Optical Durability of Candidate Solar Reflector Materials

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1. Abstract

Commercialization of concentrating solar power (CSP) technologies requires the development of advanced reflector materials that are low in cost and maintain high specular reflectance for lifetimes of 10 to 30 years under severe outdoor environments. The DOE Solar Program Multi-Year Technical Plan targets cost reductions of up to 50% to the solar concentrator. These goals should be achieved with the lightweight front-surface reflectors that include anti-soiling coatings through technology advances. The objective of this research is to identify new, cost-effective advanced reflector materials that are durable with weathering.

2. Requirements

CSP official program goals:

- 90% into a 4-mrad half-cone angle
- >10 years under outdoor service conditions
- Large-volume manufacturing cost of less than $10.8/m² ($1/ft²)

Unofficially, more aggressive goals have been pursued:

- 95% reflectivity
- 15–30-year lifetime

Unofficially, structural mirrors (e.g., self-supporting mirrors) have a cost goal of $27/m² ($2.50/ft²) and the reflectors themselves (which are not self-supporting) have the original goal adjusted for inflation to $15.46/m² ($1.44/ft²).

3. Technical Approach

Candidate reflector materials are identified based on their potential for low cost and high optical performance and durability. Materials are optically characterized prior to exposure testing and as a function of exposure time, accelerated or outdoor exposure testing (OET) at geographically diverse sites, to assess durability. An extensive database of optical materials is maintained.

4. Capabilities

Optical Characterization:

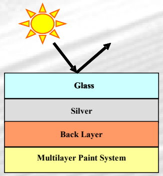
- Perkin-Elmer (PE) Lambda 9 & 900 UV-VIS-NIR spectrophotometers (250-2500 nm) w/ integrating spheres
- PE IR 883 IR spectrophotometer (2.5-50 µm)
- Devices & Services (D&S) Field Portable Specular Reflectometer (7, 15, & 25-mrad cone angle at 660 nm)

Accelerated Exposure Testing (AET):

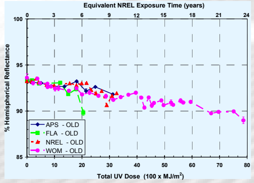
- Atlas Ci65 & Ci5000 WeatherOmeters (WOM) (1X & 2X Xenon Arc/60°C/60%RH)
- QPanel QUV (UVA 340@ 290- 340 nm/ 4 h UV at 40° / 4 h dark at 100%RH)
- 1.0 & 1.4 kW Solar Simulators (SS) (≈5X Xenon 300-500 nm. 1.0-kW SS 80°C/ 80% RH,1.4 kW-SS-4 quadrants 2 RH &T, light /dark)
- BlueM damp heat (85°C/85%RH/dark)
- BlueM Inert gas oven (600°C/dark)

5. Thick Glass Mirrors

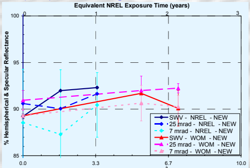
5a. Trough Mirrors



- Flabeg (4–5 mm) silvered, slumped glass mirrors with proprietary multilayer paint system commercially deployed at 9 California SEGS plants.
- Mirrors currently cost $43.2–$64.8/m² ($4–$6/ft²) for large-volume purchases.
- Initial hemispherical reflectance is 93.3%.
- New mirrors produced after FY 2003 use low-lead paint system, where the lead was reduced to the point the durability is expected to remain equivalent. Base paint of the new three-layer paint system contains 2.5% lead, the intermediate paint contains 1% lead, and the white top coat remains acrylic based with high UV-stability.
- After 2 year of accelerated and outdoor exposure, the durability of mirrors with new low-lead paint system is roughly equivalent to mirrors with original high-lead paint system.

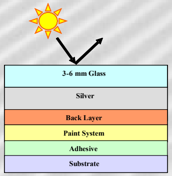


Loss of solar-weighted (SWV) reflectance of original Flabeg thick-glass mirrors as function of accelerated WOM and outdoor exposure at Phoenix, AZ (APS), Miami, FL (FLA), and Golden, CO (NREL) in Total UV Dosage.

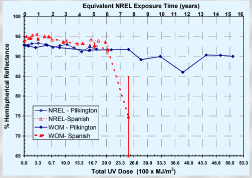


Loss of SWV and specular reflectance at 7- and 25-mrad of new Flabeg thick-glass mirrors as function of accelerated WOM (60°C/60%RH/≈3x light exposure) and outdoor exposure at NREL in Total UV Dosage.

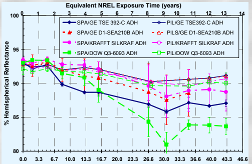
5b. Alternate Thick Glass



- Pilkington (UK) (4-mm) and "Spanish" (Cristaleria Espanola S.A—Saint-Gobain Spanish branch) glass mirrors (3-mm) with copper-free and lead-free paint for possible use at Solar Tres.
- Initial hemispherical reflectance for Spanish mirrors is 93.3% and for Pilkington is 92.8%.
- Mirrors cost ~$15 to 16/m² ($1.40 to 1.49/ft²).
- Neither Pilkington nor Spanish mirrors exposed outdoors for 72 months show degradation up to this point.
- Pilkington mirrors exhibit better durability than Spanish mirrors and adhesive-related degradation is more prevalent for Spanish mirrors exposed in WOM.
- Recently, AFG, Corning, Guardian Glass, Pilkington, and PPG glass companies and Virginia Mirror Company have expressed interest in the solar mirror market.

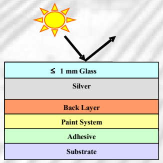


Loss of SWV of thick Pilkington and Spanish reflectors with Cu-less back-layer, Pb-free paint as a function of accelerated WOM and outdoor exposure NREL in Total UV Dosage.

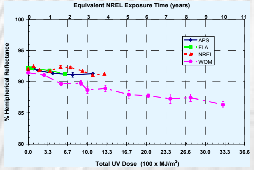


Loss of SWV of thick Pilkington and Spanish reflectors with Cu-less back-layer, Pb-free paint, and four adhesives as a function of

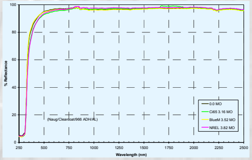
6. Thin Glass



- Thin (1-mm) lightweight glass made by wet-silvered, copper-free processes, and lead-free paints are commercially deployed.
- Initial hemispherical reflectance ≈93% to 96% and cost ~$16.1 to 43.0/m² (~$1.50 to 4.00 /ft²).
- Choice of adhesive can degrade durability of thin-glass mirrors.
- Accelerated testing of mirror constructions indicate non-mirror back-protective paint applied post-mirror manufacturing not beneficial.
- Between mirrors incorporating the new copper-free process, the Glaverbel mirror tended to outperform the Naugatuck mirror in the mirror matrix experiment after more than three years of accelerated exposure. Naugatuck used a single coat lead-free paint system and was less experienced than Glaverbel with the copper-free technique for test samples.
- CPV manufacturers concerned with durability of mirrors made with copper-free back-layer and lead-free paint system.
- The copper-free process requires stringent quality control, and the lead-free paints were developed for interior applications.
- Naugatuck Glass responded to the mirror degradation issue in FY 2006 by developing copper-free solar mirror samples with two-coat lead-free paint system plus moisture and adhesive-resistant back protection, replacing the one-coat paint system previously used in their manufacturing line. Preliminary exposure testing results encouraging and testing is ongoing.

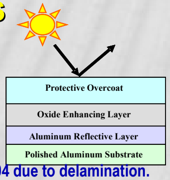


Loss of SWV of Naugatuck thin-glass mirrors with Cu back-layer and Pb-free paint as a function of outdoor exposure at APS, FLA, and NREL and accelerated WOM exposure.

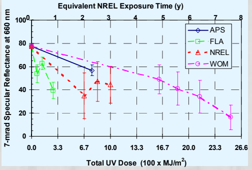


Spectral Reflectance of Naugatuck copper-free mirrors with moisture resistant coating (clear coat) laminated with 966 pressure sensitive adhesive to aluminum (Naug/Clearcoat/966 ADH/AL) after accelerated exposure in WOM and BlueM chambers and outdoors at NREL

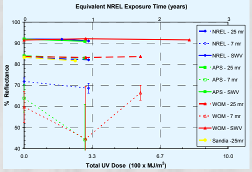
7. Aluminized Mirrors



- Mirrors with anodized aluminum substrate with PVD aluminum reflective layer and a protective oxide topcoat to enhance reflectivity have inadequate durability.
- Additional polymeric overcoat improved hemispherical durability, but specularity degraded removed from market for outdoor applications FY2004 due to delamination.
- Alanod replaced polymeric overcoat with nanocomposite oxide protective layer to solve delamination issue and tuned enhancing layer for solar. New MiroSun samples received FY2005 undergoing testing look promising. Research ongoing to replace Al PVD layer with Ag.
- Commercially available from Alanod for outdoor applications for ≈$2/ft²; initial reflectance ≈90%.

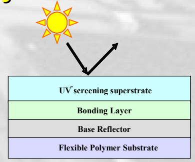


Loss of 7-mm specular reflectance at 660 nm of Alanod Miro/4270kk aluminized reflectors as a function of APS, FLA, NREL, & WOM exposure.

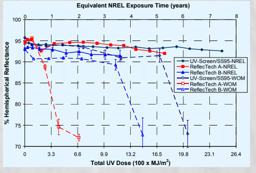


Loss of SWV, 25-, and 7-mm specular reflectance at 660 nm of Alanod MiroSun aluminized reflectors as a function of APS, NREL, Sandia, & WOM exposure.

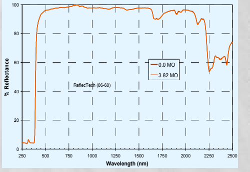
8. Silvered Polymers



- Silvered polymer with laminated UV-screening film to provide outdoor durability commercially available from ReflecTech.
- Initial hemispherical reflectance is ≈93% and cost is ≈$1.50 / ft². First pilot-plant run of most-promising construction, based on accelerated exposure testing, produced byReflecTech in FY 2001. Durability of first pilot run in WOM significantly less than anticipated.
- To improve performance, variations to baseline construction were manufactured. No degradation observed for either initial pilot run or improved prototype materials after 10 years of accelerated outdoor exposure in ACUVEX (≈7X–8X suns concentration).
- Second pilot-plant run of most-promising construction with improved UV screen was delivered FY 2005. Initial hemispherical and specular reflectivity was low due to a vacuum problem during the manufacturing process. Durability testing is ongoing.
- ReflecTech produced and delivered samples from third pilot-plant production run with improved hemispherical and specular reflectivity in second quarter of FY 2006; durability testing is ongoing.



Loss of SWV of IP prototype, initial pilot run, and most-promising variation to baseline construction as a function of outdoor exposure in Colorado and accelerated WOM exposure.



Spectral reflectance ofReflecTech third pilot run as a function of outdoor exposure in Colorado.

9. Conclusions

Glass, ReflecTech, and Alanod mirrors are commercially available and may meet the 10-year lifetime goals based on accelerated exposure testing, but predicting an outdoor lifetime based on accelerated exposure testing is risky. Recently, the construction of all of the solar reflectors has significantly changed. Because of this, all of the solar reflectors commercially available have been in outdoor real-time exposure testing for less than 3 years and their actual durability needs to be determined.