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Development of High-Temperature Persistent Photoluminescent Ceramic Tiles Based on Dy^{3+}/Eu^{2+}-Doped Strontium Aluminate Phosphors

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Abstract
This study reports the development of a persistent photoluminescent ceramic tile based on Eu^{2+}/Dy^{3+}-doped strontium aluminate ($SrAl_2O_4$: Eu^{2+}, Dy^{3+}) incorporated into a high-temperature ceramic glaze. The phosphor was synthesized using solid-state high-temperature process and subsequently incorporated at 30 wt% into a glaze formulation. The resulting formulation was applied to ceramic tiles by screen printing, followed by firing at 1115–1125 °C. FT-IR analysis confirmed the formation of the Sr–Al–O framework through characteristic Al–O and Sr–O vibrational bands, particularly in the 650–900 cm^{-1} region. The optical characterization revealed pronounced interaction with near-UV radiation, while the reflectance increased to approximately 48–51% at wavelengths above 450–500 nm. Photoluminescence excitation measurements showed a broad excitation response extending from the near-UV region, with a pronounced contribution between approximately 350 and 430 nm. The emission spectrum exhibited a broad green band in the 400–650 nm range, with maximum emission occurring around 500–520 nm, characteristic of the Eu^{2+} $4f^6 5d^1 \rightarrow 4f^7$ transition. In addition, visual examination demonstrated distinct green afterglow from the fired functionalized tile in darkness, whereas the unmodified tile showed no observable luminescence. These findings demonstrate that Eu^{2+}/Dy^{3+}-activated strontium aluminate can be incorporated into a ceramic glaze to produce a visually functional luminescent surface capable of retaining green photoluminescence after high-temperature ceramic processing.

Keywords
Dy^{3+}/Eu^{2+}-doped strontium aluminate, Phosphors, Photoluminescent tiles, High-temperature persistent photoluminescent.

1. Introduction

The development of functional surfaces that combine aesthetic characteristics with additional optical and safety-related functions has become an increasingly important direction in the ceramic industry. Ceramic tiles are no longer regarded solely as conventional flooring and wall-covering materials; their widespread use in residential, commercial, public, and architectural environments provides an attractive platform for incorporating additional functionalities into ceramic surfaces. The optical ceramics and glass-ceramics sector is projected to experience substantial growth, with its worldwide market value estimated to approach US$20.6 billion by 2030. This upward trend is largely associated with the expanding use of these materials in automotive technologies, aerospace applications, and healthcare [1]. This continuous expansion, together with increasing demand for aesthetically differentiated and multifunctional surfaces, creates an opportunity for the development of ceramic tiles with optical functionalities beyond conventional decoration.

One promising approach for imparting additional functionality to ceramic surfaces is the incorporation of persistent photoluminescent materials. Persistent photoluminescent, or long-afterglow, materials are capable of absorbing energy from an external light source and subsequently releasing part of the stored energy as visible light after the excitation source has been removed. Unlike conventional fluorescent pigments, whose emission rapidly disappears after excitation, persistent phosphors can continue emitting light for extended periods, making them attractive for applications including safety signs,

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emergency guidance, architectural decoration, pathway marking, transportation infrastructure, and low-energy lighting [2-5]. The ability to generate visible light without continuous electrical power is particularly attractive for ceramic surfaces used in corridors, stairways, public spaces, and other environments where passive visual guidance or decorative illumination may be desirable.

The practical implementation of photoluminescent ceramics, however, requires careful consideration of the thermal history associated with ceramic manufacturing. Conventional ceramic tiles are produced through high-temperature firing processes, and depending on the tile body, glaze, and manufacturing route, firing temperatures can exceed 1100 °C and may reach 1200 °C or higher. Therefore, a photoluminescent pigment intended to be incorporated into a conventional ceramic manufacturing process must possess sufficient thermal stability to retain its crystal structure, luminescent centers, and trapping characteristics during thermal treatment. This requirement represents a major materials-selection criterion because the optical properties of many organic and inorganic luminescent systems can deteriorate when exposed to elevated temperatures. In particular, degradation of the luminescent center or modification of the defect structure responsible for energy storage can result in substantial loss of afterglow performance [6, 7].

Among the various persistent phosphors investigated for practical applications, strontium aluminate activated with europium and dysprosium, generally represented as $SrAl_2O_4$: Eu^{2+}, Dy^{3+}, has attracted particular attention. The discovery that Dy^{3+} co-doping substantially enhances the brightness and persistence of Eu^{2+}-activated $SrAl_2O_4$ established this material as one of the most important non-radioactive long-afterglow phosphors [8]. Compared with earlier ZnS-based phosphors, $SrAl_2O_4$: Eu^{2+},Dy^{3+} provides higher brightness and substantially longer persistence, together with good chemical stability and the absence of radioactivity [9]. Its successful application in safety markings, luminous paints, emergency signs, and other functional products has further demonstrated its practical potential [10].

The suitability of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} for persistent luminescence originates from the synergistic roles of the host lattice and the rare-earth ions. The $SrAl_2O_4$ crystal lattice provides the host structure in which the electronic states associated with luminescence and charge trapping are established. Eu^{2+} ions act primarily as the luminescent centers. Upon excitation, electrons associated with Eu^{2+} can be promoted to higher-energy states; subsequent radiative relaxation involving the Eu^{2+} 5d–4f electronic transition produces the characteristic broad green emission of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} [11]. The emission is therefore directly associated with the electronic structure of Eu^{2+} incorporated into the strontium sites of the host lattice [12].

The role of Dy^{3+} is different and is particularly important for the persistence of the emission. Persistent luminescence requires the temporary storage of excitation energy in metastable states, commonly described in terms of charge carriers being captured by trap states within the band gap. Following excitation, a fraction of the charge carriers is captured by these traps rather than immediately recombining at the luminescence centers. The subsequent gradual release of the trapped carriers enables their return to the luminescent centers and produces delayed emission after the excitation source has been removed. Dy^{3+} co-doping modifies the defect and trapping landscape of the host and significantly enhances the persistence of the luminescence. Nevertheless, the detailed microscopic nature of the traps in $SrAl_2O_4$: Eu^{2+},Dy^{3+} remains an active subject of scientific investigation, with oxygen vacancies, cation vacancies, and dopant-associated defects proposed to contribute to the trapping process [13, 14].

Thus, the persistent luminescence of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} should not be regarded as originating from a single component. Rather, it is a cooperative phenomenon involving the $SrAl_2O_4$ host lattice, Eu^{2+} luminescent centers, and Dy^{3+}-associated trapping states. The host lattice provides the appropriate electronic environment; Eu^{2+} determines the principal visible emission; and Dy^{3+} contributes to the charge-storage process that extends the emission after removal of the excitation source [15, 16]. This combination provides a rational basis for selecting $SrAl_2O_4$: Eu^{2+}, Dy^{3+} when designing persistent luminescent ceramic surfaces.

Considering the high firing temperatures employed in ceramic tile manufacturing, the incorporation of photoluminescent phosphors into ceramic formulations presents a significant technological challenge, as the thermal history of the material can strongly influence the crystal structure, oxidation state of the activator ions, defect chemistry, and consequently the persistent luminescence performance. However, in industrial ceramic processing, the applied coating may subsequently undergo a second high-temperature firing step, to ensure its integration with the ceramic surface. Therefore, the development of a photoluminescent coating for ceramic tiles requires not only a suitable phosphor with high luminescence efficiency but also sufficient thermal stability to retain its optical functionality during the subsequent firing process [16-18]. Despite the

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well-established persistent luminescence of $SrAl_2O_4$: Eu^{2+}, Dy^{3+}, its practical integration into ceramic tile surfaces remains challenging because the phosphor must retain its luminescent functionality while being compatible with the thermal and processing requirements of ceramic glazing. In particular, the combination of phosphor dispersion, glaze formulation, surface application, and subsequent high-temperature firing can substantially influence the final optical response of the functionalized tile [19, 20].

The objective of the present work was to develop and evaluate a photoluminescent ceramic glaze containing $SrAl_2O_4$: Eu^{2+}, Dy^{3+} and to investigate its optical characteristics after industrially relevant thermal treatment. In this approach, 30 wt% of the synthesized phosphor was incorporated into a ceramic glaze formulation and applied to tile substrates by screen printing, followed by firing at 1115–1125 °C for 60 min. The resulting material was systematically evaluated using FT-IR, XRF, diffuse reflectance, and photoluminescence excitation and emission measurements. Particular attention was given to the relationship between the structural characteristics of the synthesized phosphor and its optical response after incorporation into the ceramic glaze. The broad near-UV excitation response and green emission associated with Eu^{2+}, together with the persistent-luminescence contribution of Dy^{3+}-related trapping states, were considered in assessing the suitability of the developed coating for functional ceramic surfaces. The main novelty of this study lies in demonstrating a practical glaze-based route for introducing persistent photoluminescence into ceramic tiles while maintaining the characteristic optical response of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} after high-temperature firing. This approach provides a direct connection between phosphor synthesis, ceramic glaze processing, and the fabrication of a visually functional tile surface.

2. Experimental

2.1. Chemical reagent

Strontium (II) carbonate ($SrCO_3$), aluminium (III) oxide (Al_2O_3), boric acid (H_3BO_3) were purchase from Merck company. Europium (III) oxide (Eu_2O_3), and dysprosium (III) oxide (Dy_2O_3) were prepared from Sigma Aldrich.

2.2. Experimental instrument

The photoluminescence excitation and emission spectra of the synthesized phosphorescent pigment samples were recorded at ambient temperature using a Cary Eclipse Fluorescence Spectrophotometer (Varian Inc., USA). The instrument is equipped with a pulsed xenon flash lamp as the excitation source and is capable of recording both excitation and emission spectra over the UV–visible spectral range. Fourier-transform infrared (FT-IR) spectra were acquired using a Nicolet Nexus 670 Fourier Transform Infrared Spectrometer (Thermo Nicolet, USA) over the wavenumber range of 4000–400 cm^{-1}. Diffuse/specular reflectance measurements of the phosphorescent pigment samples were performed using a Thermo Scientific Evolution UV–Vis/NIR High-Performance Spectrophotometer (Thermo Fisher Scientific, USA). Evolution-series spectrophotometers support reflectance measurements and are equipped with xenon-based illumination systems depending on the instrument configuration. The elemental composition of the synthesized phosphor was determined using a PW2404 Wavelength-Dispersive X-ray Fluorescence (WD-XRF) Spectrometer (PANalytical, Almelo, The Netherlands). The prepared phosphor pigment was mechanically dispersed and ground to reduce the particle size using an EXAKT ES-80 Three-Roll Mill (EXAKT Advanced Technologies GmbH, Norderstedt, Germany).

2.3. Synthesis of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} photoluminescence

Stoichiometric amounts of $SrCO_3$, Al_2O_3, H_3BO_3, Eu_2O_3, and Dy_2O_3 were dispersed in ethanol according to a molar ratio 1:2:0.2:0.01:0.02. The resulting suspension was subjected to ultrasonic treatment at a frequency of 25 kHz for 20 min to promote homogeneous dispersion and intimate mixing of the precursor particles. The suspension was subsequently dried at 90 °C for 24 h. The dried precursor mixture was then subjected to high-energy planetary ball milling for 2 h to further improve compositional homogeneity and reduce particle agglomeration. The resulting powder was calcined at 1300 °C for 3 h using a heating rate of 10 °C min^{-1} under a carbon-reducing atmosphere. The obtained $SrAl_2O_4$: Eu^{2+}, Dy^{3+} powder was subsequently used as the photoluminescent component in the glaze formulation.

2.4. Preparation of photoluminescence glaze

The high-temperature photoluminescent glaze was formulated using $SrAl_2O_4$: Eu^{2+}, Dy^{3+} as the luminescent phase together with conventional ceramic glaze constituents. The glaze composition, expressed in weight percentages, consisted of 30 wt% $SrAl_2O_4^{2+}$, Dy^{3+}, 23 wt% feldspar, 20 wt% SiO_2, 13 wt% CaO, 3.0 wt% ZnO, 4.0 wt% dolomite, 4.5 wt% H_3BO_3, and 2.5 wt% Al_2O_3. All raw materials were initially homogenized by ball milling for 6 h and subsequently passed through a 325-mesh sieve to obtain a uniform and finely dispersed glaze mixture. The resulting glaze powder was then mixed with water at a powder-to-

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water mass ratio of 100:80. This suspension was further homogenized using a planetary ball mill operated at 400 rpm for 1 h. The prepared photoluminescent glaze slurry was applied onto the ceramic tile surface using a screen-printing process. The resulting glaze layer had a thickness of 0.3-0.4 mm. The coated ceramic tiles were subsequently fired in a roller kiln at 1115–1125 °C for 60 min. After firing and cooling, a uniform, glossy photoluminescent glaze layer was obtained on the ceramic tile surface.

3. Results and discussion

3.1. FT-IR characterization of $SrAl_2O_4$: Eu^{2+}, Dy^{3+}

Fig. 1 presents the FT-IR spectrum of the synthesized green-emitting $SrAl_2O_4$: Eu^{2+}, Dy^{3+} phosphor over the wavenumber range of 400−4000 cm^{-1}. The spectrum is predominantly characterized by absorption bands in the low-wavenumber region, particularly between 400 and 1000 cm^{-1}. This region is associated mainly with the vibrational modes of the inorganic Sr–Al–O framework and is therefore particularly relevant for confirming the formation of strontium aluminate.

The most pronounced absorption features in the present spectrum occur at 900 cm^{-1}, 850−800 cm^{-1}, and 650 cm^{-1}. These features are consistent with the characteristic vibrational bands reported for $SrAl_2O_4$ based phosphors. In particular, bands located near 782, 849, and 898 cm^{-1} have been attributed primarily to Al–O vibrational modes, whereas the band around 646 cm^{-1} has been associated with Sr–O vibrations [7]. The close correspondence between these reported positions and the absorption features observed in Fig. 1 provides strong evidence for the formation of the Sr–Al–O framework in the synthesized material. The presence of several bands within the 700−1000 cm^{-1} region can be attributed to the different local environments of oxygen around aluminum in the strontium aluminate lattice. Because the Al–O bonds do not all possess identical bond lengths and local coordination environments, their vibrational modes are distributed over a range of wavenumbers rather than appearing as a single absorption band. Similar multiple absorption features in this region have been reported for synthesized $SrAl_2O_4$, including bands near 896, 850, 807, 784, and 643 cm^{-1} [21]. A weak spectral contribution can also be observed in the high-wavenumber region around 3400 cm^{-1}. Such a feature is generally associated with O–H stretching vibrations and can originate from surface-adsorbed moisture or hydroxyl species. A band at 3427 cm^{-1} has similarly been reported for $SrAl_2O_4$: Eu^{2+}, Dy^{3+} and assigned to O–H stretching vibrations. In the present spectrum, however, this contribution is relatively weak compared with the characteristic lattice vibrations, indicating that the dominant spectral features originate from the inorganic host lattice. The spectrum also exhibits no prominent absorption bands characteristic of organic functional groups in the 2800−3000 cm^{-1} region. The dominance of the low-wavenumber metal–oxygen vibrations is therefore consistent with the inorganic and ceramic nature of the synthesized phosphor. The FT-IR spectrum demonstrates the characteristic vibrational fingerprint of the Sr–Al–O lattice, with the observed Al–O and Sr–O bands showing good agreement with previously reported $SrAl_2O_4$-based phosphors [7, 21].

Accordingly, the FT-IR results provide clear spectroscopic evidence for the formation of the strontium aluminate host lattice in the synthesized $SrAl_2O_4$:Eu^{2+}, Dy^{3+} phosphor. The spectral profile is consistent with the expected chemical environment of the host material and confirms the development of the characteristic Sr–O and Al–O bonding network.

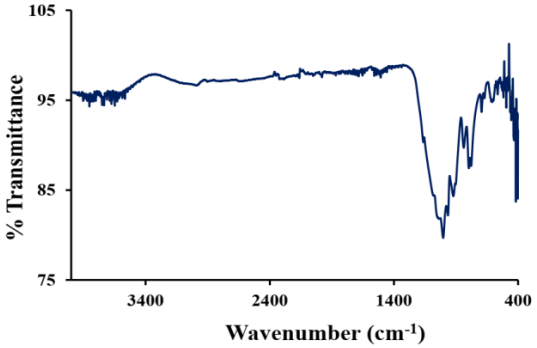

Fig 1. FT-IR of $SrAl_2O_4$:Eu^{2+}, Dy^{3+} photoluminescence pigments

3.2. XRF analysis of $SrAl_2O_4$: Eu^{2+}, Dy^{3+}

WD-XRF analysis indicated SrO and Al_2O_3 as the major detected oxide components, with measured contents of 48.54 and 50.74 wt.%, respectively. The results are reported on an oxide weight basis. Eu and Dy were not detected under the conditions of the applied measurement [12].

3.3. Optical performance of the high-temperature-fired luminescent tile

Fig. 2 compares the appearance of the blank and luminescent tiles under ambient light and in darkness. Under ambient illumination, the two tiles exhibit relatively similar appearances, whereas a distinct green emission is observed from the luminescent tile in the dark. In contrast, the blank tile exhibits no visible emission under the same conditions. This observation confirms the successful incorporation of luminescent functionality into the prepared tile and demonstrates that the resulting material retains its ability to emit visible light after excitation. The green emission indicates the presence of active

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luminescent centers within the functionalized tile coating. These centers absorb incident radiation and subsequently release the stored energy as visible light after the excitation source is removed. The observed luminescence demonstrates the potential of the prepared tile for applications requiring light emission under dark conditions. However, quantitative measurements of emission intensity and afterglow decay, together with confirmation of the firing temperature, are required to establish the retention of luminescent performance after high-temperature processing.

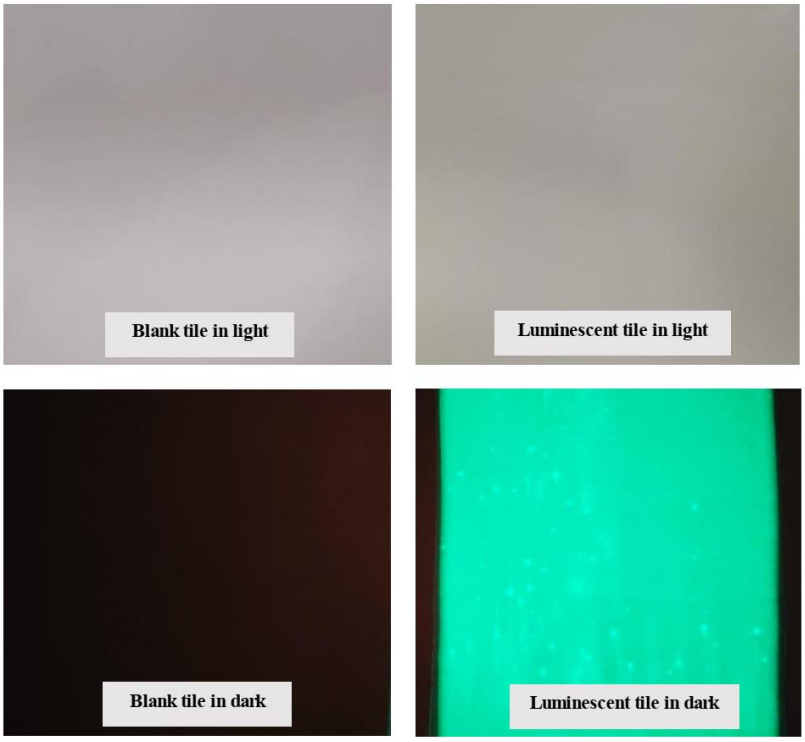

Fig 2. Photographs of the blank and photoluminescent tiles under ambient light and dark conditions, demonstrating the green light emission of the luminescent tile compared with the non-luminescent blank tile.

3.4. Reflectance analysis of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} based photoluminescence tile

Fig. 3 shows the diffuse reflectance spectrum of the photoluminescence tile over the wavelength range of 200−1000 nm. The spectrum exhibits a pronounced wavelength-dependent response in the UV and near-UV regions, followed by a relatively stable reflectance level at longer wavelengths.

At wavelengths below 450−500 nm, the reflectance decreases considerably, reaching its lowest values in the near-UV visible transition region. In contrast, at wavelengths above 450−500 nm, the reflectance increases and subsequently becomes relatively constant at 48−51%. This pronounced decrease in reflectance in the UV and near-UV regions indicates enhanced interaction of the incident radiation with the electronic states of the phosphor, resulting in increased optical absorption. The optical behavior observed in Fig. 3 is consistent with the wide-band-gap nature of the $SrAl_2O_4$ host. Strontium aluminate exhibits strong intrinsic absorption in the UV region, while incorporation of optically active Eu^{2+} ions introduces additional electronic states that can influence the optical response at longer wavelengths. The electronic configuration of Eu^{2+} in the ground state is $4f^7$, while optical excitation can promote an electron to the 5d level, resulting in the $4f^7 \rightarrow 4f^6 5d^1$ transition. These 5d states are strongly affected by the crystal-field environment provided by the $SrAl_2O_4$ lattice and consequently contribute to the UV–visible optical response of the material. The decrease in reflectance extending from the UV region toward 400−500 nm is therefore consistent with the presence of optically active states associated with the Eu^{2+} dopant in the strontium aluminate host. This behavior is particularly relevant to the luminescence mechanism of $SrAl_2O_4$: Eu^{2+}, Dy^{3+}, since excitation of Eu^{2+} followed by radiative relaxation is responsible for the characteristic visible emission of this phosphor. Eu^{2+} is widely recognized as the principal luminescent center in Eu^{2+}-activated strontium aluminate, with the broad visible emission arising predominantly from the $4f^6 5d^1 \rightarrow 4f^7$ transition [22].

The role of Dy^{3+} is associated primarily with the persistent-luminescence behavior of the material. In

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Eu^{2+}/Dy^{3+}-codoped aluminates, Dy^{3+}-related states can participate in the trapping and subsequent release of charge carriers. The trapping–detrapping process provides a mechanism for the delayed recombination of charge carriers at luminescent Eu^{2+} centers and consequently contributes to the long-lasting luminescence of the phosphor [11]. Thus, the optical response observed in Fig. 3 is consistent with the electronic structure expected for a Eu^{2+}-activated strontium aluminate system containing Dy^{3+} as a co-dopant. The relatively constant reflectance observed above 500 nm indicates that the strong wavelength-dependent optical interaction observed in the UV and near-UV regions becomes considerably weaker in the longer-wavelength region. This transition in optical behavior is consistent with the presence of strong electronic absorption processes at higher photon energies and comparatively lower absorption in the longer-wavelength region. It is important to distinguish the observed reflectance edge from a directly measured optical band gap. Since Fig. 3 represents the reflectance percentage, the Fig. primarily demonstrates the wavelength-dependent optical response and absorption region of the photoluminescence tile. The marked reduction in reflectance toward the UV region is consistent with the wide-band-gap character of the $SrAl_2O_4$ host and the contribution of dopant-related electronic states.

The reflectance spectrum, meanwhile, demonstrates a strong optical response in the UV and near-UV regions, followed by relatively stable reflectance at longer wavelengths. The reduced reflectance in the UV–near-UV region is consistent with strong optical absorption associated with the wide-band-gap strontium aluminate host and the electronic states introduced by Eu^{2+} activation. The $4f^7 \rightarrow 4f^6 5d^1$ transition of Eu^{2+} provides the fundamental electronic basis for excitation of the luminescent center, whereas the involvement of Dy^{3+} in charge trapping and detrapping contributes to the persistent-luminescence characteristics of the system [11, 22].

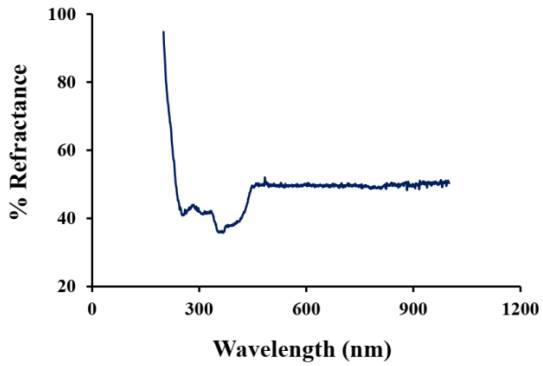

Fig 3. Reflectance of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} based photoluminescence tile

3.5. Photoluminescence excitation and emission analysis

Fig. 4 and 5 presents the photoluminescence excitation (PLE) and emission (PL) spectra of the synthesized $SrAl_2O_4$: Eu^{2+}, Dy^{3+} phosphor, respectively. These measurements provide direct information on the optical excitation pathways and luminescent response of the synthesized material. The observed spectral features can be interpreted in terms of the electronic states of the $SrAl_2O_4$ host lattice and the Eu^{2+} activator, which is the principal luminescent center in this phosphor system.

3.5.1. Photoluminescence excitation spectrum

The excitation spectrum in Fig. 4 extends from approximately 200 to 800 nm and shows a pronounced excitation response in the ultraviolet–near-visible region. The most important feature is the strong increase in excitation intensity in the region of approximately 350–430 nm, with the intensity becoming particularly pronounced above about 380 nm. This excitation behavior is consistent with the characteristic optical response of Eu^{2+} activated strontium aluminate phosphors. The excitation of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} is predominantly associated with the electronic transition of Eu^{2+} from its $4f^7$ ground-state configuration to the excited $4f^6 5d^1$ configuration. Because the 5d states are strongly influenced by the crystal field generated by the surrounding oxygen ligands, the corresponding excitation is broad rather than consisting of sharp atomic lines. Reported $SrAl_2O_4$: Eu^{2+}, Dy^{3+} phosphors commonly exhibit excitation maxima in the vicinity of 350–370 nm, in good agreement with the spectral region observed in Fig. 4 [14, 20, 22].

The relatively broad excitation response is advantageous for the optical activation of the phosphor because it indicates that excitation is not restricted to a single narrow wavelength. The observed response across the near-UV region is therefore consistent with the crystal-field-split 5d states of Eu^{2+}. The small variations and fluctuations visible in the excitation curve are superimposed on this broad spectral response and do not change the fundamental assignment of the excitation band. The excitation spectrum therefore demonstrates that the synthesized material can efficiently absorb near-UV radiation and transfer the absorbed energy to the luminescent Eu^{2+} centers. The role of Dy^{3+} is primarily related to the persistent-luminescence process through trap states and charge-storage mechanisms rather than being the principal origin of the broad excitation/emission bands [7, 14, 20, 22]

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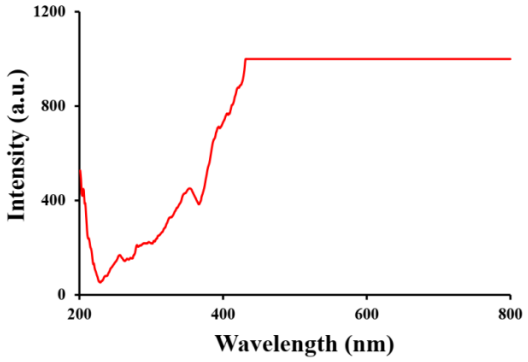

Fig 4. Excitation spectra of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} based photoluminescence tile

3.5.2. Photoluminescence emission spectrum

In the wavelength range of 400–650 nm, Fig. 5 represents the visible phosphorescence emission of the $SrAl_2O_4$: Eu^{2+}, Dy^{3+} based photoluminescence tile. The emission intensity increases markedly from approximately 400 nm and reaches its maximum in the green region around 500–520 nm. This broad emission band is characteristic of Eu^{2+} centers incorporated into the $SrAl_2O_4$ host lattice and is attributed to the allowed electronic transition from the excited $4f^65d^1$ state to the ground $4f^7$ state of Eu^{2+}.

The relatively broad nature of the emission is associated with the strong interaction of the Eu^{2+} 5d electronic state with the crystal field of the aluminate lattice. Unlike the sharp 4f-4f transitions of many trivalent lanthanide ions, the 5d→4f transition of Eu^{2+} is strongly affected by the local coordination environment, resulting in a broad emission band extending across a significant portion of the visible spectrum. For $SrAl_2O_4$:Eu^{2+}, Dy^{3+} an emission maximum near 515–520 nm is well established in the literature and corresponds to the characteristic green persistent luminescence of this host. Within the 500–650 nm region, the emission gradually extends toward longer wavelengths, indicating the broad spectral distribution of the Eu^{2+} related luminescence rather than a sharp atomic emission line. The presence of Dy^{3+} does not constitute the principal origin of this broad visible emission; instead, Dy^{3+} plays an important role in the persistent-luminescence process by providing trap-related states that facilitate the storage and subsequent gradual release of excitation energy. The released energy ultimately contributes to radiative recombination at the Eu^{2+} luminescent centers. Therefore, the spectral response between 400 and 650 nm, particularly the broad maximum around 500–520 nm, can be assigned to the characteristic Eu^{2+} phosphorescence of the $SrAl_2O_4$:Eu^{2+}, Dy^{3+} lattice. The observation of this broad visible emission confirms the effective optical activation of the strontium aluminate host by Eu^{2+} while the presence of Dy^{3+} is consistent with the persistent character of the resulting phosphor [20, 22, 23].

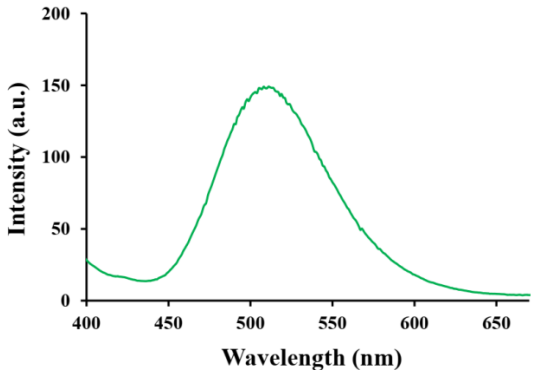

Fig 5. Emission spectra of $SrAl_2O_4$: Eu^{2+}, Dy^{3+} based photoluminescence tile

4. Conclusion

A high-temperature-compatible persistent photoluminescent ceramic tile was successfully developed by integrating $SrAl_2O_4$: Eu^{2+}, Dy^{3+} into a conventional ceramic glaze. The spectroscopic results verified the formation of the strontium aluminate host, with the FT-IR spectrum displaying the characteristic Al–O and Sr–O vibrational features of the Sr–Al–O framework. The optical measurements further established that the functionalized surface possesses a pronounced near-UV response and a broad green emission centered approximately at 500–520 nm, confirming the effective contribution of Eu^{2+} as the principal emitting center. The observed luminescence after firing at 1115–1125 °C for 60 min is particularly significant because it demonstrates the preservation of the optical functionality of the phosphor under the thermal conditions relevant to ceramic tile processing. The incorporation of 30 wt% phosphor produced a visibly distinguishable green-emitting surface, while the blank tile remained non-luminescent under identical dark conditions. The broad excitation response in the near-UV region and the characteristic Eu^{2+} emission, together with the contribution of Dy^{3+}-associated trapping states, provide a suitable basis for delayed light release following excitation. Overall, the results indicate that the proposed glaze formulation offers a practical route toward multifunctional ceramic surfaces with passive luminescent functionality. Such surfaces may be particularly relevant to decorative ceramic applications, visual guidance, safety-oriented markings, and architectural environments where light emission without continuous electrical input is desirable.

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توسعه کاشی‌های سرامیکی فوتولومینسانس پایدار در دمای بالا بر پایه فسفرهای آلومینات استرانسیم آلاییده‌شده با یون‌های Eu^{2+}/Dy^{3+}

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چکیده

در این پژوهش، توسعه یک کاشی سرامیکی فوتولومینسانس پایدار بر پایه آلومینات استرانسیم آلاییده‌شده با یون‌های Eu^{2+} و Dy^{3+} ($SrAl_2O_4^{2+},Dy^{3+}$) و ادغام آن در یک لعاب سرامیکی با قابلیت تحمل دمای بالا گزارش شده است. فسفر موردنظر با استفاده از روش حالت جامد در دمای بالا سنتز شد و سپس با نسبت وزنی ۳۰ درصد به فرمولاسیون لعاب افزوده گردید. فرمولاسیون حاصل با روش چاپ سیلک‌اسکرین روی کاشی‌های سرامیکی اعمال شد و در ادامه، نمونه‌ها در دمای ۱۱۱۵ تا ۱۱۲۵ درجه سانتی‌گراد پخت شدند. نتایج آنالیز طیف‌سنجی مادون قرمز تبدیل فوریه(FT-IR) ، تشکیل چارچوب Sr–Al–O را از طریق باندهای ارتعاشی مشخصه پیوندهای Al–O و Sr–O ، به‌ویژه در محدوده ۶۵۰ تا ۹۰۰ سانتی‌متر معکوس، تأیید کرد. مشخصه‌یابی نوری، برهم‌کنش قابل‌توجه نمونه با تابش فرابنفش نزدیک را نشان داد؛ همچنین، بازتابندگی در طول موج‌های بالاتر از حدود ۴۵۰ تا ۵۰۰ نانومتر به تقریباً ۴۸ تا ۵۱ درصد افزایش یافت. اندازه‌گیری‌های طیف تحریک فوتولومینسانس، پاسخ تحریک گسترده‌ای را در ناحیه فرابنفش نزدیک نشان داد که سهم قابل‌توجهی از آن در محدوده تقریبی ۳۵۰ تا ۴۳۰ نانومتر قرار داشت. طیف گسیل، یک باند سبز گسترده در محدوده ۴۰۰ تا ۶۵۰ نانومتر را نشان داد که بیشینه شدت گسیل آن در حدود ۵۰۰ تا ۵۲۰ نانومتر مشاهده شد. این ویژگی با گذار الکترونی ۴ $f^6 5d^1 \rightarrow 4f^7$ مربوط به یون Eu^{2+} مطابقت دارد. علاوه بر این، بررسی چشمی نمونه‌ها نشان داد که کاشی عملکردی پخت‌شده در تاریکی دارای پس‌تاب سبز قابل‌مشاهده و مشخصی است، درحالی‌که کاشی اصلاح‌نشده هیچ‌گونه تابندگی قابل‌مشاهده‌ای از خود نشان نداد. این یافته‌ها نشان می‌دهند که فسفر آلومینات استرانسیم فعال‌شده با یون‌های Eu^{2+}/Dy^{3+} را می‌توان در یک لعاب سرامیکی به کار گرفت و سطحی با عملکرد نوری ایجاد کرد که قادر است پس از فرایند پخت سرامیکی در دمای بالا، خاصیت فوتولومینسانس سبز خود را حفظ کند.

کلیدواژه‌ها

آلومینات استرانسیم آلاییده‌شده با یون‌های Eu^{2+}/Dy^{3+}، فسفرها، کاشی‌های فوتولومینسانس، فوتولومینسانس پایدار در دمای بالا.

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