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Development and Testing of Solar Reflectors

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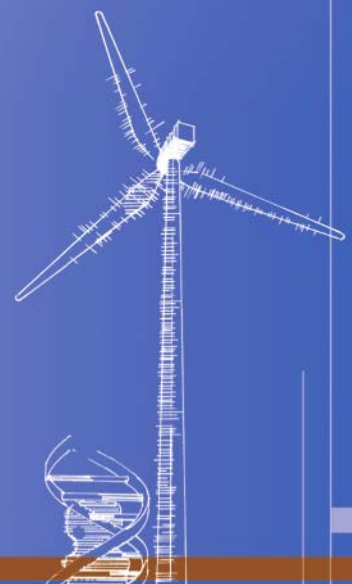

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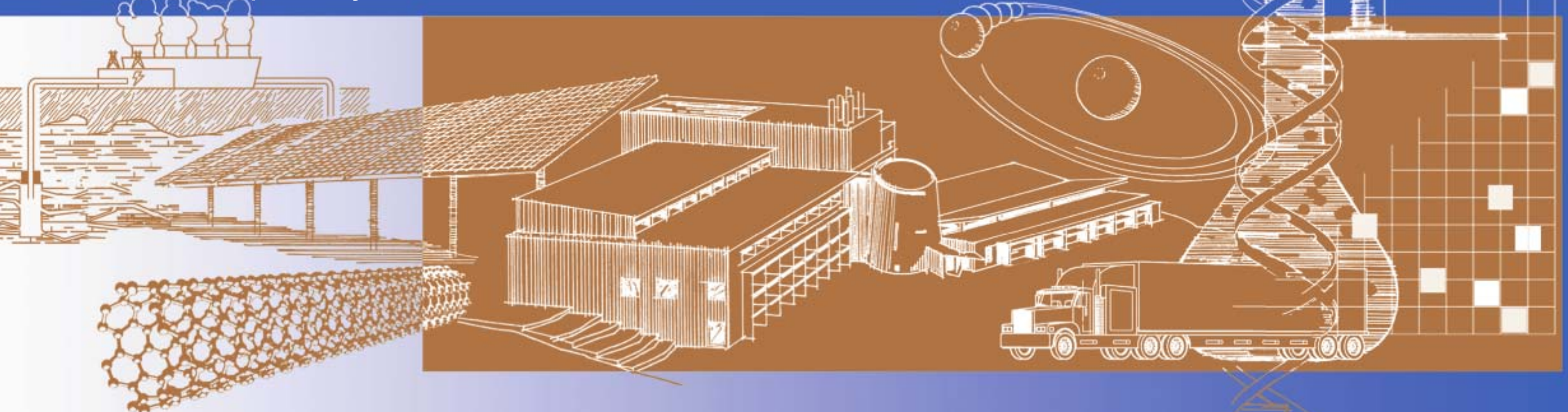

Development and Testing of Solar Reflectors

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ABSTRACT

To make concentrating solar power technologies more cost competitive, it is necessary to develop advanced reflector materials that are low in cost and maintain high reflectance for extended lifetimes under severe outdoor environments. The Advanced Materials Team performs durability testing of candidate solar reflectors at outdoor test sites and in accelerated weathering chambers. Several materials being developed by industry have been submitted for evaluation. These include silvered glass mirrors, aluminized reflectors, and front-surface mirrors. In addition to industry-supplied materials, NREL is funding the development of new, innovative reflectors, including a new commercial laminate reflector and an advanced solar reflective mirror (ASRM). To help commercialize the ASRM, a cost analysis was performed; it shows the total production cost could meet the goal. The development, performance, and durability of these candidate solar reflectors and cost analysis results will be described.

1. Objectives

The viability of CSP systems 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. Cost reductions can be achieved in lightweight front-surface reflectors that include anti-soiling coatings through technology advances, as discussed in the Solar Program Multi-Year Technical Plan [1]. The objective of this research is to identify new, cost-effective advanced reflector materials that are durable with weathering.

2. Technical Approach

Candidate reflector materials are identified based on their potential for low cost and high optical performance and durability. All candidate materials are optically characterized prior to exposure testing and as a function of exposure time to assess optical durability. These mirrors are subjected to accelerated or outdoor weathering at a variety of geographically diverse exposure sites.

3. Results and Accomplishments

3.1 Glass Mirrors

Glass mirrors have excellent durability in terms of corrosion of reflective layer, are readily available, have the confidence of the solar manufacturing industry, and are commercially deployed. However, they are heavy and fragile and curved shapes require slumped glass, which is expensive. Recently, two significant changes in mirror manufacturing have occurred in the classical wet chemistry process because of environmental concerns. The first is the method of forming a copper-free reflective mirror, and the second is the use of lead-free paints.

Trough mirrors (used in commercial solar plants), manufactured by Flabeg, use silvered, thick, slumped glass with a proprietary multilayer paint system designed for outdoor exposure. Initial hemispherical reflectance is ~93% and cost is $43.2–$64.8/m^2 for large-volume purchases. The original Flabeg mirrors (with copper back layers, original proprietary multilayer paint system, and 4-mm glass) were very durable. Flabeg converted its mirror line to 5-mm glass, the copper-free process, and a new lead-free paint system in FY 2003. The manufacturer reports durability is expected to be equivalent. Side-by-side exposure testing began in second-quarter FY 2004.

Pilkington introduced a 4-mm copper-free mirror in 2000 for interior use. Testing of samples of Pilkington and "Spanish" (Cristaleria Espanola S.A) glass mirrors (3 mm, copper-free, and lead-free paint), bonded to steel with four different candidate adhesives, was initiated in FY 2001 for possible use at Solar Tres. Initial hemispherical reflectance is 93% and their cost is ~$15 to 16/m^2. Neither Pilkington nor Spanish mirrors exposed outdoors show degradation after 30 months, but in accelerated testing (WOM) the Pilkington mirrors exhibit better optical durability and adhesive-related degradation is more prevalent with Spanish glass mirrors.

Thin-glass mirrors use traditional wet-silvered processes on thin (<1 mm), relatively lightweight glass. They have greater material costs, are more difficult to handle, and have higher associated labor costs (25%–40%) than advanced reflector technologies. Initial hemispherical reflectance is ~93% to 96% and their cost is ~$16.1 to 43.0/m^2. Choice of adhesive affects the performance of weathered thin-glass mirrors and corrosion has been observed in deployed mirrors. Initial analysis of a thin glass mirror matrix exposed in the WOM indicates commercial (non-mirror) back protective paint applied post mirror manufacturing is not beneficial. CPV manufacturers expressed significant concern regarding the durability of thin-glass mirrors made with copper-free and lead-free paint systems.

Although glass mirrors with copper backlayers and heavily leaded paints have been considered robust outdoors, the new copper-free back layer and lead-free paint systems were designed for interior mirror applications and do not have the same durability. Development of a mirror-backing paint system suitable for outdoor applications, to be applied during mirror manufacturing, will be required to provide sufficient durability.

3.2 Aluminized Mirrors

Aluminized reflectors use a polished aluminum substrate, enhanced aluminum reflective layer, and a protective oxidized topcoat [2]. The reflectors' initial reflectance is ~90% and the product was commercially available from Alanod in Germany for <\$21.52/m^2. The major concern has been poor durability of such materials in urban and industrialized (polluted) locations. An improved anodized aluminum mirror incorporated a protective polymeric overcoat onto PVD aluminized aluminum. However, specularity degraded with outdoor exposure at Arizona, Florida, and NREL, and with accelerated exposure in the WOM. Aluminized reflectors from other manufacturers exhibit similar performance. Recently, Alanod stopped selling this material for outdoor use because of problems associated with the delamination of the overcoat. The company is working to find a solution and to improve the abrasion resistance of the reflector [3].

3.3 Silvered Polymer Reflectors

A new polymeric solar reflector developed through collaborative research with ReflecTech has an initial solar-weighted hemispherical reflectance of 94%, a specular reflectance of 94% at 25-mrad (1.4°) acceptance angle, and can be supplied in roll widths up to 1.2 m for less than \$14/m^2. In FY 2001, a very small pilot run on standard commercial equipment demonstrated that all production steps could be achieved using standard commercial film converter equipment. This initial pilot-run material shows no significant loss in solar-weighted reflectance after 2.5 years of real-time outdoor exposure in Golden, CO. In addition, accelerated ACUVEX® outdoor weathering tests (natural sunlight in Phoenix, AZ, is concentrated 7 to 8 times with a Fresnel-reflector while the samples are cooled with a fan to near ambient conditions and sprayed with deionized water 8 min per natural sun hour [4]) are near a 10-year equivalent time period, and show no significant loss in solar-weighted reflectance. However, WOM results showed significant reflectance loss earlier than anticipated. Prototype materials to test modifications to the baseline construction were produced using pilot-line coating equipment. These tests were successful in identifying changes to the baseline construction that dramatically improved the accelerated weathering durability of the reflective film. These improvements were then incorporated into a new pilot plant production run delivered late FY 2004; durability testing is ongoing and the material is being deployed. We expect the new reflector to considerably outperform the original material (which has maintained durability after 10 equivalent years of ACUVEX® exposure), however testing has only recently been initiated, and further real time exposure will be needed to determine its actual lifetime.

3.3 Advanced Solar Reflective Mirror (ASRM)

A promising low-cost reflector material, developed under a subcontract with Science Applications International Corporation (SAIC) that ended 9/30/04, has a silvered specular substrate protected by an alumina coating several microns thick. The alumina hard coat is deposited by ion-beam-assisted deposition (IBAD). Samples of this "super thin glass technology" have been deposited at 20 nm/s both by batch and on a laboratory roll-coater. Many samples prepared have maintained 95% hemispherical reflectance after more than 3 years accelerated and outdoor exposure; testing is continuing. A new cost analysis shows the ASRM has the potential for a manufacturing cost lower than \$10.76/m^2, but the deposition rate must be increased to 30–50 nm/s [5,6]. Although thin oxide coatings are routinely deposited at deposition rates greater than 100 nm/s, increasing the deposition rate while maintaining the optimized IBAD deposition conditions could be difficult. For long-term durability, edge protection will be necessary and the addition of adhesion-promoting layer could improve durability. The ASRM can be transitioned to a commercial roll-coating company, with SAIC's consultation, if NREL establishes the relationship. Prior to transition, a short subcontract to evaluate different web materials, adhesion-promotion and anti-soiling layers, and use of a lower-purity alumina is warranted.

4. Conclusions

Positive progress has been made to develop an advanced solar reflector, but work has been severely limited due to a lack of funding during the last few years. Durability testing of the reflectors supplied by industry is ongoing. The glass mirrors, ReflecTech, and ASRM may meet the 10-year lifetime goals based on accelerated exposure testing. However, predicting an outdoor lifetime based on accelerated exposure testing is risky. At this time, because all solar reflectors have recently changed their production considerably, none of the solar reflectors available have been in test long enough to demonstrate the 10- to 30-year lifetime goal, outdoors in real time.

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