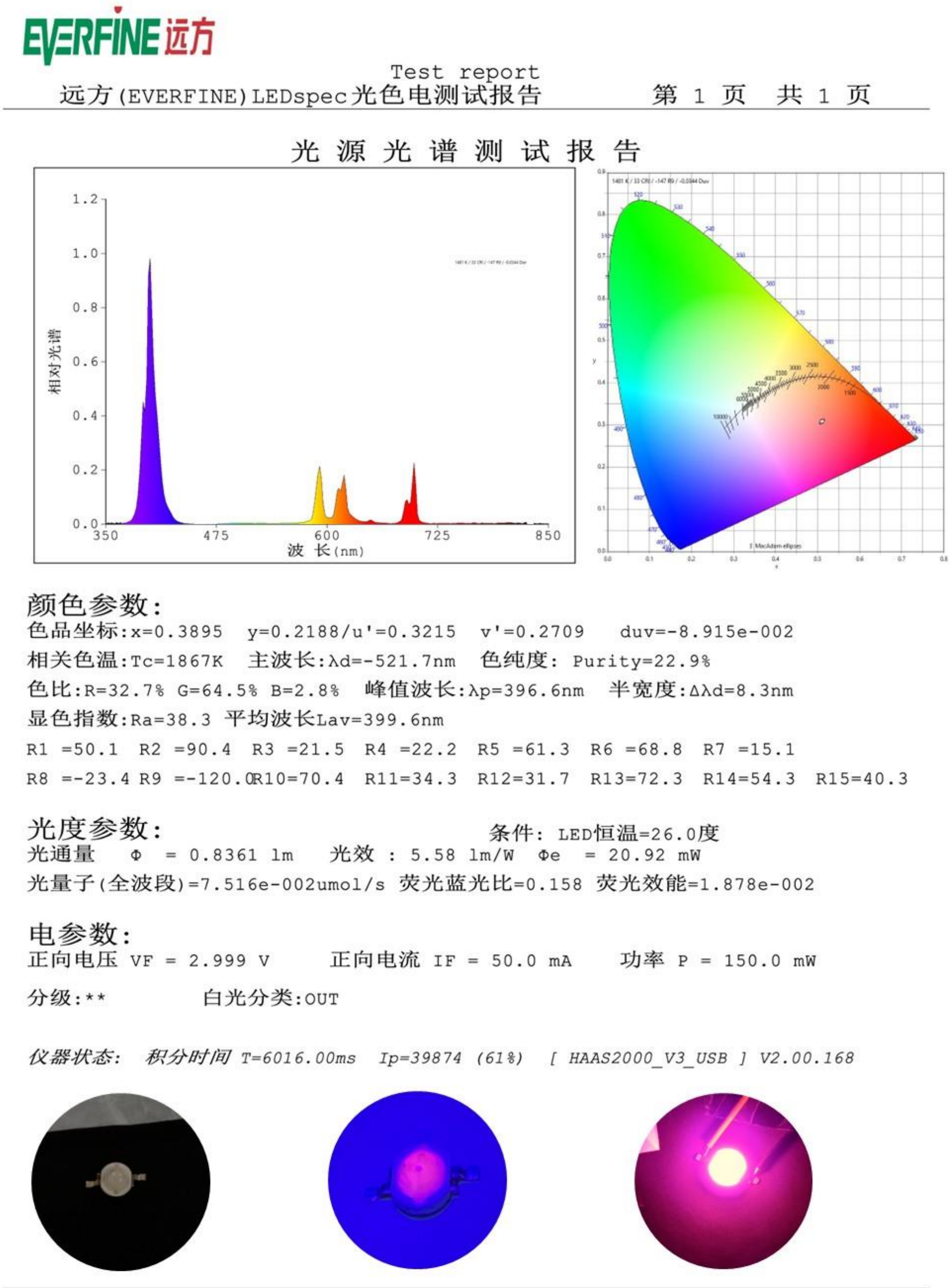

颜色参数:
色品坐标:x=0.3895 y=0.2188/u'=0.3215 v'=0.2709 duv=-8.915e-002
相关色温:Tc=1867K 主波长:λd=-521.7nm 色纯度: Purity=22.9%
色比:R=32.7% G=64.5% B=2.8% 峰值波长:λp=396.6nm 半宽度:Δλd=8.3nm
显色指数:Ra=38.3 平均波长Lav=399.6nm
R1 =50.1 R2 =90.4 R3 =21.5 R4 =22.2 R5 =61.3 R6 =68.8 R7 =15.1
R8 =-23.4 R9 =-120.0 R10=70.4 R11=34.3 R12=31.7 R13=72.3 R14=54.3 R15=40.3

光度参数: 条件: LED恒温=26.0度
光通量 Φ = 0.8361 lm 光效 : 5.58 lm/W Φe = 20.92 mW
光量子(全波段)=7.516e-002umol/s 荧光蓝光比=0.158 荧光效能=1.878e-002

电参数:
正向电压 VF = 2.999 V 正向电流 IF = 50.0 mA 功率 P = 150.0 mW
分级:** 白光分类:OUT

仪器状态: 积分时间 T=6016.00ms Ip=39874 (61%) [HAAS2000_V3_USB] V2.00.168

Figure 11. *PL spectrum of the LED fabricated using a 395 nm chip and RbY_3F_{10}:50mol%Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

6. Scientific Publications and Peer-Reviewed Journals

During the project implementation, the LEDtech-GROW team achieved the following: five papers were published in peer-reviewed journals, all of which are Open-Access per the grant agreement (with an additional two papers submitted); six poster presentations were delivered at

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international conferences; one oral talk was delivered at an international conference; and one invited talk was delivered at a domestic conference.

1. Lj. Đačanin Far, J. Periša, I. Zeković, Z. Ristić, M. Medić, M.D. Dramićanin, B. Milićević. *"Tailoring red and deep-red light: Bi^{3+} doped $Sr_2Gd_{0.2}Eu_{0.8}F_7$ phosphors for next-generation horticultural LEDs" Results in Physics 78 (2025) 108495* https://doi.org/10.1016/j.rinp.2025.108495

2. B. Milićević, A. Ćirić, K. Milenković, Z. Ristić, J. Periša, Ž. Antić, M. D. Dramićanin. "*Pr^{3+}-Activated Sr_2LaF_7 Nanoparticles as a Single-Phase White-Light-Emitting Nanophosphor". Nanomaterials 15(10) (2025) 717;* https://doi.org/10.3390/nano15100717

3. B. Milićević, A. Ćirić, Z. Ristić, M. Medić, A. N. Alodhayb, I. Radosavljević Evans, Ž. Antić, M. D. Dramićanin. "*Eu^{3+}- activated Sr_2GdF_7 colloid and nano-powder for horticulture LED applications". Journal of Alloys and Compounds 1010 (5) (2025) 177820.* https://doi.org/10.1016/j.jallcom.2024.177820

4. K. Milenković, Lj. Đačanin Far, S. Kuzman, Ž. Antić, A. Ćirić, M. D. Dramićanin, B. Milićević. "Red emission enhancement in $BaYF_5:Eu^{3+}$ phosphor nanoparticles by Bi^{3+} co-doping". *Optics Express* 32 (23) (2024) 41632-41643 https://doi.org/10.1364/OE.542685

5. J. Periša, S. Kuzman, A. Ćirić, Z. Ristić, Ž. Antić, M. D. Dramićanin, B. Milićević. "Tuneable Red and Blue Emission of Bi^{3+}-Co-Doped $SrF_2:Eu^{3+}$ Nanophosphors for LEDs in Agricultural Applications". *Nanomaterials* 14(20), 1617. https://doi.org/10.3390/nano14201617

6. A. Ćirić, M. Suta, B. Milićević, T. Förster, T. Gavrilović, Ž. Antić, M. D. Dramićanin: "Judd-Ofelt Analysis of Pr^{3+}: A Direct Emission Spectrum Approach for Advanced LED Phosphors and Scintillators"- 6th International Conference on MATERIALS SCIENCE & NANOTECHNOLOGY Future Materials 2025 Tenerife, Španija (pp 35). *Oral talk*

7. Lj. Đačanin Far, B. Milićević, J. Periša, A. Ćirić, K. Milenković, S. Kuzman, and M.D. Dramićanin: "Eu^{3+}-Doped Sr_2LaF_7 nanopowders for Indoor Plant Growth LED Applications"- Future Materials 2025, 6th International Conference on Materials Science & Nanotechnology Costa Adeje, Tenerife, Spain (pp 119-120).

8. S. Kuzman, Lj. Đačanin Far, B. Milićević, J. Periša, A. Ćirić, K. Milenković, and M.D. Dramićanin: "Emission Enhancement by Bi^{3+} Co-Doping of Red-Emitting #anophosphor for Horticulture LEDs"- Future Materials 2025, 6th International Conference on Materials Science & Nanotechnology Costa Adeje, Tenerife, Spain (pp 121).

9. K. Milenković, V. Đorđević, I. Zeković, Z. Ristić, J. Periša, B. Milićević, M. D. Dramićanin: "Microwave-assisted solvothermal method for RbY_3F_{10} doped with Eu^{3+}"- The 7th International Conference on the Physics of Optical Materials and Devices & The 4th International Conference on Phosphor Thermometry (ICOM&ICPT 2024), August 26-30, 2024, Bečići, Budva Montenegro, P-50, (pp 165).

10. S. Kuzman, B. Milićević, J. Periša, A. Ćirić, Z. Ristić, Ž. Antić, M. D. Dramićanin: "Synthesis and photoluminescent properties of Bi^{3+}-codoped $SrF_2:Eu^{3+}$ phosphor nanoparticles"- The 7th

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International Conference on the Physics of Optical Materials and Devices & The 4th International Conference on Phosphor Thermometry (ICOM&ICPT 2024), August 26-30, 2024, Bečići, Budva Montenegro, P-51, (pp 166).

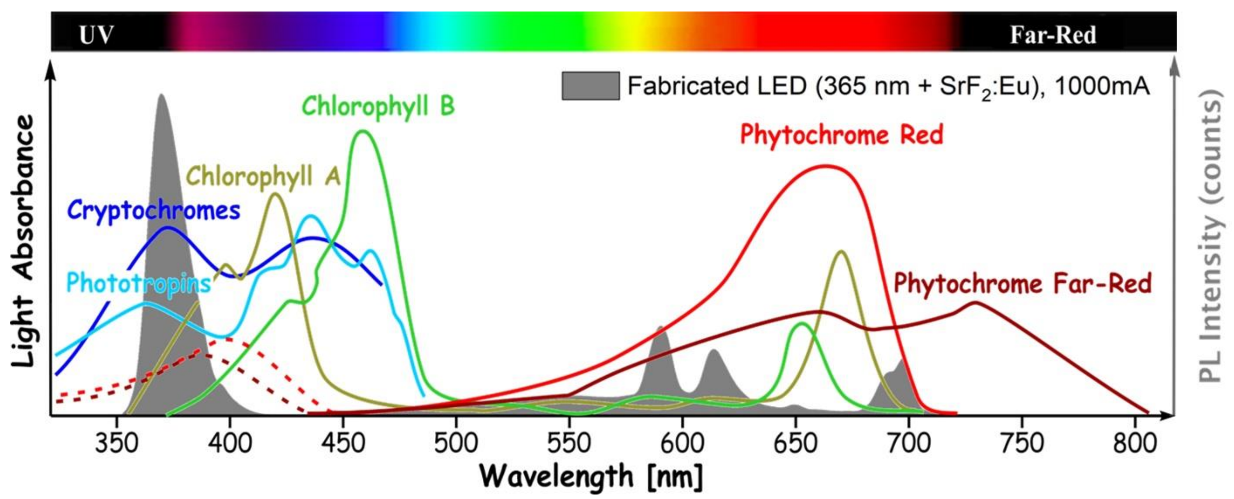
11. B. Milićević, A. Ćirić, Z. Ristić, M. Medić, I. Radosavljevic Evans, Ž. Antić, M. D. Dramićanin: "Synthesis, luminescent properties, and thermal stability of Eu^{3+}-doped Sr_2GdF_7 red-emitting nanophosphor for horticulture LEDs"- The 7th International Conference on the Physics of Optical Materials and Devices & The 4th International Conference on Phosphor Thermometry (ICOM&ICPT 2024), August 26-30, 2024, Bečići, Budva Montenegro, P-53, (pp 168).

12. K. Milenković, V. Đorđević, S. Kuzman, J. Periša, B. Milićević, Miroslav D. Dramićanin: "Three-fold enhancement of Eu^{3+} emission intensity in $BaYF_5$ nanoparticles by Bi^{3+} co-doping", -12th International Conference on Luminescent Detectors and Transformers of Ionizing Radiation (LUMDETR), June 16-21, 2024, Riga, Latvia, PA13, (pp 89).

13. S. Kuzman, B. Milićević, K. Milenković, J. Periša, M. D. Dramićanin: "Bizmuth-sensitized Eu^{3+} luminescent LED technology for effective indoor plant growth"- The 3rd Serbian Conference on Materials Application and Technology (SCOM2024), October 16-18, Belgrade, Serbia, I-1, (pp 8). *Invited talk*

LEDtech-GROW team members reached **Milestone M2.1 - LEDs fabricated** (verification: LED emission matches the PAR spectrum of plant photoreceptors (see below)).

SrF_2:10%Eu^{3+},20%Bi^{3+}



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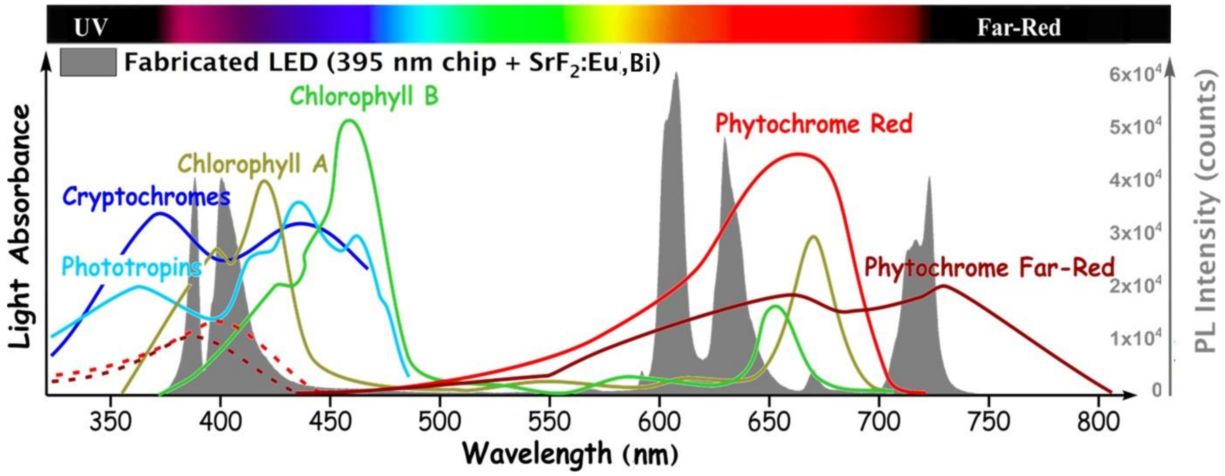
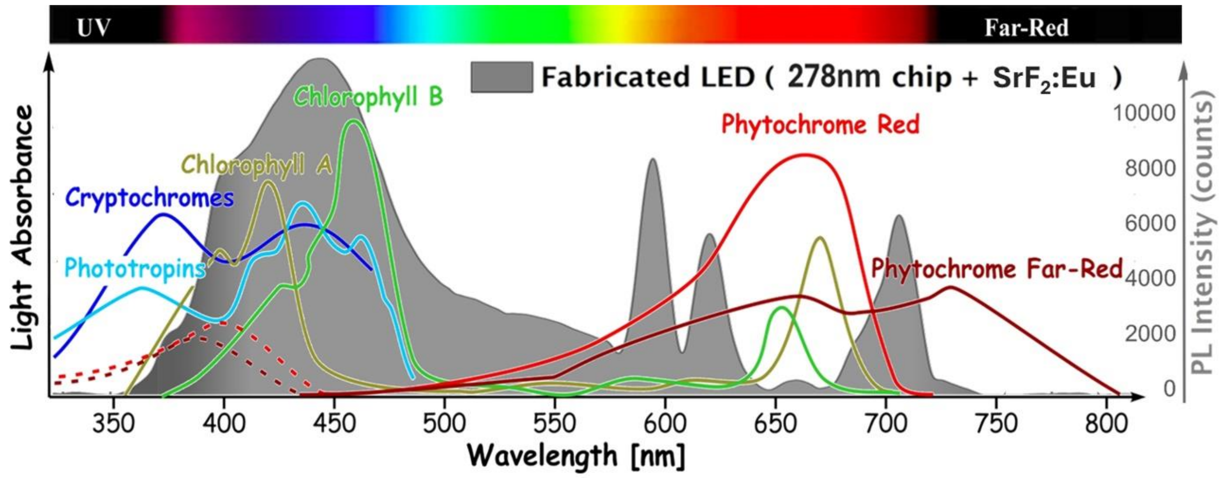
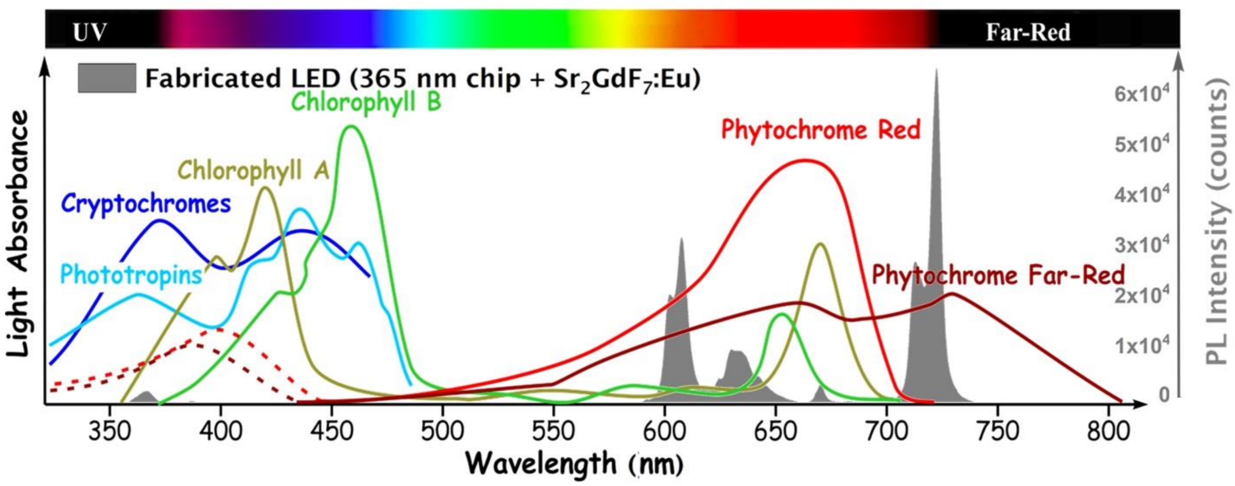
SrF_2:10%Eu^{3+},20%Bi^{3+}



SrF_2:10%Eu^{3+},20%Bi^{3+}



$SrGdF_7$: 80%Eu^{3+}



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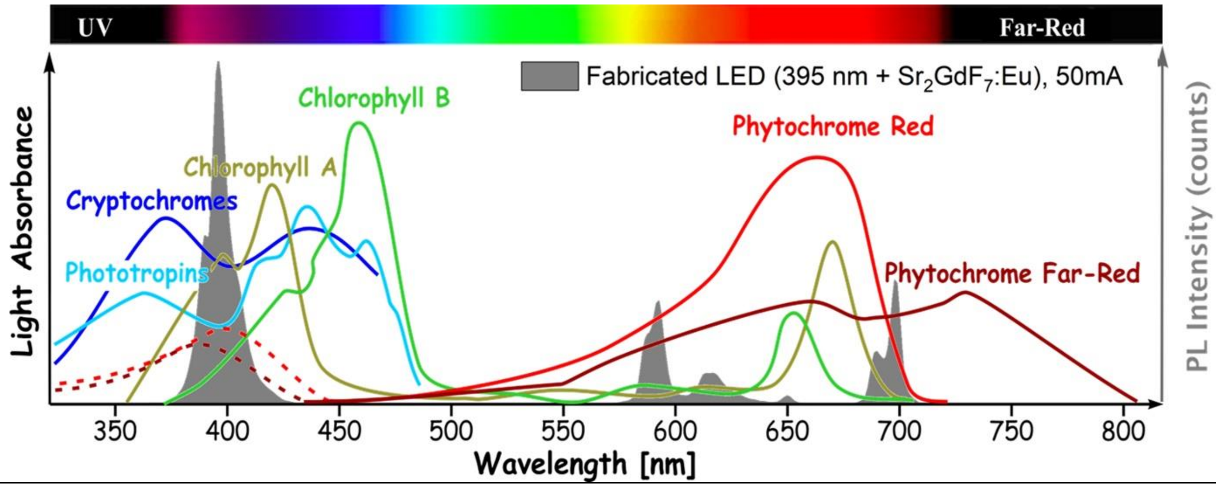
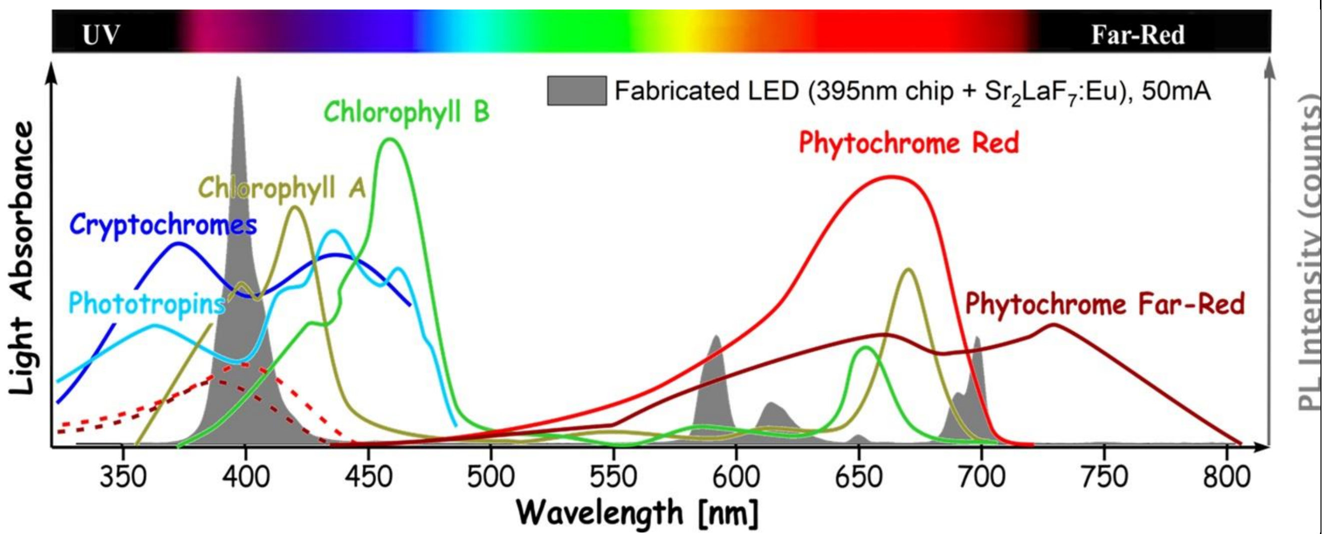
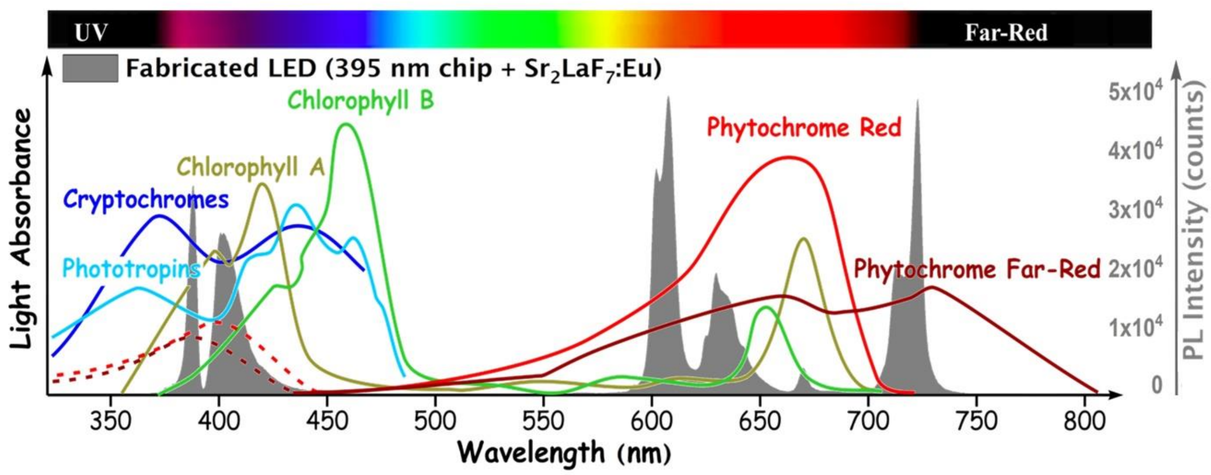
$SrGdF_7$: 80%Eu^{3+}



Sr_2LaF_7:50mol%Eu^{3+}



Sr_2LaF_7:50mol%Eu^{3+}



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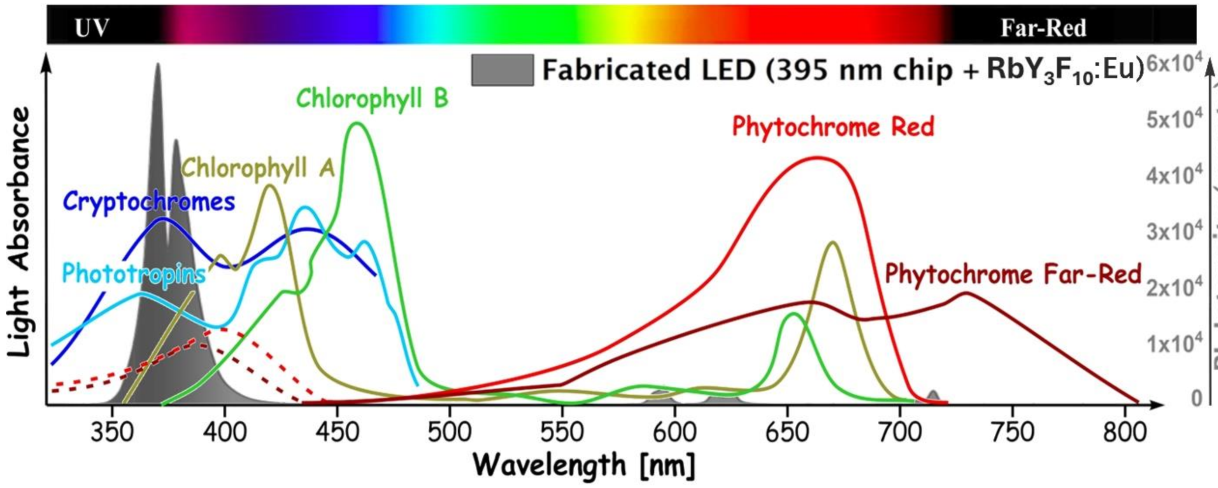
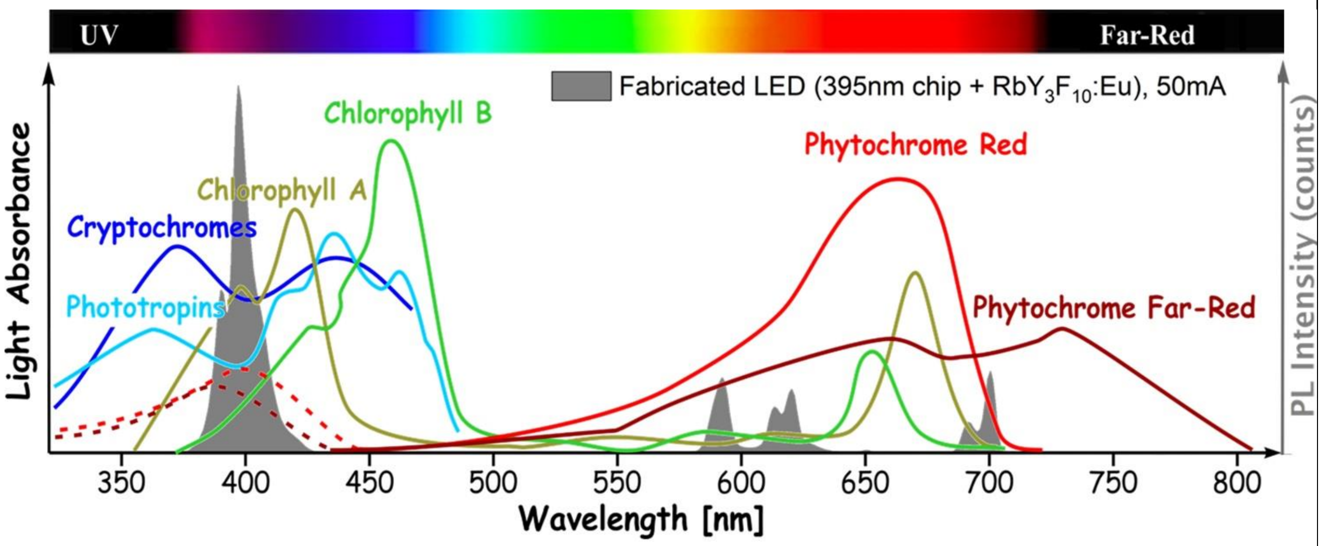
RbY_3F_{10}:50mol%Eu^{3+}



RbY_3F_{10}:50mol%Eu^{3+}



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