Polymer-Based Luminescent Coatings for Spectral Engineering in Sustainable Agriculture

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Abstract

Spectral engineering of solar radiation represents an effective passive strategy for enhancing crop productivity in protected cultivation systems. A comparative analysis of major phosphor families – including rare-earth complexes, inorganic phosphors, quantum dots, aggregation-induced emission (AIE) luminogens, and organic dyes such as perylene diimides (PDIs) – was performed with respect to photoluminescence quantum yield, spectral selectivity, photostability, and environmental safety. It is shown that the polymer matrix (e.g., polyethylene (PE), polypropylene (PP), poly(methyl methacrylate) (PMMA), and biopolymers) play a crucial role in determining optical transparency, mechanical integrity, and the aggregation behavior of the luminophore. Coating fabrication techniques, including melt extrusion, solution casting, spin coating, dip coating, and sol-gel processing, are compared in terms of film uniformity, thickness control, and scalability. Using PMMA/PDI system as a representative example, it is demonstrated that increasing the dye concentration enhances ultraviolet (UV) absorption but simultaneously promotes aggregation-induced fluorescence quenching, photobleaching, and reduced optical transparency, highlighting the need to balance spectral conservation efficiency with long-term film stability. The analysis further reveals that no single class of luminescent materials simultaneously satisfies the requirements for high conversion efficiency, weather resistance, cost-effectiveness, and environmental safety. Moreover, the agronomic benefits of spectral conversion are shown to be crop-specific, emphasizing the need for standardized protocols for optical, morphological, and field validation.

Keywords

Spectral engineering, luminescent coatings, polymer matrices, photoluminescent materials, spectral conversion, polymer films.