Ref. LEDtech-GROW (2025) 10412 - 02/01/2026

Final Report
WP4 (D4.4)

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 4.4

Final Report

Contractual Date Delivery: 02/01/2026

Project Deliverable Information Sheet

LEDtech-GROW Project	Project Ref. No. 10412
	Project Title: *LED technology based on bismuth-sensitized Eu^{3+} luminescence for cost-effective indoor plant growth*
	Call: Program PROMIS 2023
	Starting Date: 03/01/2024
	Duration: 24 months
	Project Website: https://ledtechgrow-promis.org/
	Deliverable No.: D4.4.
	Deliverable Type: Document
	Month of delivery: 24
	Contractual Delivery Date: 02/01/2026
	Actual Delivery Date: 02/01/2026
	Principal investigator: Dr. BOJANA MILIĆEVIĆ
	Abstract: This document outlines the main objectives, methods, and results of the project focused on the development and evaluation of advanced LED materials and devices. Through material synthesis, characterization, and device fabrication, the project achieved improved emission performance and validated the proposed approach. The outcomes provide a solid basis for further research and practical applications.

Document Control Sheet

Document	Title: Final Report.docx
	Distributed to LEDtech-GROW Participants
Authorship	Written by Bojana Milićević
	Contributed by Jovana Periša
	Approved by Bojana Milićević

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Executive Summary

The presented document constitutes deliverable D4.4 – Final report of the LEDtech-GROW project. It is a public document, delivered in the context of WP4 – Management, communication, dissemination, and exploitation, Task 4.1: Scientific coordination, management, and reporting.

This report provides a comprehensive overview of the project's objectives, implemented activities, and key scientific and technological results, with a particular focus on the development, characterization, and fabrication of advanced LED materials and devices for horticultural applications. It summarizes the main achievements across all work packages, highlights dissemination efforts, and outlines the overall impact of the project, demonstrating its contribution to innovation, capacity building, and future research directions in LED-based technologies.

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Abbreviations and Acronyms

	Explanation
[BYF]	$BaYF_5$
[BGF]	$BaGdF_5$
[CCT]	Correlated Color Temperature
[CIE]	Commission Internationale de l'Eclairage
[DEC]	Dissemination, Communication, and Exploitation
[DMP]	Data Management Plan
[DOI]	Digital Object Identifier
[EDTA-2Na]	Disodium ethylenediaminetetraacetate dihydrate
[ET]	Energy transfer
[FAIR data]	Findable, Accessible, Interoperable, Re-usable data
[FWHM]	Full width at half-maximum
[ICDD]	International Centre for Diffraction Data
[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*"
[Open Access]	Open access publishing (open access) means that an article is immediately provided in open access mode on the publisher or journal's website. Some publishers charge Article Processing Chargers (APCs) to make articles open.
[near-UV]	near-ultraviolet
[PAR]	Photosynthetically active radiation (400–700 nm of wavelength), an essential part of the light spectrum which typically drives photosynthesis more efficiently at the red and blue regions of the spectrum
[PL]	Photoluminescence emission spectra
[P_R]	Phytochrome photoreceptors with absorption peak in the red spectral area
[P_{FR}]	Phytochrome photoreceptors with absorption peak in far-red spectral area
[PROMIS 2023]	The Program for Excellent Projects of Young Researchers (PROMIS) is a program of the Science Fund of the Republic of Serbia intended of excellent projects for young researchers in the early phase of their careers

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[PXRD]	Powder X-ray diffraction
[QE]	Quantum efficiency
[RE]	Rare earth
[RYF]	RbY_3F_{10}
[SEF]	Sr_2EuF_7
[SGF]	Sr_2GdF_7
[SGEF]	$Sr_2Gd_{0.2-x}Eu_{0.8}F_7$
[SLF]	Sr_2LaF_7
[TEM]	Transmission electron microscopy
[VinaR]	VinaR, i.e. Vinca Repository is a joint digital repository of all laboratories and departments in Vinča Institute of Nuclear Sciences, University of Belgrade. VinaR provides open access to the publications, as well as other outputs of the research projects implemented in these institutions.
[VINS]	"Vinča" Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade
[WP]	Work package
[Zenodo]	Zenodo is a catch-all research data repository that enables researchers, scientists, EU projects, and institutions to share research results, make research results citable and search and reuse open research results from other projects. Zenodo repository is harvested by the OpenAIRE portal and hosted by the CERN cloud infrastructure.

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1. Introduction

The LEDtech-GROW project (Grant Agreement No. 10412, PROMIS 2023) is implemented at the "Vinča" Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, and is dedicated to the development of advanced LED technologies tailored for indoor plant cultivation. The project focuses on innovative phosphor-converted LED (pc-LED) systems based on bismuth-sensitized Eu^{3+}-activated single-component fluoride phosphors, designed to emit light across the full Photosynthetically Active Radiation (PAR) spectrum and efficiently stimulate plant photoreceptors.

This report provides a comprehensive overview of the implementation and outcomes of the LEDtech-GROW project across all work packages, covering scientific, technological, dissemination, and capacity-building activities. It consolidates the key results achieved within Work Packages WP1–WP4, including the synthesis and characterization of novel Eu^{3+}- and Bi^{3+}/Eu^{3+}-activated phosphors, the fabrication and performance assessment of plant-grow-targeted LED devices, structured professional development of young and early-stage researchers, and systematic dissemination, communication, and exploitation actions.

Within WP1, significant efforts were devoted to the design, synthesis, and comprehensive characterization of inorganic fluoride phosphors optimized for horticultural lighting. Structural, morphological, optical, and temperature-dependent photoluminescence studies enabled the identification of phosphor compositions with suitable emission profiles, chemical and temperature stability, and energy-transfer mechanisms. These materials served as the foundation for WP2, where novel LED fabrication strategies combining near-UV and UV semiconductor chips with single-component phosphors were developed. Detailed analyses of photoluminescence behavior, colorimetric parameters, luminous performance, and emission overlap with absorption spectra of plant photoreceptors demonstrated the strong potential of several fabricated LEDs for indoor horticultural applications.

In parallel with scientific and technological development, the project placed strong emphasis on visibility, dissemination, and open science. Through WP4, the project established key communication and visibility tools early in its implementation, including the official project website, logo, and promotional materials, ensuring a consistent project identity and broad public accessibility. Scientific publications, datasets, and public deliverables were systematically disseminated through internationally recognized repositories and communication channels.

Furthermore, WP3 played a central role in strengthening the professional development of young and early-stage researchers involved in LEDtech-GROW. Targeted trainings, workshops, webinars, international collaboration activities, and short-term research visits enhanced competencies in proposal writing, project management, intellectual property protection, open science, and advanced experimental techniques. These activities not only supported the successful execution of the project but also ensured long-term sustainability and future funding readiness.

Overall, this report demonstrates that LEDtech-GROW has been implemented in a timely, coherent, and impactful manner. By integrating innovative materials research, advanced LED fabrication, dissemination activities, and researcher capacity building, the project makes a significant contribution to the development of plant-growth-targeted lighting technologies and highlights the importance of interdisciplinary research in addressing current challenges in sustainable agriculture and energy efficiency.

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2. Summary of Deliverable D4.1 – Visibility: Website, Logo, and Leaflet (WP4, month 4)

Deliverable **D4.1,** entitled “Visibility: Website, Logo, and Leaflet,” was completed before the fourth month of the project implementation, fully in accordance with the project timeline. This deliverable focused on establishing a strong and coherent visual identity and communication infrastructure for the LEDtech-GROW project. The project website was designed, launched, and made publicly accessible at https://ledtechgrow-promis.org/, serving as the central platform for project visibility, dissemination of results, and communication with the scientific community and the wider public. The website is available in English.

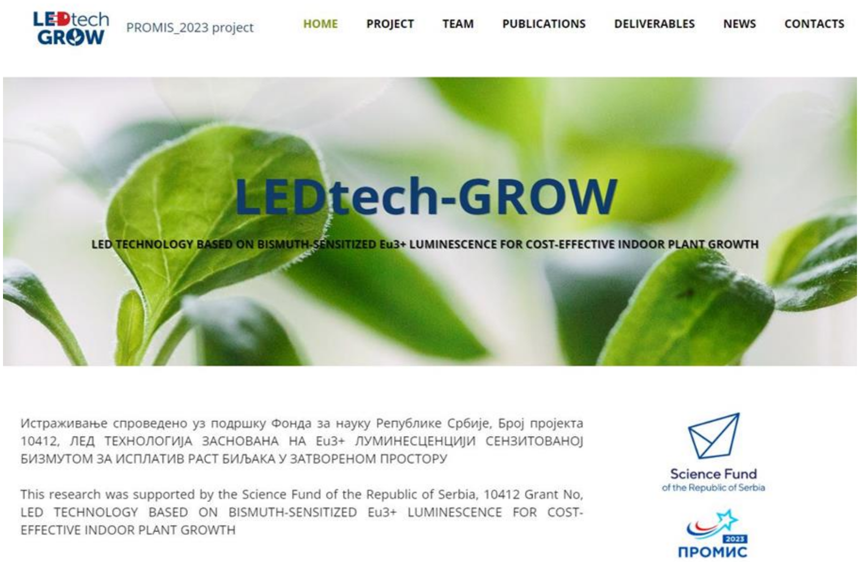

Figure 1. LEDtech-GROW project

In addition, the official project logo and promotional leaflet (https://ledtechgrow-promis.org/gallery/LEDtech-GROW-Leaflet.pdf) were developed to ensure consistent branding across all dissemination materials and communication channels. The timely completion of Deliverable D4.1 significantly contributed to the early visibility and recognition of the LEDtech-GROW project at both national and international levels.

Figure 2. LEDtech-GROW logo

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3. Summary of Deliverable D4.2 – Data Management Plan (WP4, month 6)

Deliverable **D4.2** – Data Management Plan (DMP) was completed and submitted on 1 July 2024, ahead of the contractual deadline of 2 July 2024, corresponding to **Month 6** of the LEDtech-GROW project implementation. Deliverable 4.2 was developed within **Work Package 4** (Management, communication, dissemination, and exploitation), under **Task 4.2 –** Dissemination, communication, and exploitation of knowledge, and was released as a publicly accessible document.

The **DMP** establishes a comprehensive and project-specific framework for the management of all data generated, collected, and processed throughout the entire duration of the LEDtech-GROW project. It is fully aligned with the European Commission Guidelines on Data Management in Horizon 2020, the FAIR data principles, and the contractual obligations defined in Articles 28 and 29 of the Grant Agreement between the Science Fund of the Republic of Serbia and the Vinča Institute of Nuclear Sciences (Grant Agreement No. 10412).

At the time of delivery, the DMP documented data management practices already being actively implemented during the execution of **WP1**, which focused on the design, synthesis, and characterization of plant-growth-targeted phosphors, and laid the groundwork for the systematic handling of forthcoming datasets from **WP2**, dedicated to LED fabrication and performance evaluation.

A key element is a clearly defined open-access and data-sharing strategy. The DMP specifies that all non-confidential project outputs, including scientific publications, underlying datasets, public deliverables, and dissemination materials, are to be made openly available through established, internationally recognized repositories. The **Zenodo repository**, operated by CERN and integrated within the OpenAIRE infrastructure, is designated as the primary platform for archiving open-access datasets and publications, ensuring long-term preservation, assignment of Digital Object Identifiers (DOIs), version control, and global discoverability.

In parallel, all open-access scientific publications and selected research outputs are deposited in the **VinaR repository**, which serves not only as an institutional repository of the Vinča Institute of Nuclear Sciences but also as a fully open, interoperable, and internationally visible research repository. VinaR provides unrestricted global access to deposited content, supports metadata harvesting, and ensures long-term accessibility beyond institutional boundaries, thereby significantly enhancing the visibility and citation potential of LEDtech-GROW research outputs.

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Figure 3. Zenodo and VinaR repositories are used for datasets.

Public deliverables, dissemination materials, project news, and links to deposited datasets and publications are additionally made available through the official **LEDtech-GROW project website** (https://ledtechgrow-promis.org/). By Month 6, the website had been fully launched and regularly updated, serving as a central dissemination hub for the project. It is planned to remain active throughout the project lifetime and for at least one year following project completion, ensuring sustained public access to project outputs.

The DMP also clearly distinguishes between open and restricted datasets. Data associated with scientific publications, dissemination activities, and non-commercial research findings are made openly accessible in accordance with FAIR principles. Conversely, datasets with high innovation potential or relevance for future commercialization are temporarily excluded from open access to prevent compromising intellectual property protection. Such datasets are securely stored on the ASANA internal project platform, accessible exclusively to LEDtech-GROW team members. The DMP defines concrete procedures for handling sensitive data, including the application of non-disclosure agreements, publication embargoes, and, where appropriate, the preparation of patent applications before public disclosure.

Deliverable D4.2 provides detailed guidance on data formats, metadata standards, naming conventions, licensing schemes, and versioning rules, ensuring consistency, interoperability, and reproducibility of project data. Rich metadata, including project acronym, grant number, authorship, experimental context, and licensing information, accompany all datasets deposited in Zenodo and VinaR.

Clear roles and responsibilities are defined within the DMP. Each project member is responsible for the quality, accuracy, and proper documentation of the data they generate, while overall coordination, compliance monitoring, and updates of the DMP are managed by the Principal Investigator and the project management team at the Vinča Institute of Nuclear Sciences. Costs related to open-access publishing, data archiving, and dissemination were anticipated and allocated within the approved project budget.

In conclusion, Deliverable D4.2 was delivered timely, providing a transparent framework for data management in LEDtech-GROW. By combining trusted international repositories (Zenodo), a fully open and globally visible institutional repository (VinaR), and an actively maintained project website and social media channels, the DMP ensures maximum visibility, accessibility, and long-term preservation of project results, while simultaneously safeguarding sensitive data and supporting future exploitation and innovation activities.

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Annexes of Deliverable D4.2

Annex I

Expected Data File Extensions in LEDtech-GROW

File ext.	Description	Editing software
dat	Generic data file	**Text editors (e.g. Notepad)**
txt	Text file	**Text editors (e.g. Notepad)**
doc	Text file	**MS Word**
xls	Spreadsheet	**Spreadsheet software (e.g. MS Excel)**
cvs	Spreadsheet	**Spreadsheet software (e.g. MS Excel)**
jpg	Raster image	**Standard image viewers**
png	Raster image	**Standard image viewers**
tif	Raster image	**Standard image viewers**
nb	Code	**Wolfram Mathematica**
xml	Code	**XML editors**
m	Code	**Mathworks Matlab**
pdf	Portable document format	**Standard PDF viewers**
zip	Archive file format	**Standard file archivers**
rar	Archive file format	**Standard file archivers**

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4. Summary of Deliverable D4.3 – Dissemination, communication, and exploitation plan (WP4, month 9)

This document constitutes Deliverable D4.3 – Dissemination, Communication, and Exploitation Plan, prepared within Work Package 4 (WP4): Management, Communication, Dissemination, and Exploitation of the LEDtech-GROW project. The initial version of this document was prepared and submitted in Month 9 (October 2024), and the final version was completed in Month 24 (December 2025), fully in line with the project timeline and contractual obligations.

The LEDtech-GROW project focuses on the development of advanced LED technologies for indoor plant growth, based on bismuth-sensitized Eu^{3+}-activated single-component phosphors emitting across the entire PAR spectrum of plant photoreceptors. Due to the strong scientific, technological, and societal relevance of the project, dissemination and communication activities represent a core component for ensuring visibility, transparency, and broad accessibility of project results.

Deliverable D4.3 provides a comprehensive and project-specific overview of all dissemination and communication activities implemented to date. The document builds directly upon previously completed visibility-related deliverables, particularly Deliverable D4.1 (Visibility: Website, Logo, Leaflet), which was achieved on time during the early project phase. These tools established a consistent and recognizable project identity and enabled early and continuous outreach to target audiences.

A central dissemination channel of the LEDtech-GROW project is the official project website (https://ledtechgrow-promis.org/), which functions as the main public platform for presenting project objectives, work packages, team members, news, public deliverables, scientific outputs, and dissemination materials. The website is regularly updated and serves as a repository for publications, conference contributions, newsletters, promotional materials, and announcements of public and scientific events. It ensures full visibility of the project, extending beyond institutional promotion to include concrete scientific results, researcher activities, and training outcomes.

In parallel, the project maintains an active presence on social media platforms, including LinkedIn and Instagram, which are used to communicate project findings, conference participation, published papers, outreach events, and educational activities. These channels significantly enhance real-time communication with the scientific community, early-stage researchers, and the general public, and contribute to increasing recognition of the LEDtech-GROW project at national and international levels.

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The dissemination strategy described in Deliverable D4.3 places strong emphasis on scientific dissemination through high-quality peer-reviewed publications and conference participation. In the first year of the project, team members published multiple scientific papers in internationally recognized journals in materials science, optics, and nanotechnology (Annex VI). In parallel, the team actively participated in numerous international scientific conferences, delivering invited talks, oral presentations, and poster contributions, thereby ensuring direct knowledge exchange with the international scientific community (Annex VII). Detailed lists of publications and conference contributions are continuously updated on the project website.

In addition to scientific dissemination, Deliverable D4.3 highlights public outreach and science communication activities carried out by the LEDtech-GROW team. These include participation in major public events such as the European Researchers' Night, the International Fair of Techniques and Technical Achievements, and institutional events organized by the Science Fund of the Republic of Serbia. Promotional materials, including the project leaflet and posters, were actively used to communicate project goals and results to non-specialist audiences, with a particular focus on broader public interested in sustainable agriculture and advanced lighting technologies.

Furthermore, the deliverable presents media visibility achieved through press releases and published articles in national magazines, which contributed to increasing awareness of LEDtech-GROW beyond the scientific community (Annex IV). These activities ensured that the project reached diverse audiences and reinforced the societal relevance of research on energy-efficient and plant-growth-targeted LED technologies.

An important component of the dissemination and communication activities addressed in Deliverable D4.3 is the professional development of young and early-stage researchers. The document reports participation of team members in numerous specialized training events, workshops, webinars, and information days related to scientific publishing, project management, open science, data management, and advanced characterization techniques (Annex VII).

Overall, Deliverable D4.3 demonstrates that dissemination and communication within the LEDtech-GROW project are systematic, timely, and strongly integrated with scientific and outreach activities. By combining a well-structured web presence, active social media engagement, intensive scientific dissemination, public outreach, and continuous researcher training, the project ensures full visibility and effective communication of its results. This approach significantly contributes to maximizing the scientific, educational, and societal impact of LEDtech-GROW during the project implementation and beyond.

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Annexes of Deliverable D4.3

Annex II

Microsoft Word (a) and Microsoft PowerPoint (b) documents created to be used in LEDtech-GROW Project

a)

Ref. LEDtech-GROW (2024) 10412 - 01/07/2024

Deliverable title

WPX (DX.Y)

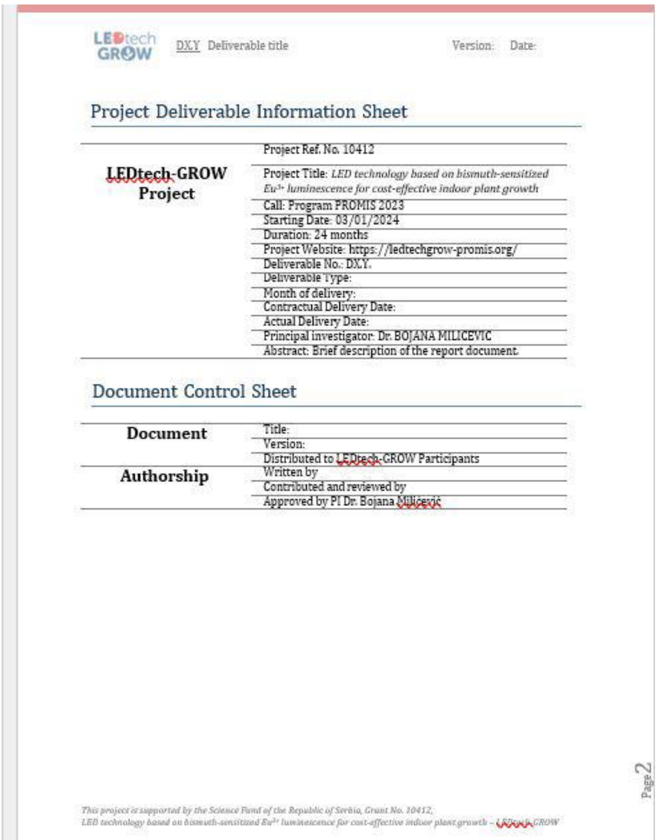
LEDtech-GROW

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

PROGRAM-PROMIS-2024-2025

Grant Agreement: 10412

Deliverable DX.Y
(Deliverable title)
Version: ____
Contractual Date Delivery: (date)



DX.Y Deliverable title Version: Date:

Project Deliverable Information Sheet

LEDtech-GROW Project	Project Ref. No. 10412
	Project Title: *LED technology based on bismuth-sensitized Eu^{3+} luminescence for cost-effective indoor plant growth*
	Call: Program PROMIS 2023
	Starting Date: 03/01/2024
	Duration: 24 months
	Project Website: https://ledtechgrow-promis.org/
	Deliverable No.: DX.Y.
	Deliverable Type:
	Month of delivery:
	Contractual Delivery Date:
	Actual Delivery Date:
	Principal investigator: Dr. BOJANA MILICEVIC
	Abstract: Brief description of the report document.

Document Control Sheet

Document	Title:
	Version:
	Distributed to LEDtech-GROW Participants
Authorship	Written by
	Contributed and reviewed by
	Approved by PI Dr. Bojana Milićević

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Page 2

b)

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Annex III

Leaflet, deliverable D4.1 (WP4), April 2024

PROJECT FLOW

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LEDtech GROW

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

OMAS Group

Science Fund of the Republic of Serbia — VINČA Institute of Nuclear Sciences, University of Belgrade, National Institute of the Republic of Serbia — Promis2023

PROJECT

In light of global urbanization, the key to long-term agricultural development is a more efficient use of arable land, labor, and modern technology.

Indoor plant factories are promising solutions for future horticulture production and food supply to densely populated urban areas. The light-emitting-diode (LED) is revolutionizing general illumination with the promise of enormous energy savings when widespread adoption occurs.

However, current LED technologies for plant cultivation are less developed compared to LEDs for general lighting. LEDtech-GROW offers innovation in the field of LEDs that entirely satisfy the needs of plants and cannot be achieved with any LED technology currently available.

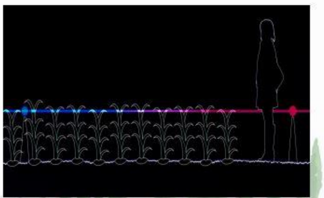
We will develop inorganic phosphors that convert as much electrical energy as possible into a Photosynthetically Active Radiation (PAR) spectrum of plant photoreceptors.

Objective 1

The development of high-efficient and moisture-resistant plant-grow-targeted single-component phosphors based on double- and triple-wavelength emission for the whole PAR spectrum.

Site substitution engineering will be implemented *via* suitable and efficient energy transfer between $Bi^{3+} \rightarrow Eu^{3+}$ to adjust the multi-color emission of phosphors.

A unique green synthesis based on environmentally acceptable components will be used.



LEDtech-GROW project results will contribute to the development of improved inorganic phosphors and LED technologies for other applications where efficient, high-quality lighting is crucial.

The focus is on the issues in the field of materials science, such as resemblances of emission spectra of phosphors to the PAR spectrum of plant photoreceptors and fabrication of novel generation of plant-growth-LEDs.

Objective 2

The fabrication of LED devices based on dual- and triple-wavelength emitting single-component phosphors.

To fabricate the pc-LEDs, two distinctive strategies will be employed:

1. The novel LED chip-on-board fabrication strategy that combines near-UV semiconductor chip and representative triple-wavelength emitting plant-grow-targeted single-component phosphor, and

2. A strategy that combines blue semiconductor chips and representative red and far-red double-wavelength emitting single-component phosphors, which is a common way of white LEDs chip-on-board fabrication.

The outcomes of this project activity can be used to develop new innovative technologies beyond the proposed LED technology for artificial indoor plant growth.

Истраживање је спроведено уз подршку Фонда за науку Републике Србије, 10412, LED TECHNOLOGY BASED ON BISMUTH-SENSITIZED Eu^{3+} LUMINESCENCE FOR COST-EFFECTIVE INDOOR PLANT GROWTH– LEDTech-Grow/
This research was supported by the Science Fund of the Republic of Sebia, 10412, LED TECHNOLOGY BASED ON BISMUTH-SENSITIZED Eu^{3+} LUMINESCENCE FOR COST-EFFECTIVE INDOOR PLANT GROWTH– LEDTech-Grow
Овај летак је сачињен уз финансијску подршку Фонда за науку Републике Србије. За садржину ове публикације искључиво је одговоран Институт за нуклеарне науке Винча, Институт од националног значаја за Републику Србију, и та садржина не изражава ставове Фонда за науку Републике Србије./
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Annex IV

Article published in Movem magazine, May 2024.

MLADE NAUČNICE IZ SRBIJE KOJE MENJAJU SVET

YOUNG FEMALE SCIENTISTS FROM SERBIA WHO CHANGE THE WORLD

Autor / Author ASHOK MURTY
Fotografije / Photo KATARINA ŠOŠKIĆ
Lokacija / Location SMOKVICA

IMENA Bojana Milićević, Marina Stamenković i Jelena Veljin verovatno vam ne zvuče poznato. Greška, velika greška! (Da parafraziramo lik Vivijen iz kultnog filma „Zgodna žena" koju je interpretirala Džulija Roberts). A za to što smo odlučili da ih (više nego zasluženo) gurnemo pod reflektore zaslužan je Fond za nauku Republike Srbije koji nastavlja svoju predanost podršci mladih istraživača kroz Program za izvrsne projekte mladih istraživača i naučnika u ranoj fazi karijere – PROMIS 2023 u okviru kojeg će u naredne dve godine finansirati 30 projekata sa ukupnim budžetom od 4 miliona evra. Program PROMIS 2023 okuplja 156 naučnika iz 42 naučnoistraživačke organizacije u Srbiji. Ovi projekti ne samo da jačaju kapacitete mladih naučnika, već i grade temelje za njihovu buduću konkurentnost na globalnom nivou doprinoseći razvoju nauke kako u Srbiji, tako i u svetu.

Odlučili smo da ove tri mlade naučnice, koje se pre ovoga nisu ni poznavale, okupimo na jednoj čajanci na kojoj su jedna drugoj pokušale da predstave projekte.

BOJANA, NA ŠTA SE ODNOSI TVOJ PROJEKAT, UKRATKO?

Bojana: U skladu sa stalnim rastom svetske populacije i sve manjom obradivom zemljištu, poljoprivreda se suočava sa izazovima koji zahtevaju inovativna rešenja. Upravo u tom kontekstu, projekat LED-Tech-GROW predstavlja tehnologiju koja koristi neorganske fosfore kako bi stvorila svetlost koja direktno doprinosi rastu biljaka, povećanju prinosa i očuvanju životne sredine.

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THE NAMES of Bojana Milićević, Marina Stamenković and Jelena Veljin probably do not sound familiar to you. Big mistake. Big! (To paraphrase the character of Vivian interpreted by Julia Roberts in the iconic film "Pretty Woman"). And the fact that we decided to (more than deservedly) push them under the spotlight is due to the Science Fund of the Republic of Serbia, which continues to be dedicated to supporting young researchers through the Programme for Excellent Projects of Young Researchers and Scientists in the Early Stage of Career - PROMIS 2023, within which in the next two years, it will finance 30 projects with a total budget of 4 million euros. The PROMIS 2023 Programme brings together 156 scientists from 42 scientific research organisations in Serbia. These projects not only strengthen the capacities of young scientists, but also build the foundations for their future competitiveness at the global level, contributing to the development of science both in Serbia and in the world.

We decided to gather these three young scientists, who did not even know each other before this, at a tea party where they tried to present their projects to each other.

BOJANA, WHAT IS YOUR PROJECT ABOUT, IN A NUTSHELL?

Bojana: In accordance with the constant growth of the world's population and the decreasing amount of arable land, agriculture is facing challenges that require innovative solutions. It is in this context that the LED-Tech-GROW project presents a technology that uses inorganic phosphors to create light that directly contributes to plant growth, yield increase and environmental protection.

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A ČIME SI SE TI BAVILA, JELENA?

Jelena: Većina proizvedenog poljoprivrednog otpada, transportuje se na deponije ili spaljuje na otvorenim mestima oslobađajući gasove staklene bašte u našu atmosferu tokom razlaganja. Kod nas u zemlji i regionu je česta praksa da se spaljuju njive otvorenim plamenom, upravo u takvim i sličnim procesima se dobija biougalj – materijal koji se dobija od poljoprivrednih ostataka. Manji deo nastalog poljoprivrednog otpada se iskoristi u stočarstvu, za loženje, ili za proizvodnju briketa/peleta, a još manji deo se kompostira, podvrgava anaerobnoj digestiji (proizvodnja biogasa) ili pirolizi...

A TI, MARINA, U ŠTA SI SE TI UPUSTILA KROZ SVOJ PROJEKAT?

Marina: U sklopu projekta REDIRECT istraživački tim u Srbiji započeo je istraživanje procesa autofagije i njegovog potencijalnog uticaja na isporuku, transport i imunski odgovor prilikom primene RNK vakcine. Ovo istraživanje postavlja temelje za buduća istraživanja i konkurentnost zemlje u svetu istraživanja u ovom domenu. Istraživanje sprovodi tim sastavljen od stručnjaka iz Instituta za nuklearne nauke Vinča, Instituta za virusologiju, vakcine i serume „Torlak" i Fakulteta za fizičku hemiju.

Pored naučnog značaja, ovo istraživanje ima i širu društvenu korist. Informisanje javnosti o karakteristikama i sigurnosti ovih vakcina može doprineti povećanju obuhvata imunizacije, što je ključno za zaštitu najugroženijih kategorija, poput dece. Takođe, implementacija transfera RNK tehnologije koju su podržali Ministarstvo zdravlja i Svetska zdravstvene organizacije na Institutu za vakcine „Torlak" može imati pozitivne ekonomske aspekte za zemlju.

JELENA, ŠTA MOŽEMO STVARNO DA URADIMO KAKO BISMO KAO VRSTA DOPRINELI REŠENJU PROBLEMA GLOBALNOG ZAGREVANJA?

Jelena: Ukoliko koristimo pirolizu da transformišemo otpad biomase u biougalj umesto da ga ostavimo po strani da se razgradi, ekološki problemi se mogu ublažiti dok se proizvode korisni materijali i energija. Piroliza je termičko razlaganje ugljeničnih materijala u okruženju bez kiseonika na visokim temperaturama, između 600 i 900 stepeni Celzijusa, a to nije isto što i sagorevanje ili spaljivanje.

Moje koleginice i ja, kroz ovaj projekat, pokušaćemo da koristeći poljoprivredni otpad proizvedemo biougalj, da rad u laboratoriji optimizujemo na takav način da se što manje rastvarača koristiti u procesu proizvodnje i da na kraju tom biouglju damo dodatnu vrednost koristeći ga kao inovativni materijal u senzorici i određivanju pesticida u vodama. Ova istraživanja su ključna ne samo za razvoj senzorske tehnologije, već i za podizanje nivoa svesti o klimatskim promenama i održivom korišćenju resursa. Upotreba biouglja može doprineti poboljšanju kvaliteta zemljišta, smanjenju emisije štetnih gasova i smanjenju upotrebe pesticida.

BOJANA, VERUJEM DA SE NEGDE I PREKLAPAMO U NAČINU NA KOJI RAZMIŠLJAMO O OVOJ PROBLEMATICI.

AND WHAT WERE YOU WORKING ON, JELENA?

Jelena: Most of the produced agricultural waste is transported to landfills or it is incinerated in open areas, releasing greenhouse gases into our atmosphere during decomposition. In our country and the region, it is a common practice to burn fields with an open flame, and it is precisely in such and similar processes that biochar is generated - material obtained from agricultural residues. A smaller part of the generated agricultural waste is used in animal husbandry, for burning, or for the production of briquettes/pellets, and an even smaller part is composted, subjected to anaerobic digestion (biogas production) or pyrolysis...

AND YOU, MARINA, WHAT DID YOU GET YOURSELF INVOLVED IN WITH YOUR PROJECT?"

Marina: As part of the REDIRECT project, the research team in Serbia started researching the process of autophagy and its potential impact on delivery, transport and immune response when applying an RNA vaccine. This research lays the foundation for some future researches and the country's competitiveness in the world of research in this domain. The research is carried out by a team of experts from the Institute of Nuclear Sciences in Vinča and the Institute of Virology, Vaccines and Sera "Torlak" and the Faculty of Physical Chemistry.

In addition to scientific importance, this research has wider social benefits. Informing the public about the characteristics and safety of these vaccines can contribute to increasing immunization coverage, which is crucial for the protection of the most vulnerable categories, such as children. Furthermore, the implementation of RNA technology transfer supported by the Ministry of Health and the World Health Organization at the "Torlak" Vaccine Institute can have positive economic aspects for the country.

JELENA, WHAT CAN WE, AS A SPECIES, REALLY DO REGARDING OUR CONTRIBUTION TO THE GLOBAL WARMING PROBLEM?

Jelena: If we use pyrolysis to transform biomass waste into biochar instead of leaving it aside to decompose, environmental problems can be mitigated while producing useful materials and energy. Pyrolysis is the thermal decomposition of carbon materials in an oxygen-free environment at high temperatures, between 600 and 900 degrees Celsius, which is not the same as burning or incineration.

Through this project, my colleagues and I try to use agricultural waste to produce biochar, to optimize the work in the laboratory in such a way that as few solvents as possible are used in the production process, and in the end to give that biochar additional value by using it as an innovative material in sensor technology and determination of pesticides in water. These researches are crucial not only for the development of sensor technology, but also for raising awareness of climate change and sustainable use of resources. The use of biochar can contribute to improving the quality of the soil, reducing the emission of harmful gases and reducing the use of pesticides.

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Bojana: Tako je. Jedinstvenost projekta LED-Tech-GROW leži u njegovom pristupu za osvetljenje u potpuno zatvorenom prostoru koristeći isključivo prirodnu svetlost koju emituju fosforni materijali. Ova tehnologija se pokazala izuzetno efikasnom, naročito u svetlu sve češćih klimatskih promena, suša i požara koji sve više ugrožavaju obradivo zemljište.

DRUGI KLJUČNI ELEMENT PROJEKTA JE NJEGOVA POTPUNA PRIRODNOST. NE KORISTE SE VEŠTAČKA ĐUBRIVA ILI HEMIKALIJE, VEĆ SE FOKUS STAVLJA NA STVARANJE OPTIMALNIH USLOVA ZA RAST BILJAKA, ISKLJUČIVO UZ POMOĆ PRIRODNE SVETLOSTI. OVO NIJE SAMO EKOLOŠKI PRIHVATLJIV PRISTUP, VEĆ I EFIKASAN NAČIN DA SE OBEZBEDI DOVOLJNO HRANE ZA SVE VEĆI BROJ STANOVNIKA PLANETE.

Marina: Ako se ne varam, fosfor jeste prirodni element koji emituje svetlost. Ali kako ga možemo „izdresirati" tako da ta svetlost bude baš onakvih karakteristika koje su nam potrebne?

Bojana. Jedna od ključnih karakteristika fosfornih materijala koje se koriste u okviru ovog projekta jeste njihova sposobnost da emituju određenu boju svetlosti. Kroz analize istraživači su utvrdili da su crvena i plava boja najkorisnije biljkama jer ih apsorbuju hlorofil i drugi biljni fotoreceptori. To znači da biljke mogu efikasnije da apsorbuju svetlost i da brže rastu, što rezultira većim prinosima.

MARINA, NI PRED TOBOM NIJE LAK ZADATAK, ZAR NE?

Marina: Veoma je važno istaći da su vakcine koje proizilaze iz ovog istraživanja bezbedne. Rezultati studije će značajno unaprediti efikasnost i bezbednost vakcina, uz mogućnost modifikacije procesa autofagije radi bolje delotvornosti budućih vakcina. Iako se radi o bazičnom istraživanju, očekuje se da će rezultati imati veliki uticaj na kliničku praksu i unapređenje zdravlja populacije. Činjenica je da ovo istraživanje predstavlja atraktivan pristup za prevenciju infektivnih bolesti, ali takođe ima i veliki potencijal i za terapiju protiv tumora.

ONO ŠTO JA MOGU DA ZAKLJUČIM JESTE DA SU U NAUCI SVE VIŠE PRISUTNA ISTRAŽIVANJA U KOJIMA SE UKLJUČUJU RAZLIČITE OBLASTI. JELENA, TO JE SLUČAJ I SA OVIM NA ČEMU TI RADIŠ?

Jelena: Projekat EnviroChar je jedan veliki multidisciplinarni poduhvat koji okuplja stručnjake iz različitih oblasti hemije što omogućava holistički pristup problemu. Uzimajući u obzir činjenicu da je ova vrsta istraživanja ključna za održivu budućnost, projekat EnviroChar predstavlja primer kako nauka može da pruži inovativna rešenja za aktuelne ekološke izazove.

A TI EKOLOŠKI IZAZOVI PREDSTAVLJAJU DODATNI MOTIV ZA TEBE, BOJANA, JE L' TAKO?

Bojana: Tako je. Pored toga što doprinose rastu biljaka, neorganski fosfori su veoma stabilni u spoljašnjim uslovima sa visokom vlagom, što ih čini idealnim za upotrebu u poljoprivredi. Ova tehnologija predstavlja pravi paradigmeni pomak u osvetljenju biljaka pružajući efikasno rešenje za buduće izazove u proizvodnji hrane. Promis projekt nije samo naučni poduhvat, već i praktično rešenje za sve veće izazove koje donosi rast svetske populacije. Uvođenjem ove tehnologije, možemo se nadati da ćemo osigurati dovoljno hrane za sve i očuvati našu planetu za buduće generacije.

ALI, PITANJE KOJE ČESTO MENI POSTAVLJAJU, A VERUJEM I VAMA DVEMA, JESTE KOLIKO SMO MI OVDE UOPŠTE RELEVANTNI NA NEKOM GLOBALNOM NIVOU?

Marina: Odgovoriću u svoje ime, ali verujem da se odnosi i na to čime se vas dve bavite. Moj projekat pod imenom REDIRECT predstavlja samo početak, već sada možemo zaključiti da Srbija ima svetlu naučnu budućnost i da će, zahvaljujući ovakvim projektima, biti konkurentna u globalnoj areni istraživanja.

BOJANA, I BELIEVE THAT WE SOMEHOW SHARE THE SAME VIEWS ABOUT THIS ISSUE?

Bojana: That's right. The uniqueness of the LED-Tech-GROW Project lies in its approach to lighting in a completely enclosed space, using only natural light emitted by phosphorus materials. This technology has proven to be extremely effective, especially in the light of increasingly frequent climate changes, droughts and fires that are increasingly threatening arable land.

ANOTHER KEY ELEMENT OF THE PROJECT IS THE FACT IT IS COMPLETELY NATURAL. NO ARTIFICIAL FERTILIZERS OR CHEMICALS ARE USED, BUT THE FOCUS IS ON CREATING OPTIMAL CONDITIONS FOR PLANT GROWTH USING ONLY NATURAL LIGHT. THIS IS NOT ONLY AN ENVIRONMENTALLY FRIENDLY APPROACH, BUT ALSO AN EFFECTIVE WAY TO PROVIDE ENOUGH FOOD FOR THE EVER-INCREASING POPULATION IN OUR PLANET.

Marina: If I'm not mistaken, phosphorus is a natural element that emits light. But how can we "train" it so that light has exactly the properties we need?

Bojana: One of the key characteristics of the phosphorus materials used in this project is their ability to emit a certain colour of light. By conducting analyses, the researchers determined that red and blue are the most useful colours for plants, because they are absorbed by chlorophyll and other plant photoreceptors. This means plants can absorb light more efficiently and grow faster, resulting in higher yields.

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MARINA, YOUR TASK DOES NOT SEEM EASY EITHER, DOES IT?

Marina: It is very important to point out that the vaccines resulting from this research are safe. The results of the study will significantly improve the efficiency and safety of vaccines, with the possibility of modifying the autophagy process for better efficiency of future vaccines. Although this is a basic research, the results are expected to have a major impact on clinical practice and population health improvement. The fact is that this research represents an attractive approach for the prevention of infectious diseases, but it also has great potential for tumour therapy.

WHAT I CAN CONCLUDE IS THAT THERE IS MORE AND MORE RESEARCH IN SCIENCE INVOLVING DIFFERENT FIELDS. JELENA, THAT IS ALSO THE CASE WITH WHAT YOU ARE WORKING ON?

Jelena: The EnviroChar project is a large multidisciplinary undertaking that brings together experts from different chemistry disciplines, which enables a holistic approach to the problem. Considering the fact that this type of research is crucial for a sustainable future, the EnviroChar Project is an example of how science can provide innovative solutions to current environmental challenges.

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AND THOSE ENVIRONMENTAL CHALLENGES REPRESENT AN ADDITIONAL MOTIVE FOR YOU, BOJANA, DON'T THEY?

Bojana: That's right. In addition to promoting plant growth, inorganic phosphorus is very stable in high humidity outdoor conditions, making it ideal for agricultural use. This technology represents a real paradigm shift in plant lighting, providing an efficient solution to future challenges in food production. The Promis Project is not only a scientific endeavour, but also a practical solution to the increasing challenges triggered by the growth of the world's population. By introducing this technology, we can hope to ensure enough food for everyone and preserve our planet for future generations.

BUT THE QUESTION THAT I AM OFTEN ASKED, AND I BELIEVE YOU TWO AS WELL, IS HOW RELEVANT ARE WE HERE ON A GLOBAL LEVEL?

Marina: I will answer on my own behalf, but I believe it also refers to what you two do. My project called REDIRECT is only the beginning, and we can already conclude now that Serbia has a bright scientific future and that, thanks to such projects, it will be competitive in the global research arena.

PROJEKAT LEDTECH-GROW: SVETLOSNA TRANSORMACIJA POLJOPRIVREDE

Dr Bojana Milićević radi u Centru izuzetnih vrednosti za konverziju svetlosne energije – CONVERSE, u Institutu za nuklearne nauke Vinča. Njen obrazovni put obuhvata doktorat iz fizičke hemije na Univerzitetu u Beogradu, kao i postdoktorske studije na Univerzitetu u Kini. Tokom studija u Kini, Bojana se posvetila istraživanju led dioda i fosfora, što je postavilo osnovu za projekat LEDtech-GROW u okviru programa PROMIS 2023, Fonda za nauku.

PROJEKAT REDIRECT: AUTOFAGIJA KAO KLJUČ ZA RNK VAKCINE

Dr Marina Stamenković dolazi sa Medicinskog fakulteta, Univerziteta u Beogradu gde je docent na Katedri za imunologiju i radi na Institutu za mikrobiologiji i imunologiju. Marina, zajedno sa svojim timom, sprovodi projekat REDIREKT u okviru programa PROMIS 2023, Fonda za nauku.

PROJEKAT ENVIROCHAR: BIOUGALJ KAO ODRŽIVO REŠENJE

Na Prirodno-matematičkom fakultetu Univerziteta u Novom Sadu, tim stručnjaka predvođen vanrednim profesorom dr Jelenom Beljin radi na projektu pod nazivom „EnviroChar", koji se fokusira na proizvodnju biouglja. Projekat će razviti odgovarajući biouglje u skladu sa zelenim principima i zelenom hemijom i primeniti ga u ekološkoj, analitičkoj i elektroanalitičkoj hemiji kao materijal za razvoj metoda za određivanje i uklanjanje postojanih organskih zagađivača iz vodene sredine.

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LEDTECH-GROW PROJECT: LIGHT TRANSFORMATION OF AGRICULTURE

Dr. Bojana Milićević works at the Centre of Exceptional Values for the Conversion of Light Energy - CONVERSE, at the Institute of Nuclear Sciences in Vinča. Her educational path includes a PhD in physical chemistry at the University of Belgrade, as well as postdoctoral studies at a university in China. During her studies in China, Bojana devoted herself to the research of LEDs and phosphorus, which laid the foundation for the LEDtech-GROW Project within the PROMIS 2023 program of the Science Fund.

REDIRECT PROJECT: AUTOPHAGY AS THE KEY TO RNA VACCINES

Dr. Marina Stamenković comes from the Faculty of Medicine, University of Belgrade, where she is an assistant professor at the Department of Immunology and works at the Institute of Microbiology and Immunology. Marina, together with her team, implements the REDIRECT project within the PROMIS 2023 Programme of the Science Fund.

THE ENVIROCHAR PROJECT: BIOCHAR AS A SUSTAINABLE SOLUTION

At the Faculty of Science and Mathematics of the University of Novi Sad, a team of experts led by associate professor, Dr. Jelena Veljin, is working on a project called EnviroChar, which focuses on the production of biochar. The project will develop a suitable biochar in accordance with green principles and green chemistry and apply it in ecological, analytical and electroanalytical chemistry as a material for the development of methods determining and removing persistent organic pollutants from the aquatic environment.

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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

Article published in Biznis magazine, September 2024, No. 36. *(https://biznis.rs/wp-content/uploads/2025/06/Broj-36.pdf)*

KLJUČ ZA DUGOROČNI RAZVOJ POLJOPRIVREDE

REVOLUCIJA U TEHNOLOGIJI LED RASVETE ZA UZGOJ BILJAKA

DR BOJANA MILIĆEVIĆ, VIŠI NAUČNI SARADNIK INSTITUTA ZA NUKLEARNE NAUKE „VINČA", UNIVERZITETA U BEOGRADU

U kontekstu globalne urbanizacije ključ za dugoročni razvoj poljoprivrede je efikasnije korišćenje obradivih površina, radne snage i moderne tehnologije. Zatvorene fabrike za uzgoj biljaka se sve više nameću kao obećavajuće rešenje u okviru moderne poljoprivrede i snabdevanja hranom gusto naseljenih urbanih područja. Revoluciju u oblasti rasvete predstavlja LED tehnologija koja pruža mogućnost ogromne uštede energije, međutim trenutne LED tehnologije za uzgoj biljaka nisu razvijene kao one za opštu rasvetu.

U Centru izuzetnih vrednosti za konverziju svetlosne energije – CONVERSE, u Institutu za nuklearne nauke Vinča, Institutu od nacionalnog značaja za Republiku Srbiju, Univerziteta u Beogradu, tim stručnjaka predvođen dr Bojanom Milićević radi na projektu pod nazivom „LED tehnologija zasnovana na Eu3+ luminescenciji senzitovanoj bizmutom za isplativ rast biljaka u zatvorenom prostoru - LEDtech-GROW", razvija savremenu i efikasnu LED rasvetu za uzgoj biljaka kao ključno rešenje za uspešnu buduću proizvodnju u zatvorenim uslovima.

Dr Bojana Milićević

Projekat LEDtech-GROW donosi inovacije u oblasti LED tehnologije, koje su specijalno prilagođene potrebama biljaka. LEDtech-GROW planira razvoj neorganskih materijala koji će efikasno pretvarati električnu u svetlosnu energiju koja je specifična za fotosintetske procese kod biljaka, što je različito od svetlosti potrebne za opštu rasvetu.

Kako LED svetla mogu spasiti poljoprivredu: novi pristupi za održivu proizvodnju hrane u uslovima rastuće urbanizacije

Prema procenama Organizacije za hranu i poljoprivredu Ujedinjenih nacija, očekuje se da će svetska populacija u narednih 30 godina porasti za dve milijarde, sa trenutnih 7,7 milijardi na 9,7 milijardi do 2050. godine. Ovaj rast ima ozbiljne posledice na ravnotežu između rastuće populacije i obradivih površina. Prema trenutnim procenama, količina obradivih površina po osobi u svetu drastično opada, smanjujući se sa 0,38 hektara u 1970. godini na 0,23 hektara u 2000. godini, s predviđenim padom na samo 0,15 hektara po osobi do 2050. godine.

Poljoprivreda u 2050. godini trebalo bi da proizvede oko 50 odsto više hrane, stočne hrane i bioenergije nego u 2012. godini, kao i da snabdeva urbanizovana područja na isplativ način. Ključno pitanje je da li današnja poljoprivreda i snabdevanje hranom mogu zadovoljiti buduće potrebe uzimajući u obzir rastuće pritiske na već ograničene obradive površine, kao i intenziviranje negativnih posledica klimatskih promena.

Inovacije kao ključ za održivu poljoprivredu

Inovacije su neophodne ne samo za poboljšanje efikasnosti u pretvaranju dostupnih resursa u proizvod, već i za očuvanje ograničenih prirodnih resursa. Zatvorene fabrike za uzgoj biljaka sa veštačkom svetlošću predstavljaju obećavajuća rešenja za buduću poljoprivrednu proizvodnju. Trenutne strategije veštačke rasvete bazirane na plavim i crvenim LED svetlima imaju nedostatke kao što su odvojeno napajanje, nesklad u spektralnoj distribuciji i promena boje sa promenom snage. Stoga je kontrolisani LED izlaz koji odgovara spektru fotosintetskog aktivnog zračenja biljnih fotoreceptora neophodan u zatvorenim fabrikama i staklenicima zbog svog potencijala da poboljša prinos i ubrza procese rasta biljaka u odsustvu sunčeve svetlosti.

Napredak u razvoju neorganskih materijala za LED rasvetu

Naučni timovi se suočavaju sa značajnim izazovima u razvoju materijala koji se koriste za LED osvetljenje, s obzirom na potrebu za optimizacijom svetlosnog spektra koji stimuliše rast i razvoj biljaka. Istraživanja u ovoj oblasti su pokazala da neorganski materijali, kao što su aluminati, garneti i perovskiti, aktivirani četvorovalentnim jonima mangana pokazuju nisku kvantnu efikasnost (manje od 50 odsto) i široku emisiju u duboko-crvenim talasnim dužinama, što smanjuje efikasnost LED svetala i ne zadovoljava spektralne zahteve biljaka. Sa druge strane, fluoridni materijali aktivirani jonima mangana su pokazali značajno veću kvantnu efikasnost, međutim, njihova sinteza je izuzetno opasna, a nedostatak duboke-crvene emisije ne može dovoljno stimulisati fitohromne fotoreceptore biljaka. Takođe, poznato je da fluoridni materijali aktivirani jonima mangana nisu stabilni u vlažnim okruženjima, kao što su staklenici i zatvorene fabrike za uzgoj biljaka, zbog njihove sklonosti ka hidrolizi i stvaranju mangan-oksida i hidroksida. Kao rešenje, istraživači se okreću materijalima

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LED technology based on bismuth-sensitized Eu^{3+} luminescence for cost-effective indoor plant growth – LEDtech-GROW

aktiviranim trovalentnim jonima europijuma koji nude visoku stabilnost, efikasnost i uske crvene i narandžaste emisione linije, dok u specifičnim slučajevima može doći i do emisije intenzivne duboko-crvene svetlosti koja je neophodna za razvoj biljaka u zatvorenim fabrikama i staklenicima. Nedavne studije su pokazale da se može ostvariti do 20 odsto uštede energije za bele LED diode korišćenjem europijum-aktiviranih nanočestica.

LEDtech-GROW projekat ima za cilj razvoj materijala na nano i submikronskoj skali sa preciznom kontrolom optičkih svojstava putem prenosa energije, što otvara brojne mogućnosti za sledeću generaciju LED svetala specijalizovanih za uzgoj biljaka. Ova tehnologija koristi plave emitere – jone bizmuta, kao i crveno i duboko-crvene emitere – jone europijuma, omogućavajući optimalnu ravnotežu između apsorpcije, emisije i prilagodljivosti spektralnog oblika, pokrivajući ceo spektar fotosintetski aktivnog zračenja biljnih fotoreceptora. Neorganski materijali koji kombinuju plavu emisiju koja potiče od jona bizmuta sa jedinstvenom crvenom i dubokom crvenom emisijom jona europijuma povećavaju svetlosni izlaz za fotoreceptore, kao što su kriptohromi i fitohromi, dok istovremeno obezbeđuju visoki kvalitet boje. Da bi se postigla optimalna višebojna emisija materijala neophodan je i efikasan prenos energije između jona bizmuta i europijuma.

Materijali koji su pažljivo odabrani pokazuju snažnu emisiju zbog visoke koncentracije aktivatorskog jona, otpornost na vlagu, što je od suštinskog značaja u zatvorenim fabrikama i staklenicima zbog visokih vlažnosti u kojima funkcionišu, i precizno usklađivanje sa fotosintetski aktivnim spektrom zračenja, što je ključno za kontrolu biljnih metaboličkih procesa, rasta, cvetanja i količine biljnih prinosa.

Poboljšanje efikasnosti i stabilnosti svetlosnih izvora u vlažnim i zahtevnim uslovima

Tradicionalna LED rasveta koristi poluprovodničke čipove na bazi galijum ili galijum-indijum nitrida u kombinaciji sa neorganskim materijalima za konverziju svetlosti, što omogućava proizvodnju vidljive svetlosti. Pomenuti materijali apsorbuju deo plave ili bliske ultraljubičaste svetlosti i emituju svetlost na većim talasnim dužinama. Najčešće, za proizvodnju belih LED svetala koristi se plavi poluprovodnički čip, žuti i crveno emitujući neorganski materijali. Sličan pristup se koristi i za proizvodnju LED svetala namenjenih uzgoju biljaka. Međutim, prilikom upotrebe LED svetala pobuđenih plavim čipovima može doći do neslaganja u bojama što dalje može uticati na efikasnost rasvete za biljke.

Istraživanja u okviru LEDtech-GROW projekta obuhvataju kombinovanje poluprovodničkog čipa baziranog na bliskom ultraljubičastom svetlu i neorganskih materijala aktiviranih jonima bizmuta i europijuma koji emituju plavu, crvenu i duboko-crvenu svetlost, a koji su sintetisani u našoj laboratoriji. Plava emisija stimuliše fotoreceptore kao što su kriptohromi i fototropin, uska crvena i duboko-crvena emisija fitohromne fotoreceptore, dok se celokupna emitovana svetlost poklapa sa apsorpcionim spektrom hlorolofila a i b. Korišćenjem ove tehnologije i sam čip emituje male količine bliske ultraljubičaste svetlosti koja može stimulisati pterin fotoreceptor i poboljšati cirkadijalni ritam i fototropizam biljaka.

Uticaj na održivu poljoprivredu i bezbednost hrane

LEDtech-GROW nudi rešenja u pogledu dizajniranja LED svetla koja direktno utiču na ubrzani razvoj biljaka i povećanje njihovog prinosa u zatvorenim fabrikama i staklenicima. Usled klimatskih promena, kao što su rastuće temperature i sve učestalije suše, požari i invazije štetočina, dolazi do gubitka biljnih vrsta i povećane potražnje za hranom. Naš projekat radi na razvoju LED tehnologije čiji je potencijal da obezbedi neometan razvoj biljaka u zatvorenim sistemima, smanjenje potreba za pesticidima i đubrivima, kao i izloženost radnika opasnim hemijskim agensima. Ujedno, manja potrošnja vode i hemikalija u proizvodnji hrane takođe doprinosi očuvanju životne sredine i poboljšanju nutritivnog kvaliteta i bezbednosti hrane.


Primer LED svetala namenjenih uzgoju biljaka

Projekat LEDtech-GROW, finansiran kroz Program PROMIS 2023 Fonda za nauku Republike Srbije, predstavlja značajan iskorak u modernizaciji poljoprivrede i očuvanju životne sredine. Ovaj inovativni projekt fokusira se na napredne aspekte nauke o materijalima, istražujući kako se emisioni spektri sintetisanih neorganskih materijala usklađuju sa fotosintetski aktivnim zračenjem biljnih fotoreceptora, te na razvoj nove generacije LED svetala koja su posebno dizajnirana za poboljšanje rasta biljaka u odsustvu sunčeve svetlosti. U budućnosti, naš rad će se usmeriti na unapređenje metoda uzgoja biljaka i sveobuhvatno praćenje njihovog razvoja.

Planiramo da istražimo nove pristupe u tehnologiji uzgoja, uključujući optimizaciju uslova rasta, poboljšanje hranljivih materija i primenu naprednih tehnika za kontrolu okoline. Naša nastojanja će uključivati saradnju sa stručnjacima iz različitih oblasti, uključujući agronome, biotehnologe i inženjere, kako bismo integrisali najnovija saznanja i tehnologije u naš rad. Cilj nam je da stvorimo efikasne i održive metode uzgoja koje će omogućiti bolje rezultate u poljoprivredi i doprineti ukupnom poboljšanju proizvodnje hrane, čime ćemo dodatno podržati održivu poljoprivredu i zaštitu životne sredine. ■

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Annex V

Poster presentation for the youth population at the 15th European Researchers' Night, September 2024.

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Annex VI

List of scientific publications – regularly updated in the DCE Plan and LEDtech-GROW Website

No.	AUTHORS	ARTICLE TITLE	JOURNAL	STATUS
1.	**Bojana Milićević**, **Aleksandar Ćirić**, Zoran Ristić, Mina Medić, Abdullah N. Alodhayb, Ivana Radosavljević Evans, Željka Antić, Miroslav D. Dramićanin	**Eu^{3+}- activated Sr_2GdF_7 colloid and nano-powder for biomarker and horticulture LED**	Journal of Alloys and Compounds (M21a)	Accepted
2.	**Katarina Milenković, Ljubica Đačanin Far, Sanja Kuzman,** Željka Antić**, Aleksandar Ćirić,** Miroslav D. Dramićanin**, Bojana Milićević**	**Red emission enhancement in $BaYF_5$:Eu^{3+} phosphor nanoparticles by Bi^{3+} co-doping**	Optics Express (M21)	Accepted
3.	**Jovana Periša, Sanja Kuzman, Aleksandar Ćirić, Zoran Ristić,** Željka Antić, Miroslav Dramićanin, **Bojana Milićević**	**Tuneable red and blue emission of Bi^{3+}-codoped SrF_2:Eu^{3+} nanophosphors for agricultural LEDs**	Nanomaterials (M21)	Accepted
4.	**Bojana Milićević**, **Aleksandar Ćirić**, **Katarina Milenković**, Zoran Ristić, **Jovana Periša**, Željka Antić, Miroslav D. Dramićanin	**Pr^{3+}-Activated Sr_2LaF_7 Nanoparticles as a Single-Phase White-Light-Emitting Nanophosphor**	Nanomaterials (M21)	Accepted
5.	**Ljubica Đačanin Far**, **Jovana Periša**, Ivana Zeković, Zoran Ristić, Mina Medić, Miroslav D. Dramićanin, **Bojana 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 (M21)	Accepted
6.	**Ljubica Đačanin Far**, **Jovana Periša**, Zoran Ristić, Anatolijs Šarakovskis, Vladimir Pankratov, Abdullah Alodhayb, Lukasz Marciniak, **Sanja Kuzman**, Miroslav D. Dramićanin, **Bojana Milićević**	**Eu^{3+}-Doped Sr_2LaF_7 Nanopowders as Efficient Red and Deep-Red Emitters for Advanced Horticultural Lighting**	Progress in Theoretical and Experimental Physics (M21a)	Submitted
7.	**Aleksandar Ćirić,** Markus Suta, Tom Förster, **Bojana Milićević,** Tamara Gavrilović, Željka Antić, Miroslav Dramićanin	**Algorithm for Judd-Ofelt analysis of Pr^{3+} from the emission spectrum: case study of Sr_2LaF_7:Pr^{3+} nano-powder**	Advanced Optical Materials (M21a)	Submitted

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Annex VII

List of Poster presentations at scientific congresses – regularly updated in the DCE Plan and LEDtech-GROW Website

No.	AUTHORS	PRESENTATION TITLE	CONGRESS	DATE	PLACE
1.	**Katarina Milenković**, Vesna Đorđević, Sanja Kuzman, Jovana Periša, Bojana 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 (https://www.cfi.lu.lv/en/lumdetr2024/)	June 16-21, 2024	Riga, Latvia
2.	**Bojana Milićević**, Aleksandar Ćirić, Zoran Ristić, Mina Medić, Ivana Radosavljevic Evans, Željka Antić, Miroslav 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 (https://icomonline.org/)	August 26-30, 2024	Bečići, Budva, Montenegro
3.	**Sanja Kuzman**, Bojana Milićević, Jovana Periša, Aleksandar Ćirić, Zoran Ristić, Željka Antić, Miroslav	**Synthesis and photoluminescent properties of Bi^{3+}- codoped $SrF_2:Eu^{3+}$ phosphor nanoparticles**	The 7th International Conference on the Physics of Optical Materials and Devices & The 4th International Conference on Phosphor Thermometry (https://icomonline.org/)	August 26-30, 2024	Bečići, Budva, Montenegro
4.	**Katarina Milenković**, Vesna Đorđević, Ivana Zeković, Zoran Ristić, Jovana Periša, Bojana Milićević, Miroslav 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 (https://icomonline.org/)	August 26-30, 2024	Bečići, Budva, Montenegro
5.	**Ljubica Đačanin Far**, Bojana Milićević, Jovana Periša, Aleksandar	**Eu^{3+}-Doped Sr_2LaF_7 nanopowders for Indoor Plant**	6th International Conference on MATERIALS SCIENCE & NANOTECHNOLOGY	October 27-30, 2025	Tenerife, Spain (pp 119-120).

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	Ćirić, Katarina Milenković, Sanja Kuzman, and Miroslav D. Dramićanin	**Growth LED Applications**	Future Materials 2025 (https://materialsconference.yuktan.com/poster-presenters)		
6.	**Sanja Kuzman**, Ljubica Đačanin Far, Bojana Milićević, Jovana Periša, Aleksandar Ćirić, Katarina Milenković, and Miroslav D. Dramićanin	**Emission Enhancement by Bi^{3+} Co-Doping of Red-Emitting nanophosphor for Horticulture LEDs**	6th International Conference on MATERIALS SCIENCE & NANOTECHNOLOGY Future Materials 2025 (https://materialsconference.yuktan.com/poster-presenters)	October 27-30, 2025	Tenerife, Spain (pp 121).

List of Invited and Oral presentations at scientific congresses – regularly updated in the DCE Plan and LEDtech-GROW Website

No.	AUTHORS	PRESENTATION TITLE	CONGRESS	DATE	PLACE
1.	**Sanja Kuzman**, Bojana Milićević, Katarina Milenković, Jovana Periša, Miroslav D. Dramićanin (Invited talk)	**Bismuth-Sensitized Eu^{3+} Luminescent LED Technology for Effective Indoor Plant Growth**	The 3rd Serbian Conference on Materials Application and Technology – SCOM2024 (https://www.razvojnauke.org/)	October 16-18, 2024	Belgrade, Serbia
2.	**Aleksandar Ćirić**, Markus Suta, Bojana Milićević, Tom Förster, Tamara Gavrilović, Željkiroslav Antić, M. D. Dramićanin (*Oral talk)*	**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 (https://materialsconference.yuktan.com/featured-speakers)	October 27-30, 2025	Tenerife, Španija (pp 35)

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List of general public events

No.	ATTENDEE	PRESENTATION	EVENTS	DATE	PLACE
1.	Bojana Milićević Jovana Periša	**Principal investigators of 30 projects supported under the PROMIS 2023 program were presented at the ceremony**	The Science Fund celebrated 5 years since its establishment (https://fondzanauku.gov.rs/2024/03/fond-za-nauku-svecano-obelezio-5-godina-od-osnivanja/)	March 20, 2024	Belgrade, Serbia
2.	Jovana Periša	**Leaflet and promotional material**	The 66th International Fair of Techniques and Technical Achievements	March 21-24, 2024	Belgrade, Serbia
3.	Bojana Milićević, Sanja Kuzman	**Revolutionizing LED technology for plant growth**	15th European Researchers' Night, (https://nocistrazivaca.rs/radionice_i_programi/ledtech-grow/)	September 27, 2024	Belgrade, Serbia

List of training events

No.	TRAINING ATTENDEE	TRAINING TITLE	TRAINING ORGANIZED	DATE	PLACE
1.	All team members	**How to make the best use unfunded project proposals?**	Marija Šola Spasić, coordinator of Management Office projects at Vinca Institute for Nuclear Sciences, National Institute of the Republic of Serbia, University of Belgrade	February 6, 2024	Online
2.	Ljubica Đačanin Far, Bojana Milićević	**Training for preparing, writing, and managing Horizon projects**	The European Training Academy (EUTA)	February 22, February 23, February 27, March 1, 2024	Belgrade, Serbia
3.	All team members	**Protection of Trade Secrets**	The Intellectual Property Office of the Republic of Serbia (Lecturer: Aleksandra Mihailović, Asst. Director)	March 5, 2024	Online

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4.	All team members	**Introduction to Patents**	The Intellectual Property Office of the Republic of Serbia (Lecturer: Nataša Milovanović, Head of the Department for Mechanical Engineering, Electrotechnics and General Technology)	March 12, 2024	Online
5.	All team members	**International Protection of Inventions**	The Intellectual Property Office of the Republic of Serbia (Lecturer: Aleksandra Mihailović, Asst. Director)	March 19, 2024	Online
6.	All team members	**Software protection with a patent**	The Intellectual Property Office of the Republic of Serbia (Lecturer: Nataša Milovanović, Head of the Department for Mechanical Engineering, Electrotechnics and General Technology)	March 26, 2024	Online
7.	All team members	**Compiling an application for the protection of an invention**	The Intellectual Property Office of the Republic of Serbia (Lecturer: Jelena Tomić Keser, Head of the Department for Chemistry and Chemical Technology)	April 2, 2024	Online
8.	Bojana Milićević, Sanja Kuzman	**LEDtech-GROW**	The European Researchers' Night, Faculty of Physical Chemistry, Belgrade, Serbia	September 28, 2024	Online
9.	Bojana Milićević, Sanja Kuzman, Jovana Periša	**Excel Masterclass**	Aleksandar Grašić	October 3, 2024	Online
10.	All team members	**Introduction to JADE®**	International Centre for Diffraction Data (ICDD)	April 23, 2025	Online
11.	All team members	**Open Science and Obligations for Participants in the Science Fund of the Republic of Serbia Program**	Vinča Institute for Nuclear Sciences, University of Belgrade	May 13, 2025	Belgrade, Serbia
12.	Ljubica Đačanin Far, Jovana Periša, Katarina Milenković	**Horizon Europe Info Days – WIDERA Work Programme 2025**	European Commission	May 20	Online
13.	Bojana Milićević, Sanja	**Horizon Europe Info Days – Cluster**	European Commission	May 20, 2025	Online

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	Kuzman, Aleksandar Ćirić	**6: Food, Bioeconomy, Natural Resources, Agriculture and Environment**			
14.	All team members	**Powder X-ray Diffraction – Better Data Equals Better Results**	International Centre for Diffraction Data (ICDD)	May 21, 2025	Online
15.	All team members	**The ICDD Raman File: Design, Content and Applications**	International Centre for Diffraction Data (ICDD)	June 25, 2025	Online

5. Summary of Deliverable D1.1 – Report on Eu^{3+} and Bi^{3+}/Eu^{3+}-activated phosphors synthesis (WP1, month 12)

This report (Deliverable D1.1) presents the synthesis of Eu^{3+}- and Bi^{3+}/Eu^{3+}-activated inorganic fluoride phosphors developed within the LEDtech-GROW project under WP1. Detailed descriptions of the synthesis methodologies, tools, and procedures are provided at the project deliverables repository (https://ledtechgrow-promis.org/Deliverables/). Below, we focus on a concise overview and summary of all synthesized phosphor materials specifically designed for plant-targeted LED applications in horticulture, ensuring alignment with the scientific objectives and planned activities of WP1.

Synthesis of colloidal and powder Eu^{3+}-doped Sr_2GdF_7 nanoparticles – WP1, subactivity 1.2

Table 1 *The amounts of precursors needed for synthesizing $Sr_2Gd_{1-x}F_7$:xmolEu^{3+} samples.*

Samples	$Sr(NO_3)_2$ (g)	$Gd(NO_3)_3 \cdot 6H_2O$ (g)	$Eu(NO_3)_3 \cdot 6H_2O$ (g)	NH_4F (g)	EDTA (g)
SGF (x=0.00)	1.0582	1.1284	–	1.1111	0.9306
SGF_5Eu (x=0.05)	1.0582	1.0720	0.0557		
SGF_10Eu (x=0.10)	1.0582	1.0156	0.1115		
SGF_40Eu (x=0.40)	1.0582	0.6770	0.4460		
SGF_60Eu (x=0.60)	1.0582	0.4514	0.6690		
SGF_80Eu (x=0.80)	1.0582	0.2257	0.8919		
SEF (x=1.00)	1.0582	–	0.9306		

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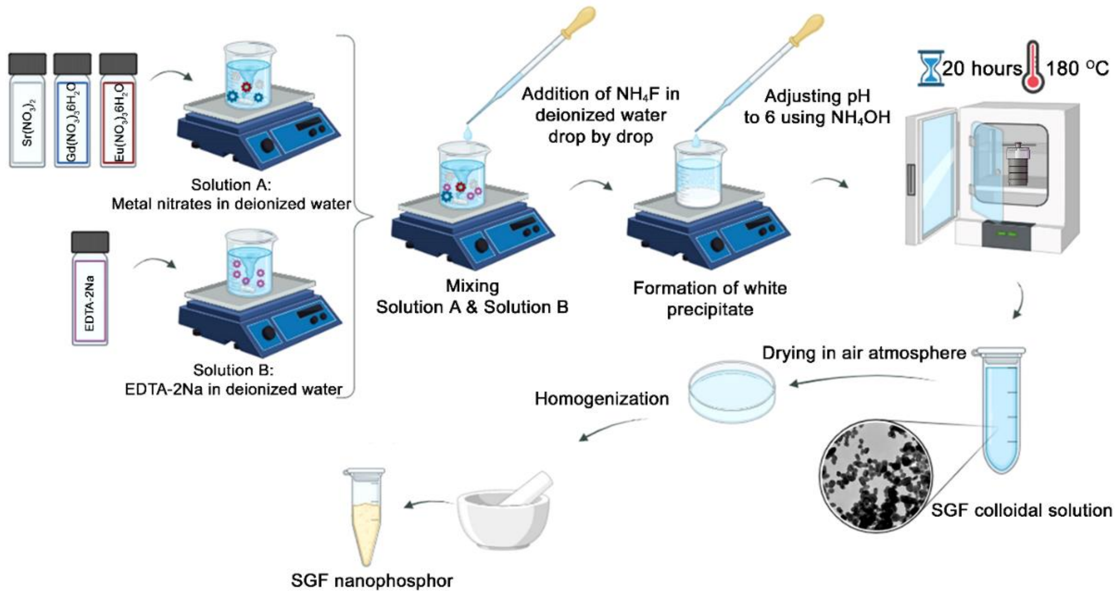

Figure 4. Schematic illustration of the colloidal and powder SGF:Eu nanophosphors preparation.

Synthesis of powder Bi^{3+}-doped Sr_2EuF_7 nanoparticles – WP1, subactivity 1.2

Table 2 The amounts of precursors needed for synthesizing $Sr_2Eu_{1-x}F_7$:xmol% Bi^{3+}.

Samples	$Sr(NO_3)_2$ (g)	$Bi(NO_3)_3$ (g)	$Eu(NO_3)_3·6H_2O$ (g)	NH_4F (g)	EDTA (g)
SEF_1Bi (x=0.01)	1.0582	0.0099	1.1041	1.1111	0.9306
SEF_2Bi (x=0.02)		0.0197	1.0929		
SEF_5Bi (x=0.05)		0.0494	1.0595		
SEF_10Bi (x=0.10)		0.0988	1.0037		

Synthesis of powder Bi^{3+}-doped $Sr_2Gd_{0.2}Eu_{0.8}F_7$ nanoparticles – WP1, subactivity 1.2

Table 3 The amounts of precursors needed for synthesizing Bi^{3+}-doped $Sr_2Gd_{0.2-x}Eu_{0.8}F_7$:xmol% Bi^{3+}.

Samples	$Sr(NO_3)_2$ (g)	$Gd(NO_3)_3·6H_2O$ (g)	$Bi(NO_3)_3$ (g)	$Eu(NO_3)_3·6H_2O$ (g)	NH_4F (g)	EDTA (g)
SGEF_0Bi (x=0.00)	1.0582	0.1947	-	0.8922	1.1111	0.9306
SGEF_0.2Bi (x=0.002)		0.1922	0.0025			
SGEF_1Bi (x=0.01)		0.1849	0.0099			
SGEF_5Bi (x=0.05)		0.1460	0.0494			
SGEF_10Bi (x=0.10)		0.0973	0.0988			

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Bi^{3+}-doped Sr_2LaF_7 – WP1, subactivity 1.2

***Table 4** The amounts of precursors needed for synthesizing Sr_2LaF_7:5mol%Bi^{3+}.*

Precursors	n [mol]	m [g]
$Sr(NO_3)_2$	0.005	1.05815
$La(NO_3)_3 \cdot 6H_2O$	0.002375	1.0284
$Bi(NO_3)_3$	0.000125	0.0494
NH_4F	0.03	1.1111
EDTA	0.0025	0.9306

Bi^{3+}-codoped $Sr_2La_{0.9}Eu_{0.1}F_7$ – WP1, subactivity 1.2

***Table 5** The amounts of precursors needed for synthesizing $Sr_2La_{0.9}Eu_{0.1}F_7$.*

Precursors	n [mol]	m [g]
$Sr(NO_3)_2$	0.005	1.05815
$La(NO_3)_3 \cdot 6H_2O$	0.00225	0.9743
$Eu(NO_3)_3 \cdot 6H_2O$	0.00025	0.1115
$Bi(NO_3)_3$	-	-
NH_4F	0.03	1.1111
EDTA	0.0025	0.9306

***Table 6** The amounts of precursors needed for synthesizing $Sr_2La_{0.8}Eu_{0.1}Bi_{0.1}F_7$.*

Precursors	n [mol]	m [g]
$Sr(NO_3)_2$	0.005	1.05815
$La(NO_3)_3 \cdot 6H_2O$	0.002	0.8660
$Eu(NO_3)_3 \cdot 6H_2O$	0.00025	0.1115
$Bi(NO_3)_3$	0.00025	0.0988
NH_4F	0.03	1.1111
EDTA	0.0025	0.9306

Synthesis of Eu^{3+}-doped SrF_2 and Bi^{3+}, Eu^{3+}-doped SrF_2 nanoparticles – WP1, subactivity 1.1

***Table 7.** Precursors for synthesis of 1 mmol of SrF_2: x mol% Eu^{3+} (x= 1, 5, 10, 15, 20) samples.*

Sample	Abbreviated name	$Sr(NO_3)_2$ (g)	$Eu(NO_3)_3 \cdot 6H_2O$ (g)	NaF (g)	EG (ml)
$Sr_{0.99}Eu_{0.01}F_2$	SrF_2:1Eu	0.2095	0.00446	0.0840	15
$Sr_{0.95}Eu_{0.05}F_2$	SrF_2:5Eu	0.2010	0.0223		
$Sr_{0.9}Eu_{0.1}F_2$	SrF_2:10Eu	0.1905	0.0446		
$Sr_{0.85}Eu_{0.15}F_2$	SrF_2:15Eu	0.1799	0.0669		
$Sr_{0.8}Eu_{0.2}F_2$	SrF_2:20Eu	0.1693	0.0892		

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Table 8. Precursors for synthesis of 1 mmol of SrF_2: 10mol% Eu^{3+}, y mol% Bi^{3+} (y= 5, 10, 15, 20, 30, 40, 50) samples.

Sample	Abbreviated Name	$Sr(NO_3)_2$ (g)	$Eu(NO_3)_3\cdot 6H_2O$ (g)	$Bi(NO_3)_3$ x5H_2O (g)	NaF (g)	EG (ml)
$Sr_{0.4}Eu_{0.1}Bi_{0.5}F_2$	SrF_2:10Eu5Bi	0.1799	0.0446	0.0243	0.0840	15
$Sr_{0.8}Eu_{0.1}Bi_{0.1}F_2$	SrF_2:10Eu10Bi	0.1693		0.0485		
$Sr_{0.75}Eu_{0.1}Bi_{0.15}F_2$	SrF_2:10Eu15Bi	0.1587		0.0725		
$Sr_{0.7}Eu_{0.1}Bi_{0.2}F_2$	SrF_2:10Eu20Bi	0.1481		0.0970		
$Sr_{0.6}Eu_{0.1}Bi_{0.3}F_2$	SrF_2:10Eu30Bi	0.1269		0.1455		
$Sr_{0.5}Eu_{0.1}Bi_{0.4}F_2$	SrF_2:10Eu40Bi	0.1058		0.1940		
$Sr_{0.4}Eu_{0.1}Bi_{0.5}F_2$	SrF_2:10Eu50Bi	0.0846		0.2425		

Table 9. Exact amounts of precursors used for the synthesis of 1mmol of SrF_2:20Bi sample

Sample	Abbreviated name	$Sr(NO_3)_2$ (g)	$Bi(NO_3)_3\cdot 5H_2O$(g)	NaF (g)	EG (ml)
$Sr_{0.8}Bi_{0.2}F_2$	SrF_2:20Bi	0.1693	0.0970	0.0840	15

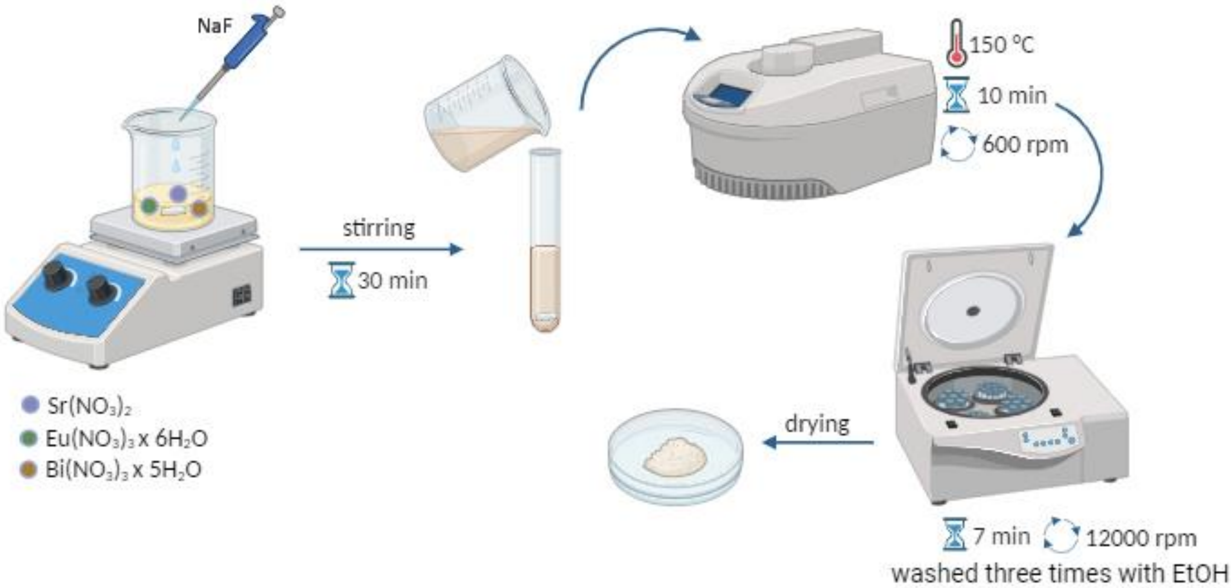

Figure 5. Schematic illustration of the precipitation synthesis of SrF_2:Eu,Bi nanoparticles.

Synthesis of Eu^{3+}-doped BaF_2 nanoparticles – WP1, subactivity 1.1

Table 10. Precursors for synthesis of 1 mmol of BaF_2: x mol% Eu^{3+} (x= 1, 5, 10, 15, 20) samples.

Sample	Abbreviated name	$Ba(NO_3)_2$ (g)	$Eu(NO_3)_3\cdot 6H_2O$ (g)	NaF (g)	EG (ml)
$Ba_{0.99}Eu_{0.01}F_2$	BaF_2:1Eu	0.2587	0.0045	0.0840	15
$Ba_{0.95}Eu_{0.05}F_2$	BaF_2:5Eu	0.2483	0.0223		
$Ba_{0.9}Eu_{0.1}F_2$	BaF_2:10Eu	0.2352	0.0446		
$Ba_{0.85}Eu_{0.15}F_2$	BaF_2:15Eu	0.2221	0.0669		
$Ba_{0.8}Eu_{0.2}F_2$	BaF_2:20Eu	0.2091	0.0892		

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Synthesis of Eu^{3+}-doped $BaYF_5$ and Bi^{3+}, Eu^{3+}-doped $BaYF_5$ nanoparticles – WP1, subactivity 1.2

Table 11. *The precursor quantities for the synthesis of BYF:10Eu, yBi (y = 0, 5, 10, 20, 30, 50 mol%).*

Bi^{3+} (mol%)	$Ba(NO_3)_2$ (mmol)	$Y(NO_3)_3·6H_2O$ (mmol)	$Eu(NO_3)_3·6H_2O$ (mmol)	$Bi(NO_3)_3$ (mmol)	NH_4F (mmol)
0	1.00	0.90	0.10	/	7.00
5		0.85		0.05	
10		0.80		0.10	
20		0.70		0.20	
30		0.60		0.30	
50		0.40		0.50	

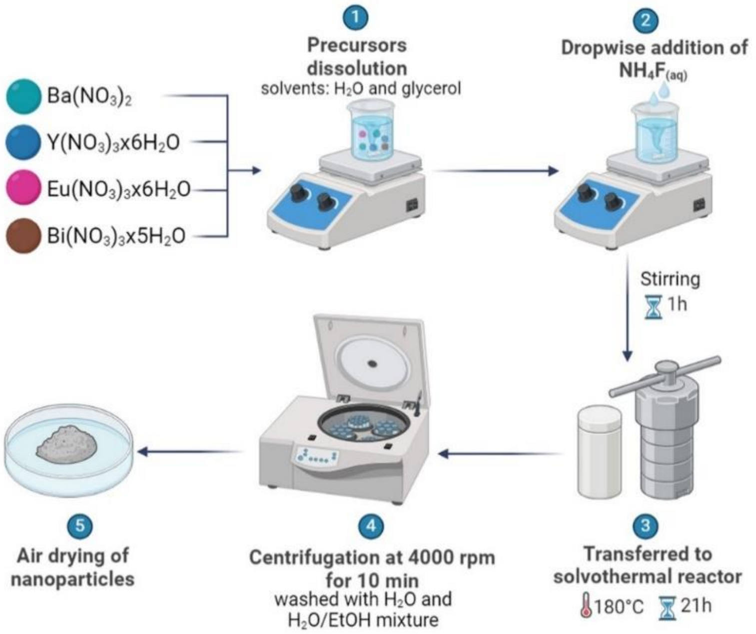

Figure 6*. Schematic illustration of the solvothermal synthesis of BYF: Eu, Bi nanoparticles. The precursors were initially dissolved in a water-glycerol mixture and fluoride ions were added dropwise (steps 1, 2). After vigorous stirring, the resulting mixture was transferred to a Teflon-lined autoclave and heated to 180°C for 21 h (step 3). The resulting nanoparticles were subsequently washed, centrifuged, and left to dry in air (steps 4, 5).*

Synthesis of Eu^{3+}-doped $BaGdF_5$ and Bi^{3+}, Eu^{3+}-doped $BaGdF_5$ nanoparticles – WP1, subactivity 1.2

Table 12. *Precursors for synthesis of $BaGdF_5$: 10 mol% Eu^{3+} sample.*

$BaGdF_5$	$Ba(NO_3)_2$ (g)	$Gd(NO_3)_3·6H_2O$ (g)	$Eu(NO_3)_2·H_2O$ (g)	NH_4F (g)
BGF:10Eu	0.2570	0.4059	0.0447	0.2590

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Synthesis of Eu^{3+}-doped RbY_3F_{10} nanoparticles – WP1, subactivity 1.2

Table 13. Precursors for the synthesis of RbY_3F_{10}: x mol% Eu^{3+} sample.

RbY_3F_{10}	RbF (g)	Y_2O_3 (g)	$Eu(NO_3)_3\cdot 6H_2O$ (g)	NH_4F(g)	EDTA(g)	Citric acid(g)
RYF:10Eu_1	0.0522	0.1525	0.0670	0.1850	/	0.2880
RYF:10Eu_2					/	/
RYF:10Eu_3					0.4384	
RYF:10Eu_4					0.0730	
RYF:1Eu		0.1678	0.0067			
RYF:5Eu		0.1610	0.0335			
RYF:15Eu		0.1441	0.1006			
RYF:30Eu		0.1186	0.2010			
RYF:50Eu		0.0847	0.3350			

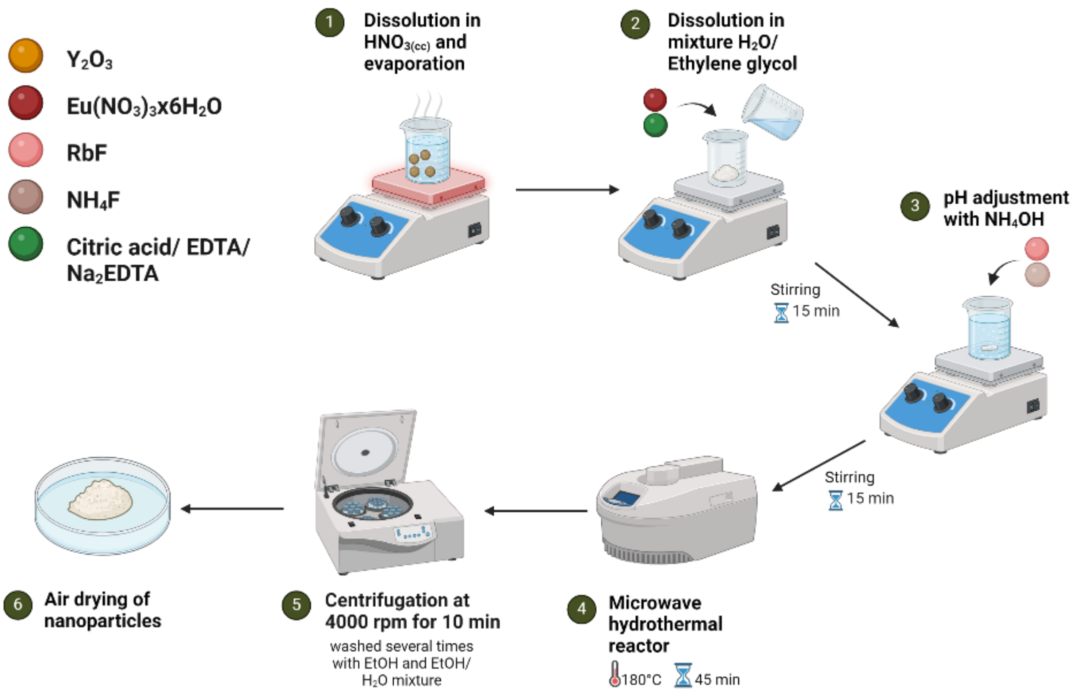

***Figure 7**. Schematic illustration of the solvothermal synthesis of RbY_3F_{10}: Eu nanoparticles.*

Synthesis of Eu^{3+}-doped GdF_3 nanoparticles – WP1, subactivity 1.1

Table 14. Precursors for the synthesis of GdF_3: 10 mol% Eu^{3+} samples.

GdF_3	$Gd(NO_3)_3\cdot 6H_2O$ (g)	$Eu(NO_3)_2\cdot 5H_2O$ (g)	NH_4F (g)
10 mol.% Eu	1.6248	0.1784	0.4444

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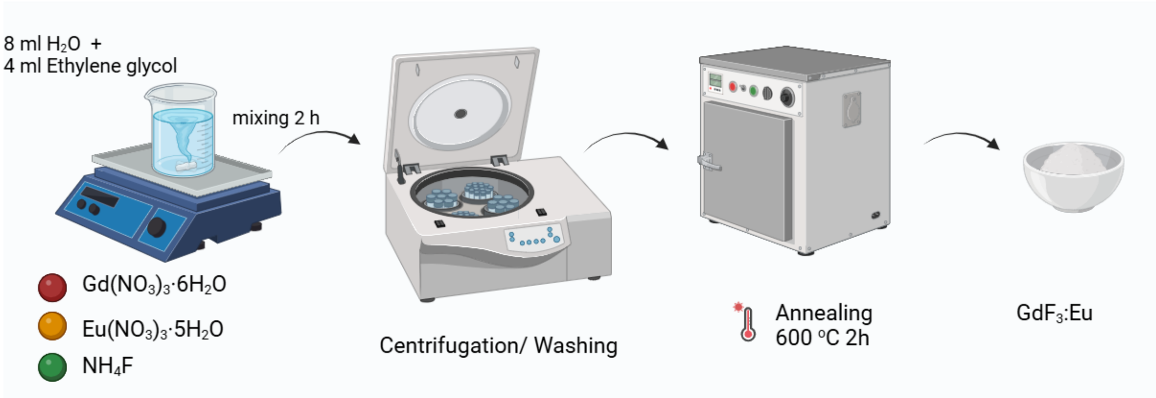

Figure 8. Schematic illustration of the precipitation synthesis of GdF_3:Eu nanoparticles.

6. Summary of Deliverable D1.2 – Report on Eu^{3+} and Bi^{3+}/Eu^{3+}-activated phosphors properties (WP1, month 15)

Deliverable D1.2 – *Report on Eu^{3+} and Bi^{3+}/Eu^{3+}-activated phosphors properties,* the LEDtech-GROW project is a public document, delivered in the context of **WP1** - *Design, synthesis, and characterization of plant-grow-targeted phosphors*, ***Subactivity 1.3*** - *Structural, morphological, and optical analysis of phosphors [month: 6-15]* and ***Subactivity 1.4*** - *Temperature-dependent photoluminescence, quantum efficiency, and chemical stability of phosphor [month: 6-15]*. This document outlines the detailed properties of prepared Eu^{3+} and Bi^{3+}/Eu^{3+}-activated phosphors for sharing and disseminating information related to the LEDtech-GROW project.

Properties of Sr_2GdF_7:Eu^{3+} and Sr_2GdF_7:Bi^{3+}, Eu^{3+}

Structure, morphology, and diffuse reflectance of Eu^{3+}-doped Sr_2GdF_7 – WP1, subactivity 1.3

Powder X-ray diffraction (PXRD) patterns of $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0, 0.05, 0.10, 0.40, 0.60, 0.80, and 1.00) nanophosphors are shown in Figure , with Rietveld refinement fits for the two end members, Sr_2GdF_7 (SGF) and Sr_2EuF_7 (SEF), given as Figure b-c (R_{wp} = 2.72% and 3.43 %, respectively). The patterns of Sr_2GdF_7 and Sr_2EuF_7 were fitted using a structural model in the cubic space group $Fm\overline{3}m$ (225), with Sr and Gd ions on Wyckoff site 4a with m-3m symmetry and F ions on Wyckoff site 8c with -43m symmetry. Transmission electron microscopy (TEM) images of representative colloidal SGF_40%Eu^{3+} particles, obtained with different magnifications, are shown in Figure e-f. Nanoparticles show a similar quasi-spherical shape with the average particle size estimated to be 24 ± 2 nm (see the histogram fitted with a log-normal distribution, based on around 200 particles, Figure e inset). The room temperature diffuse reflectance spectra of $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0, 0.05, 0.10, 0.40, 0.60, 0.80, and 1.00) samples in the 300–650 nm wavelength range, which display typical optical features of Eu^{3+} ions. The absorption peaks of Eu^{3+} ions, which are located at 317, 360, 381, 394, 414, 464, 525, and 587 nm correspond to the

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following electronic transitions: $^7F_0 \rightarrow {}^5H_3$, $^7F_0 \rightarrow {}^5D_4$, $^7F_0 \rightarrow {}^5G_6$, $^7F_0 \rightarrow {}^5L_6$, $^7F_0 \rightarrow {}^5D_3$, $^7F_0 \rightarrow {}^5D_2$, $^7F_0 \rightarrow {}^5D_1$, and $^7F_1 \rightarrow {}^5D_0$, respectively, with the highest absorption at around 394 nm.

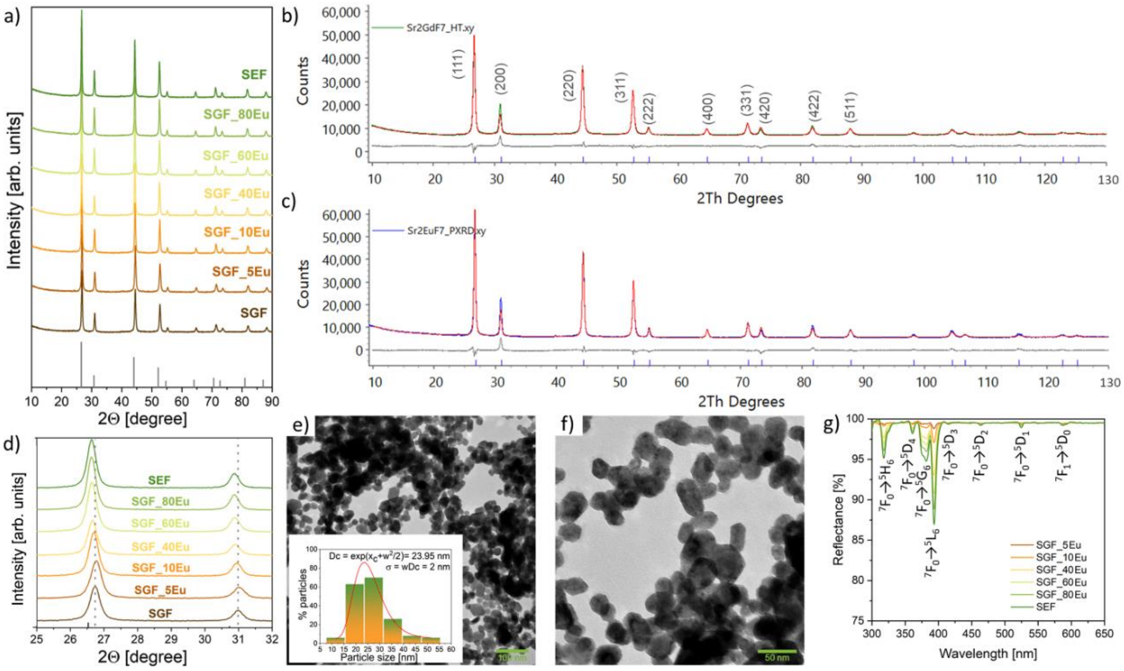

__Figure 9__. (a) PXRD patterns of $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0.05, 0.10, 0.40, 0.60. 0.80, and 1.00) nanophosphors; (b, c) Rietveld fits for Sr_2GdF_7 and Sr_2EuF_7. Green (SGF) and blue (SEF) curves represent the observed pattern, in each case, the red curves are the calculated patterns, and the difference curves are shown in grey, while blue tick marks represent the positions of the Bragg peaks; (d) Enlarged (111) and (200) diffraction peaks showing a shift toward lower Bragg angels due to the replacement of Gd with Eu ions in the host material; (e, f) TEM images under different magnification with the particle size distribution of representative colloidal SGF:40mol% Eu^{3+} given as Inset in Figure 9e; (g) Room temperature diffuse reflectance spectra for all $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0.05, 0.10, 0.40, 0.60. 0.80, and 1.00) samples.

Photoluminescent properties of Eu^{3+}-doped Sr_2GdF_7 – WP1, subactivity 1.3

The room temperature photoluminescence excitation spectra of all $Sr_2Gd_{1-x}Eu_xF_7$ colloids recorded in the 250–330 nm (λ_{em} = 698 nm) and 310–570 nm (λ_{em} = 593 nm) ranges are given in Figure a-b, showing lines that correspond to transitions within the $4f^6$ configuration of Eu^{3+} and $4f^7$ configuration of Gd^{3+}. Photoluminescence emission spectra of all $Sr_2Gd_{1-x}Eu_xF_7$ colloids recorded at room temperature are given in Figure 10c (λ_{ex} = 273 nm) and Figure 10d (λ_{ex} = 394 nm). The energy level diagram and energy transfer mechanism of Gd^{3+} and Eu^{3+} in SGF are shown in Figure 10e.

The asymmetry ratio values obtained from the emission spectra do not vary significantly as a function of Eu^{3+} concentration, as shown in Figure 10f. The Eu^{3+} deep-red emission ($^5D_0 \rightarrow {}^7F_4$) in SGF:Eu phosphors have a full width at a half-maximum of around 10 nm and fits the absorption band of phytochrome photoreceptors, P_{FR}. Furthermore, the Eu^{3+} red emission bands ($^5D_0 \rightarrow {}^7F_1$ and $^5D_0 \rightarrow {}^7F_2$) matched the red-adsorbing phytochrome photoreceptors, P_R, indicating that SGF:Eu may be an effective nanophosphor for horticulture LED applications. Figure 10h displays the normalized photoluminescent lifetime decay curves of the $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0.05, 0.10, 0.40, 0.60, 0.80, and 1.00) colloids recorded at room temperature. As the Eu^{3+} concentration increased, the $^5D_0$-level lifetimes gradually decreased from 12.0 to 6.9 ms. The shortening of the lifetime with increasing concentration indicates the activation of concentration-quenching mechanisms.

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Chromaticity coordinates (x,y) on the CIE chromaticity diagram, a two-dimensional color space that describes all the colors observed by the human eye, can be used to quantify apparent color. We derived the CIE chromaticity coordinates from the photoluminescent spectra to evaluate the color of the synthesized samples, as shown in Figure 10i and Table 15. For all the samples, CIE coordinates are almost identical for the highly doped samples (x = 0.62, y = 0.38; λ_{dom} = 598 nm; color purity = 99.1%) and placed in the orange-red portion of the diagram, confirming that there is no significant change in the local symmetry around Eu^{3+} across the series and consequently in the emission spectra. Inset in Figure 10i shows the translucent white color of colloids under daylight and the red appearance of colloids under UV light.

Table 15 *Chromaticity coordinates (x,y) of SGF:Eu*

	SGF_5Eu	SGF_10Eu	SGF_40Eu	SGF_60Eu	SGF_80Eu	SEF
CIE (x, y) coordinates	(0.565,0.398)	(0.586,0.396)	(0.611,0.384)	(0.615,0.381)	(0.616,0.381)	(0.614,0.383)

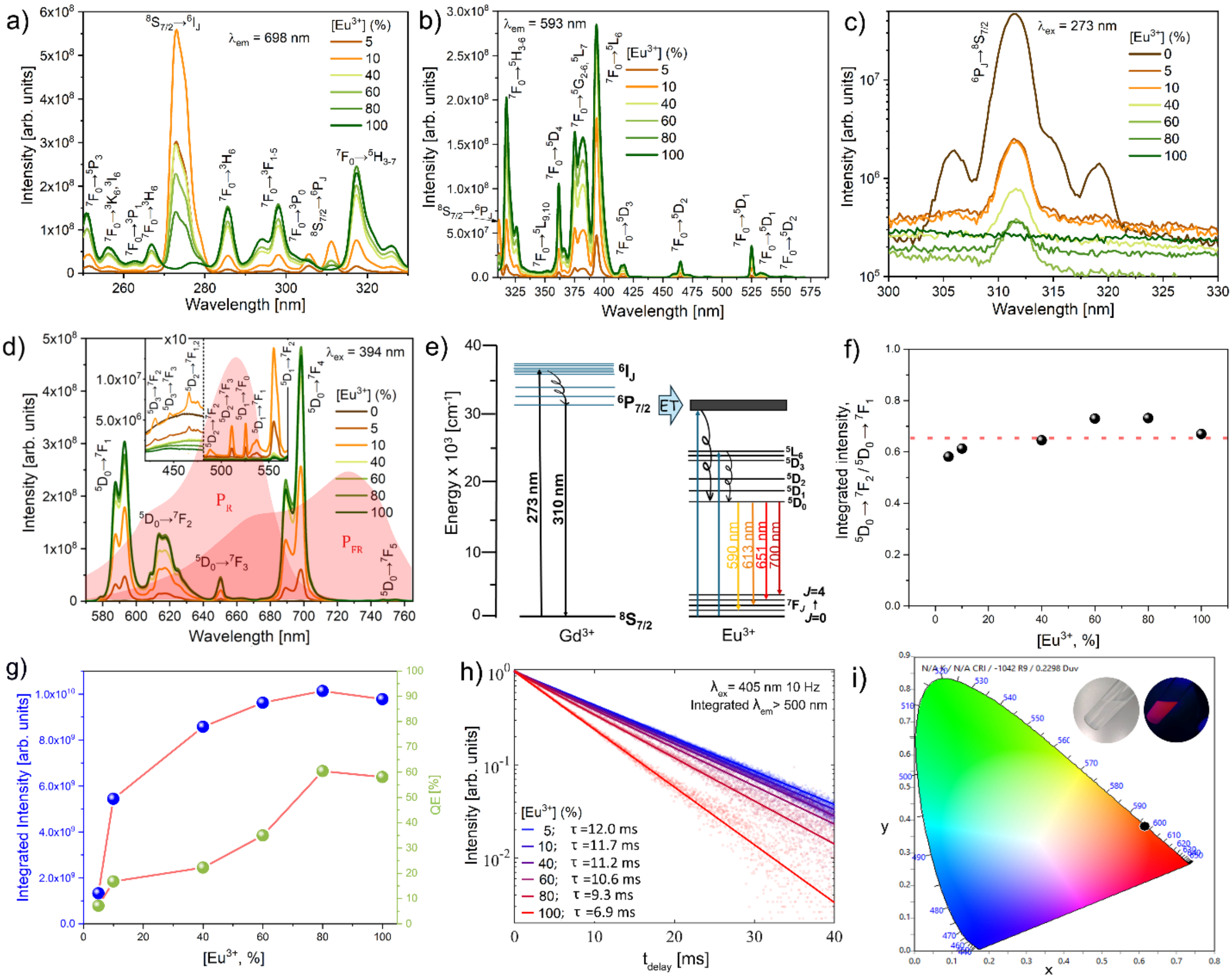

Figure 10*. Room temperature photoluminescence of $Sr_2Gd_{1-x}Eu_xF_7$ (x = 0.05, 0.10, 0.40, 0.60. 0.80, and 1.00) colloids: a) excitation spectra under λ_{em} = 698 nm; b) excitation spectra under λ_{em} = 593 nm; c) emission spectra under λ_{ex} = 273 nm; d) emission spectra under λ_{ex} = 394 nm (red pattern is the absorption spectra of P_R and P_{FR} photoreceptors); e) energy level diagram and energy transfer mechanism of Gd^{3+} and Eu^{3+} in SGF; f) asymmetry ratio as a function of Eu ions concentration; g) integrated emission intensity as a function of Eu ions concentration (blue dots) and quantum*

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efficiency as a function of Eu ions concentration (green dots); h) lifetime decay curves as a function of Eu ions concentration; and i) CIE diagram with calculated coordinates of SGF_80Eu (Inset: appearance of colloid under daylight and near UV light).

Temperature-dependent photoluminescence measurements of Eu^{3+}-doped SGF – WP1, subactivity 1.4

To determine the temperature stability, temperature-dependent photoluminescence measurements in steady-state and time domains were recorded in the 25–200 °C temperature range on dried samples in powder form. Figure 11a shows the white color of powders under daylight and the red appearance under UV light, which becomes more intense as Eu^{3+} concentration increases. Figure 11b shows the lifetime, while Figure 11c shows the emission intensity as a function of temperature for two representative samples, SGF_5Eu (with the lowest Eu^{3+} content in the series) and the SGF_80Eu sample, with the highest emission intensity.

The powder sample of the highest emission intensity, SGF_80Eu, with a ceramic binder and placed it on top of a 365 nm near-UV LED chip to demonstrate the application potential of these materials in LEDs. Photographs of the fabricated LED device, presented in Figure 11d, display a red light when the power supply is on. In addition, Figure 11e shows the PL spectrum of the fabricated LED device with CIE coordinates (0.5759, 0.3893) and low correlated color temperature (CCT = 1534 K).

Table 16. *QE values and temperature stability for some previously reported far-red phosphors*

Far-red-emitting phosphors	λ_{ex} (nm), λ_{em} (nm)	QE (%)	Thermal stability (I_{373K}/I_{303K})	Thermal stability (I_{423K}/I_{303K})
SGF_80Eu	**394, 698**	**60.4**	**83%**	**66%**
Li_2MgZrO_4:Mn^{4+}	335, 675	32.3	75%	58%
Ca_2LuSbO_6:Mn^{4+}	345, 683	39.1	66%	48%
La_2ZnTiO_6:Mn^{4+}	342, 708	-	81%	64%
$CaYAlO_4$: Mn^{4+}	370, 710	26	50%	70%
$NaLaMgWO_6$:Mn^{4+}	342, 700	60	-	57%
$Ca_9MY_{0.667}(PO_4)_7$:Eu^{3+} (M = Li, Na)	394, 700	-	-	-
Lu_2GeO_5:Bi^{3+},Eu^{3+}	313,710	43	70%	51%

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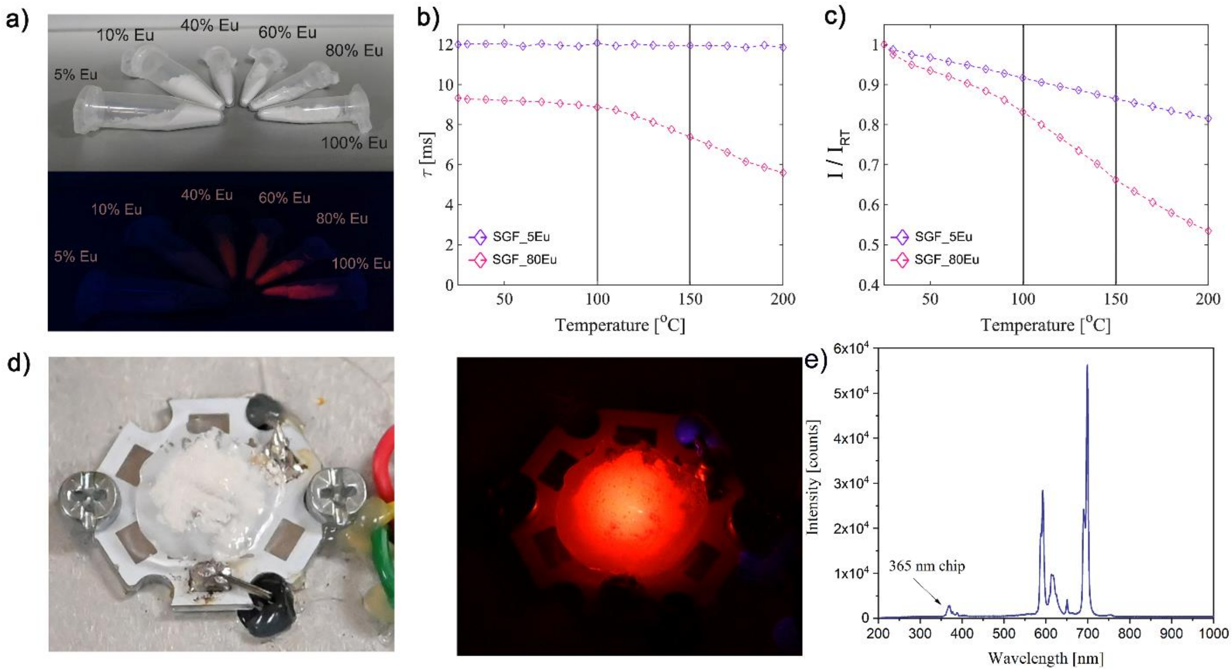

Figure 11. a) Appearance of nanopowders under daylight and near UV light. Temperature-dependence of b) lifetime and c) emission intensity for the whole set of nanopowders. d) A fabricated LED device comprising a semiconductor chip and SGF_80Eu nanopowders displays a red light when the electrical power supply is on. e) PL spectrum of the fabricated LED.

Structural and optical properties of Bi^{3+}-doped $Sr_2Gd_{0.2}Eu_{0.8}F_7$ nanoparticles – WP1, sub-activity 1.3

Powder X-ray diffraction patterns of $Sr_2Gd_{0.2}Eu_{0.8}F_7$:$x$$Bi^{3+}$($x$ = 0.25, 1, 5, and 10 mol%) nanophosphors are shown in Figure . The patterns of $Sr_2Gd_{0.2}Eu_{0.8}F_7$:$x$$Bi^{3+}$ are in accordance with the cubic space group $Fm\overline{3}m$ (225). All observed reflections were accounted for in the PXRD patterns of all samples, and the absence of extra peaks confirms the phase purity of the materials prepared.

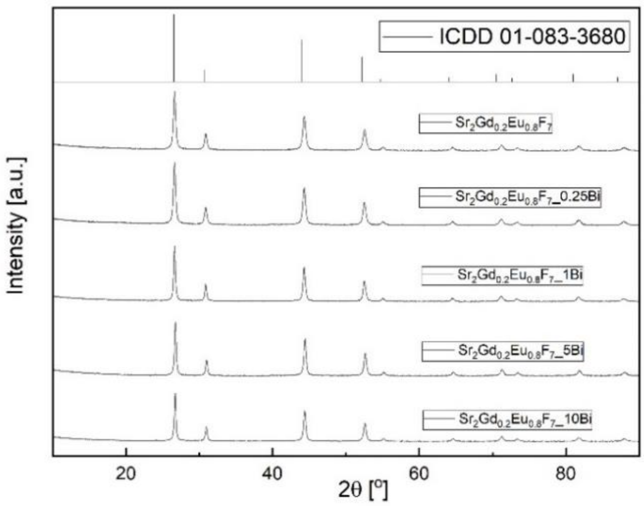

Figure 12. *PXRD patterns of $Sr_2Gd_{0.2}Eu_{0.8}F_7$:xBi^{3+} (x = 0.25, 1, 5, and 10 mol%) nanophosphors.*

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The room temperature photoluminescence emission spectra of all of Bi^{3+}-co-doped $Sr_2Gd_{0.2}Eu_{0.8}F_7$ powders were recorded in the 420–750 nm (λ_{ex} = 391 nm). Emissions correspond to 4*f*–4*f* transitions of Eu^{3+} placed at ~592 nm ($^5D_0 \rightarrow {}^7F_1$), ~613 nm ($^5D_0 \rightarrow {}^7F_2$), ~650 nm ($^5D_0 \rightarrow {}^7F_3$), and ~700 nm ($^5D_0 \rightarrow {}^7F_4$). Europium ions' emission intensity monotonically increases in the co-doped samples up to 1 mol% of Bi^{3+}, while the further addition of Bi^{3+} decreases the emission intensity. CIE coordinates and correlated color temperature values are presented in Table 17.

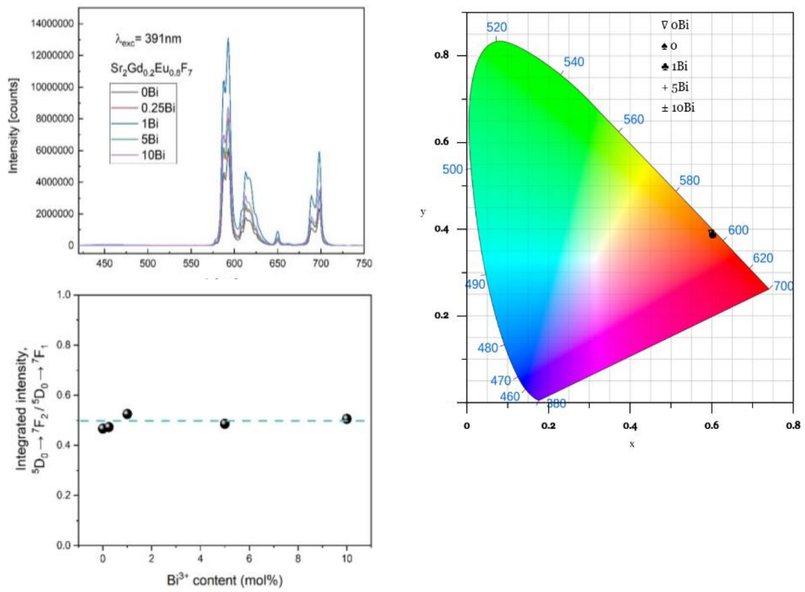

Figure 13. Photoluminescence spectra of $Sr_2Gd_{0.2}Eu_{0.8}F_7$: xBi^{3+} (x = 0.25, 1, 5, and 10 mol%) nanophosphors; the integrated intensity of the $^5D_0 \rightarrow {}^7F_2$ and $^5D_0 \rightarrow {}^7F_1$ transitions, known as the asymmetry ratio; and CIE chromaticity diagram.

Table 17. Chromaticity coordinates (x,y) of $Sr_2Gd_{0.2}Eu_{0.8}F_7$: xBi^{3+} *(x = 0.25, 1, 5, and 10 mol%) nanophosphors.*

	$Sr_2Gd_{0.2}Eu_{0.8}F_7$ (SGEF)	SGEF_0.25Eu	SGEF_1Eu	SGEF_5Eu	SGEF_10Eu
CIE (x, y) coordinates	(0.598,0.388)	(0.601,0.389)	(0.601,0.387)	(0.600,0.389)	(0.602,0.389)
CCT	1727.5	1729.6	1737.0	1730.8	1734.1

Properties of Sr_2LaF_7:Bi^{3+},Eu^{3+}

Structural and optical properties of Bi^{3+}-doped Sr_2LaF_7 (5 mol% Bi^{3+}) – WP1, subactivity 1.3

Powder X-ray diffraction patterns of Sr_2LaF_7:10mol% Eu^{3+} and Sr_2LaF_7 :5mol% Bi^{3+} nanophosphors are shown in Figure . The patterns of Sr_2LaF_7:10mol% Eu^{3+} and Sr_2LaF_7 :5mol% Bi^{3+} match well with the International Centre for Diffraction Data (ICDD) Card No. 00-053-0774, with the cubic space group $Fm\bar{3}m$ (225).

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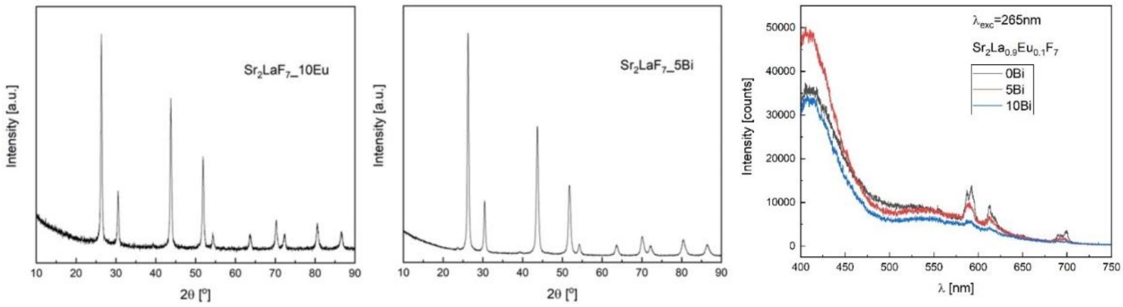

***Figure 14**. PXRD patterns of Sr_2LaF_7 :10mol% Eu^{3+} and Sr_2LaF_7 :5mol% Bi^{3+} nanophosphors (up) and room temperature photoluminescence spectra of $Sr_2La_{0.9}Eu_{0.1}F_7$:xBi^{3+} (x=0, 5, and 10mol%) nanophosphors (down).*

Properties of SrF_2:Eu^{3+} and SrF_2:Bi^{3+},Eu^{3+}

Structure and morphology of Eu^{3+}-doped SrF_2 and Bi^{3+}, Eu^{3+}-doped SrF_2 nanoparticles – WP1, subactivity 1.3

Figures 15a and 15b show the X-ray pattern of SrF_2:*x*Eu (*x*= 1, 5, 10, 15, 20 mol%) and SrF_2: 10Eu*y*Bi (*y*= 5, 10, 15, 20, 30, 40 mol%) presented with the International Centre for Diffraction Data (ICDD) Card No. 01-086-2418. The X-ray diffraction examination of the synthesized samples proved a single-phase cubic structure with *Fm-3m* (225) space group (including the SrF_2:20Bi sample, Figure 16a). Traces of contamination or other phase peaks were not observed in either set of samples, indicating that dopant Eu^{3+}/Bi^{3+} ions were embedded into the SrF_2 lattice. On the contrary, in the case of SrF_2:10Eu50Bi sample, additional peaks originate from a different phase, suggesting the upper limit of dopant ions concentration in the made material has been reached (Figure 16b).

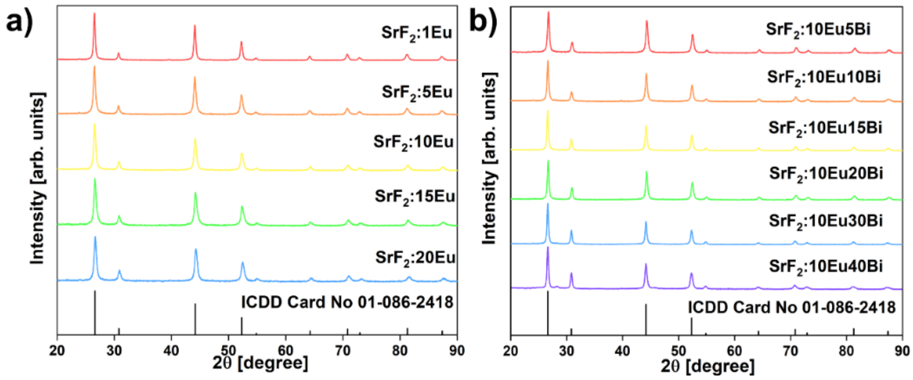

***Figure 15.** XRD patterns of a) SrF_2:xEu (x= 1, 5, 10, 15, 20 mol%) and SrF_2: 10Eu,yBi (y= 5, 10, 15, 20, 30, 40 mol%) samples presented with the ICDD card No. 01-086-2418.*

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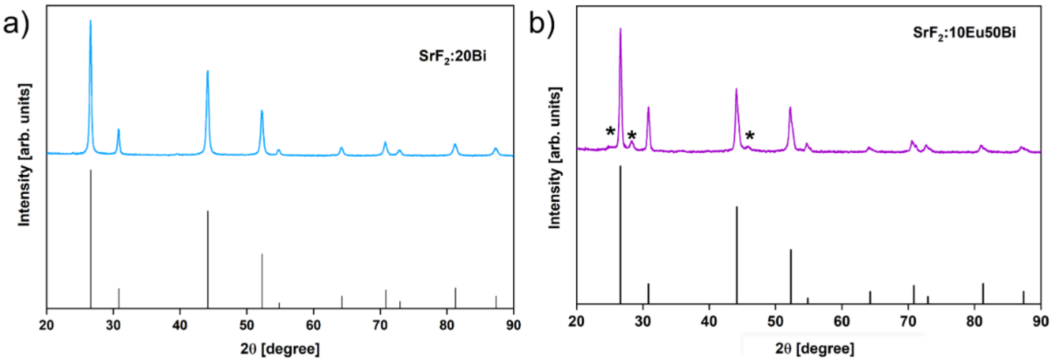

Figure 16. *PXRD patterns of a) SrF_2:20Bi, and b) SrF_2:10Eu50Bi samples. The diffraction peaks are indexed according to the ICDD card No. 01-086-2418.*

Additionally, the mean crystallite size and structural parameters are presented in Table 18 (parameters for SrF_2:xEu (x= 1, 5, 10, 15, 20 mol%), SrF_2:10EuyBi (y= 5, 10, 15, 20, 30, 40 mol%), and SrF_2:20Bi sample). The average crystallite size (CS) was calculated to be in the nanometer domain (~14–25 nm) for all the samples.

Table 18. *Selected structural parameters of the SrF_2:xEu (x= 1, 5, 10, 15, 20 mol%), SrF_2:10EuyBi (y= 5, 10, 15, 20, 30, 40 mol%) and SrF_2:20Bi nanopowders.*

ICDD card 01-086-2418	a=b=c (Å)	CS (Å)	Strain	GOF	Rwp (%)	Rp (%)	Re (%)
SrF_2:1Eu	5.7970(2)	183.5(11)	0.14(6)	1.0426	7.65	5.77	7.34
SrF_2:5Eu	5.7979(3)	131.2 (11)	0.24(9)	1.0247	7.38	5.77	7.20
SrF_2:10Eu	5.79128(14)	150.2(5)	0.15(3)	1.0261	7.42	5.74	7.23
SrF_2:15Eu	5.7973(5)	117.9 (10)	0.19(9)	1.0567	7.38	5.78	6.98
SrF_2:20Eu	5.7838(5)	123.7 (13)	0.14(3)	1.0936	7.50	5.98	6.86
SrF_2:10Eu5Bi	5.7907(4)	149.0 (18)	0.23(11)	1.1974	8.73	6.79	7.29
SrF_2:10Eu10Bi	5.7914(3)	188(2)	0.06(10)	1.1738	8.64	6.59	7.36
SrF_2:10Eu15Bi	5.7942(4)	209(2)	0.08(7)	1.4142	10.68	7.96	7.55
SrF_2:10Eu20Bi	5.7918(5)	178(3)	0.123(5)	1.4067	10.86	8.10	7.72
SrF_2:10Eu30Bi	5.8023(5)	250(18)	0.220(9)	1.7336	12.84	9.49	7.40
SrF_2:10Eu40Bi	5.8080(13)	201(5)	0.23(8)	1.6523	12.63	9.14	7.87
SrF_2: 20Bi	5.8011(3)	250.5(16)	0.241(5)	1.1840	8.75	6.63	7.39

* Rwp—the weighted profile factor; ** Rp—the profile factor; *** Re—the expected weighted profile factor; GOF—the goodness of fit.

A transmission electron microscopy (TEM) image of the representative SrF_2:10Eu20Bi sample is shown in Figure 17a. Nanoparticles exhibit a pseudo-spherical shape with the average particle size estimated to be 14.2 ± 0.3 nm (see the histogram fitted with a Gaussian distribution, based on around 60 particles, using the largest axis of the grain, Figure 17b). The calculated average particle size roughly equals the crystallite size obtained using X-ray diffraction.

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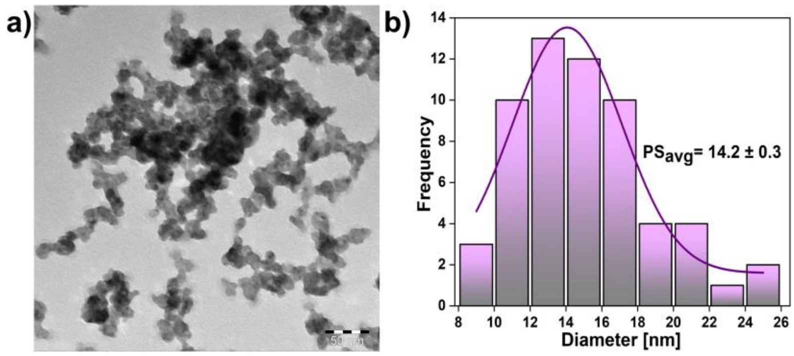

Figure 17. a) TEM images of the representative SrF_2:10Eu20Bi sample, b) particle size distribution histogram.

Photoluminescence properties of Eu^{3+}-doped SrF_2 and Bi^{3+}, Eu^{3+}-doped SrF_2 nanoparticles – WP1, subactivity 1.3

The photoluminescence (PL) emission spectra of Eu^{3+} - doped set of samples: SrF_2:1Eu, SrF_2:5Eu, SrF_2:10Eu, SrF_2:15Eu, and SrF_2:20Eu recorded at room temperature are displayed in Figure 18a (λ_{exc} = 405 nm). Figure 18c shows the diffuse reflectance spectra of Bi^{3+} co-doped SrF_2:10Eu (Bi^{3+} mol% = 5, 10, 15, 20, 30, and 40) samples in the 220–500 nm wavelength range. Figure 18d shows PL emission spectra of Bi^{3+}-co-doped samples in the 550–725 nm spectral region recorded at room temperature under 265 nm excitation. The integrated emission intensity in the 550 – 725 nm wavelength range shows that the sample with the highest emission intensity- SrF_2:10Eu20Bi has twice as bright PL compared to the Bi-free SrF_2:10Eu phosphor (Figure 18e). ET between bismuth (Bi^{3+}) and europium (Eu^{3+}) ions in inorganic hosts involves Bi^{3+} ions absorbing energy and transitioning from their ground state to excited states, followed by energy transfer to Eu^{3+} ions, exciting them from their ground to higher states (Figure 18f).

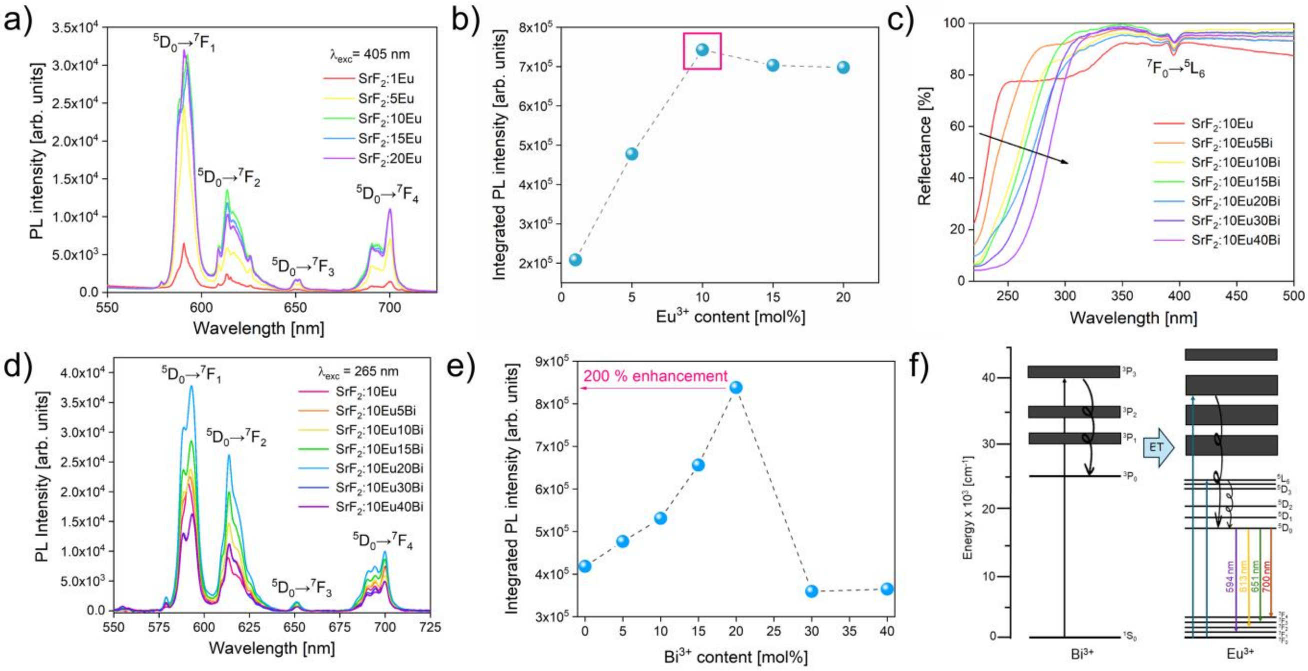

Figure 18. a) Room temperature PL emission spectra under λ_{exc} = 405 nm of samples doped with only Eu^{3+} ions, b) Integrated intensity of PL spectra presented in a), c) Diffuse reflectance spectra of samples doped with 10 mol% of Eu^{3+} ions and co-doped with Bi^{3+} ions, d) Room temperature PL emission spectra under λ_{exc} = 265 nm of co-doped samples, e) Integrated intensity of PL spectra presented in d), and f) schematic representation of the possible ET between Bi^{3+} and Eu^{3+} ions.

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Figure 19a shows the room temperature PL emission spectra (λ_{exc} = 265 nm)of SrF_2:20Bi, SrF_2:10Eu, and SrF_2:10Eu20Bi samples in the 380–725 nm spectral region, showing both blue and red-light components in different ratios. Figure 19b shows the CIE chromaticity diagram for SrF_2:20Bi, SrF_2:10Eu, and SrF_2:10Eu*y*Bi samples (*y*= 5, 10, 15, 20, 30, and 40 mol%). The CIE chromaticity coordinates move from blue for the SrF_2:20Bi sample, to pinkish for SrF_2:10Eu, and orange-red areas with the increase of Bi^{3+} content in SrF_2:10Eu*y*Bi, showing the color tunability in the produced series (CIE values are listed in Table 19).

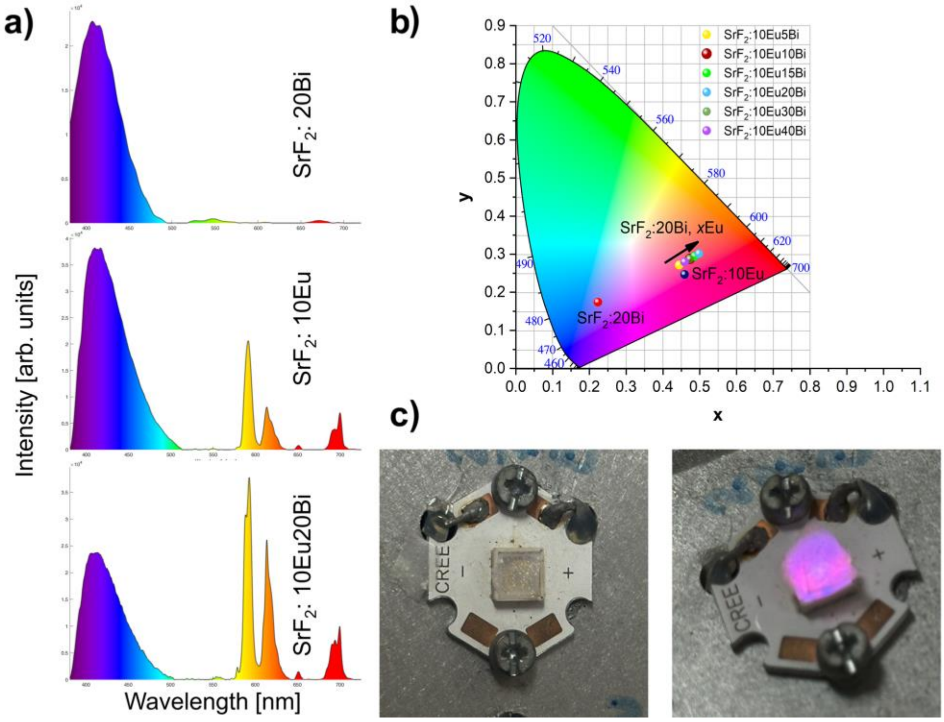

***Figure** 19. a) The room temperature PL emission spectra of SrF_2:20Bi, SrF_2:10Eu, and SrF_2:10Eu20Bi samples showing both blue and red-light components in different ratios (λ_{exc} = 265 nm), b) CIE chromaticity coordinates, and c) Fabricated LED device displaying pinkish violet light.*

Emission spectra of SrF_2:10Eu,*y*Bi (*y* = 5, 10, 15, 30, and 40 mol%) samples in the 380–725 nm spectral region are presented in Figure 20.

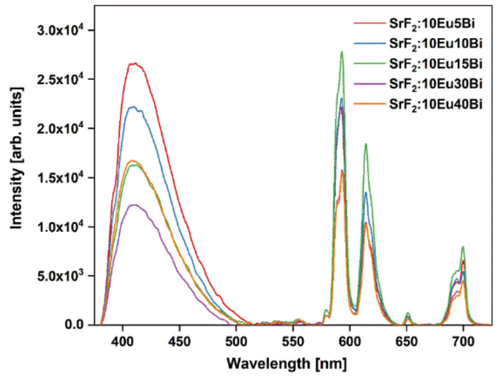

***Figure 20** The room temperature PL emission spectra of SrF_2:10EuxBi (x = 5, 10, 15, 30, and 40 mol%) samples measured in 380–725 nm spectral range showing both blue and red-light components in different ratios (λ_{exc} = 265 nm).*

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Balancing blue and red-light components is vital for optimizing plant health and maximizing yield in controlled environments. The integrated PL area in the 380–500 nm (blue) and 575–725 nm (red) wavelength range was used to determine the blue- and red-light emission portion. Table 19 shows that single-doped Bi^{3+} and Eu^{3+} SrF_2 exhibit strong blue emissions corresponding to the host material; however, increasing Bi^{3+} concentration enhances Eu^{3+} red emission in Eu^{3+}/ Bi^{3+} - activated samples. **The highest red/blue emission portion 40.8 : 59.2 was found for the sample SrF_2:10Eu20Bi.**

Table 19. *Blue and red emission portions for the SrF_2:20Bi, SrF_2:10Eu, and SrF_2:10EuyBi (x = 5, 10, 15, 20, 30, and 40 mol%) samples.*

Sample	% Blue	% Red	CIE (x, y) coordinates
SrF_2:20Bi	100.0	0.0	(0.223, 0.174)
SrF_2:10Eu	85.0	15.0	(0.399, 0.247)
SrF_2:10Eu5Bi	76.5	23.5	(0.444, 0.271)
SrF_2:10Eu10Bi	71.6	28.4	(0.474, 0.288)
SrF_2:10Eu15Bi	61.9	38.1	(0.486, 0.294)
SrF_2:10Eu20Bi	59.2	40.8	(0.498, 0.301)
SrF_2:10Eu30Bi	66.7	33.3	(0.473, 0.287)
SrF_2:10Eu40Bi	73.1	26.9	(0.459, 0.279)

To demonstrate the potential application of the obtained material in LED fabrication, the powder sample with the highest emission intensity, SrF_2:10Eu20Bi, was mixed with a ceramic binder and placed on top of a 275 nm near-UV chip. Photographs of the fabricated LED device, presented in Figure 19c, display strong pinkish-violet light when the power supply is on.

Properties of $BaF_2:Eu^{3+}$

Crystal structure of BaF_2 nanoparticles – WP1, subactivity 1.3

Figure 21 displays the X-ray pattern of BaF_2, referenced against the International Centre for Diffraction Data (ICDD) Card No. 01-085-1341.

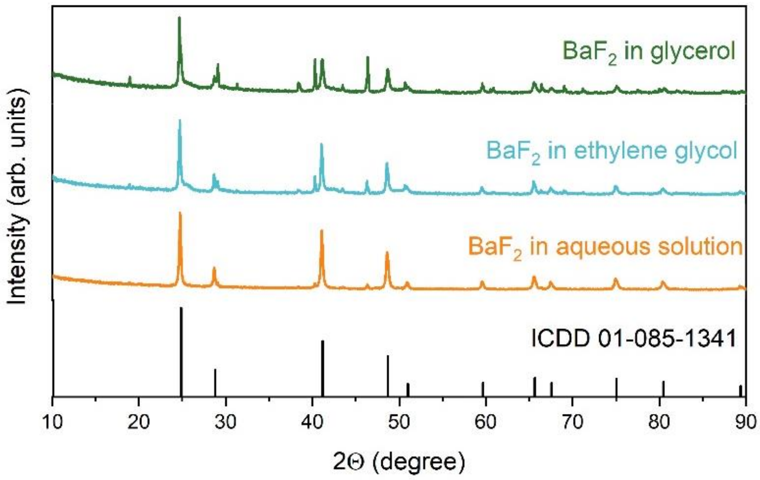

Figure 21. *XRD patterns of BaF_2 powders synthesized via microwave route at 150 °C for 10 min in water, ethylene glycol, and glycerol.*

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Properties of $BaYF_5:Eu^{3+}$ and $BaYF_5:Bi^{3+},Eu^{3+}$

PXRD and Morphology Analysis – WP1, subactivity 1.3

Despite the addition of Eu^{3+} and Bi^{3+} ions, the main diffraction peaks of BYF: xEu, x = 1−20 mol% (Figure 22a) and BYF:10Eu, $y Bi^{3+}$, y = 0−50 mol% nanophosphors (Figure 22b), correspond to the main reflections from 111, 200, 220, 311, 222, 400, 331, 420, 422, and 511 crystal planes and resemble standard cubic data of ICDD No. 01-080-2728 for single-phase $BaYF_5$, space group $Fm\overline{3}m$ (225). Table 20 shows the results of the structural analysis: crystallite size (CS), microstrain values, unit cell parameters, unit cell volume (CV), and data fit parameters (R_{wp}, R_p, R_e, GOF) of BYF:10Eu, yBi (y = 0, 5, 10, 20, 30, and 50 mol%) nanophosphors. The CS of BYF:10Eu is estimated to be 19.6 nm, and the lattice constant a is 5.8925 Å (CV = 204.60 Å^3). The influence of Bi^{3+} doping in the BYF: 10Eu lattice causes crystal lattice expansion up to a = 5.9942 Å, CV = 215.37 Å^3 for the sample BYF:10Eu, 50Bi.

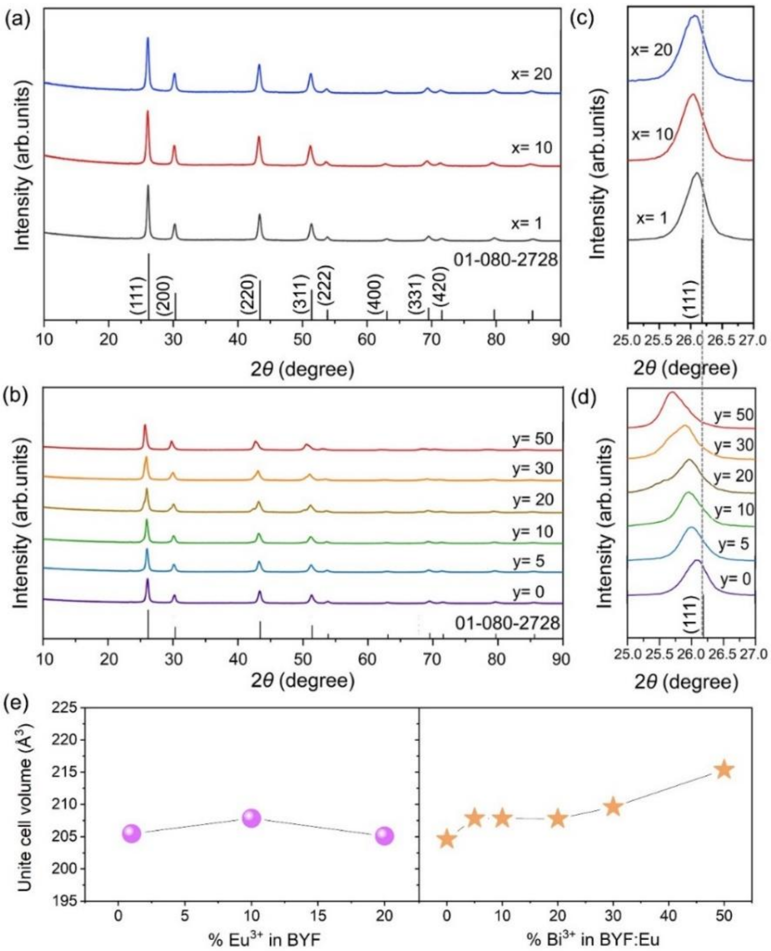

Figure 22. PXRD patterns of (a) BYF: xEu (x = 1, 10, and 20 mol%) and (b) BYF:10Eu, yBi (y = 0, 5, 10, 20, 30, and 50 mol%) nanoparticles; (c) The evolution of the (111) diffraction peak magnified from (a); (d) The evolution of the (111) diffraction peak magnified from (b); (e) The values of the unit cell volume versus Eu^{3+} and Bi^{3+} contents in BYF (purple circles) and BYF: 10Eu (orange stars), respectively.

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Table 20. Results of the structural analysis of BYF: 10Eu, yBi nanophosphors, where y = 0, 5, 10, 20, 30, and 50 mol% Bi^{3+}

Bi^{3+} content (mol%)	0	5	10	20	30	50
a=b=c (Å)	5.8925 (3)	5.9236 (4)	5.9235 (5)	5.9227 (6)	5.9401 (6)	5.9942 (5)
CV Å^3)	204.60 (4)	207.85 (5)	207.84 (6)	207.76 (7)	209.60 (7)	215.37 (6)
CS (Å)	196 (3)	274 (5)	305 (12)	198 (11)	100 (6)	95 (5)
Strain	0.46 (3)	0.64 (2)	0.75 (2)	1.03 (6)	0.23 (3)	0.26 (3)
GOF	1.1254	1.5272	1.6212	1.6678	2.9693	3.6494
*R_{wp}	4.23	5.79	6.14	6.42	11.08	13.43
**R_p	3.16	4.45	4.66	4.95	7.57	8.71
***R_e	3.75	3.79	3.78	3.85	3.73	3.68

* R_{wp}—the weighted profile factor; ** R_p—the profile factor; *** R_e—the expected weighted profile factor; GOF—the goodness of fit.

Figure 23 shows SEM images of BYF:10Eu phosphor nanoparticles with a particle size distribution. Nanoparticles are of a quasispherical shape, as well as a high degree of crystallinity. The average crystalline size of BYF: 10Eu nanoparticles, considering more than 100 particles, was estimated to be 33 ± 2 nm (see Figure 23c).

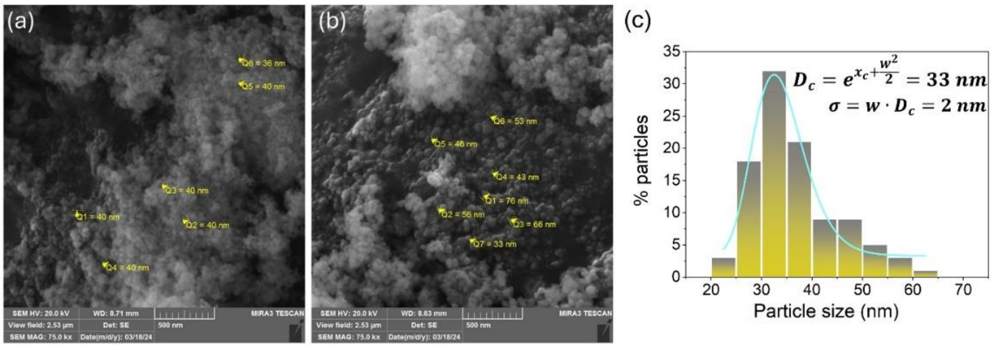

Figure 23. (a, b) SEM images of solvothermally synthesized BYF: 10Eu phosphor nanoparticle; (c) The particle size distribution.

Spectroscopic Properties – WP1, subactivity 1.3

Figure 24 shows the photoluminescence excitation and emission spectra of Bi-free BYF with varying Eu^{3+} contents.

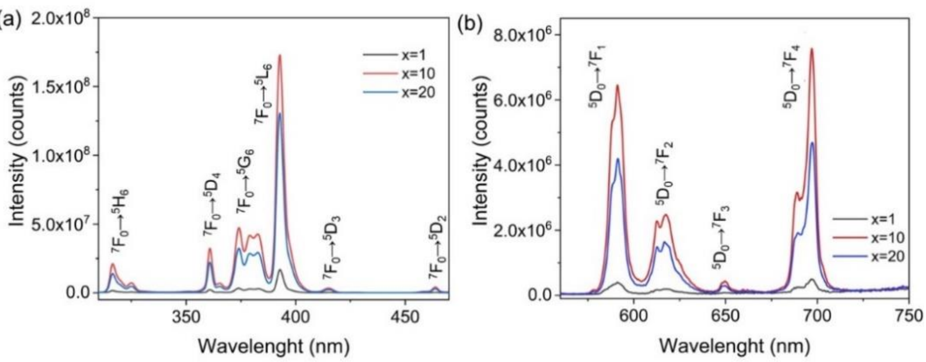

Figure 24. Room temperature photoluminescence for all BYF:xEu (x = 1, 10, and 20 mol%) samples: (a) Excitation spectra under λ_{em} = 592 nm; (b) Emission spectra under λ_{ex} = 391 nm;

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The room temperature diffuse reflectance spectra of BYF:10Eu, *y*Bi (*y* = 0, 5, 10, 20, 30, and 50 mol%) samples were measured in the 220–500 nm wavelength range. It is observed that the UV band edge tends to shift towards lower energy with an increase of Bi^{3+} content in the BYF: Eu. This red shift with the change of Bi^{3+} content indicates a strong absorption of Bi^{3+}, which lies in the UV region. The room temperature photoluminescence excitation spectra of all BYF: Eu, Bi samples recorded in the 250–330 nm (λ_{em} = 698 nm) wavelength range are given in Figure 25b. The photoluminescence emission spectra of all BYF: Eu, Bi samples recorded at room temperature are displayed in Figure 25c (λ_{ex} = 265 nm). Figure 25d shows that europium's photoluminescent intensity continually increases until the Bi^{3+} content reaches 20 mol%, while the further addition of Bi^{3+} decreases the emission intensity. The integrated emission intensity in the 520 – 720 nm wavelength range shows that the representative BYF: 10Eu, 20Bi sample has a 216% emission enhancement compared to the Bi-free BYF: 10Eu phosphor. Figure 25e shows the translucent white color of representative BYF: 10Eu, 20Bi phosphor nanoparticles under daylight (left) and the red appearance under UV light (right).

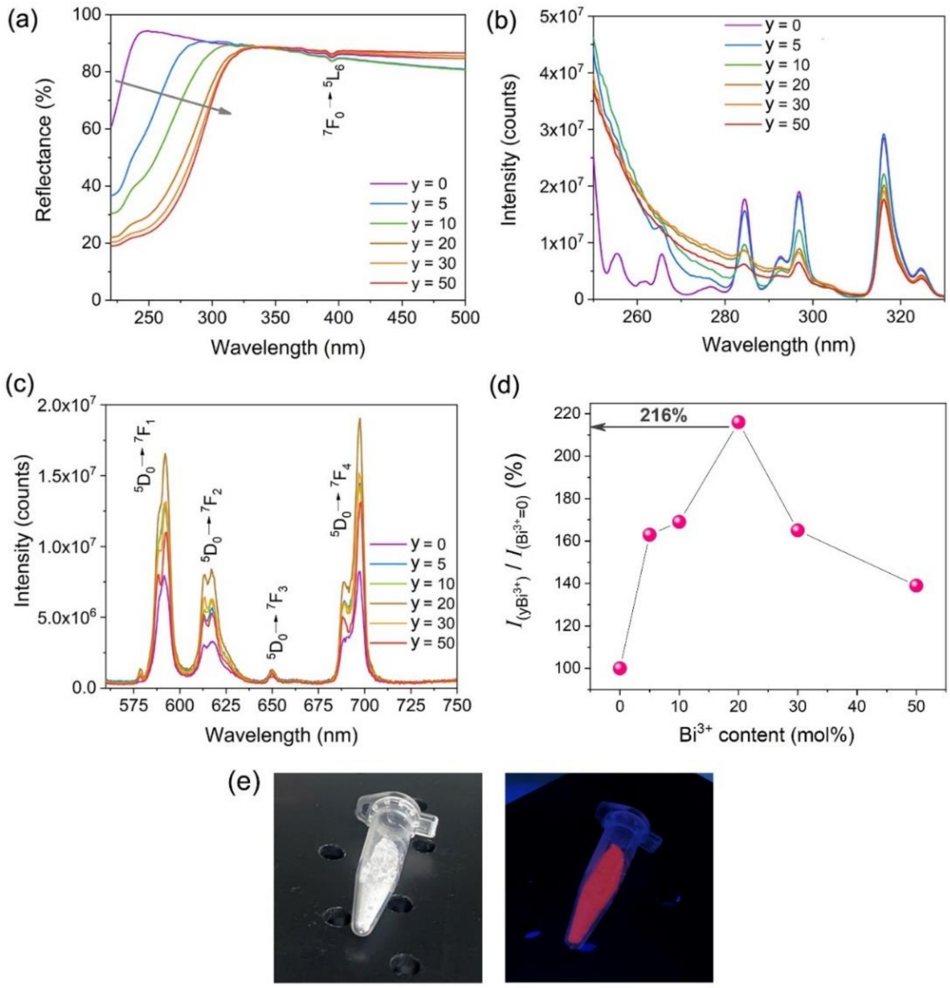

Figure 25. (a) Room temperature diffuse reflectance spectra for BYF: 10Eu, yBi (y = 0, 5, 10, 20, 30, and 50 mol%) samples; Room temperature photoluminescence for BYF: 10Eu, yBi (y = 0, 5, 10, 20, 30, and 50 mol%) samples: (b) Excitation spectra under λ_{em} = 698 nm; (c) Emission spectra under λ_{ex} = 265 nm; (d) Ratio of the integrated emission intensity for BYF: 10Eu samples with varied Bi concentration and Bi-free BYF: 10Eu sample as a function of Bi^{3+} ions concentration; (e) The appearance of representative BYF: 10Eu, 20Bi phosphor nanoparticles under daylight (left) and UV light (right).

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Energy transfer in BYF: Bi Eu, phosphor nanoparticles – WP1, sub-activity 1.3

Energy transfer from a sensitizer to an activator can occur *via* radiative transfer, exchange interaction, or multipole-multipole interaction. Dips in the sensitizer's emission spectra that correlate to the absorption spectrum of activated ions demonstrate the possibility of radiative energy transfer from the sensitizer to the activator. As shown in Figure 26b, the emission spectra of BYF: 20Bi, 20Eu clearly show a dip that overlaps with the absorption of Eu^{3+}, indicating that the energy transfer has a radiative character. On the other hand, Figure 26a reveals that 20mol% Bi^{3+} and Eu^{3+} concentrations less than or equal to 10 mol% contribute to a non-radiative character of energy transfer in BYF: Bi, Eu.

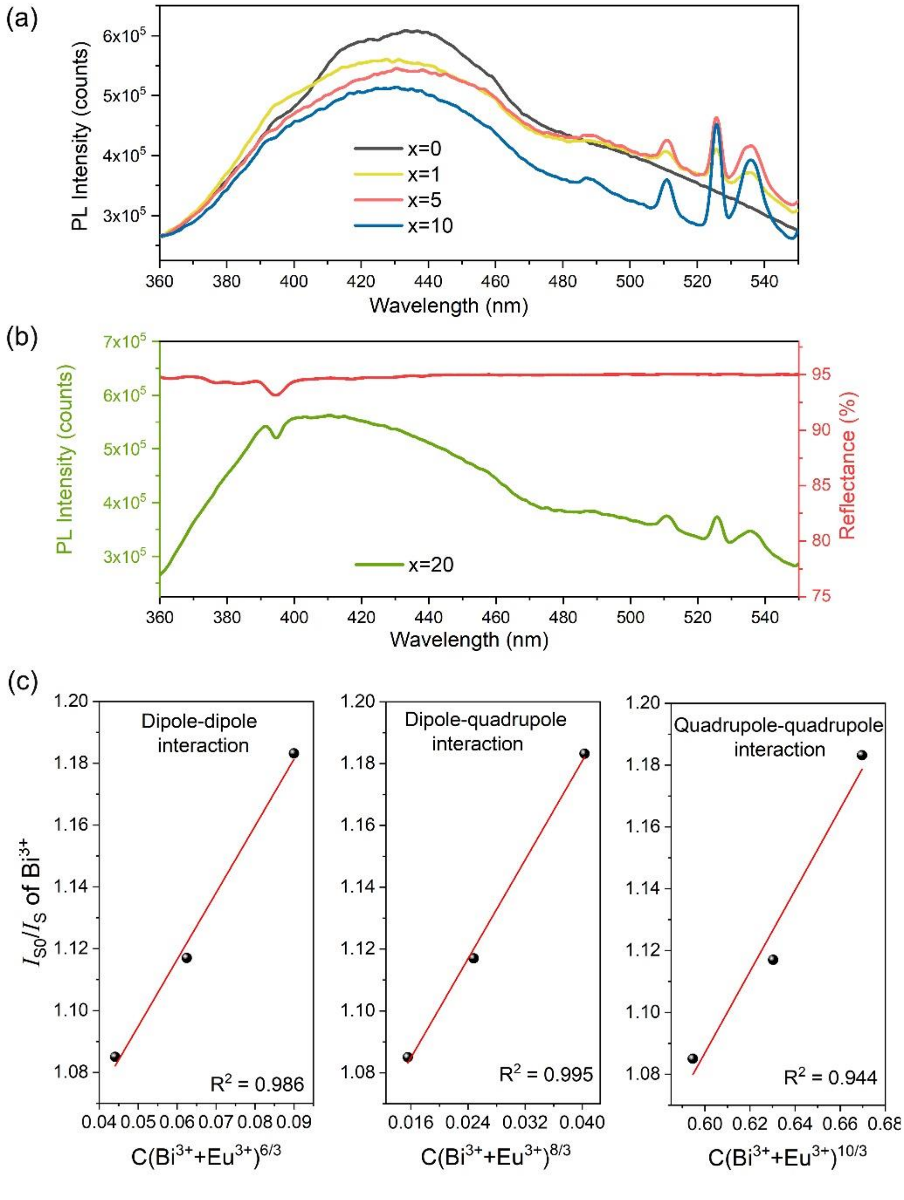

Figure 26. (a) The emission spectra of BYF: xEu, 20Bi (x = 0, 1, 5, and 10 mol%) nanoparticles; (b) Overlap of the emission spectrum of BYF: 20Eu, 20Bi and absorption of BYF: 10Eu; (c) Plots of I_{S0}/I_S versus $C(Bi^{3+}+Eu^{3+})^{6/3}$, $C(Bi^{3+}+Eu^{3+})^{8/3}$ and $C(Bi^{3+}+Eu^{3+})^{10/3}$.

Energy transfer efficiencies (η_T) of as-prepared samples increases with the increase of Eu^{3+} content, with maximum values of 16% for the representative BYF: 10Eu, 20Bi sample.

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Properties of $RbY_3F_{10}:Eu^{3+}$

Structure and morphology of Eu^{3+}-doped RbY_3F_{10} nanoparticles – WP1, sub-activity 1.3

Figure 27 shows the X-ray pattern of prepared undoped RbY_3F_{10} presented with the International Centre for Diffraction Data (ICDD) Card No. 01-085-9553.

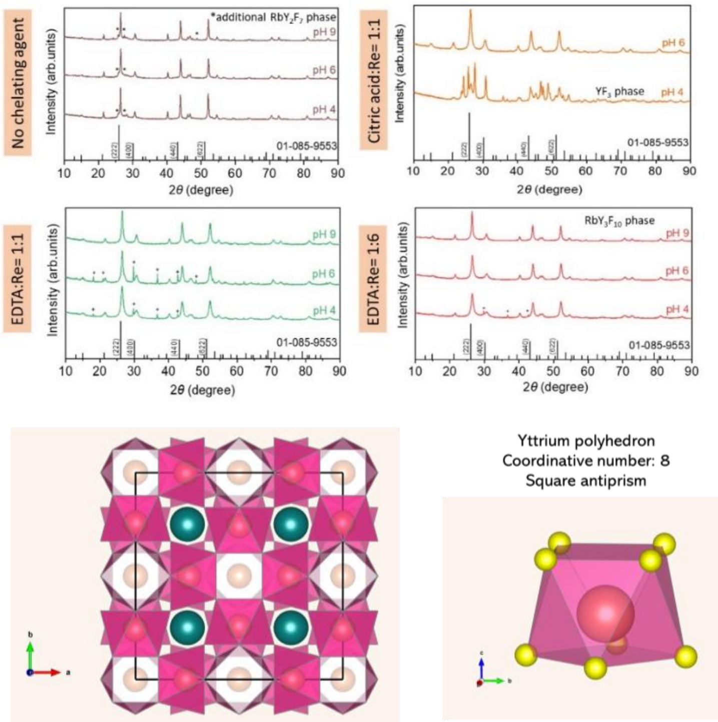

Figure 27. PXRD patterns of RbY_3F_{10} nanophosphors prepared via different chelating agents and the three-dimensional schematic view of the crystal structure.

Figure 28 shows SEM images of RbY_3F_{10} phosphor nanoparticles synthesized using different chelating agents. Nanoparticles are spherical, as well as having a high degree of crystallinity. The average crystalline size of RbY_3F_{10} nanoparticles was estimated to be in the range between 50 and 90 nm.

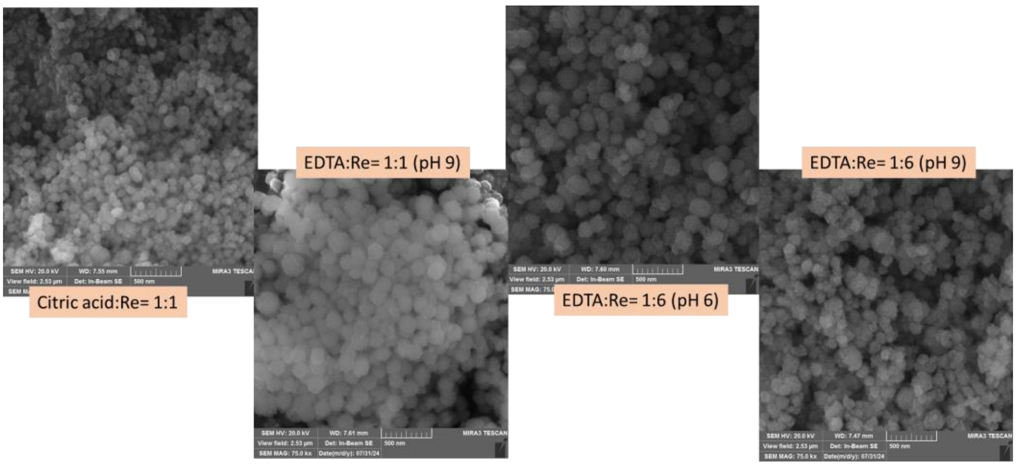

Figure 28. SEM images of the synthesized RbY_3F_{10} phosphor nanoparticle.

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Photoluminescence of Eu^{3+}-doped RbY_3F_{10} nanoparticles – WP1, sub-activity 1.3

Figure 29(left) shows the X-ray pattern of prepared undoped RbY_3F_{10}:xEu^{3+} (*x* = 0, 1, 5, 10, 30, 50, and 75 mol*%)* presented with the International Centre for Diffraction Data (ICDD) Card No. 01-085-9553. The XRD of the sample doped with 75 mol% of Eu^{3+} displays a few additional peaks. This observation indicates that the high amount of Eu^{3+} leads to the crystallization of an additional compound to pure-phase RbY_3F_{10}. Therefore, Eu^{3+} co-doping of RbY_3F_{10} is possible for Eu^{3+} concentrations equal to or less than 50 mol%. The photoluminescence emission spectra of all RbY_3F_{10}:xEu^{3+} (*x* = 1, 5, 10, 30, and 50 mol*%)* samples recorded at room temperature are displayed in Figure 29 (right, λ_{ex} = 405 nm).

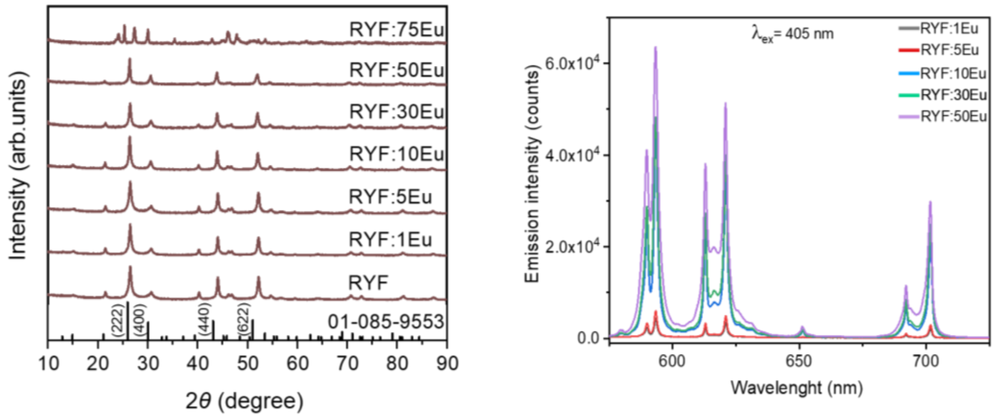

Figure 29. *PXRD patterns of RbY_3F_{10}:xEu^{3+} (x = 0, 1, 5, 10, 30, 50, and 75 mol%) nanophosphors (left) and room temperature emission spectra of RbY_3F_{10}:xEu^{3+} (x = 1, 5, 10, 30, and 50 mol%) recorded under λ_{ex} = 405 nm.*

Additionally, a large band gap of approximately 9 eV has been observed for the fluoride host RbY_3F_{10}:Eu^{3+}, as shown in Figure 30. This value aligns with literature data for other fluoride hosts, such as K_2SiF_6 and K_2TiF_6, which have band gaps around 8 eV.

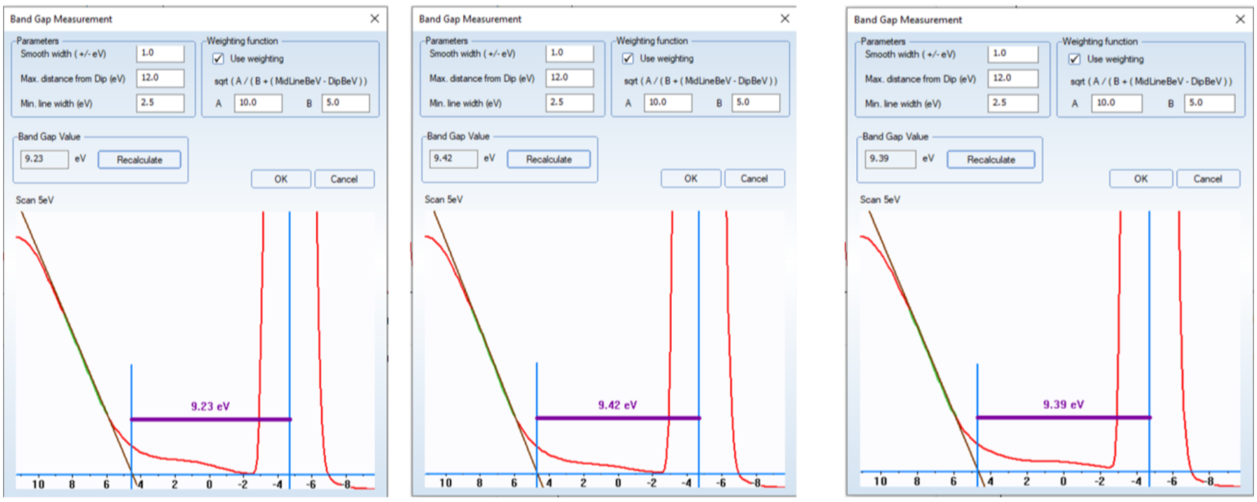

Figure 30. *Band gap calculation of RbY_3F_{10}:10mol%Eu^{3+}.*

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Properties of $LuF_3:Eu^{3+}$

Structure analysis of Eu^{3+}-doped LuF_3 – WP1, sub-activity 1.3

Figure 31 shows the X-ray pattern of LuF_3:*x*Eu (*x*= 5, 10, 15, and 20 mol%) presented with the International Centre for Diffraction Data (ICDD) Card No. 00-032-0612. The X-ray diffraction examination of the synthesized samples proved a single phase in agreement with the orthorhombic *Pmma* structure of LuF_3. Traces of contamination or other phase peaks were not observed in either set of samples, indicating that dopant Eu^{3+} ions were embedded into the LuF_3 lattice. Table 21 shows the results of the structural analysis: crystallite size (CS), microstrain values, unit cell parameters, unit cell volume (CV), and data fit parameters (R_{wp}, R_p, R_e, GOF) of LuF_3:xEu nanophosphors. The CS of LuF_3:xEu are in the range between 18,4 and 25,1 nm.

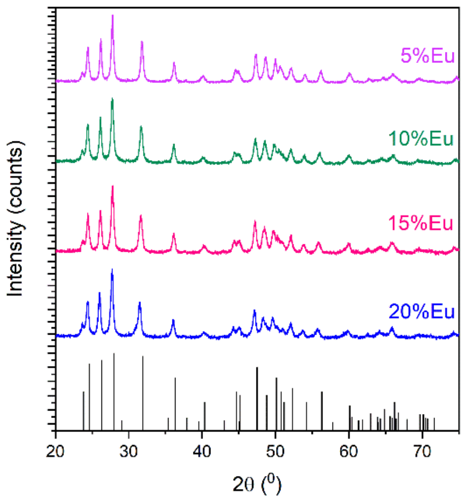

Figure 31. *XRD patterns of LuF_3:xEu (x= 5, 10, 15, and 20 mol%) samples presented with the ICDD card No. 00-032-0612.*

Table 21. *Results of the structural analysis of LuF_3: xEu nanophosphors, where x = 5, 10, 15, and 20 mol% Eu^{3+}*

ICDD 00-032-0612	LuF_3:5Eu	LuF_3:10Eu	LuF_3:15Eu	LuF_3:20Eu
CS (A)	193 (7)	208 (3)	184(17)	251(5)
Strain	0.13 (3)	0.33 (3)	0.213(5)	0.43(3)
GOF	2.1936	1.7154	1.8069	1.6841
Rwp	15.39%	14.08%	12.82%	11.65%
Rp	11.30%	10.72%	9.55%	8.78%
Re	7.02%	8.21%	7.09%	6.92%
a	6.1585(11)	6.1773(14)	6.2045(13)	6.2176(15)
b	6.7757(13)	6.7829 (15)	6.7997(14)	6.8061(17)
c	4.4836(9)	4.4733(11)	4.4734(10)	4.4589(12)

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Photoluminescence spectra of Eu^{3+}-doped LuF_3 – WP1, sub-activity 1.3

The room temperature photoluminescence spectra, recorded in the wavelength range 500 – 750 nm, are displayed in Figure 32 (λ_{ex} = 393 nm). Figure 32 shows that europium's photoluminescent intensity increases until the Eu^{3+} content reaches 10 mol%, while the further addition of Eu^{3+} decreases the emission intensity.

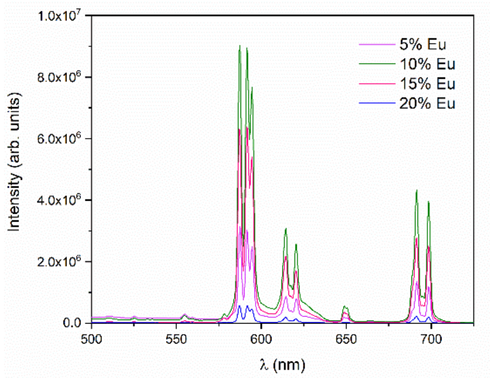

Figure 32. The room temperature photoluminescence spectra of LuF_3:xEu (x= 5, 10, 15, and 20 mol%) samples.

7. Summary of Deliverable D2.1 – Report on fabricated plant-grow-targeted LEDs based on near-UV and blue-semiconductor chip (WP2, month 18)

The presented document constitutes Deliverable D2.1 – *Report on fabricated plant-grow-targeted LEDs based on near-UV and blue semiconductor chips*, of the LEDtech-GROW project. It is a public document, delivered in the context of **WP2** - *Design, fabrication, and LEDs performance,* ***Subactivity 2.1*** *- A novel strategy for fabrication of plant-grow-targeted LEDs based on a near-UV chip [month: 12-24] and* ***Subactivity 2.2*** *- Common strategy for fabrication of double-wavelength emitting pc-LEDs based on a blue chip [month: 12-24]*. This document presents a description of the design and fabrication process for LEDs used in plant growth applications, intended for sharing and distributing information related to the LEDtech-GROW project.

The list of selected phosphors for LED fabrication

A novel LED fabrication strategy for plant growth applications combines near-UV or UV semiconductor chips and representative triple-wavelength emitting single-component phosphors based on Bi^{3+} and Eu^{3+} activators and their efficient energy transfer (ET). This strategy offers broadband blue emission that may sensitize the various cryptochrome and phototropin photoreceptors (pterin (380), flavin (447 nm), Phototropin, and Zeitlupes, LOV (390, 457, and 480 nm). The list of two selected phosphors coated on the 278 nm LED chip is as follows:

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- SrF_2: Bi^{3+}, Eu^{3+}
- $BaYF_5$: Bi^{3+}, Eu^{3+}

The list of six selected phosphors coated on the 395 nm LED chip includes a representative red and far-red double-wavelength emitting Eu^{3+}-activated single-component phosphor is as follows:

- SrF_2: Bi^{3+}, Eu^{3+}
- $BaYF_5$: Bi^{3+}, Eu^{3+}
- Sr_2GdF_7: Eu^{3+}
- Sr_2GdF_7: Bi^{3+}, Eu^{3+}
- Sr_2LaF_7: Eu^{3+}
- RbY_3F_{10}:Eu^{3+}

LED fabrication *via* triple-wavelength emitting single-component SrF_2:Bi^{3+}, Eu^{3+} phosphors

The SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on the (*i*) 278 nm and (*ii*) 395 nm LED chips (LED accessories purchased on the market). The mixed resin, which contains *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.

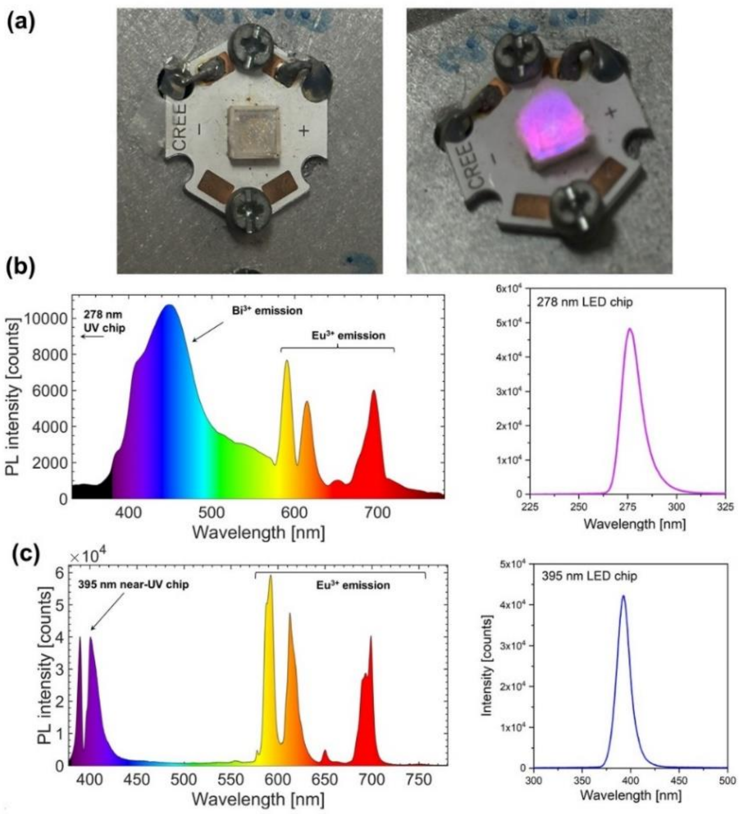

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Figure 33. *(a) Photograph of the fabricated LED device emitting pinkish-violet light, using a 278 nm LED chip combined with* SrF_2*:10%*Eu^{3+}*,20%*Bi^{3+} *phosphor; (b) PL spectrum of the LED based on 278 nm chip, with the emission of the bare 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.*

LED fabrication *via* triple-wavelength emitting single-component $BaYF_5$: Bi^{3+}, Eu^{3+} phosphors

The $BaYF_5$:10%Eu^{3+},20%Bi^{3+} phosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on the (*i*) 278 nm and (*ii*) 395 nm LED chips. The mixed resin was deposited on top of an LED chip using the Doctor blade (tape casting) technique and then dried for 48 hours.

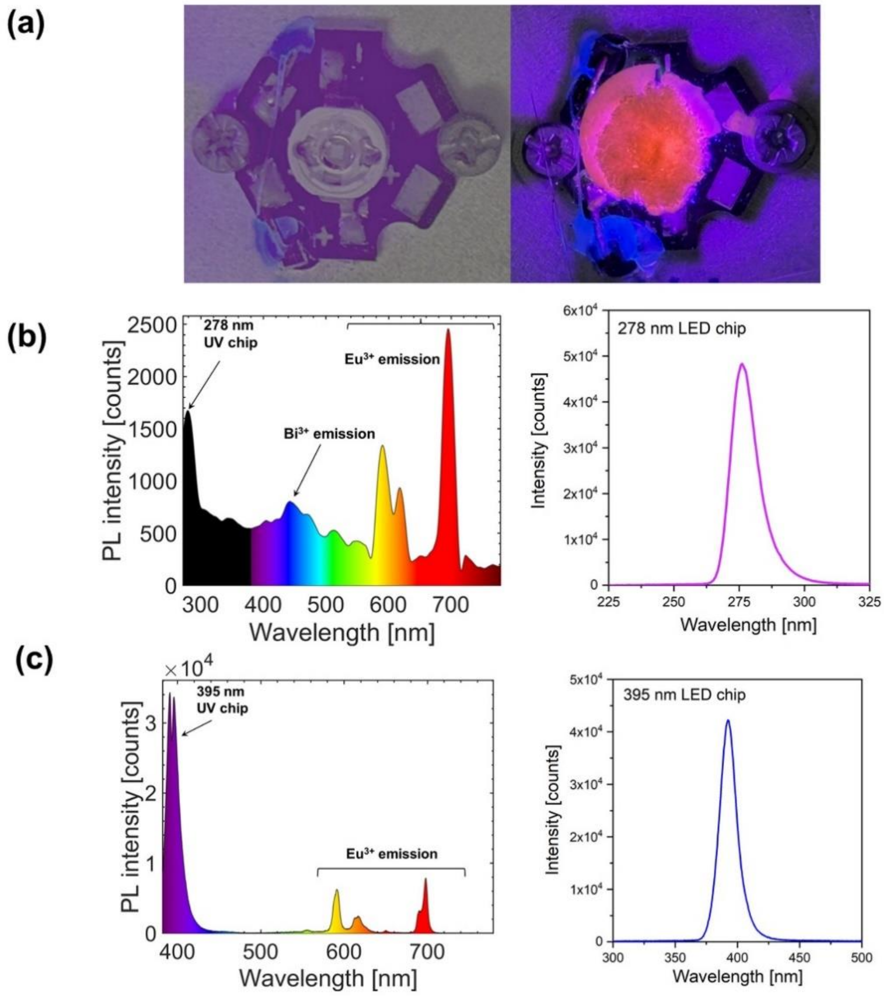

Figure 34. *(a) Fabricated LED device displaying violet light (LED based on 395 nm LED chip and* $BaYF_5$*:10%*Eu^{3+}*,20%*Bi^{3+} *phosphor); (b) PL spectrum of the LED based on 278 nm chip, with the emission of the bare chip (without phosphor) shown on the right for comparison; (c) PL spectrum of the LED based on 395 nm chip, with the corresponding emission from the bare chip (without phosphor) shown on the right.*

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LED fabrication *via* double-wavelength emitting single-component Sr_2GdF_7: Bi^{3+}, Eu^{3+} phosphors

The $Sr_2Gd_{0.19}Eu_{0.8}Bi_{0.01}F_7$ phosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on the near-UV LED chip. The mixed resin was deposited on top of a 395 nm LED chip using the Doctor blade (tape casting) technique, then dried for 48 hours. Photographs of the fabricated LED device, presented in Figure 35a, display a strong red light when the power supply is on. The PL spectrum of the fabricated LED, composed of a 395 nm chip and $Sr_2Gd_{0.19}Eu_{0.8}Bi_{0.01}F_7$ phosphor, reveals strong emissions in the near-UV, orange/red, and far-red regions (see Figure 35b). Figure 35b (right) presents the emission of the 278 nm LED chip before the red phosphor was applied. A noticeable dip at 391 nm confirms the strong absorption of UV light by Eu^{3+} ions. Due to its strong emissions in the near-UV, orange/red, and far-red regions, this LED shows significant potential for indoor horticultural applications. As a result, the next phase of our work will focus on evaluating its performance in this context.

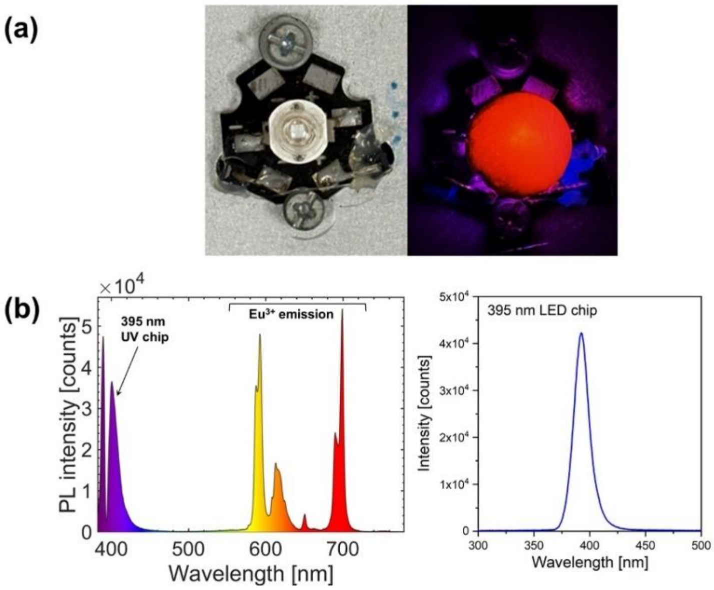

Figure 35. *(a) A fabricated 395nm-chip-based LED device comprising a semiconductor chip and* $Sr_2Gd_{0.19}Eu_{0.8}Bi_{0.01}F_7$ *nanopowders displays a red light when the electrical power supply is on; and (b) PL spectrum of the LED based on 395 nm chip, with the corresponding emission from the bare chip (without phosphor) shown on the right.*

LED fabrication *via* double-wavelength emitting single-component Sr_2GdF_7: Eu^{3+} phosphors

The Sr_2GdF_7:80%Eu^{3+} nanophosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on a 365 nm LED chip. The mixed resin 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 36a, display a 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, reveals strong emissions in the red and far-red regions with noticeably weaker near-UV LED component (see Figure 36b).

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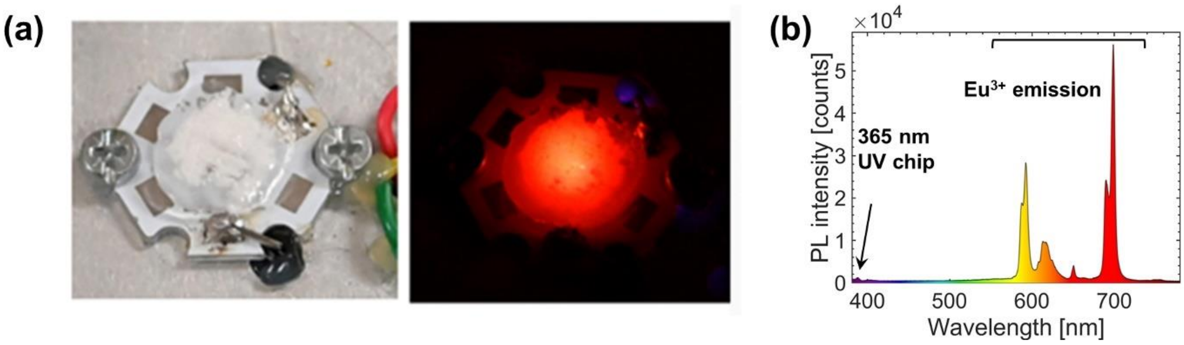

Figure 36. (a) A fabricated LED device comprising a 365 nm semiconductor chip and SGF_80Eu nanopowders displays a red light when the electrical power supply is on; and (b) PL spectrum of the fabricated 365nm-chip-based LED.

LED fabrication *via* double-wavelength emitting single-component Sr_2LaF_7: Eu^{3+} phosphors

The Sr_2LaF_7:50Eu^{3+} nanophosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on the 395 nm LED chip. The mixed resin, which contains *Ceramabind* and SLF:50Eu phosphor, was deposited on top of the LED chip using the Doctor blade (tape casting) technique, then dried for 48 hours.

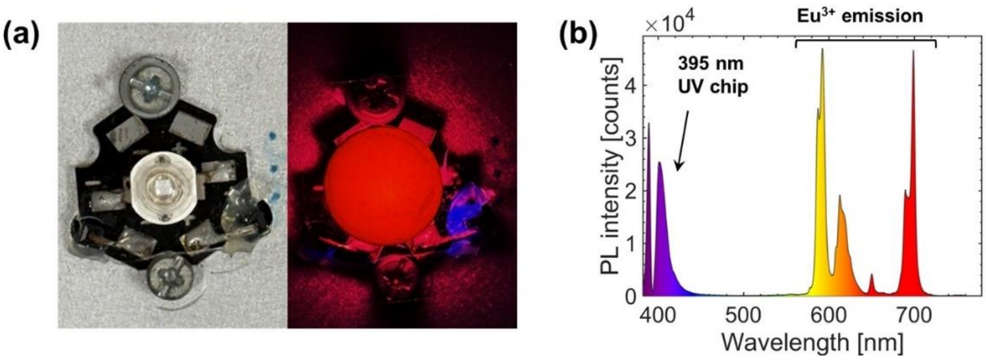

Figure 37. *A fabricated LED device comprising a semiconductor chip and Sr_2LaF_7:50mol%Eu^{3+} nanopowders displays a red light when the electrical power supply is on; PL spectrum of the fabricated 395nm-chip-based LED.*

LED fabrication via double-wavelength emitting single-component RbY_3F_{10}: Eu^{3+} phosphors

The RbY_3F_{10}:50Eu^{3+} nanophosphor was separately mixed with high-temperature inorganic binder - *Aremco-CeramabindTM 643-2* before being deposited on the 395 nm LED chip. The mixed resin, which contains *Ceramabind* and RbY_3F_{10}:50Eu^{3+} phosphor, was deposited on top of the LED chip using the Doctor blade (tape casting) technique, then dried for 48 hours.

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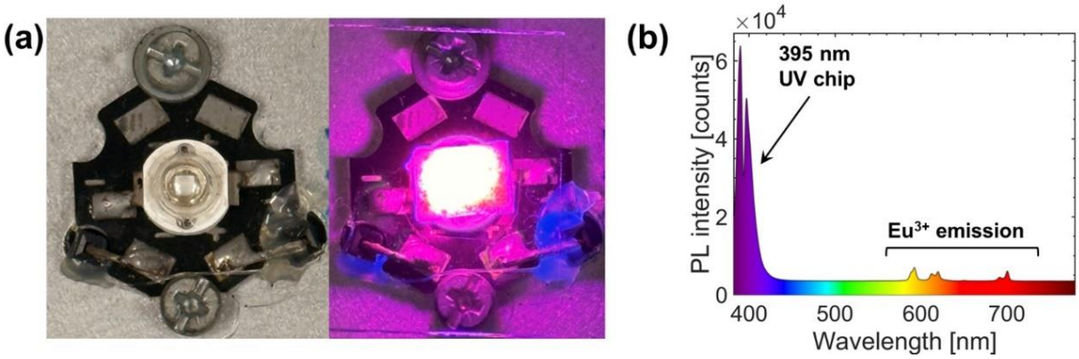

Figure 38. A fabricated LED device comprising a semiconductor chip and RbY_3F_{10}:50mol%Eu^{3+} nanopowders displays a violet/pinkish light when the electrical power supply is on; and (b) PL spectrum of the fabricated 395nm-chip-based LED.

8. Summary of Deliverable D2.2 – Report on the LEDs performance (WP2, month 23)

Four selected Eu^{3+}-based phosphors, used as layers on the LED chips, are as follows:

- SrF_2: Bi^{3+}, Eu^{3+}
- Sr_2GdF_7: Eu^{3+}
- Sr_2LaF_7: Eu^{3+}
- RbY_3F_{10}:Eu^{3+}

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 39a, 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 39b). Figure 39b (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. Figure 39c 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 39c (right) shows the emission of the 395 nm LED chip before the red phosphor was

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applied. A noticeable dip at 391 nm confirms UV absorption by Eu^{3+} ions.

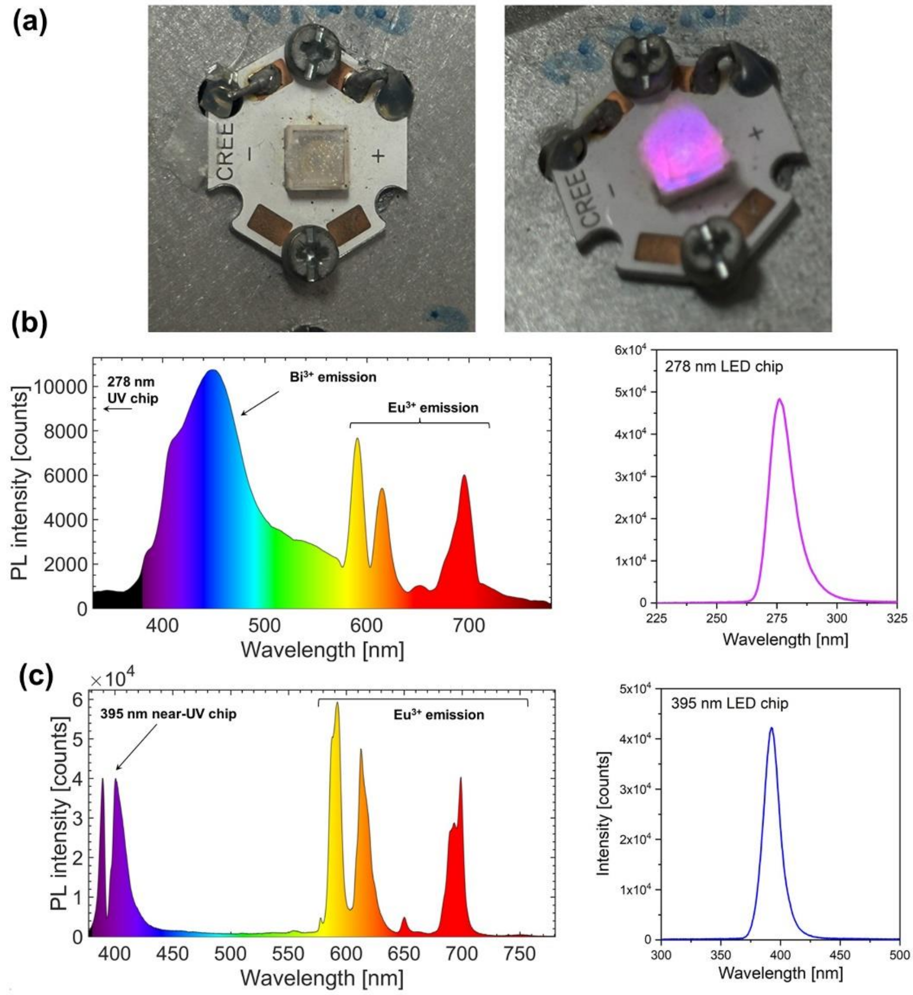

__Figure 39__. (a) Photograph of the fabricated LED device emitting pinkish-violet light, using a 278 nm LED chip combined with SrF_2:10%Eu^{3+},20%Bi^{3+} phosphor; (b) PL spectrum of the LED based on 278 nm chip, with the emission of the bare chip (without phosphor) shown on the right for comparison; (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 UV illumination are shown in Figure 40. 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

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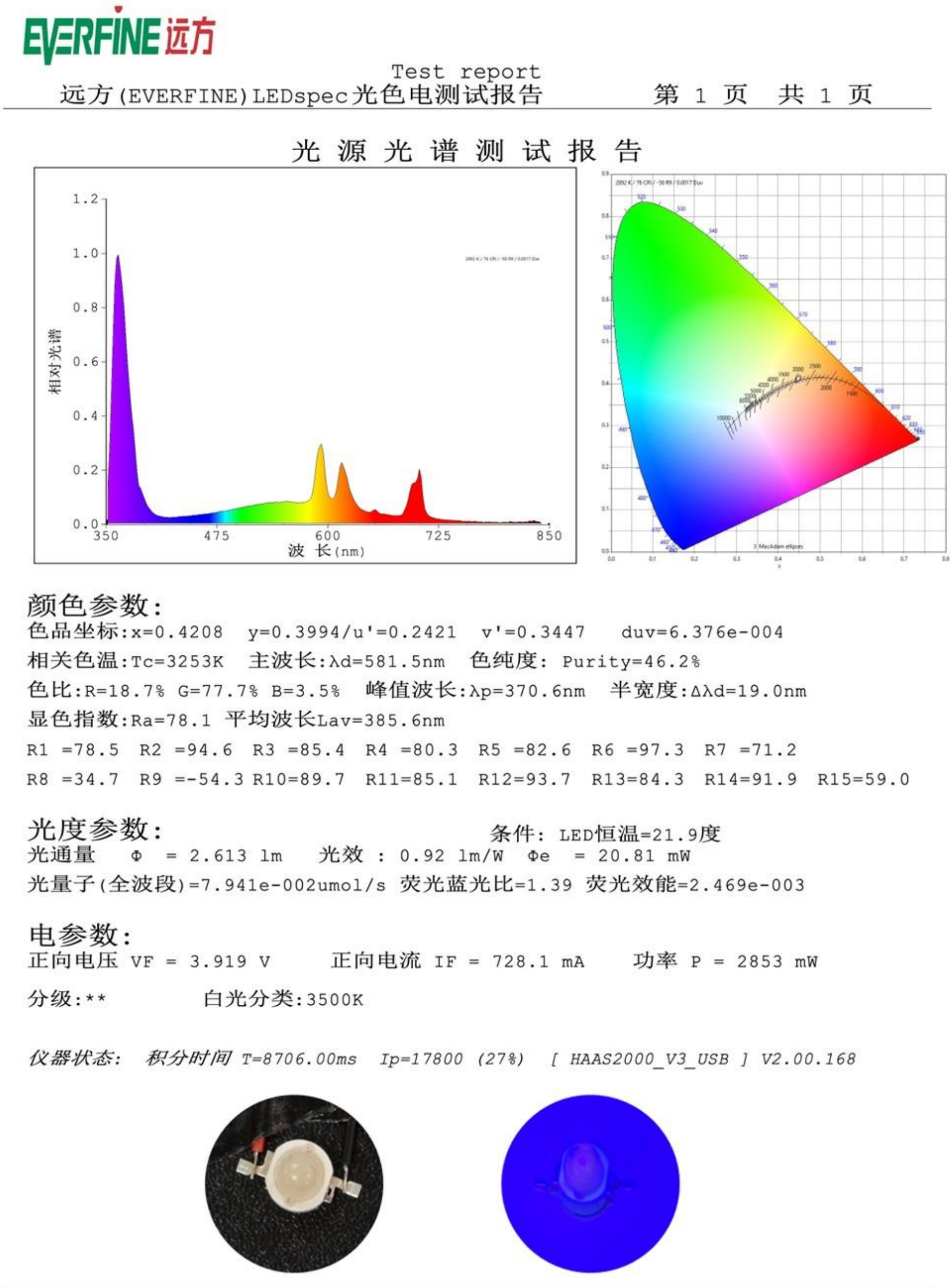
with orange/red and far-red emissions (Figure 40). The absence of blue emission indicates that this LED configuration does not meet the spectral requirements for indoor plant cultivation. Consequently, an alternative LED design was developed by combining the same phosphor with a 395 nm UV chip, as shown in Figure 40.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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=0.4208 y=0.3994/u'=0.2421 v'=0.3447 duv=6.376e-004
相关色温:Tc=3253K 主波长:λd=581.5nm 色纯度: Purity=46.2%
色比:R=18.7% G=77.7% B=3.5% 峰值波长:λp=370.6nm 半宽度:Δλd=19.0nm
显色指数:Ra=78.1 平均波长Lav=385.6nm
R1 =78.5 R2 =94.6 R3 =85.4 R4 =80.3 R5 =82.6 R6 =97.3 R7 =71.2
R8 =34.7 R9 =-54.3 R10=89.7 R11=85.1 R12=93.7 R13=84.3 R14=91.9 R15=59.0

光度参数: 条件: LED恒温=21.9度
光通量 Φ = 2.613 lm 光效 : 0.92 lm/W Φe = 20.81 mW
光量子(全波段)=7.941e-002umol/s 荧光蓝光比=1.39 荧光效能=2.469e-003

电参数:
正向电压 VF = 3.919 V 正向电流 IF = 728.1 mA 功率 P = 2853 mW
分级:** 白光分类:3500K

仪器状态: 积分时间 T=8706.00ms Ip=17800 (27%) [HAAS2000_V3_USB] V2.00.168

__Figure 40__. 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.

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

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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.

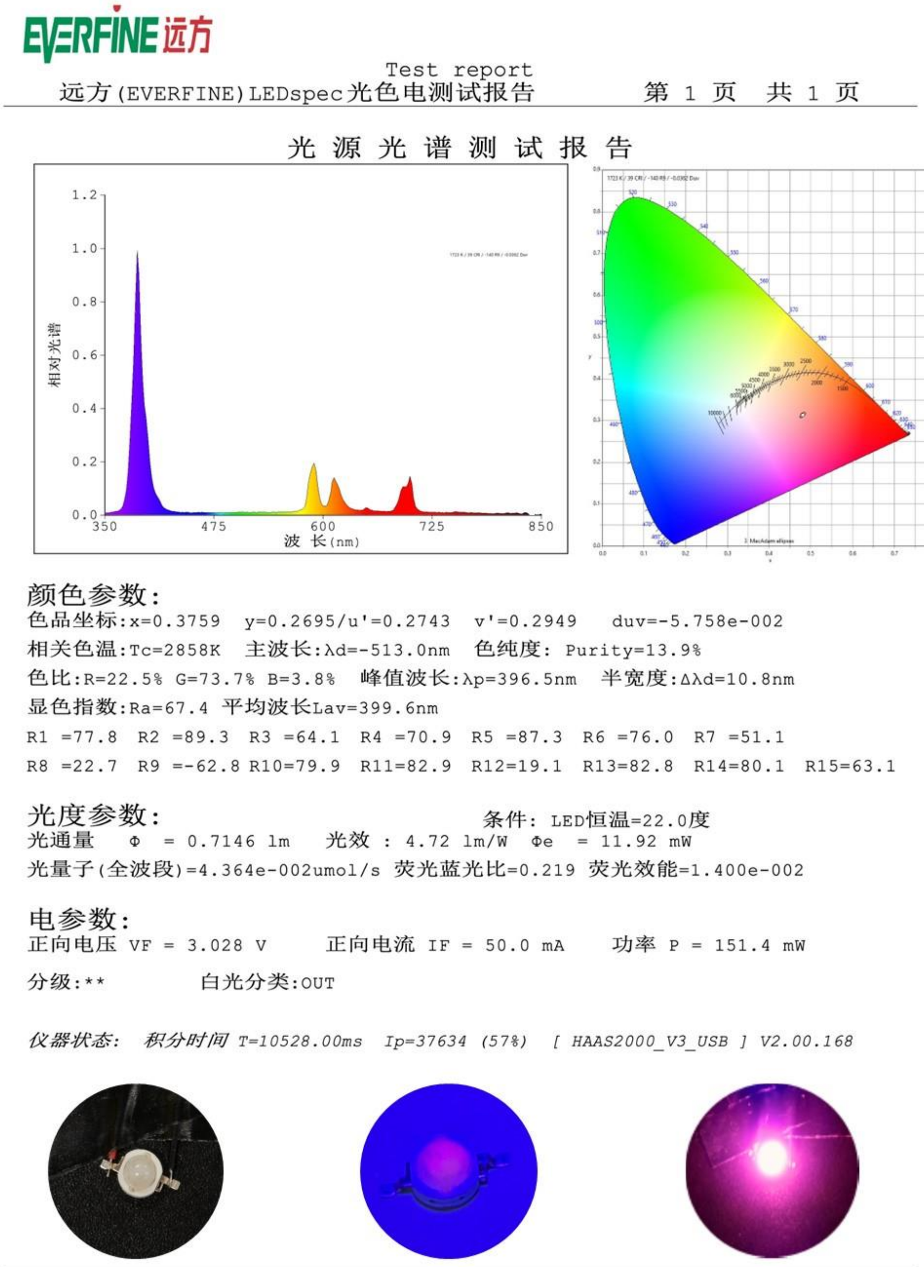

__Figure 41__. PL spectrum of the LED fabricated using a 395 nm chip and SrF_2:10%Eu^{3+}, 20%Bi^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.

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

LED fabrication - methodology 1

The Sr_2GdF_7:80%Eu^{3+} 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 42a, 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 42b).

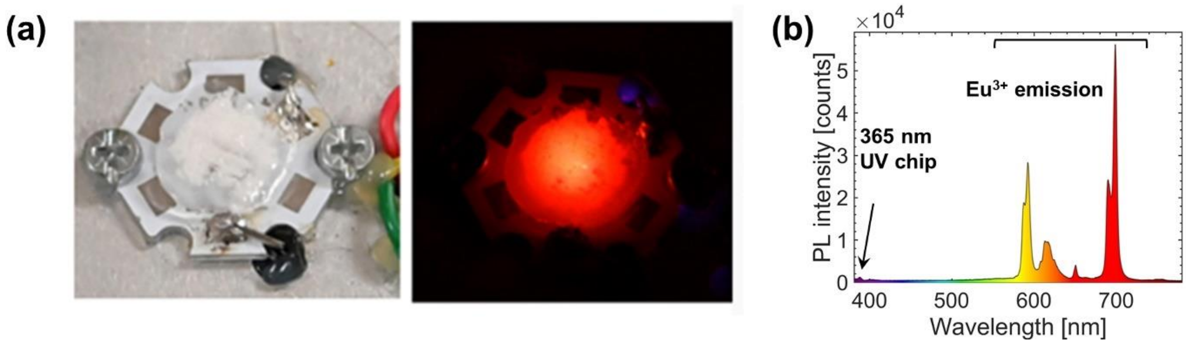

***Figure 42**. (a) A fabricated LED device comprising a 365 nm semiconductor chip and SGF_80Eu nanopowders displays a red light when the electrical power supply is on; and (b) PL spectrum of the fabricated 365nm-chip-based LED.*

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 43. 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 43). 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 44 and 45.

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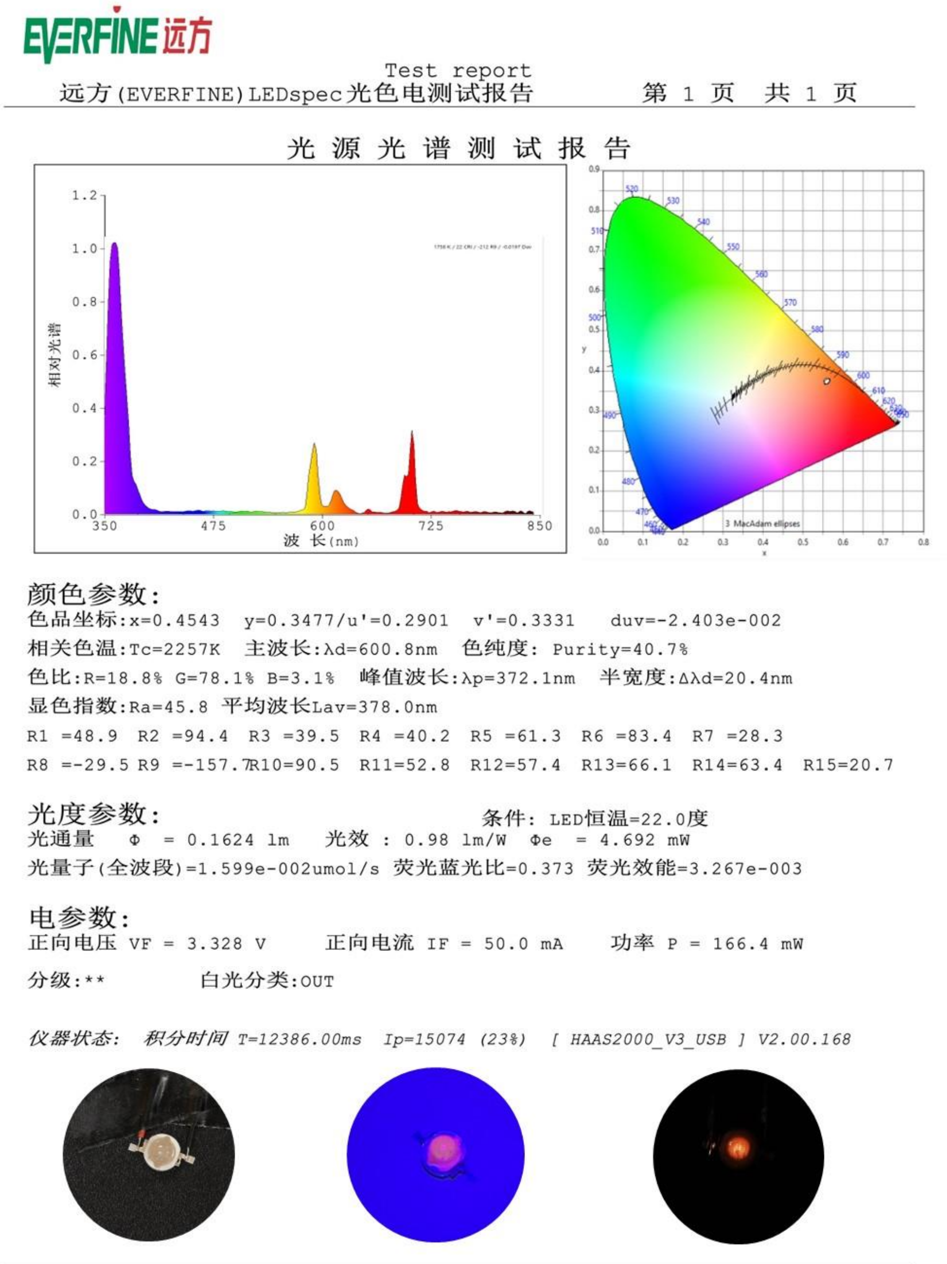

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Test report

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=0.4543 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 43**. 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 44), 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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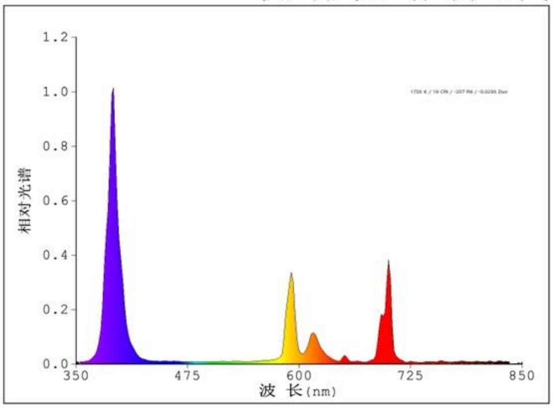
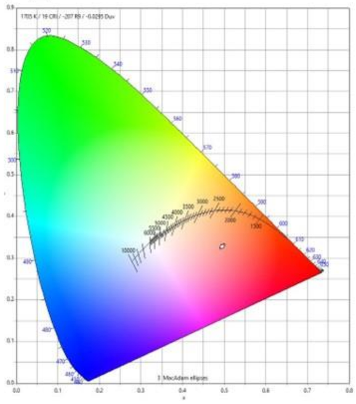
Test report
远方(EVERFINE)LEDspec光色电测试报告 第 1 页 共 1 页

光 源 光 谱 测 试 报 告





颜色参数:
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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 44**. 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 45), 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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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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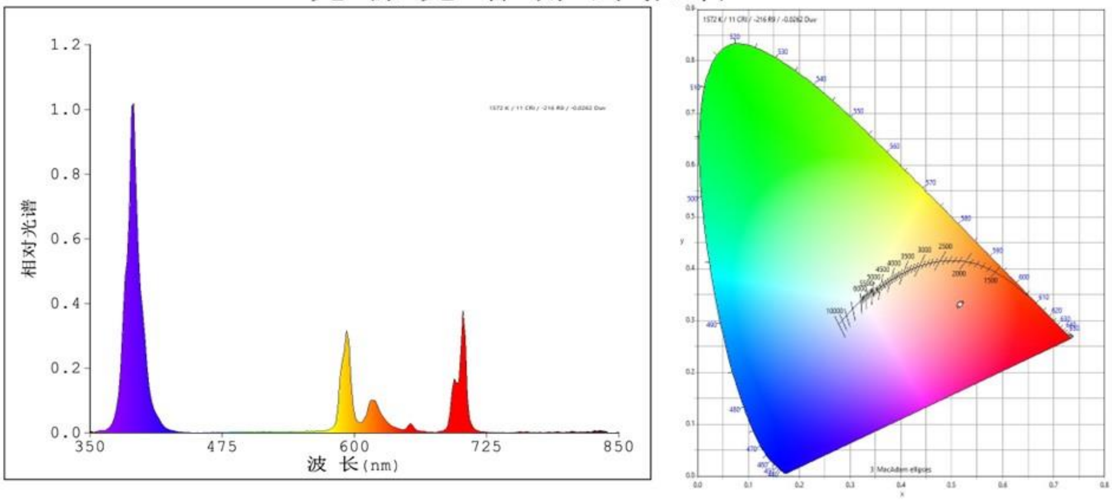

颜色参数:

色品坐标:x=0.4100　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 =-193.0 R10=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 45**. 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.*

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 46a, 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 46b (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.

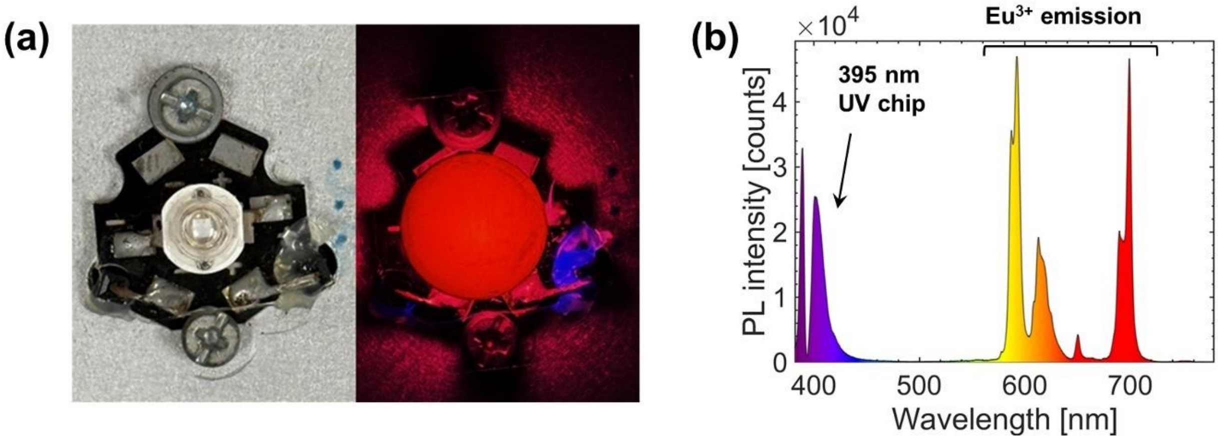

Figure 46. *A fabricated LED device comprising a semiconductor chip and Sr_2LaF_7:50mol%Eu^{3+} nanopowders displays a red light when the electrical power supply is on; PL spectrum of the fabricated 395nm-chip-based LED.*

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 47). 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 47. 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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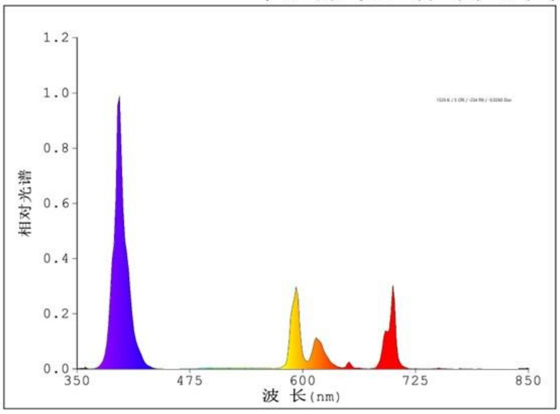

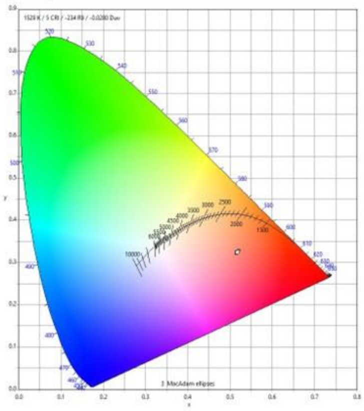

颜色参数:
色品坐标:x=0.3993 y=0.2448/u'=0.3108 v'=0.2858 duv=-7.348e-002
相关色温:Tc=2011K 主波长:λd=-510.6nm 色纯度: Purity=20.8%
色比:R=22.3% G=75.2% B=2.5% 峰值波长:λp=397.3nm 半宽度:Δλd=9.1nm
显色指数:Ra=29.3 平均波长Lav=400.6nm
R1 =27.1 R2 =90.3 R3 =24.0 R4 =1.7 R5 =36.8 R6 =90.9 R7 =11.7
R8 =-47.6 R9 =-180.6R10=92.6 R11=5.3 R12=55.6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

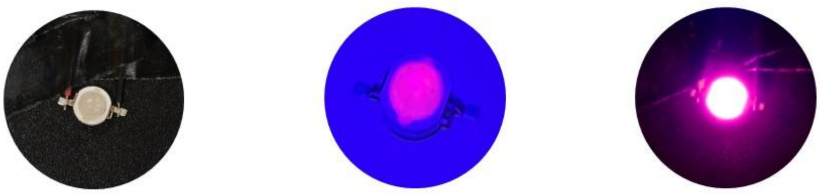

Figure 47. *PL spectrum of the LED fabricated using a 395 nm chip and Sr_2LaF_7:50mol%Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

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

LED fabrication - methodology 1

The RbY_3F_{10}:50Eu^{3+} nanophosphor was mixed separately with a high-temperature inorganic

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binder, Aremco-CeramabindTM 643-2, before being deposited onto the 395 nm LED chip. The 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 48a, 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 48b). 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.

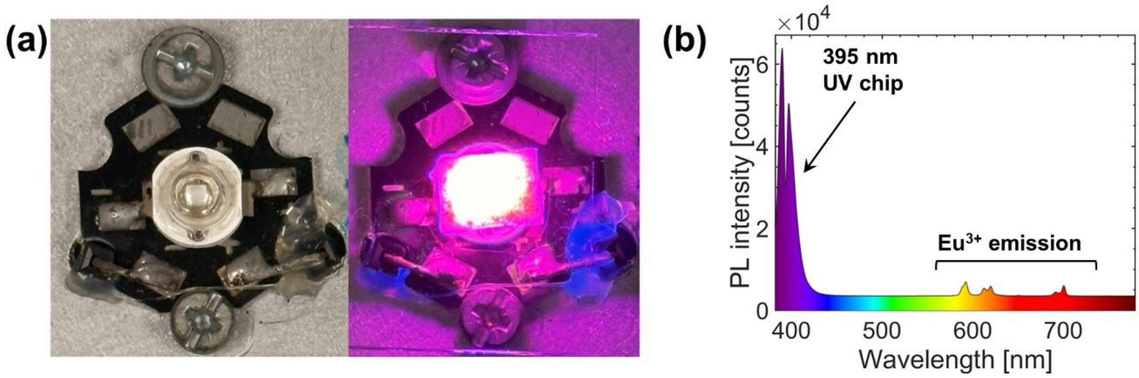

Figure 48. *A fabricated LED device comprising a semiconductor chip and RbY_3F_{10}:50mol%Eu^{3+} nanopowders displays a violet/pinkish light when the electrical power supply is on; and (b) PL spectrum of the fabricated 395nm-chip-based LED.*

LED fabrication - methodology 2

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 49). 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 49. 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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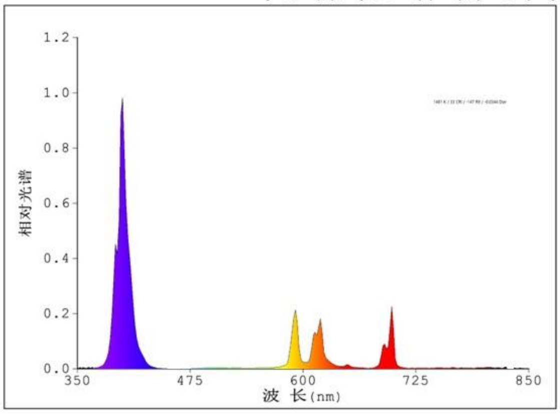

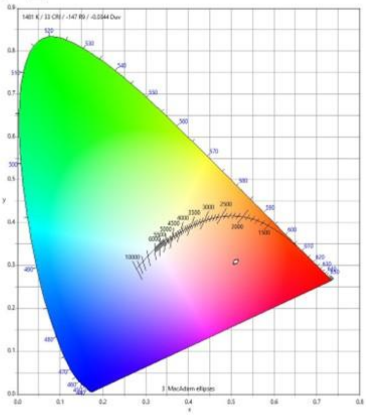

颜色参数:
色品坐标:x=0.3895 y=0.2188/u'=0.3215 v'=0.2709 duv=-8.915e-002
相关色温:Tc=1867K 主波长:λd=-521.7nm 色纯度: Purity=22.9%
色比:R=32.7% G=64.5% B=2.8% 峰值波长:λp=396.6nm 半宽度:Δλd=8.3nm
显色指数:Ra=38.3 平均波长Lav=399.6nm
R1 =50.1 R2 =90.4 R3 =21.5 R4 =22.2 R5 =61.3 R6 =68.8 R7 =15.1
R8 =-23.4 R9 =-120.0R10=70.4 R11=34.3 R12=31.7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

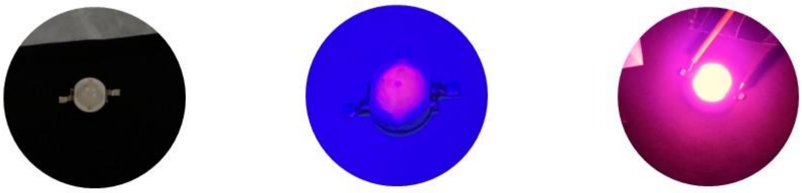

Figure 49. *PL spectrum of the LED fabricated using a 395 nm chip and RbY_3F_{10}:50mol%Eu^{3+} phosphor (driving current: 50 mA); corresponding CIE chromaticity diagram of the LED emission; key performance characteristics of the LED; and photographs of the fabricated device.*

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9. Summary of Deliverable D3.1 – Report on the professional development of young and early-stage researchers (WP3, month 24)

Deliverable D3.1 – *Report on the professional development of young and early-stage researchers,* of the LEDtech-GROW project is a public document, delivered in the context of **WP3** - *Professional development of young and early-stage researchers,* ***Subactivity 3.1*** - *Research Management Capacity Enhancement [month: 6-20],* ***Subactivity 3.2*** - *Innovation and IPR Management [month: 6-20], and* ***Subactivity 3.3*** - *Research Capacity Building and Knowledge Transfer [month: 6-24]*. This document outlines the activities implemented to enhance proposal writing and project management skills, raise awareness of intellectual property and patent protection, ensure compliance with open science principles, and advance specialized scientific knowledge. Detailed information on these activities is available on the project website at https://ledtechgrow-promis.org/Deliverables/. Overall, WP3 plays a crucial role in ensuring the long-term sustainability, impact, and visibility of the LEDtech-GROW project.

The LEDtech-GROW project recognizes that the success of research initiatives depends not only on scientific excellence but also on the continuous professional development of researchers. In this context, Work Package 3 (WP3) is dedicated to strengthening the skills and competencies of young and early-stage researchers, enabling them to operate effectively within the national and international research community.

WP3 – Capacity Building, Professional Development, and Research Support

During the project, LEDtech-GROW team members participated in a total of **2 workshops, 4 specialized trainings, 8 webinars, and 2 Horizon Europe Info Days**, covering key areas relevant to the successful execution of research and innovation activities (See Annex VII). These activities were selected to address concrete project needs, including proposal preparation, project budgeting and management, intellectual property protection, open science compliance, and advanced experimental methodologies.

Proposal Development, Funding Strategies, and Project Management

An important early activity within WP3 was the workshop *“How to Make the Best Use of Unfunded Project Proposals?”*, held on February 6, 2024, and attended by all project team members. The workshop focused on systematic analysis of evaluator feedback, identification of proposal weaknesses, strategic restructuring, and adaptation to alternative funding schemes. As a direct outcome, the team applied the acquired methodology to improve proposal quality, contributing to the submission of **four competitive project proposals** during the project lifetime.

To further strengthen capacity in European funding schemes, **two team members** completed the **European Training Academy (EUTA)** program on Horizon Europe proposal preparation and project management (February–March 2024). The training consisted of four intensive sessions

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addressing call analysis, consortium building, excellence–impact–implementation structure, ethical aspects, budgeting rules, cost eligibility, reporting obligations, and risk management. Knowledge gained through EUTA directly supported the preparation and submission of an **EUREKA network project proposal** and improved internal coordination in ongoing project planning.

International Collaboration and Short-Term Research Visit

WP3 included a **short-term research visit to the Institute of Resources Utilization and Rare Earth Development, Guangdong Academy of Sciences (Guangzhou, P.R. China)**, attended by two LEDtech-GROW team members. The visit enabled direct exchange of methodologies, discussion of phosphor synthesis and LED fabrication strategies, and joint evaluation of experimental results.

A key outcome of this visit was the **testing and validation of developed LED systems using state-of-the-art equipment**, allowing comparative analysis of optical and performance data obtained in Serbia and China. This significantly improved data reliability and contributed to the refinement of ongoing experiments. The collaboration also resulted in the preparation of a **bilateral Serbia–China project proposal**, strengthening long-term international research cooperation.

Intellectual Property and Innovation-Oriented Training

To support innovation and the protection of research outputs, all team members attended a series of **five online webinars** dedicated to intellectual property rights and patent protection (Annex VII). Topics included trade secret protection, fundamentals of patent systems, international patent strategies, software-related IP, and preparation of patent applications. These trainings increased awareness of innovation pathways and supported the identification of research results with potential for further protection and exploitation within the LEDtech-GROW framework.

Horizon Europe Policy Alignment and Info Days

LEDtech-GROW researchers actively participated in **Horizon Europe Info Days**, including the **WIDERA Work Programme 2025** and **Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture and Environment**. Participation in these events improved understanding of EU research priorities, open access policies, research assessment reforms, and science-for-policy mechanisms. As a result, new project ideas aligned with European calls were developed, leading to **one submitted proposal and one additional proposal in preparation**.

Advanced Scientific Training and Analytical Skills

To enhance experimental quality and data interpretation, all team members attended **ICDD webinars** focused on **powder X-ray diffraction (PXRD)** and **Raman spectroscopy**. These trainings strengthened skills in experimental design, phase identification, and spectral analysis, directly supporting WP1 and WP2 research activities. In addition, an **Excel training** on data processing, visualization, and basic statistical analysis improved consistency and clarity in reporting experimental results.

Open Science, Data Management, and Dissemination

All team members completed the workshop *“Open Science and Obligations for Participants in the Science Fund of the Republic of Serbia Program”* (May 13, 2025), covering open-access publishing, research data management, and institutional repositories. As a result, project outputs were

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systematically deposited in **Zenodo** and **VinaR**, ensuring compliance with national and international open science requirements and increasing visibility and reproducibility of results. For more information see https://doi.org/10.5281/zenodo.14935996, https://doi.org/10.5281/zenodo.14936085, https://doi.org/10.5281/zenodo.14937727, https://doi.org/10.5281/zenodo.15782065, https://doi.org/10.5281/zenodo.18086075, https://vinar.vin.bg.ac.rs/handle/123456789/14106, https://vinar.vin.bg.ac.rs/handle/123456789/14936, https://vinar.vin.bg.ac.rs/handle/123456789/15745, https://vinar.vin.bg.ac.rs/handle/123456789/13836, https://vinar.vin.bg.ac.rs/handle/123456789/13948?locale-attribute=sr_RS.

Dissemination activities included participation in national and international conferences, science fairs, and outreach events, including the **European Researchers' Night** and the **International Fair of Technics**. Scientific dissemination resulted in **five open-access journal publications** (with two additional manuscripts submitted), **six poster presentations at international conferences**, **one oral presentation at an international conference**, and **one invited talk at a domestic conference** (Annex VII). In addition, project results were communicated to a broader audience through **two popular science and business articles** published in *MOVEM* and *Biznis* magazines (Annex IV).

WP3 delivered measurable outcomes in terms of researcher training, international collaboration, dissemination, and future funding readiness. The activities directly supported scientific excellence, improved experimental quality, strengthened international partnerships, and contributed to the preparation of multiple competitive project proposals, ensuring continuity of research and impact beyond the duration of the LEDtech-GROW project.

10. Conclusions

LEDtech-GROW team members reached **Milestone M1.1 - A list of Eu^{3+} and Bi^{3+}/Eu^{3+}-activated phosphors defined** (verification: Single-phase crystal structure and appropriate phosphors' emission that matches the PAR spectrum). The list is as follows:

1. Eu^{3+}-doped Sr_2GdF_7 colloidal and powder nanoparticles

2. Eu^{3+}-doped RbY_3F_{10} powder nanoparticles

3. Bi^{3+}, Eu^{3+}-doped SrF_2 nanopowders

LEDtech-GROW team members reached **Milestone M1.2 - High-performance phosphors selected** (verification: Superior moisture resistance, QE > 50%, FWHM < 50 nm, and low thermal quenching of luminescence up to 150 °C). The list is as follows:

1. Sr_2GdF_7:80 mol% Eu^{3+} nanoparticles (QE=60.4%, Thermal stability= 83%)

2. SrF_2:10mol%Eu^{3+}, 20mol%Bi^{3+} nanoparticles (highest red/blue emission portion 40.8 : 59.2).

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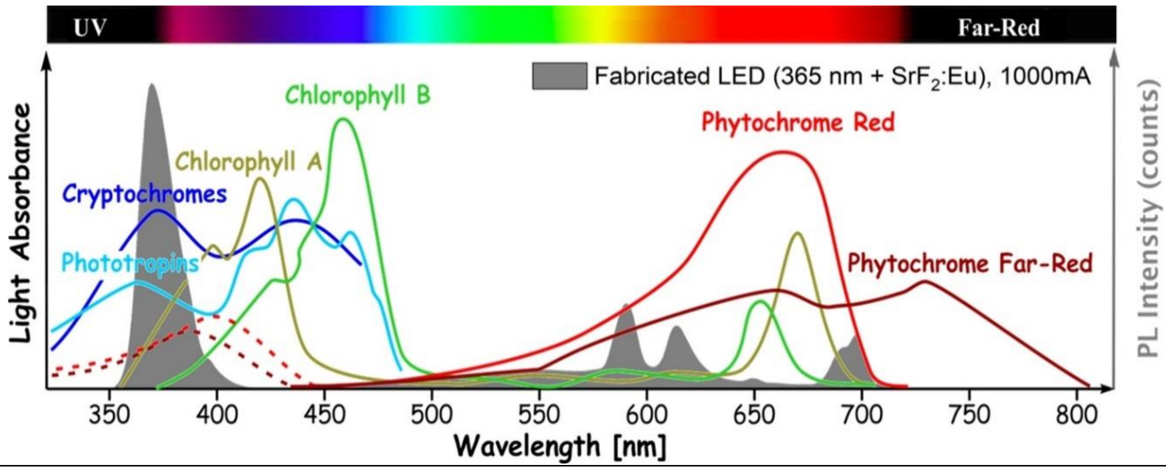
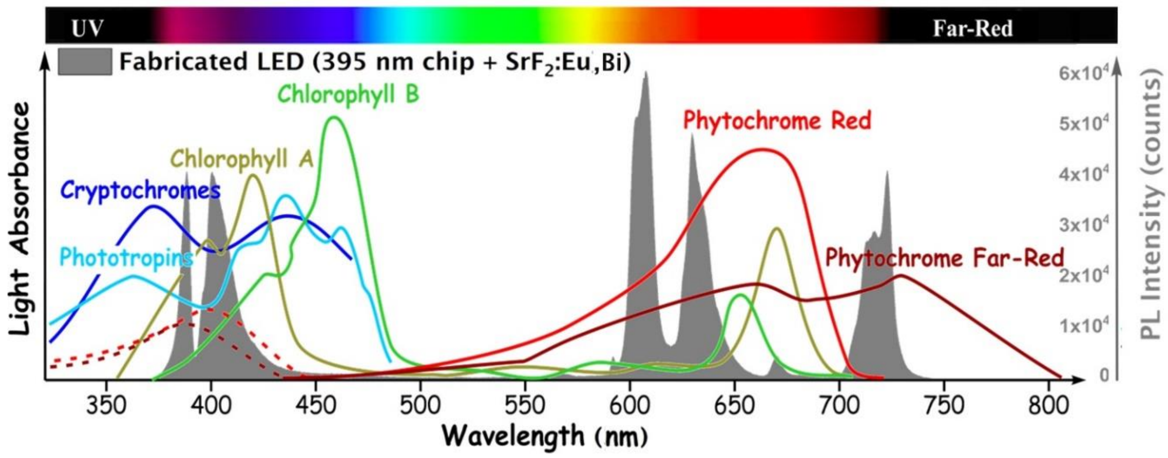
3. $BaYF_5$:10mol%Eu^{3+}, 20mol%Bi^{3+} nanoparticles (energy transfer efficiencies (ηT) of 16%).

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+}



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



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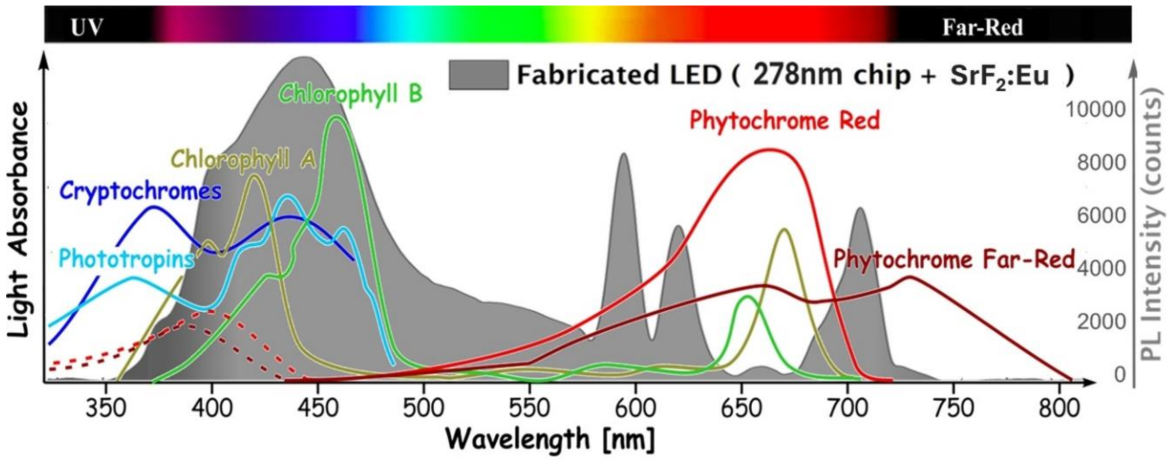
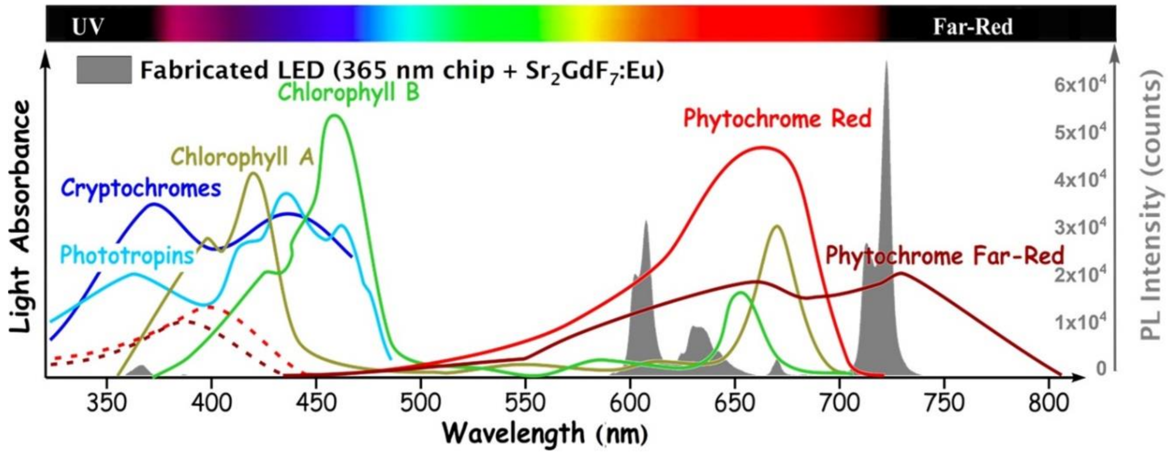
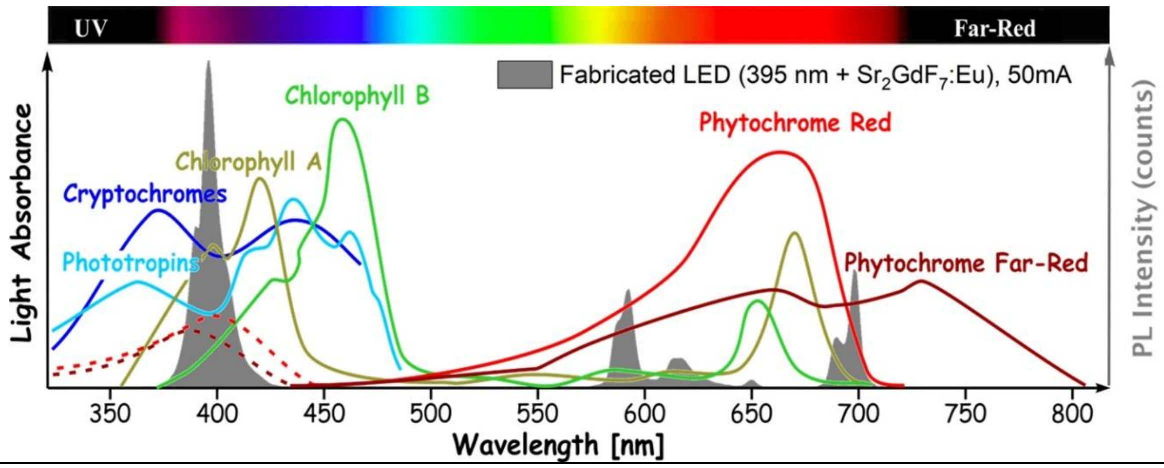
SrF_2:10%Eu^{3+},20%Bi^{3+}



Sr_2GdF_7: 80%Eu^{3+}



Sr_2GdF_7: 80%Eu^{3+}



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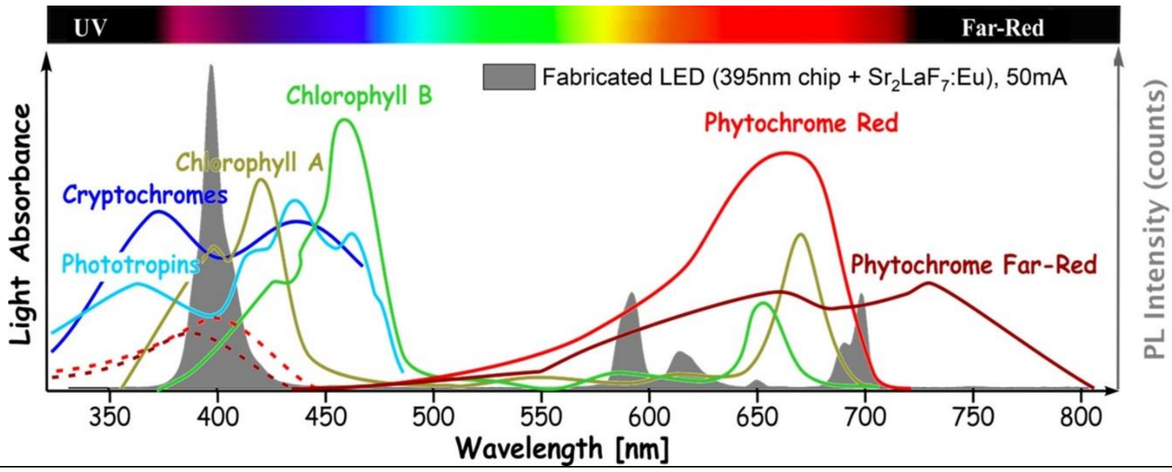
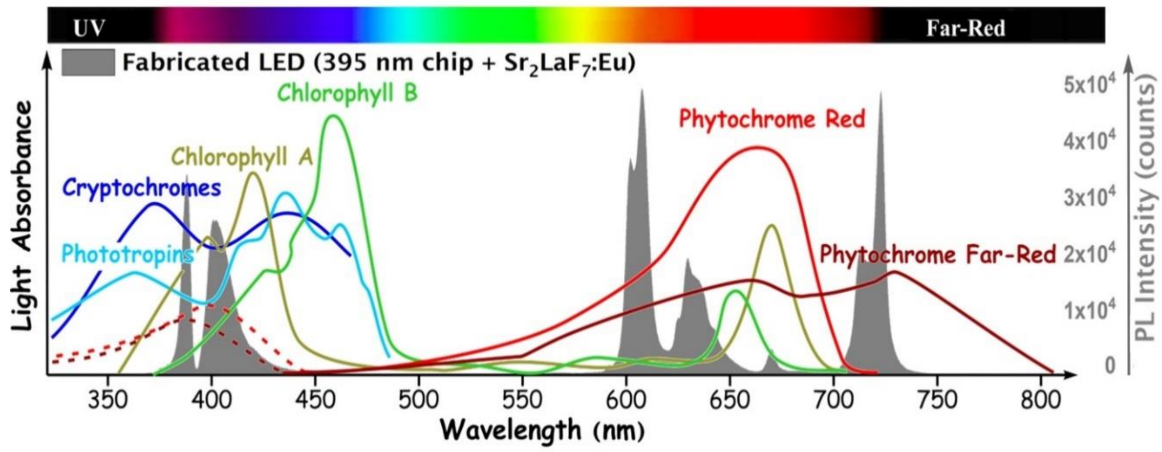
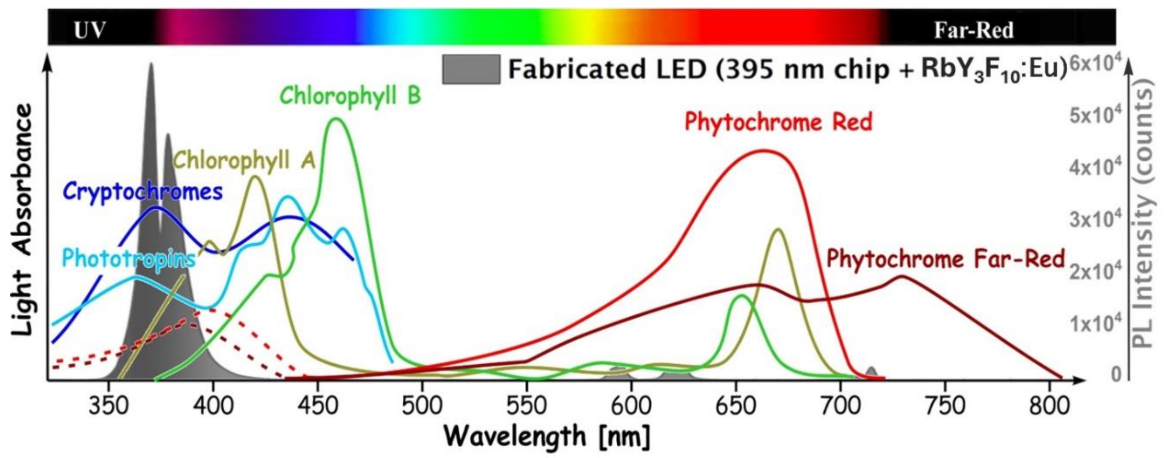
Sr_2LaF_7:50mol%Eu^{3+}



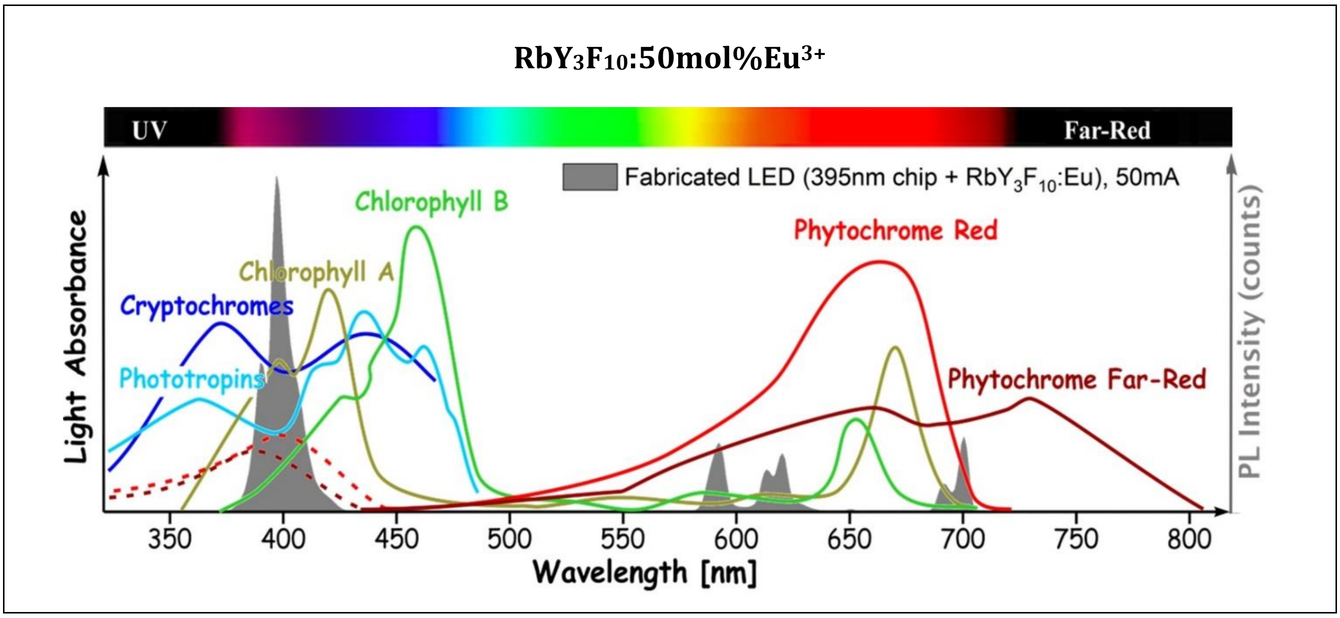
Sr_2LaF_7:50mol%Eu^{3+}



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



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



The LEDtech-GROW team members successfully achieved **Milestone M3.1**, **Professional development of young and early-stage researchers** completed. Verification was provided through the completion of European Training Academy courses and intellectual property rights (IPR) training, as well as active participation in dissemination and proposal preparation activities. Team members attended 2 workshops, 4 specialized trainings, 8 webinars, and 2 information days. In terms of scientific dissemination, they delivered six poster presentations at international conferences, one oral presentation at an international conference, and one invited talk at a domestic conference. In addition, the team submitted four project proposals as principal investigators, with funding decisions currently pending.

The ability to convert UV into blue and red light in inorganic phosphors for LEDs in agricultural applications is essential to boost the photosynthesis of plants in greenhouses. For example, plants like tomatoes, peppers, and orchids benefit from red light during their flowering and fruiting stages. For plants like strawberries or cucumbers, red light will support better fruit production. Leafy greens like lettuce, spinach, and kale thrive under blue light as it promotes healthy leaf growth. Also, blue light helps young seedlings develop strong, healthy leaves and stems, giving them a solid start. **Therefore, the tunable red and blue emission achieved in Bi^{3+}-co-doped $SrF_2:Eu^{3+}$ nanoparticles demonstrates that this LED configuration exhibits the most favorable properties among all fabricated devices, offering balanced spectral coverage and the highest potential for supporting plant growth throughout all developmental stages.**

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