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INVESTIGATION OF A HIGH-REFLECTANCE COATING FOR WIDE-SPECTRUM VISUAL STIMULATION

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Abstract – This study presents a performance comparison of low-cost, spray-applied reflective coatings for use on custom 3D-printed substrates, targeting visual stimulation applications such as ophthalmic prototypes. $BaSO_4$ and TiO_2 mixtures were evaluated against commercial references under broadband illumination to assess their spectral uniformity and practical applicability. While TiO_2 achieved higher reflectance in the red-NIR region, $BaSO_4$ demonstrated more balanced performance across the visible spectrum and superior adhesion. Standard white paints showed significantly lower and inconsistent reflectance, highlighting their inability to serve as reflectance standards.

Keywords: visual stimulation, high-reflectance coating, 3D-printed substrates, ophthalmic prototyping, Lambertian surface

1. INTRODUCTION

Visual stimulation systems, particularly those based on Ganzfeld configurations [1], require highly reflective, diffusely scattering surfaces to ensure spatially uniform luminance across the entire visual field. This condition is essential in ophthalmic instruments for retinal stimulation, pupillometry, and functional testing [2–4].

Among the most effective solutions for achieving spatial uniformity are integrating spheres, internally coated with high-reflectance Lambertian materials such as $BaSO_4$ or PTFE. These configurations, widely used in photometric and biomedical applications [3, 5], are capable of producing full-field homogeneous illumination with luminance uniformity exceeding 94% [6]. The performance of such systems strongly depends on the optical properties of the inner coating, making material selection a critical design factor [7, 8].

This study investigates the spectral and practical performance of low-cost reflective coatings, manually applied to custom 3D-printed substrates, to enable compact and affordable visual stimulation setups. The tested coatings are compared to calibrated commercial references to assess their reflectance characteristics and their ability to approximate ideal Lambertian behavior across the visible spectrum.

2. METHODS AND PROCEDURES

This work evaluates low-cost reflective coatings applied by airbrush on custom 3D-printed substrates, with the goal of enabling accessible fabrication of reflective surfaces for visual stimulation setups. The test targets were fabricated using a commercial FDM 3D printer and PLA filament. Each sample measured 40 × 30 mm and had a flat surface geometry. To enhance adhesion while preserving sufficient surface roughness, the printed parts were manually sanded with progressively finer abrasive papers, up to grit 600. This process resulted in a smooth but non-glossy surface, minimizing print artifacts while favoring mechanical retention of the coating. The coatings were formulated from aqueous suspensions of barium sulfate ($BaSO_4$, 99.5 % purity, D_{50} = 0.7 µm) and titanium dioxide (TiO_2, 98 % purity, rutile phase). TiO_2 particles were assumed to be in the typical submicrometer range for pigment grade materials ($D_{50} \approx$ [200, 300] nm). A commercial transparent acrylic varnish was used as a base layer and between reflective coats to promote adhesion and mechanical stability of the deposited particles. Coatings were applied using an airbrush with a 0.3 mm nozzle at 2 bar, in successive thin layers to ensure uniform deposition. The same procedure was tested on curved surfaces and yielded consistent, adherent coatings without visible defects. In addition to $BaSO_4$ and TiO_2, two commercially available white coatings were tested for comparison: a white acrylic paint and a matte white spray paint. All samples were visually inspected and evaluated in terms of surface appearance, opacity, adhesion, and spectral reflectance.

3. RESULTS AND DISCUSSION

Reflectance measurements were performed using a Hamamatsu PMA11 spectrometer over the [300, 800] nm spectral range, under broadband illumination from a Xenon lamp. Samples were mounted on a fixed holder, and the detector head was positioned at a fixed distance and inclined at 45° with respect to the surface normal. The reflectance performance of $BaSO_4$, TiO_2, white acrylic paint, and matte white spray paint was evaluated and compared against two calibrated Spectralon® reference tiles with nominal reflectance of 99 % (REF99) and 50 % (REF50) [9], used as baseline standards. Figure 1 shows the recorded spectra in arbitrary units, while Figure 2 displays the spectral reflectance using REF99 as reference.

As expected, REF50 closely follows the spectral profile of REF99 with approximately half the intensity, confirming the consistency and reliability of the measurement procedure across samples.

Among the tested materials, titanium dioxide (TiO_2) exhibited the highest reflectance in the [550, 800] nm range, outperforming barium sulfate ($BaSO_4$) in terms of peak intensity. This makes TiO_2 a strong candidate for applications requiring high diffuse reflectance in the red and

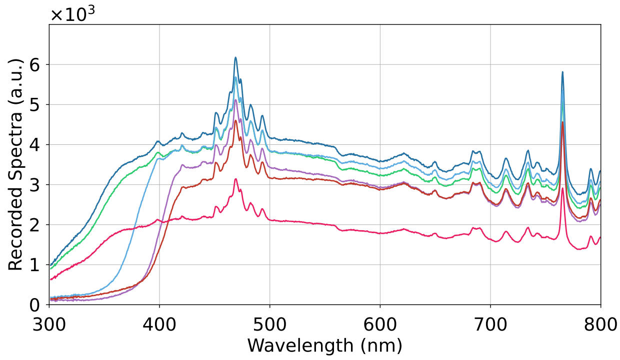

Figure 1. Recorded spectra (a.u.) of: REF99 (●), $BaSO_4$ (●), TiO_2 (●), acrylic paint (●), paint spray (●), REF50 (●).

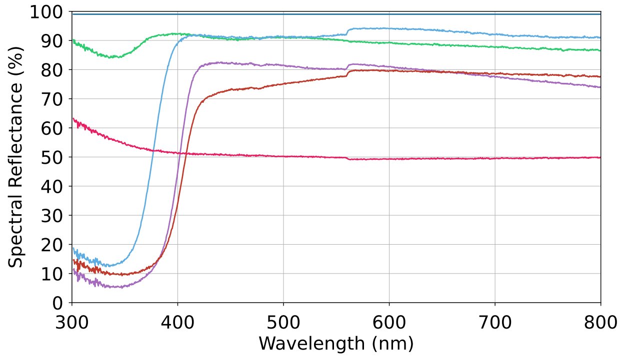

Figure 2. Spectral reflectance of: REF99 (●), $BaSO_4$ (●), TiO_2 (●), acrylic paint (●), spray paint (●), REF50 (●).

near-infrared regions. However, in the blue and near-UV range [300, 450] nm, TiO_2 showed a sharp decline in reflectance, reaching a pronounced minimum around 390 nm. This behavior is likely due to increased absorption or reduced scattering efficiency, related to its electronic structure in the lower visible spectrum.

Table 1 highlights this non-uniformity, showing that while TiO_2 reaches the highest maximum reflectance (94.3 %), it also exhibits the lowest minimum (12.3 %) across the spectrum. This spectral imbalance, along with its glossy appearance and low opacity, could limit its suitability for uniform visual stimulation.

Sample	Normalized Area (%)	Max (%)	Min (%)
REF99	100.00	99.00	99.00
BASO4	90.13	92.47	83.97
TIO2	85.11	94.30	12.33
ACRYLIC	69.92	82.57	4.96
PAINTSPR	67.36	79.90	9.25
REF50	51.05	63.23	49.04

Table 1. Normalized reflectance with respect to REF99, including maximum and minimum values.

While TiO_2 coatings excel in red-NIR reflectance, their limited adhesion—particularly in thicker layers where flaking was observed—further reduces their durability. In contrast, $BaSO_4$ coatings appeared matte, optically uniform, and well-adherent to the PLA substrate, with scattering properties close to Lambertian behavior. All coatings were applied using the same procedure and yielded consistent spectral trends, though no formal statistical analysis was conducted. Qualitative observations revealed partial fragility in all samples, yet only $BaSO_4$ maintained structural stability without cracks or detachment.

White acrylic and matte spray paints exhibited lower and more irregular reflectance, with a pronounced decline below 450 nm, confirming their inadequacy for broadband visual stimulation. While $BaSO_4$ did not reach the maximum reflectance of TiO_2, it offered a more balanced spectral profile, greater application reliability, and a non-glossy appearance, making it a practical and low-cost option for reflective surfaces in custom devices. Future work will include long-term durability testing under environmental and mechanical stress.

4. CONCLUSIONS

This work evaluated the reflectance performance of low-cost coatings applied to 3D-printed substrates, targeting custom optical and ophthalmic systems. Among the tested materials, $BaSO_4$-based coatings offered the best compromise between spectral uniformity, mechanical adhesion, and diffuse reflection, closely approximating the behavior of Spectralon® standards. In contrast, TiO_2 showed higher peak reflectance but poor adhesion and spectral imbalance, while commercial white paints proved inadequate.

The proposed airbrush-applied $BaSO_4$ coating is low-cost, easy to apply, and compatible with custom geometries, making it well-suited for use in laboratory prototypes or test systems for visual stimulation. Future work may explore improvements in coating consistency and durability for extended experimental use.

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