An LED Approach for Measuring the Photocatalytic Breakdown of Dye on Titanium Dioxide Coated Surfaces

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ABSTRACT

A simple method to estimate the photocatalytic reactivity performance of spray-on titanium dioxide (TiO₂) coatings for transmissive glass surfaces was developed. This novel technique provides a standardized method to evaluate the efficiency of photocatalytic material systems under a variety of illumination levels. To date, photocatalysis assessments have generally been conducted using mercury black lights. Illumination levels for these types of lamps are difficult to vary, consequently limiting their use for assessing material performance under a diverse range of simulated environmental conditions. This new technique uses a stable ultraviolet (UV) gallium nitride (GaN) light emitting diode (LED) array instead of a traditional black light lamp to initiate and sustain photocatalytic breakdown. This method was tested with a UV-resistant dye (Crystal Violet) applied to a TiO₂ coated glass slide. Experimental control is accomplished by applying Crystal Violet to both TiO₂ coated slides and uncoated control slides. A slide is illuminated from the dye side by the UV LED array at various light levels representative of outdoor and indoor conditions. To monitor degradation of the dye over time, a temperature-stabilized white light LED, whose emission spectrum overlaps with the dye absorption spectrum, is used to illuminate the opposite side of the slide. Using a spectrometer, the amount of light from the white LED transmitted through the slide as the dye degrades is monitored as a function of wavelength and time. In this way, the rate of dye degradation for photocatalytically coated versus uncoated slide surfaces can be compared. Results demonstrate that the dye transmission increased much more rapidly on the photocatalytically coated slides than on the control uncoated slides, and that dye degradation is dependent on illumination level. For photocatalytic activity assessment purposes, this experimental configuration and methodology minimizes many external variable effects and enables small changes in absorption to be measured. This research demonstrates the use of this alternative, innovative LED light source design over traditional mercury black light lamp systems and non-LED lamp approaches. This novel technology begins to address the need for a standard method that can assess the performance of photocatalytic materials before deployment for large-scale, real-world use.

INTRODUCTORY TO PHOTOCATALYSIS

In the presence of UV light (320–400 nm) and water, the photocatalyst TiO₂ has two unique qualities:

1. Breakdown Properties—accelerated decomposition of compounds:
   - Organic and inorganic compounds (i.e., Volatile Organic Compounds—VOCs, Polychlorinated Biphenyls—PCBs, pesticides, Nitrogen Oxides—NOₓ)
   - Antimicrobial/antibacterial (i.e., bacterium, fungi, viruses)

2. Self-Cleaning Properties—creates highly washable surface state:
   - Contact angle between the photocatalyst surface and water is reduced
   - Induces superhydrophilicity

REVIEW OF RELATED WORK

This study examined the photocatalytic breakdown of Crystal Violet, a strongly absorbing dye that is relatively insensitive to direct UV photodecomposition. After the application of dye, the slide was exposed to UV radiation and illuminated from below with a temperature-stabilized white light Cree, Inc., LED. The white light LED produces light from approximately 450–600 nm, which overlaps well with the Crystal Violet absorption spectrum. The LED was powered by a constant current source and temperature stabilized to 20 °C with a thermostatic cooler system, producing a light source that was stable to better than 0.1% over several hours. A calibrated Analytical Spectral Devices, Inc., Full Range (350–2500 nm) spectroradiometer was used to measure the transmission of white light through the slide over time. See schematic design in Figure 4.

EXPERIMENTAL METHOD

This method was tested with a UV-resistant dye (Crystal Violet) applied to a TiO₂ coated glass slide. Experimental control is accomplished by applying Crystal Violet to both TiO₂ coated slides and uncoated control slides. A slide is illuminated from the dye side by the UV LED array at various light levels representative of outdoor and indoor conditions. To monitor degradation of the dye over time, a temperature-stabilized white light LED, whose emission spectrum overlaps with the dye absorption spectrum, is used to illuminate the opposite side of the slide. Using a spectrometer, the amount of light from the white LED transmitted through the slide as the dye degrades is monitored as a function of wavelength and time. In this way, the rate of dye degradation for photocatalytically coated versus uncoated slide surfaces can be compared. Results demonstrate that the dye transmission increased much more rapidly on the photocatalytically coated slides than on the control uncoated slides, and that dye degradation is dependent on illumination level. For photocatalytic activity assessment purposes, this experimental configuration and methodology minimizes many external variable effects and enables small changes in absorption to be measured. This research demonstrates the use of this alternative, innovative LED light source design over traditional mercury black light lamp systems and non-LED lamp approaches. This novel technology begins to address the need for a standard method that can assess the performance of photocatalytic materials before deployment for large-scale, real-world use.

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SUMMARY

1. A simple method for evaluating photocatalytic titanium dioxide reactivity under different lighting conditions is under development.
2. UV LED sources allow for simple control of light level.
3. White light LEDs have spectra that overlap the Crystal Violet absorption spectrum and many other dyes.
4. Initial studies have demonstrated stability and repeatability of experimental set-up and design.

This project was largely funded through a research grant from Department of Homeland Security, Science and Technology Directorate. This project includes joint work of employees of the National Aeronautics and Space Administration and its associated contractor team. Participation in this work by Science Systems and Applications, Inc., was supported by the NASA Innovative Partnerships Program at the John C. Stennis Space Center, Mississippi, under Task Order NNS04AB54T.