Solar Optical Materials Research and Development

Gary Jorgensen, Greg Barber, Cheryl Kennedy, Rod Mahoney, Tom Mancini, Kent Terwilliger

CSP Peer Review

November 8, 2001

Albuquerque, NM

Outline

- Background
- Current Status
- Important Accomplishments
- Problematic Issues
- Summary

Background

- Objectives
  - Identify and evaluate advanced solar optical materials for CSP applications that meet industry's needs and goals
  - Investigate failure mechanisms to allow improvements in candidate material constructions
- Importance
  - Industry has urgent need for less expensive solar mirrors having greater optical durability
  - Addresses both near-term (reliability) and long-term (cost) CSP issues
  - Can provide tangible contribution to 50-75% cost reduction required by CSP technologies to become economically viable
    - Reflector
    - Structure
    - Drive/controls
    - Manufacturing

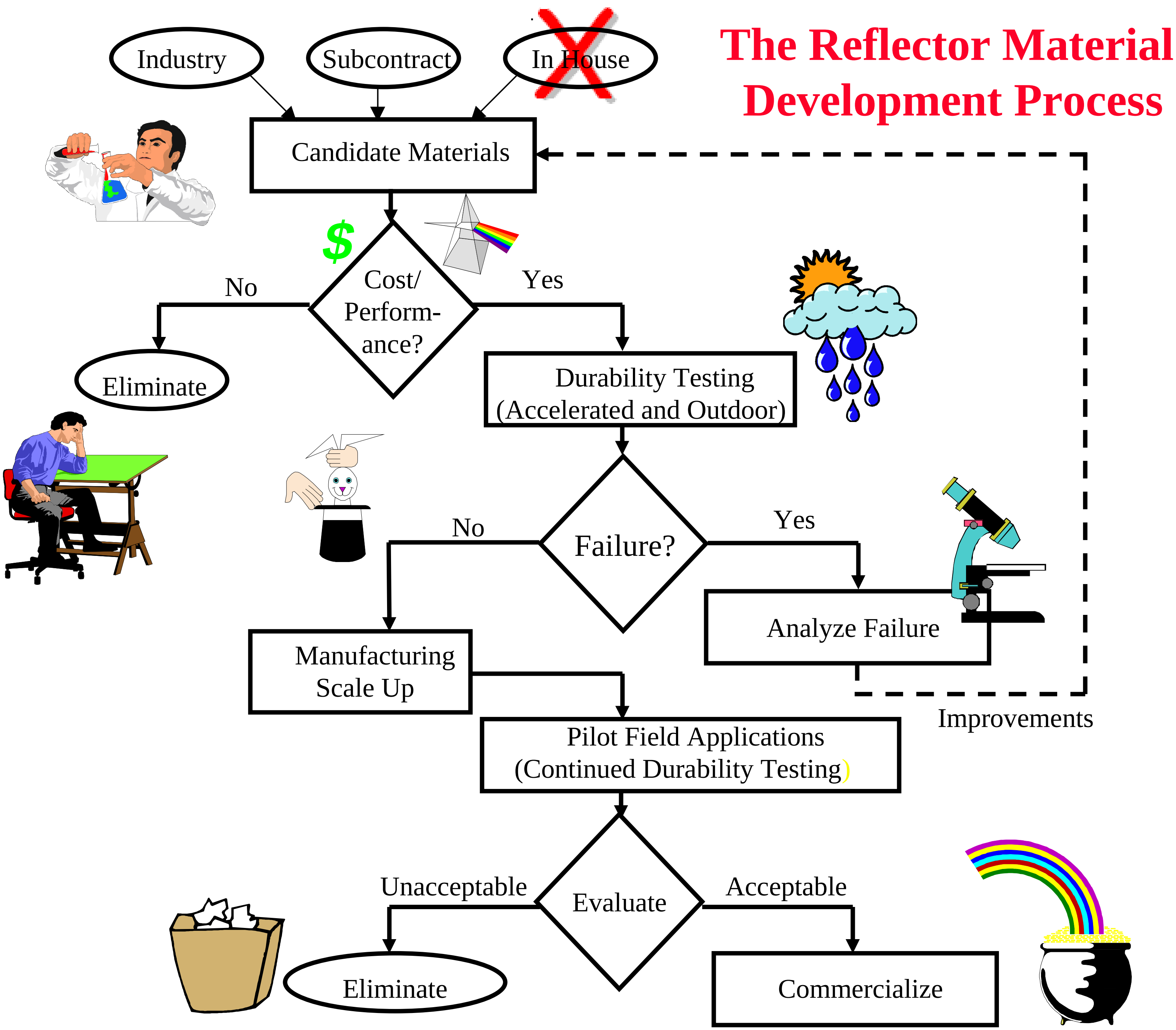
Current Status

- Recent programmatic/strategic assessments completed
  - FY00 expert panel review
  - Strategic plan for optical materials (OM) R&D developed
  - Activities modulated by funding limitations
- Promising candidate materials under consideration
  - New thin glass formulations
  - New thick glass products
  - Super thin glass construction
  - All-polymeric material
  - Commercial laminate
  - Aluminized reflector

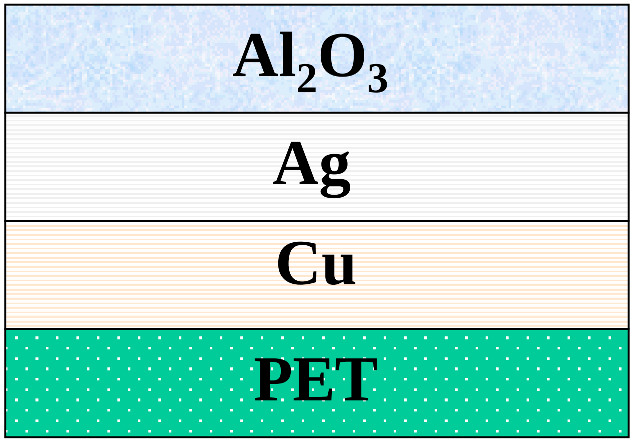
Recommended and Ongoing (underlined) Prioritized Activities

1. Accelerated testing of optical performance of near-term materials
2. Expand analysis and fundamental understanding of material failure mechanisms
3. Actively participate on Advanced Concentrator Team (ACT) to integrate strategic activities
4. Maintain outdoor test sites and procedures
5. Create an optical materials database on the CSP Sun♦Lab Website
6. Screen new/improved materials using advanced testing capabilities
7. Enhanced solar mirror cleaning technologies
8. State-of-the-art knowledge of developments in optical materials

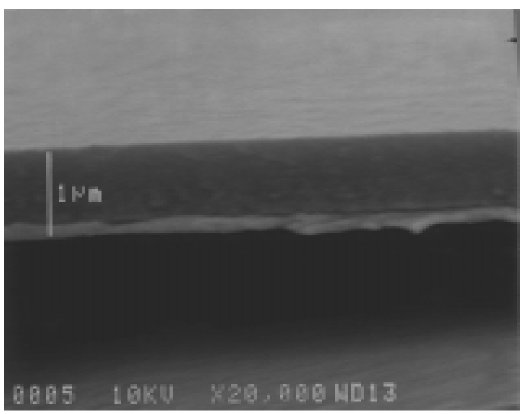
The Reflector Material Development Process



SAIC IBAD "Super Thin Glass" Mirror



SEM of Al_2O_3/Ag/Cu/PET:



- Benefits of polymer substrate and durability of glass. Ion Beam Assisted Deposition (IBAD) is used to deposit very hard (cleanable) dense (protective) alumina topcoat.
- Subcontracted effort by SAIC McLean, VA
- Cost depends on deposition rate; ~$1/ft^2 with a deposition rate of 30-60 nm/s.
- Samples are highly reflective (>95%) with excellent durability
- Roll coater demonstrated; levelized substrate identified; structural facet deployment planned in FY03

Solar Mirror Chronology

- Early 1980's: Thick glass mirrors
- Mid 1980's - Early 1990's: Stretched membrane designs; metallized polymer reflectors
- Mid 1990's: Thin glass mirrors
- Late 1990's: Protected front surface reflectors
- Others

Promising Solar Mirrors

Examples of promising solar mirrors shown here.

Important Accomplishments

- Promising candidates identified and failures eliminated
  - New / improved formulations of thin glass mirrors devised
  - Super-thin glass construction being developed by subcontractor
  - Commercial laminate construction being pursued jointly with industry
  - All polymeric mirror being tested
  - Interactions with industry on commercial aluminized reflector
- Aggressive 5-year goals for mirror development met
- Activities reviewed by expert panel and strategic plan developed
- State-of-the-Art deposition system activated; process parameters explored; successful constructions fabricated; activity terminated

Key Patents

- Schissel, P. O., et al, "Durable Metallized Polymer Mirror", U. S. Patent # 5,361,172, November 1, 1994.
- King, D. E., et al, "Molecular Assemblies as Protective Barriers and Adhesion Promotion Interlayer", U. S. Patent # 5,487,792, January 30, 1996.
- Jorgensen, G. J., et al, "A Durable Corrosion and Ultraviolet-Resistant Silver Mirror", NREL IR# 97-33, provisional patent filed August 5, 1999.

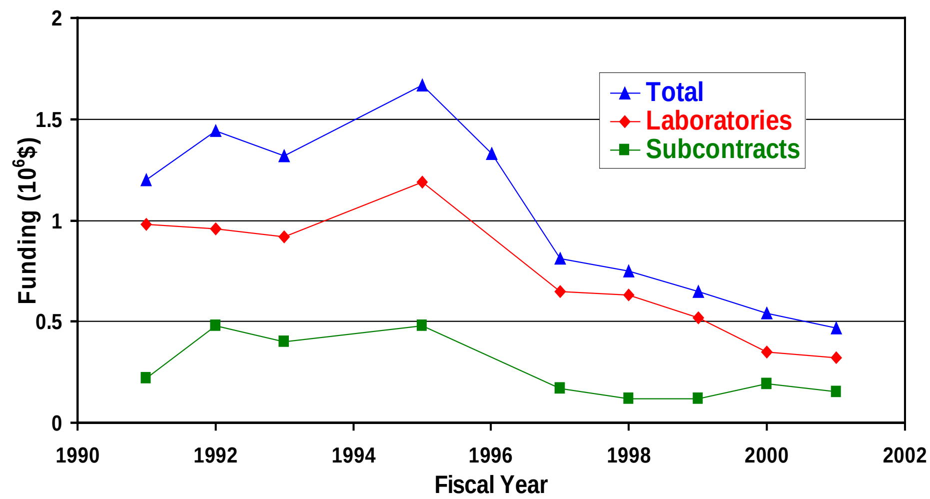
Major Publications

- "Silvered-PMMA Reflectors", Schissel, P., Jorgensen, G., Kennedy, C., and Goggin, R., *Solar Energy Materials & Solar Cells* 33 (1994) 183-197.
- "Role of Inorganic Oxide Interlayers in Improving the Adhesion of Sputtered Silver Film on PMMA", Schissel, P., Kennedy, C., and Goggin, R., *J. Adhesion Sci. Technol*., 9/4 (1995) 413-424.
- "Optical Performance and Durability of Solar Reflectors Protected by an Alumina Coating", Kennedy, C.E., Smilgys, R.V., Kirkpatrick, D.A., and Ross, J.S., *Thin Solid Films* 304 (1997) 303-309.
- "Interfacial Chemistry of Accelerated Weathered Metallized Polymer Materials", King, D., and Jorgensen, G., *Service Life Prediction of Organic Coatings, A Systems Approach, ACS Symposium Series 722*, D.R. Bauer and J.W. Martin, Eds., American Chemical Society, (1999) 288-297.
- "Applicability of Highly Reflective Aluminum Coil for Solar Concentrators", Fend, T., Jorgensen G., and Küster, H., *Solar Energy*, 68/4, (2000) 361-370.
- "Use of Uniformly Distributed Concentrated Sunlight for Highly Accelerated Testing of Coatings", Jorgensen, G., Bingham, C., King, D., Lewandowski, A., Netter, J., Terwilliger, K., and Adamsons, K., In *Service Life Prediction Methodology and Metrologies*; Martin, J. W., and Bauer, D. R., Eds.; ACS Symposium Series 805; American Chemical Society, Oxford University Press: Washington, DC (2001); (in press).

Problematic Issues

- Progress slowed
- Threat of losing key core capabilities
  - Loss of analytical characterization support
  - One accelerated test chamber deactivated
  - Three outdoor exposure test site decommissioned
  - Specular reflectometer in need of repair/upgrade

Funding Trends (in FY01 $'s)

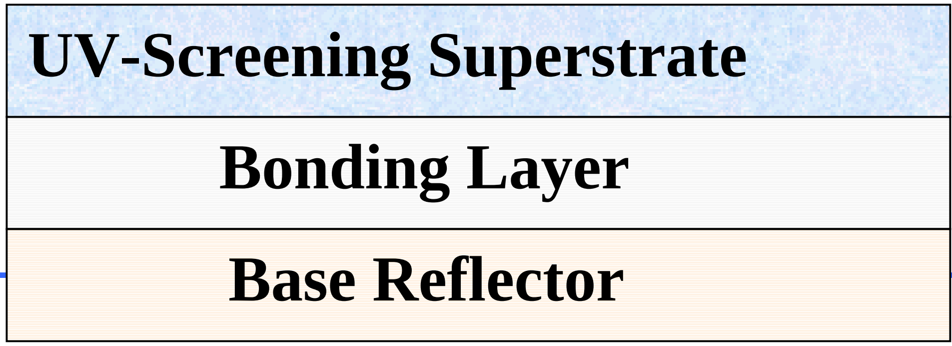


Summary

- Urgent immediate and near-term needs exist to keep the program alive, but the ultimate success of CSP technologies will depend on addressing important long-term concerns
- Addresses several critical CSP Program needs:
  - Need dramatic reduction in costs
  - Need more than mere incremental improvement in performance
- Addresses specific concerns identified in multi-path technology roadmaps
  - Hardcoats for troughs
  - Moderately steep curvatures for small dishes
  - Manufacturing issues related to 10kW dish systems
  - Increases confidence of prospective solar manufacturers
  - Supports long term R&D efforts

Commercial Laminate Reflector

- Joint patent by Sun⌛Lab and industry partner (ReflecTech).
- Base commercial silvered polymer with UV-screening film laminated to provide outdoor durability.
- Initial hemispherical reflectance is ~92% and cost is ~$1.50 / ft^2.
- 2000 ft^2 of pilot plant product produced by ReflecTech during FY01; additional 2000 ft^2 to be produced in FY02.
- Material being deployed in field systems by solar manufacturers.



Thick Glass Mirrors

- Excellent durability, readily available, and manufacturer confidence
- Heavy and fragile; curved shapes are difficult & costly
- Initial hemispherical reflectance is ~88-92%; cost is ~\$1.50-4.00 /ft^2.
- Testing of samples of Pilkington and "Spanish" glass mirrors (copper-less and lead-free paint), bonded to steel with four different candidate adhesives, was initiated during FY01; possible use at Solar Tres.

Wind Damage to Glass Mirrors

1.0 mm Glass
Ag
Adhesion Layer
Paint
Adhesive
Substrate

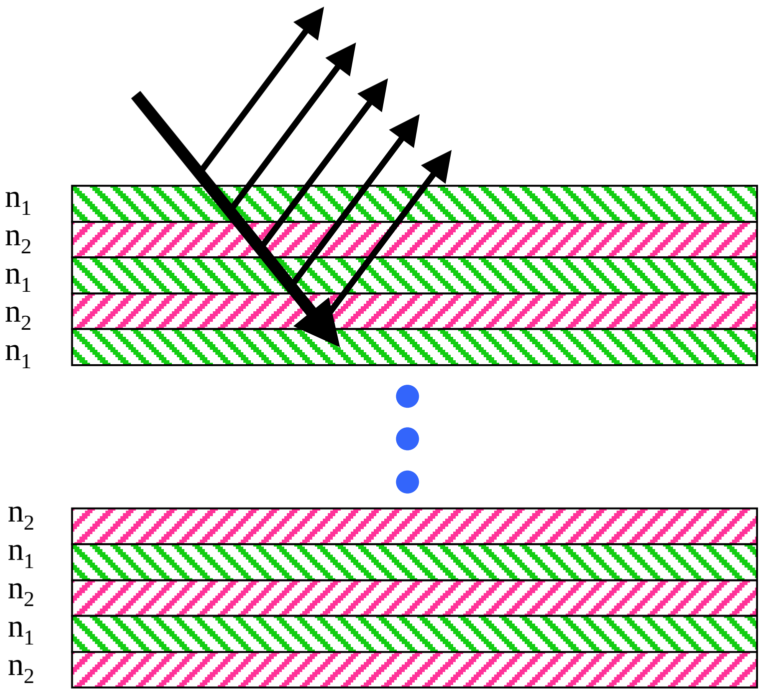
Thin Glass Mirrors

≤1.0 mm Glass
Ag
Cu
Paint
Adhesive
Substrate

Photo of in-service corrosion:

- Durability of wet silvered processes using a thin, relatively lightweight glass; greater material costs, difficult to handle, and higher associated labor costs
- Initial hemispherical reflectance is ~93 to 96% and cost is ~\$1.50 to 4.00 /ft^2.
- Deployed in commercial installations; choice of adhesive adversely affects performance; corrosion seen in the field
- During FY01, degradation mechanisms were investigated and standard mirror painting practices were surveyed.
- Accelerated testing of new sample constructions (mirror type / back protective paint / adhesive / substrate) has begun.

All-Polymeric Reflector



- Alternating polymers are coextruded; multiple reflectance produced due to mismatched indices of refraction.
- Benefit of a polymer substrate, potential for very high reflectance (~99%), no metal reflective layer to corrode.
- Samples provided in FY99 had poor UV durability.
- 3M has agreed to provide samples with improved UV screening layers and is interested in incorporating abrasion resistant hardcoat.

Front Surface Aluminized Reflector

- Front surface aluminized reflectors; anodization provides inadequate durability; polymeric overcoat improves durability
- Acrylic overcoated material failed in accelerated testing; replaced by fluoropolymer overcoat; new formulation under test.
- Structural facets for field deployment were fabricated during FY00.
- Product is commercially available from Alanod in cooperation with the DLR in Germany for <\$2/ft^2; initial reflectance ~90%.