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Advanced Reflectors

Project Title: Advanced CSP R&D

Program Team: CSP

Presenter: Cheryl Kennedy

Organization: NREL

Contact Info: cheryl.kennedy@nrel.gov

Date: May 24-27, 2010

Overview

Budget

- FY09 Funding: 725K
  - Adv Ref: 475K
  - Adv Ref FOA: 250K
- FY10 Funding: 1680K
  - Adv Ref: 1280K
  - Adv Ref FOA: 400K

Barriers

- High capital costs
- Plant performance
- Component reliability
- High O&M

Partners

Interactions/collaborations:

Main Industry Collaborations:

- 3M
- Abengoa
- Alanod
- Alcan
- ASG
- Evonik
- Flabeg
- Dunmore
- Guardian
- JDSU
- Naugatuck
- ReflecTech
- RioGlass
- Saint Gobain
- Samsung
- SES
- SkyFuel
- Valspar

FOA Support:

- 3M
- Abengoa
- Alcoa
- PPG

CRADA:

- 3M
- SolFocus

Laboratory:

- Ciemet
- DLR
- Sandia

University:

- CSM
- Harvey Mudd
- Metro
- UCB

Challenges, Barriers or Problems

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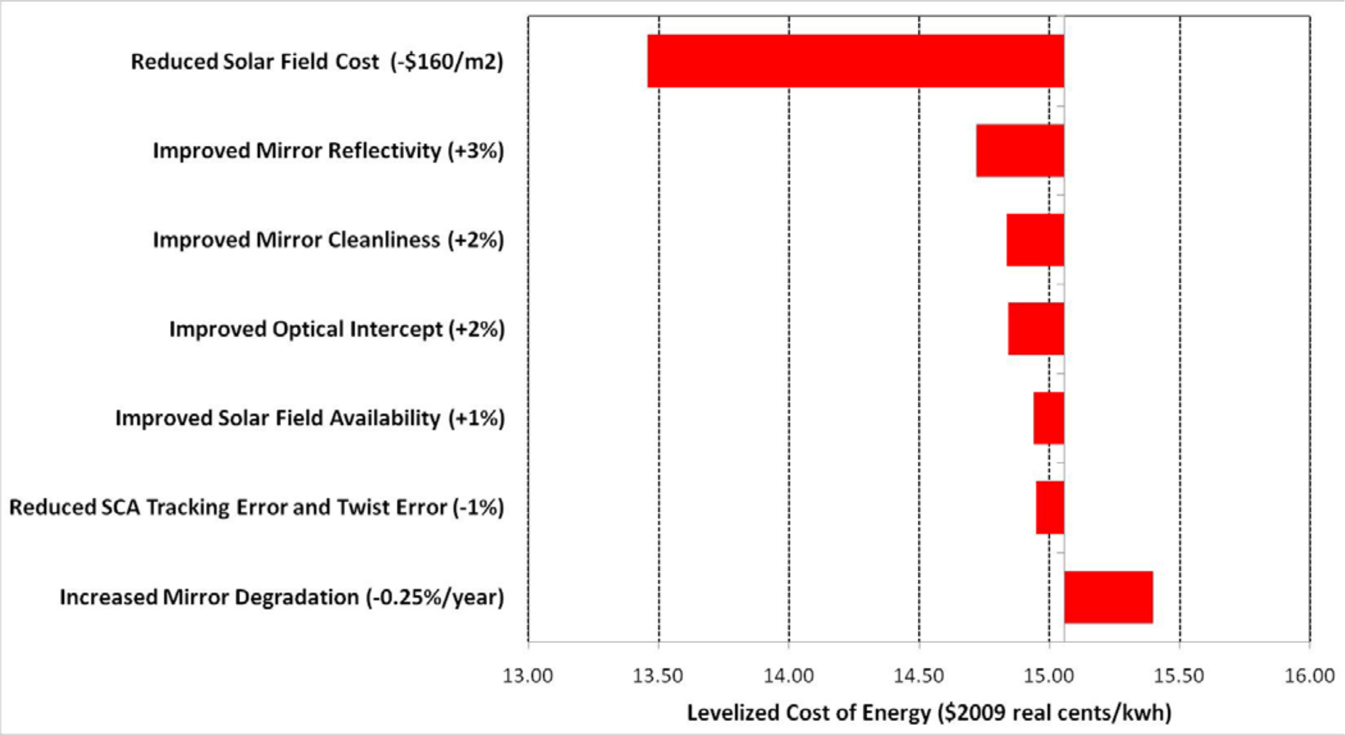
- Mirrors represent 21% and collector frame 35% of collector field material cost
- Reflectance (ρ) has 1:1 correspondence with LCOE (ρ↓5% → LCOE ↑5%)
- Current silvered low-iron glass solar mirrors ρ_{ave} is 93%; the ρ_{max} is 98.6% for silver



- Critical to improving plant performance & reducing trough LCOE by 0.3 – 1.6 ¢/kW-h
  - Performance improvements: mirror reflectance, durability, & cleanliness
  - Cost reductions: mirror, collector frame, & installation labor

Objectives

- To develop, validate, and aid commercialization of advanced reflector systems that can dramatically reduce cost of electricity generated by CSP:
  - Develop advanced reflector materials that maintain >95% specular reflectance (cone angle is technology dependent) for long lifetimes (30 years) under severe outdoor environments and are low in cost.
  - Test durability of optical materials to determine lifetime of solar reflector materials
- Support Advanced Reflector FOA projects and industry/program needs
  - Technical advice & review
  - Optical characterization & durability testing of materials developed under CSP FOA subcontracts to determine their lifetime.

Approach

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- Advanced Reflector
  1. Mirror Characterization and Testing
  2. Service Lifetime Prediction (SLP)
  3. Advanced Reflector Coatings Development
  4. Antisoiling Coatings and low-to-no H_2O Cleaning methods
  5. Reflector and Durability Standards Development

- Advanced Reflector and Baseload FOA Support
  - 3M – Hardcoats for Polymeric Mirrors
  - Alcoa*– Aluminum Intensive Collector (supporting structure ‡ & reflector †)

    *Alcoa FOA Support in Advanced CSP Concepts in FY09 and in Line Focus Systems in FY10.

    †In FY10, Advanced CSP R&D supported Alcoa reflector durability

    ‡In FY10, Line Focus Systems supported with VSHOT and 2-axis tracking.
  - Abengoa – Advanced Front Surface Polymeric Reflector
  - PPG – High Value Mirrors
  - Baseload – RFP & proposal review

Approach

- Advanced Reflector research plan in line with CSP roadmaps
- Near-term research directed at:
  - Measure optical and material properties of potential solar materials:
    - Optical: Hemispherical & specular reflectance , transmittance
    - Material: Abrasion, adhesion, barrier, mechanical, thermal stability
    - Surface analytical: composition, morphology, stoichiometry
  - To determine optical material durability samples are characterized initially and as a function of outdoor and accelerated exposure time
  - Support NREL, SNL, universities, FOA and CSP industry partners

Approach

- Long-term, fundamental research directed at:
  - Develop Service Lifetime Prediction (SLP) methodology & acceleration factors for basic families of solar mirrors :
    - Metalized (Ag & Al) polymer
    - Silvered glass
    - Anodized aluminum (enhanced reflectance)
    - Front surface mirrors
    - Multilayer all-polymeric
  - Develop advanced reflector coatings using lessons learned & technology improvements
  - Develop antisoiling coatings and low-to-no H_2O cleaning methods
  - Support development of qualification tests and standards on solar mirror reflectance measurements & durability testing

FY10 Milestones:

Advanced Reflectors

1. Mirror Characterization and Testing
   - Implement web accessible database. ***4** (3/10) – behind*
     - *(new cyber security & procurement requirements delayed placement of subcontract; expanded scope at no additional cost)*
   - Report on solar mirror durability***4** (9/10) – on track*
   - Design and build spectral specular reflectance (SSR) (i.e. 2-mrad laboratory) instrument ***4** (9/10) – on track*
2. Service Lifetime Prediction (SLP)
   - Report application of SLP methodology to 3M silvered polymer "Solar Reflector 1000" ***4** (9/10) – behind*
     - *(waiting receipt of 3M samples)*

FY10 Milestones:

Advanced Reflector & Baseload FOA Support

- Report on VSHOT and 2-axis tracking for Alcoa collector ***4*** *(4/10) – behind*
  - *(being edited)*
- Report on status of FOA projects ***4*** *(9/10) – on track*
- Report on VSHOT and 2-axis tracking for PPG prototype glass trough mirrors from Phase III ***4*** *(9/10) – delayed*
  - *(PPG recently began 6-mo no-cost extension near end of Phase II)*

FY 11 Proposed Milestones:

Advanced Reflectors

- Report durability of candidate solar mirrors ***4** (9/11)*
- Develop advanced FSM incorporating antisoiling coatings & characterize improvements ***5** (9/11)*
- Report consensus reflectance measurement procedure between NREL, DLR, and Ciemet and results of round-robin mirror testing ***5** (12/10)*
- Complete expansion of Advanced Optical Materials Laboratories and bring all tools to fully operational status for DOE National Laboratories Research projects FOA under American Recovery and Reinvestment Act ***3** (9/11)*

Advanced Reflector & Baseload FOA Support

- Report on status of FOA projects ***4** (9/11)*

1. Mirror Characterization & Durability Testing Task

- FY09 & FY10– Characterize industry supplied solar reflectors, analyze data, and report status of mirror durability

Mirror Characterization

- Samples *supplied by:*
  - *Industry*
  - *Subcontracts*
  - *Developed in-house*

- Measure optical and mechanical properties of potential solar materials.

- Characterize samples initially and as a function of exposure time in outdoor (OET) and accelerated exposure testing (AET).
  - *Typically characterize >1000 samples/mo*

Accomplishments / Progress / Results

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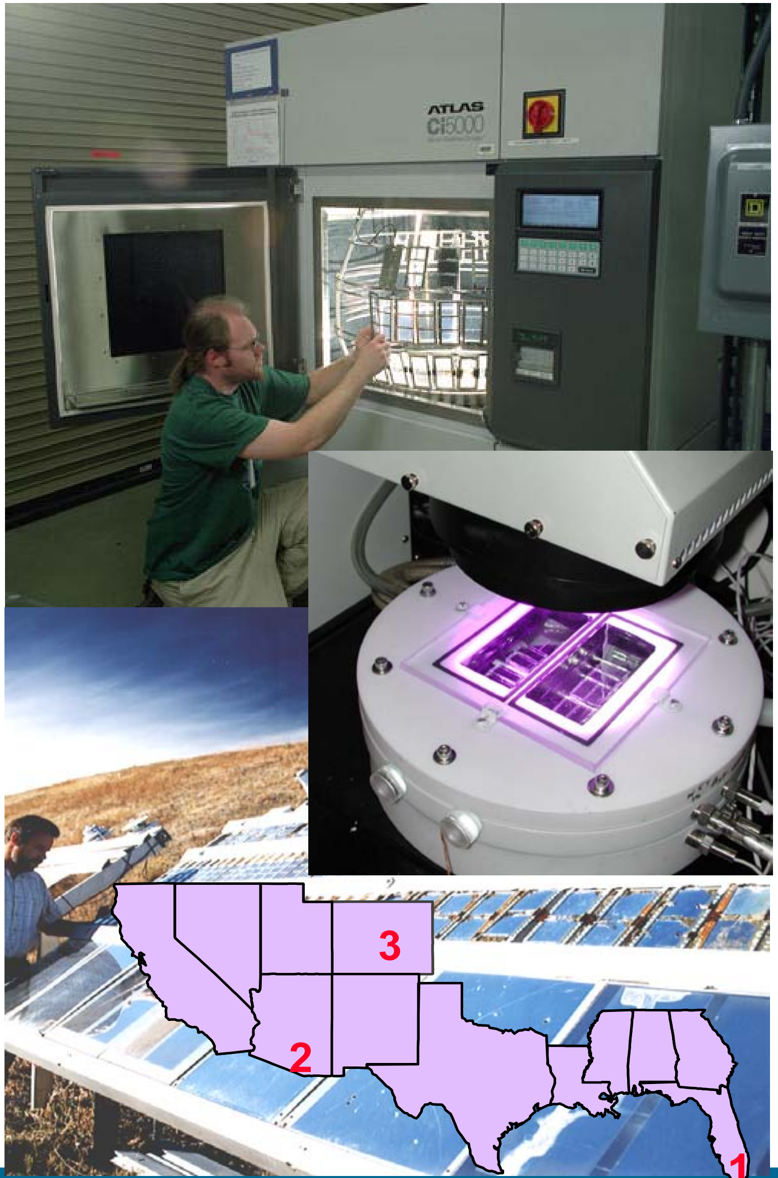
Durability Testing

- Durability of solar materials tested as a function of exposure time
- Samples are exposed at three outdoor exposure test sites and in several accelerated exposure test chambers
  - *Roughly 10,000 advanced reflector & solar selective samples are currently under test for CSP (& CPV) industry*

Database of solar materials contains

- >1000 experiments
- >30,000 samples
- >500,000 measurements
- Dirty/Clean measurements
- >24 yr



Approximation of Solar-weighted Specular Reflectance

- Measure spectral hemispherical reflectance: $\rho_{2\pi}(\lambda)$
- Compute solar-weighted hemispherical reflectance:

$$\rho_{2\pi} = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} \rho_{2\pi}(\lambda)\, I(\lambda)\, d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} I(\lambda)\, d\lambda}$$

- Then measure specular reflectance, $\rho_s(\theta,\lambda)$, as function of acceptance angle at a particular wavelength (e.g., $\lambda \approx 660$ nm)
- Solar-weighted specular reflectance is often approximated[1] as:

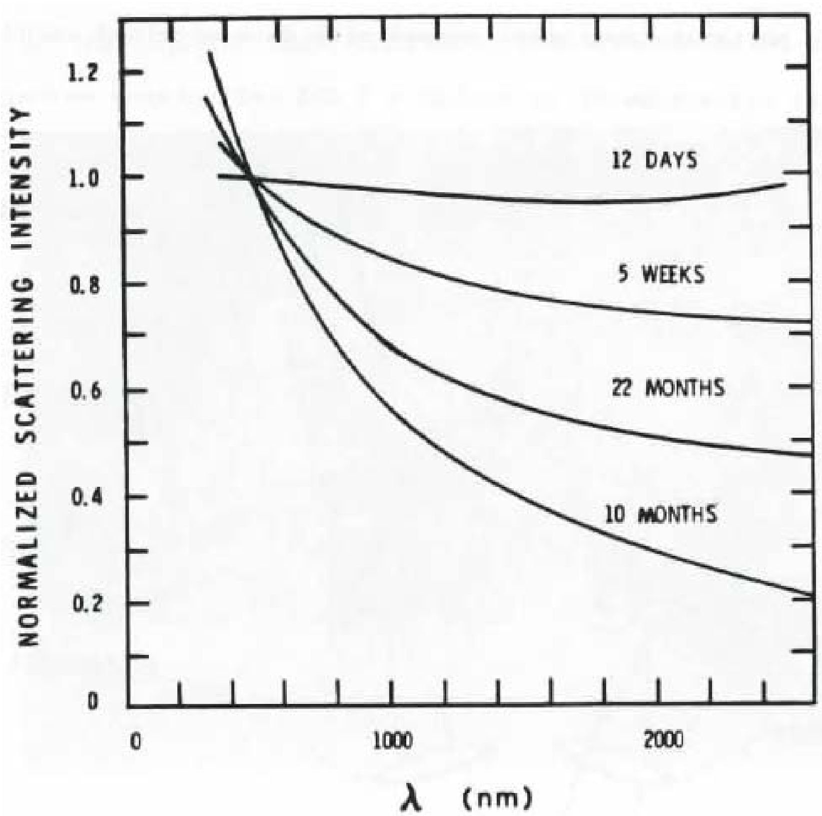
$$\rho_s(\theta) = \rho_{2\pi} * \frac{\rho_s(\theta,\lambda)}{\rho_{2\pi}(\lambda)}$$

[1] Pettit, R.B., “Characterizing Solar Mirror Materials Using Portable Reflectometers”, SAND82-1714, September 1982.

Specularity is wavelength dependent

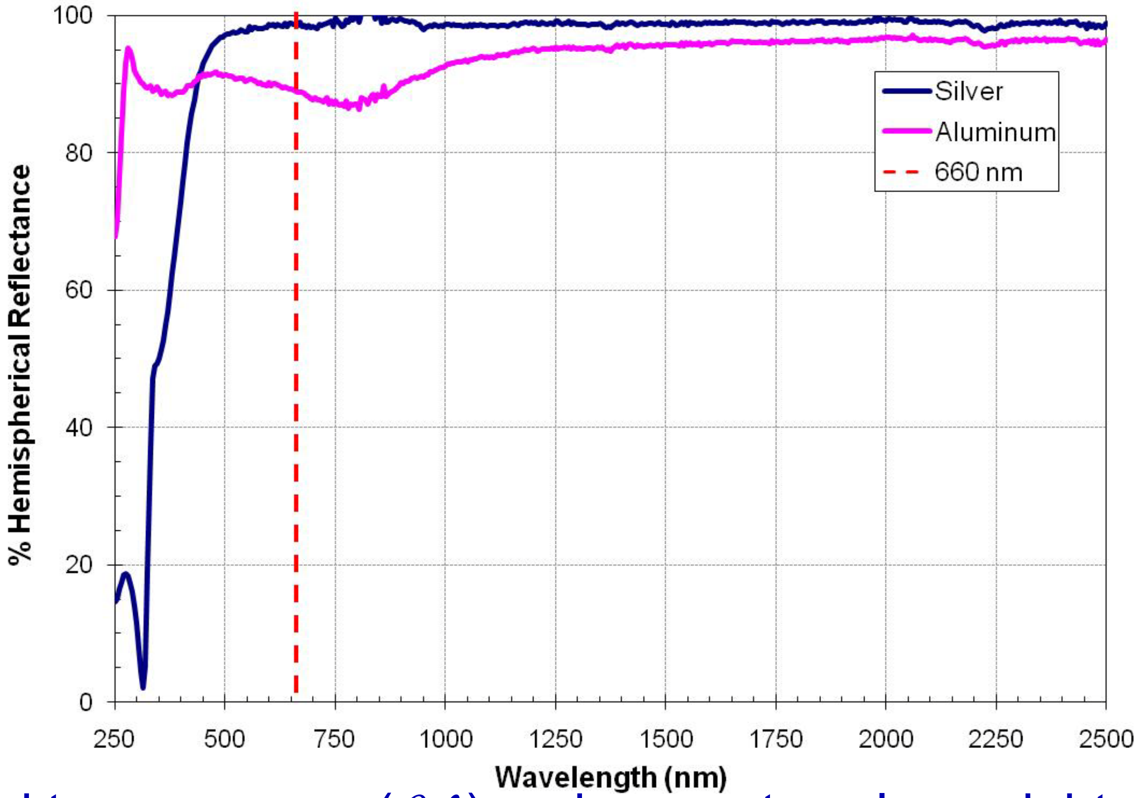
- But specularity (σ) is wavelength (λ) dependent:

$$\rho_s(\theta,\lambda) = \rho_{2\pi}(\lambda)\left\{1 - \exp\left[\frac{-\theta^2}{2\sigma^2(\lambda)}\right]\right\}$$



Wavelength dependence of specular reflectance loss caused by dust accumulation during outdoor exposure[1]

Specularity is wavelength dependent



- Therefore, need to measure $\rho_s(\theta,\lambda)$ and compute solar-weighted specular reflectance:

$$\rho_s(\theta) = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} \rho_s(\theta,\lambda)\, I(\lambda)\, d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} I(\lambda)\, d\lambda}$$

Spectral Specular Reflectometer (SSR)

- Desire spectral specular reflectance, $\rho_s(\lambda,\theta)$
  - λ = 300-2500 nm
  - θ = 2 – 50 mrad
- Pinhole diameter selects acceptance angle θ
- Measure spectral specular reflectance for several values of θ
- Spectral hemispherical reflectance, $\rho_{2\pi}(\lambda)$, measured by UV-VIS-NIR with integrating sphere
- Fit equation to obtain $\sigma(\lambda)$

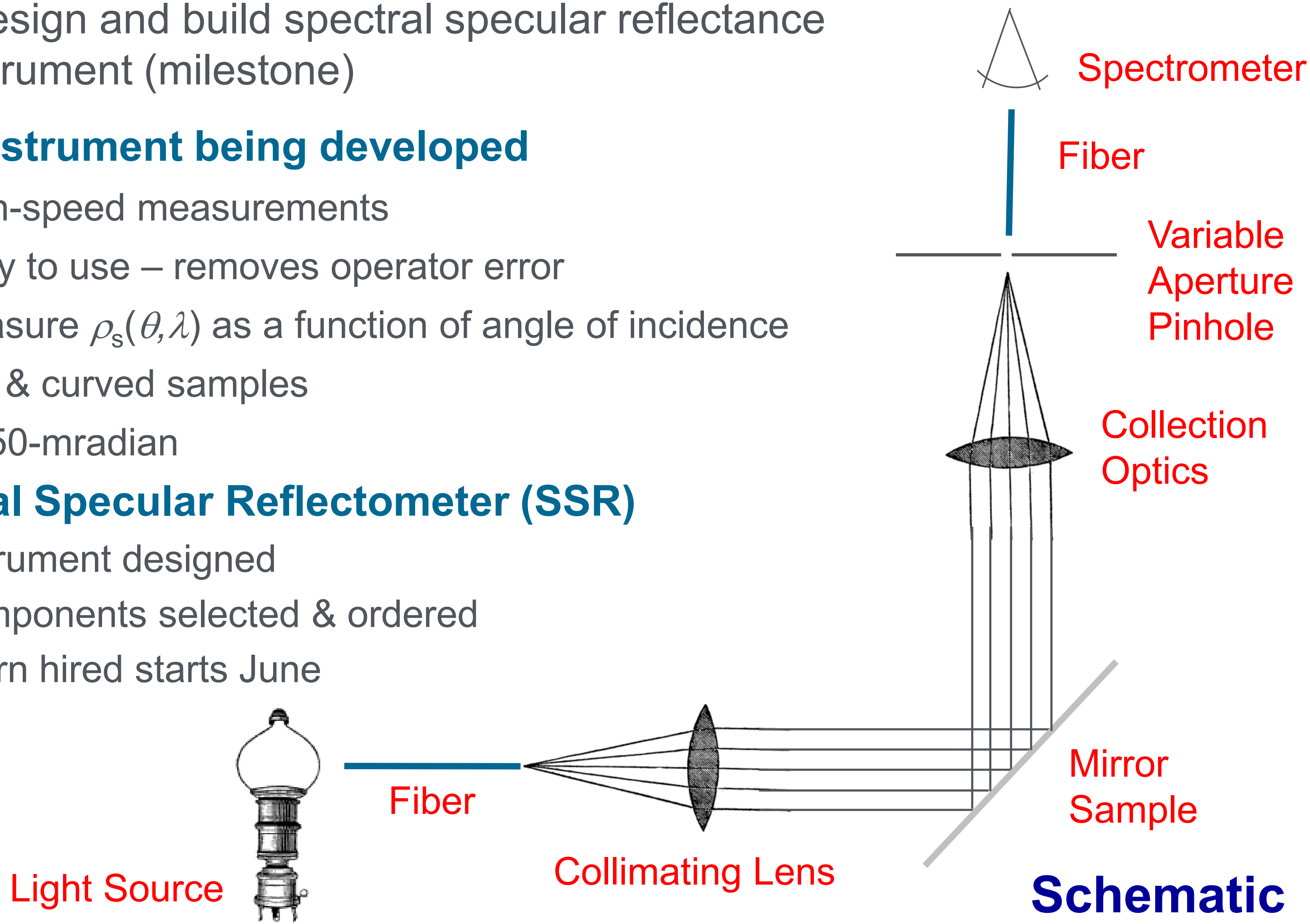
$$\rho_s(\lambda,\theta) = \rho_{2\pi}(\lambda) * \left\{1 - e^{-[\theta/\sigma(\lambda)]^2/2}\right\}$$

- $\sigma(\lambda)$ allows specular reflectance at any θ (and all λ) to be calculated

Accomplishments / Progress / Results

FY10 – Design and build spectral specular reflectance (SSR) instrument (milestone)

- **New instrument being developed**
  - High-speed measurements
  - Easy to use – removes operator error
  - Measure $\rho_s(\theta,\lambda)$ as a function of angle of incidence
  - Flat & curved samples
  - 2 - 50-mradian
- **Spectral Specular Reflectometer (SSR)**
  - Instrument designed
  - Components selected & ordered
  - Intern hired starts June



Schematic

Upgrade database

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FY10 – Implement web accessible database (milestone)

- **Current Database**
  - Older DOS menu driven RS/1 that is difficult to use
  - Database has been fractured into data in RS/1 & Access/Excel
  - Tracking samples, processing & transferring data is labor intensive & inefficient
- **Upgrade database with goals**
  - Improved samples tracking & scheduling with automatic updating of graphs
  - Data web accessible with non-PI data available
  - PI secure password protected log-in, graphing, & file transfer
- **Database upgrade programming underway**
  - Subcontract placed w/ EMagenit
  - Delivery delayed because
    - New cyber-security & procurement regulations delayed subcontract start date > 6 mo
    - Resulting in NREL's project in queue behind existing EMagenit contracts
    - Scope expanded at no extra cost because scheduling system developed for another project would give additional capabilities

Accomplishments / Progress / Results

- Three-part database program being developed contains:
  1. Scheduler program to manage technicians, samples, and equipment internally.
  2. Schedule reader program for technicians to view assigned samples, technicians, and equipment scheduling.
  3. Data viewer to chart reflectance and durability data for distribution to clients.

  – Delivery of 3-parts of program on or before May 31 for β-testing
  – Roll-out and implementation of full web-accessible database planned for June 30; date dependent on β-testing results
- Final roll-out will be as link from NREL's Deployment & Industry Partnerships office web page of NREL's databases

Architecture of Glass Mirror

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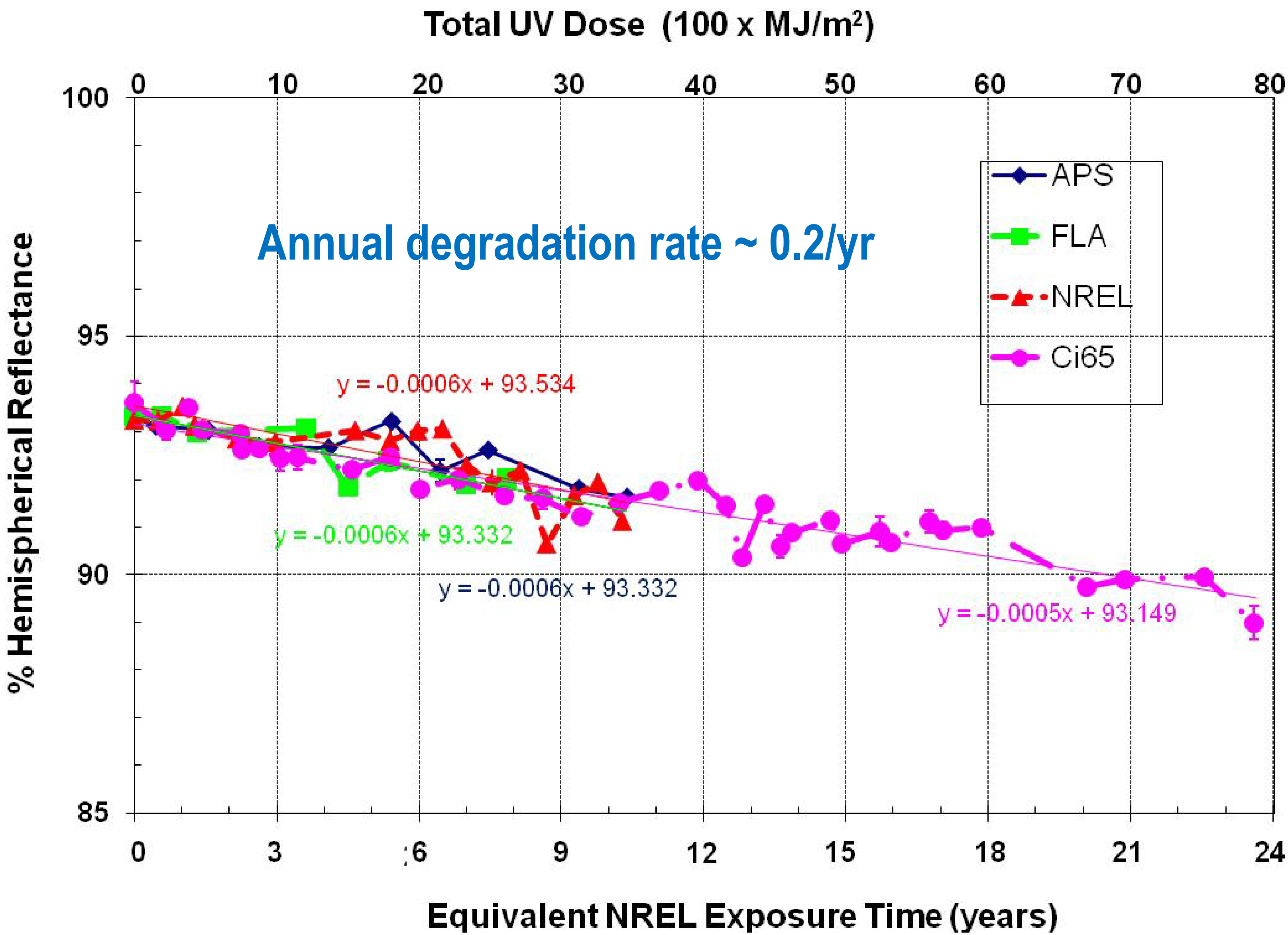
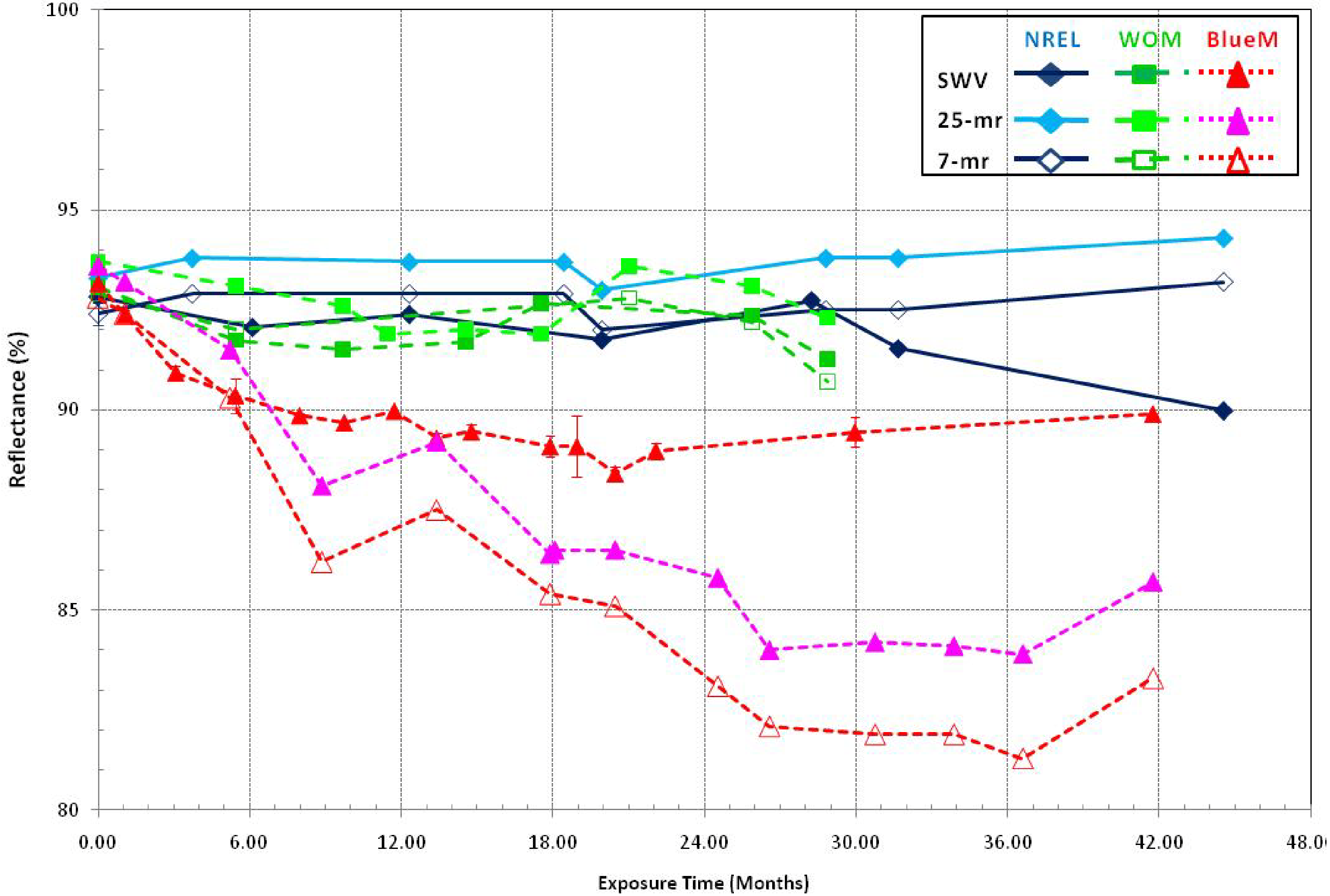
- **Low-iron Glass** (1-mm to 4-mm thick)
- **Reflective Layer** (wet-silver)
- **Back Layer** (Cu)
  (Cu-less)
- **1st coat Paint Layer** (20% Pb →2.5% Pb)
  (lead-free <0.15% or <5 ppm Pb)
- **2nd coat Paint Layer** (10% Pb →1% Pb)
  (lead-free <0.15% Pb or < 5 ppm
- **UV / Moisture / Adhesive Barrier Layer**
- **Adhesive** (PS, spray)
- **Substrate** (SS, Al)

High-Pb thick glass mirror are durable



Durability of low-Pb glass mirror being evaluated



Alternate Thick Glass Mirror

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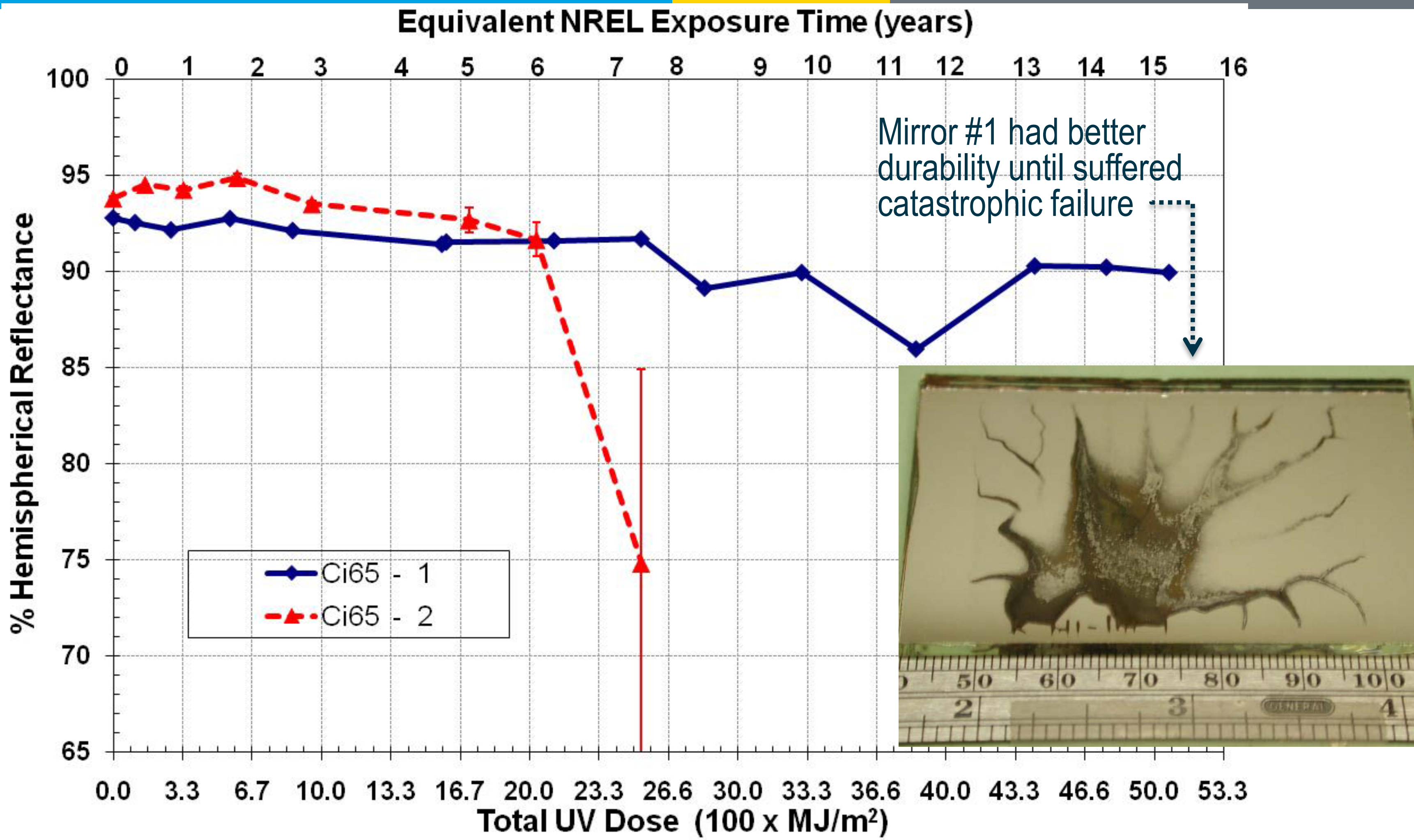

Mirrors without coatings designed for exterior environments have not proven to be durable outdoors

Thin Glass Mirror

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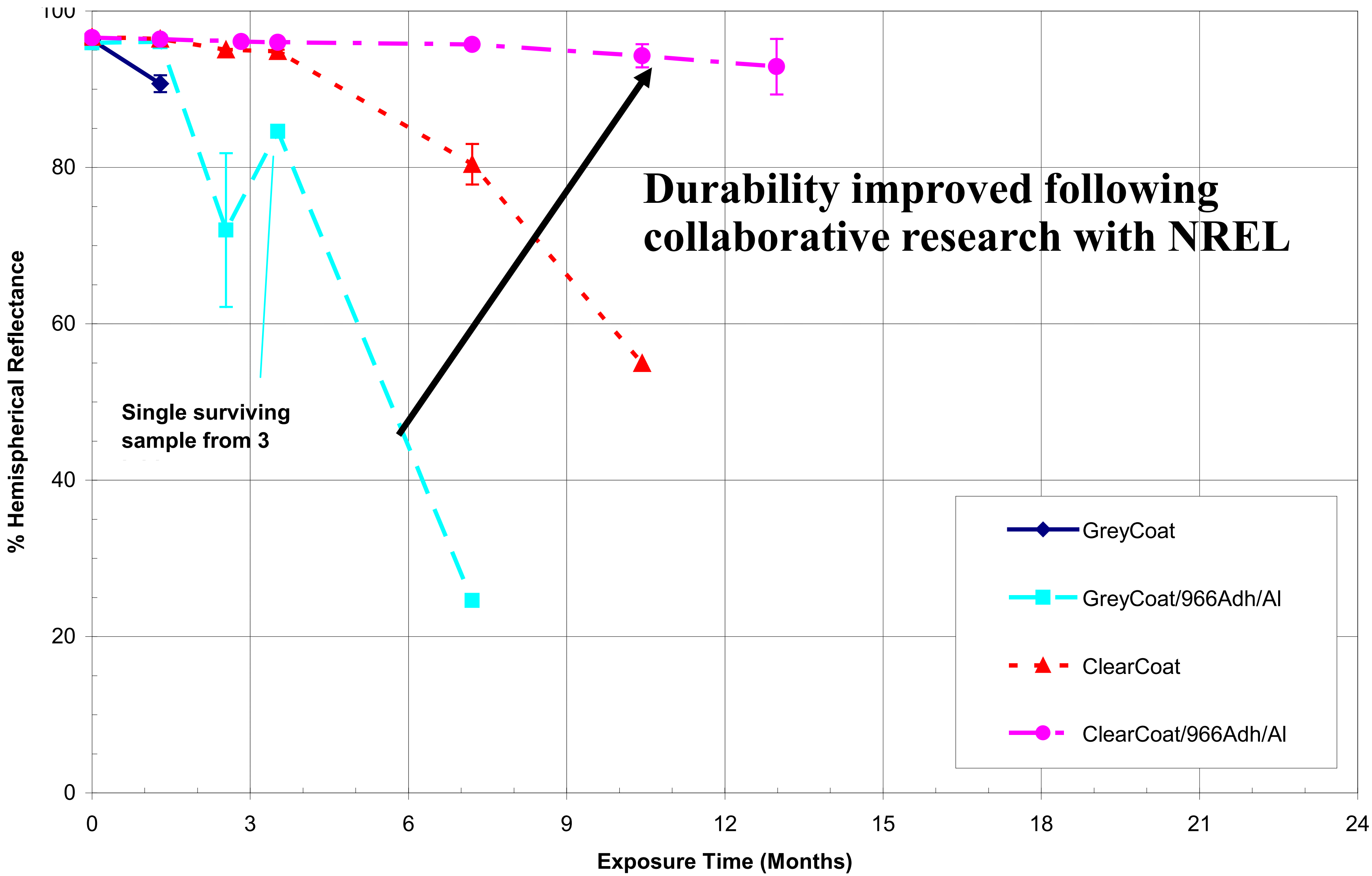

Quality Control Important for Durable Solar Glass Mirrors

- Glass
  - Ag since float (<6 mo)
  - Fe content (sand, campaign)
  - Glass thickness
  - Glass cleanliness
- Silver
  - Silver air side of glass
  - Glass cleanliness
  - Glass sensitization ($SnCl_2$ vs $PdCl_2$)
  - Silver thickness ($0.8 < t < 1.2$ g/m^2)
- Back layer
  - Copper vs. copper-free
  - Separate lines needed
  - Glaverbel vs. Valspar copper-free process
- Paint system
  - Lead or Lead-free
  - Different Pb-free definitions EU:(<0.15% Pb) vs. US:(1-5 PPM Pb depending on state)
  - Valspar vs. Fenzi paint system
  - 1, 2, 3 coat paint system
  - Wax content in outer layer of paint
- Adhesive
  - Chlorine-scrubbed
  - Low-bleed paths
- Self-cleaning advantage

Failure can have Catastrophic Impact

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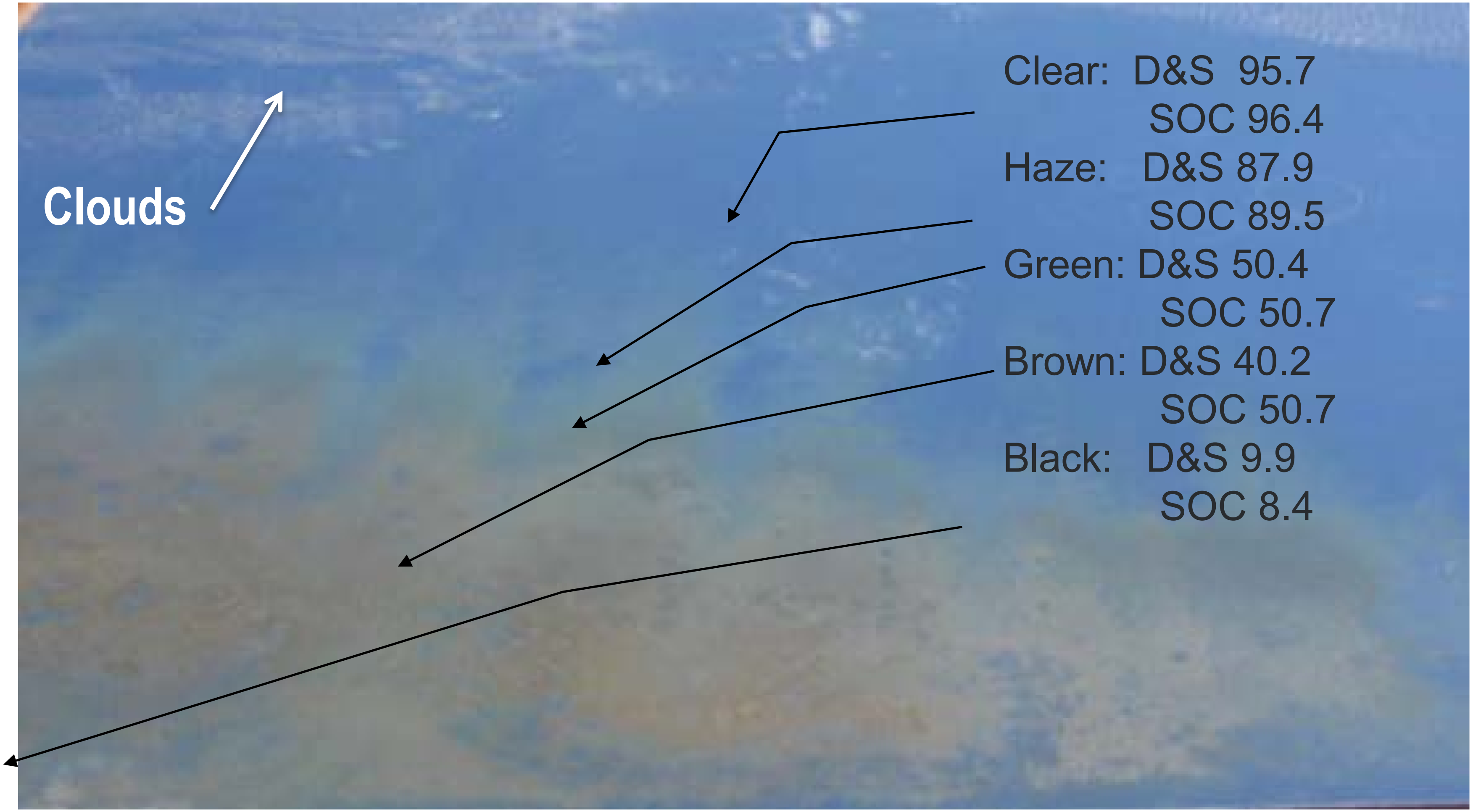
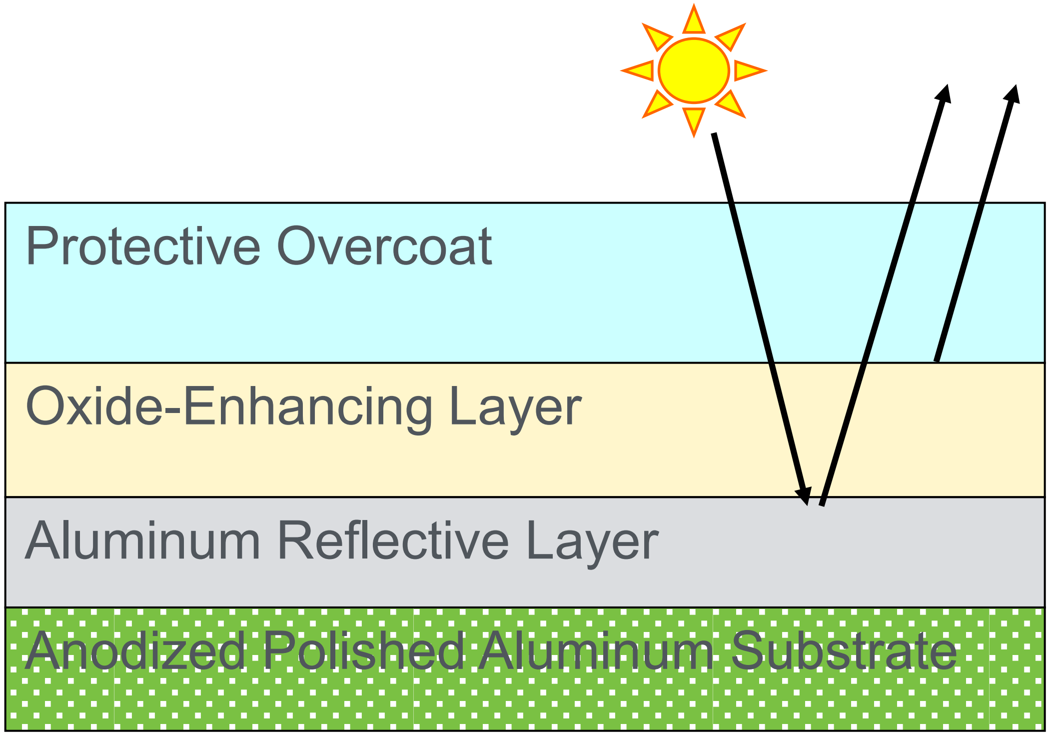


Corrosion observed after <2 years in field

Anodized Aluminum Mirror



Architecture of aluminized mirrors

- Alanod
- Alcoa (CSP FOA subcontract)
- Alcan
- Aluminum Coil Anodizing (ACA)

Industry Collaboration with Alanod

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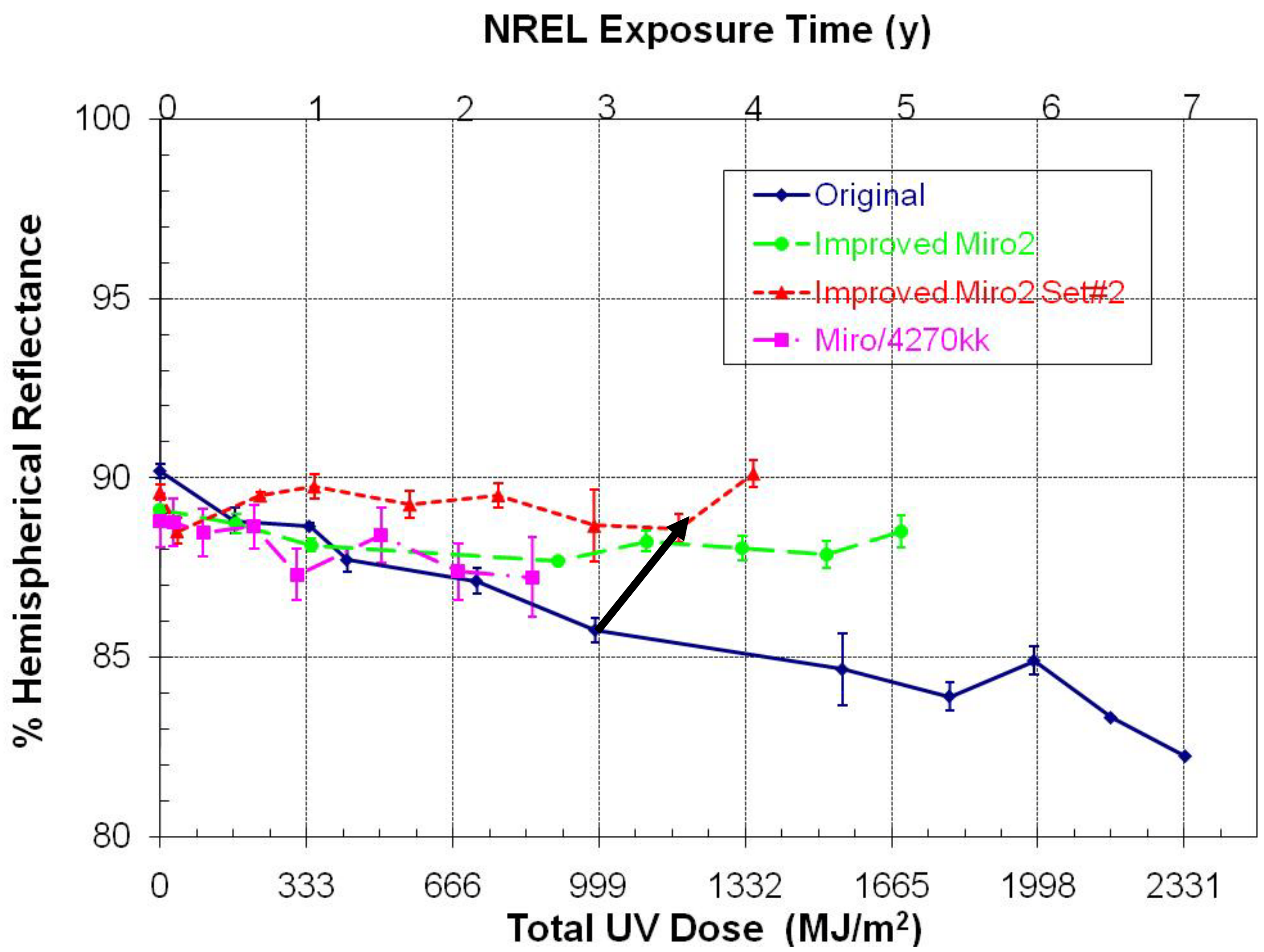
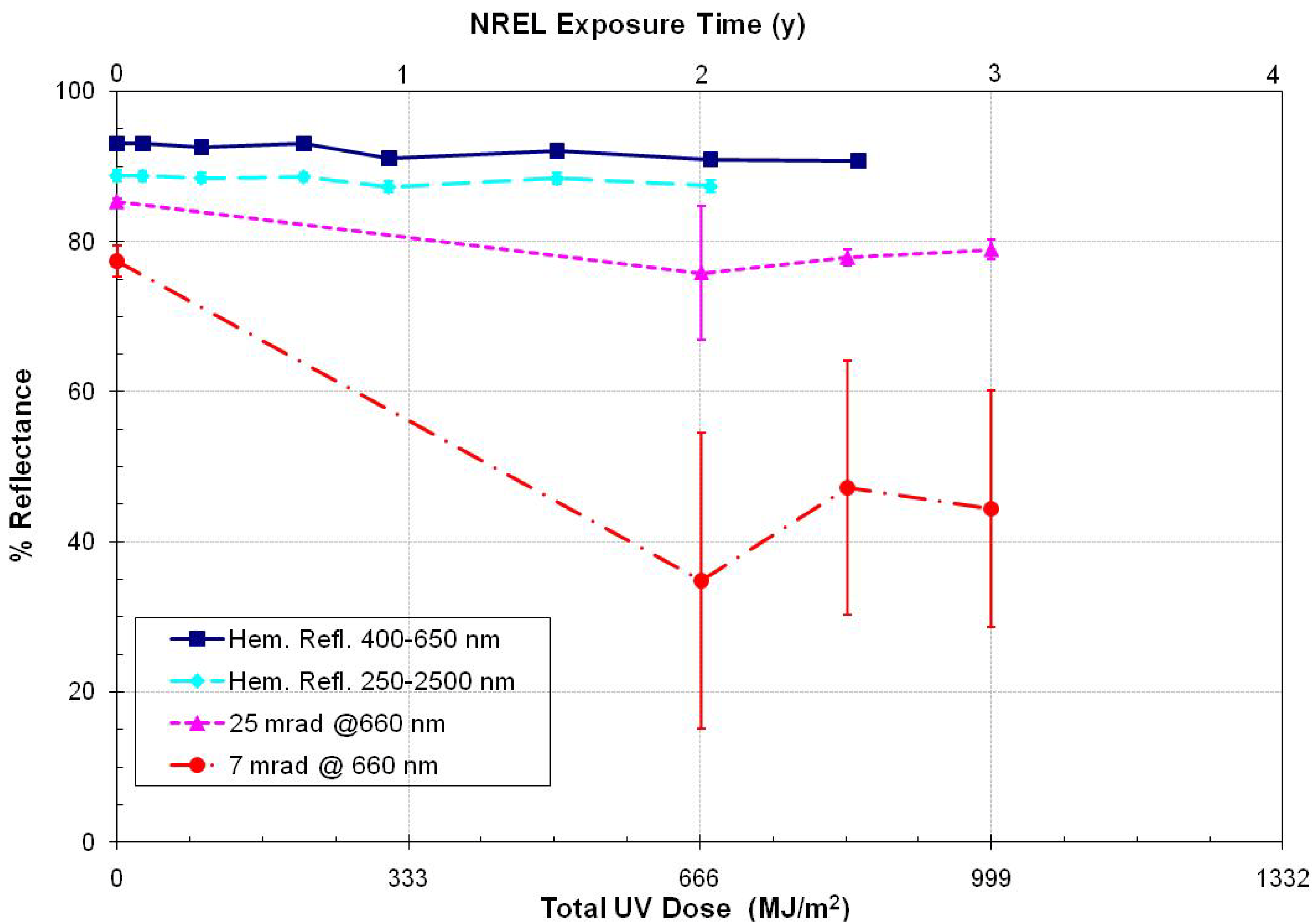


Durability improved with better polymer protective overcoats following collaborative research with NREL

Drop in 7-mrad specular reflectance 1st indication of problem



Delamination occurred at all sites

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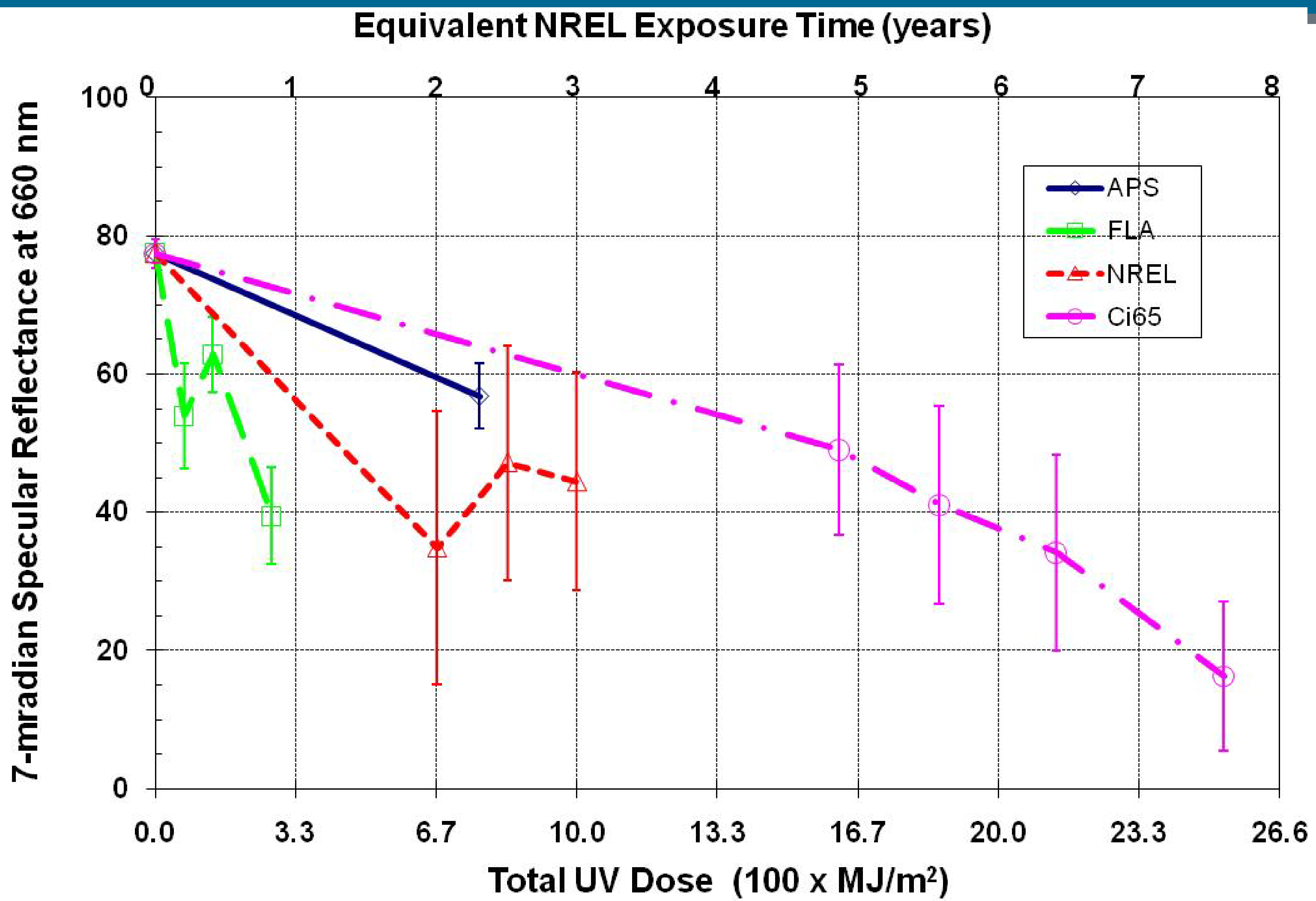
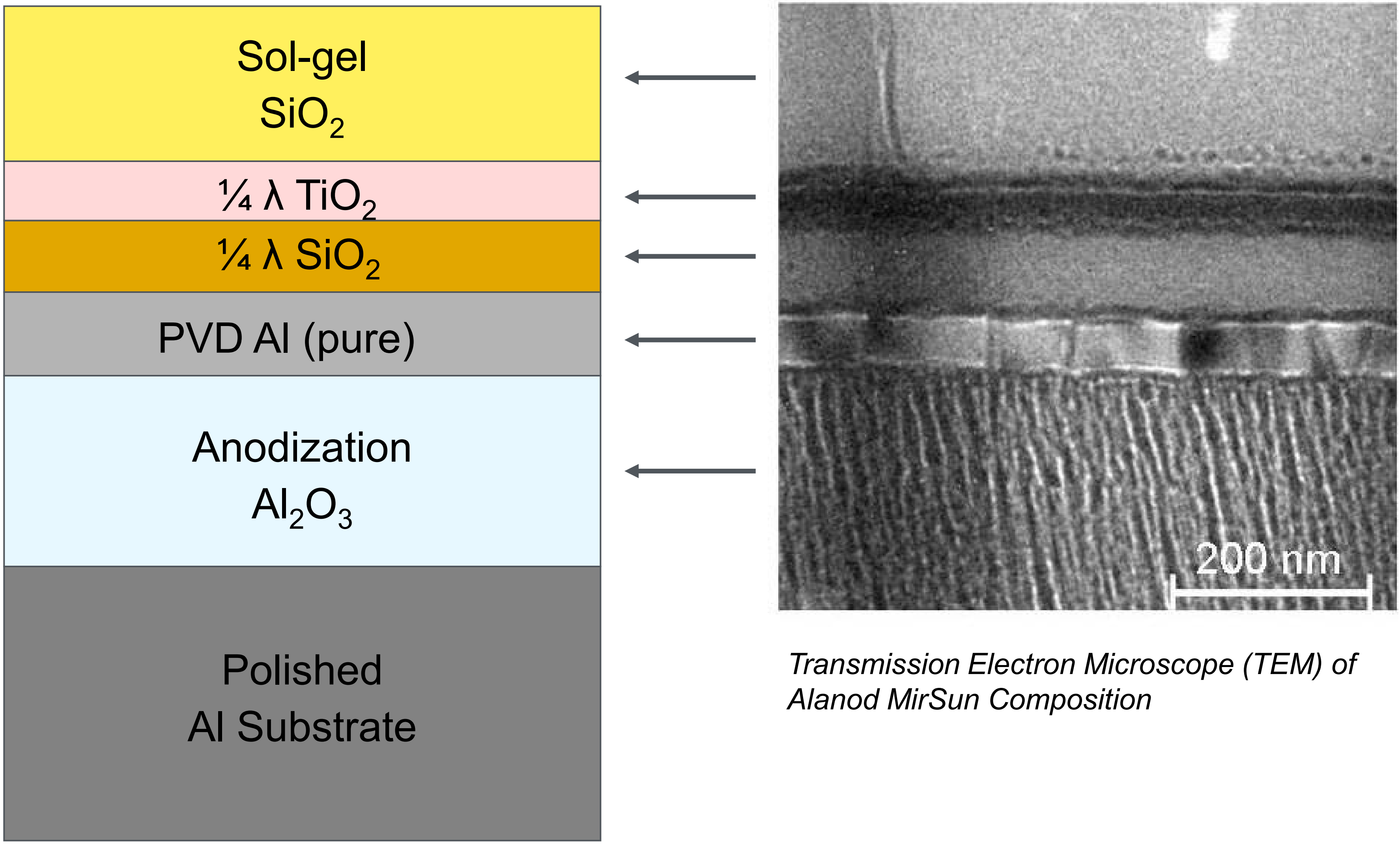


Delamination reported & production stopped. Alanod replaced polymer overcoat with Sol-gel nanocomposite SiO_2 & developed new tests to reveal delamination failures

Composition of Alanod MIRO-Sun



Transmission Electron Microscope (TEM) of Alanod MirSun Composition

Alanod Aluminized Reflector with Nanocomposite oxide layer

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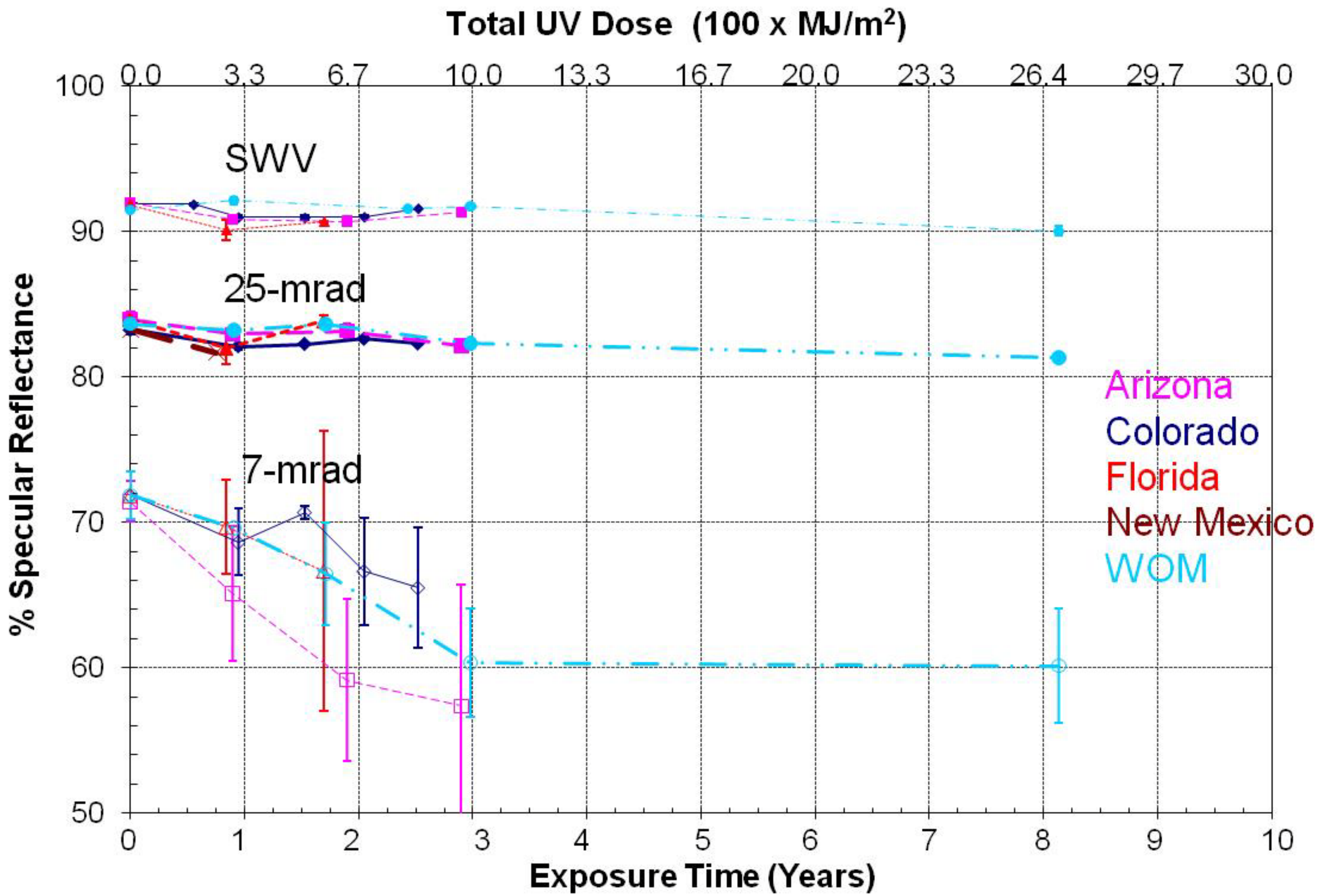
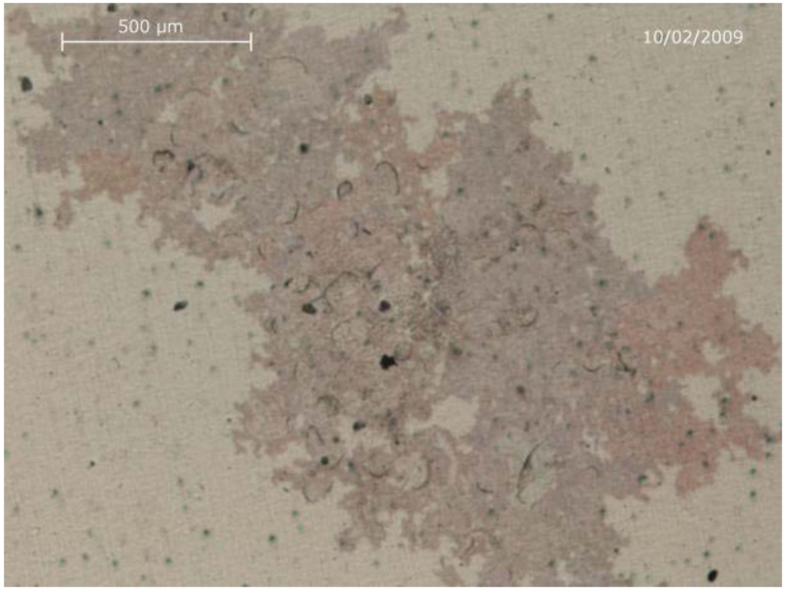


Newer version MiroSunA (production >11/09) has better 7-mrad specular reflectance & improved nanocomposite than this previous MiroSun version

Outdoor testing

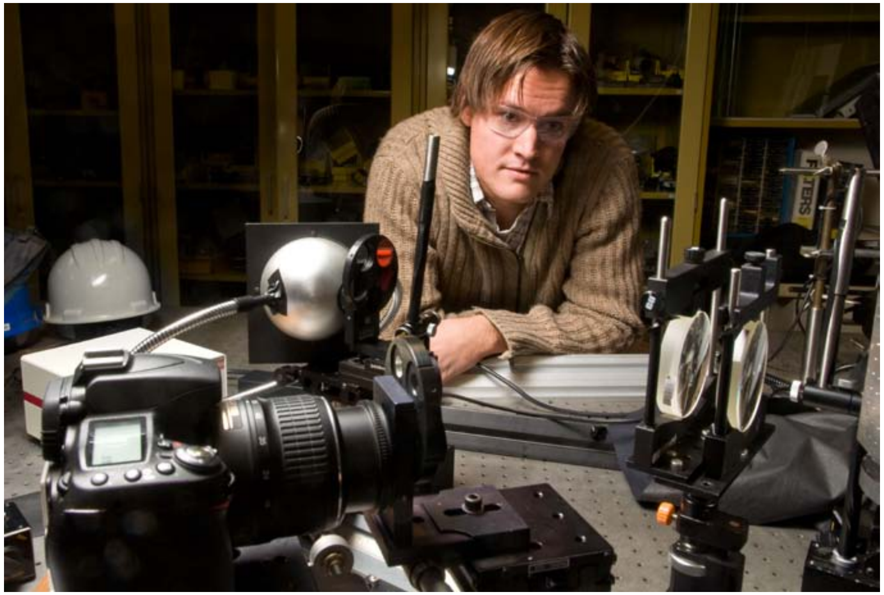
- Small red - brown corrosion spots observed for samples exposed outdoors at all sites:
  – Florida
  – Golden
  – Almeria
  – Köln
  – Ennepetal
- Outdoor corrosion spots not reproduced for samples in accelerated exposure testing (AET) in:
  – Ci5000 (2 sun, 60°C, 60%RH)
  – BlueM (dark, 85°C, 85%RH)
  – Samples degraded with homogeneous dullness.

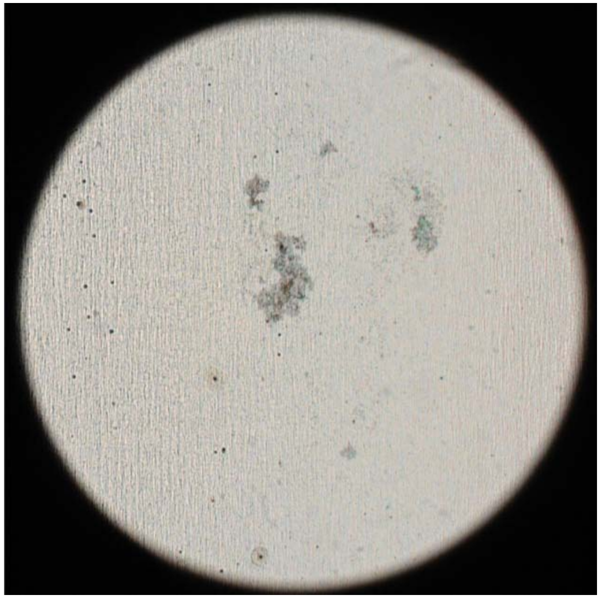


Corrosion spot after 3 years of outdoor exposure in Almeria

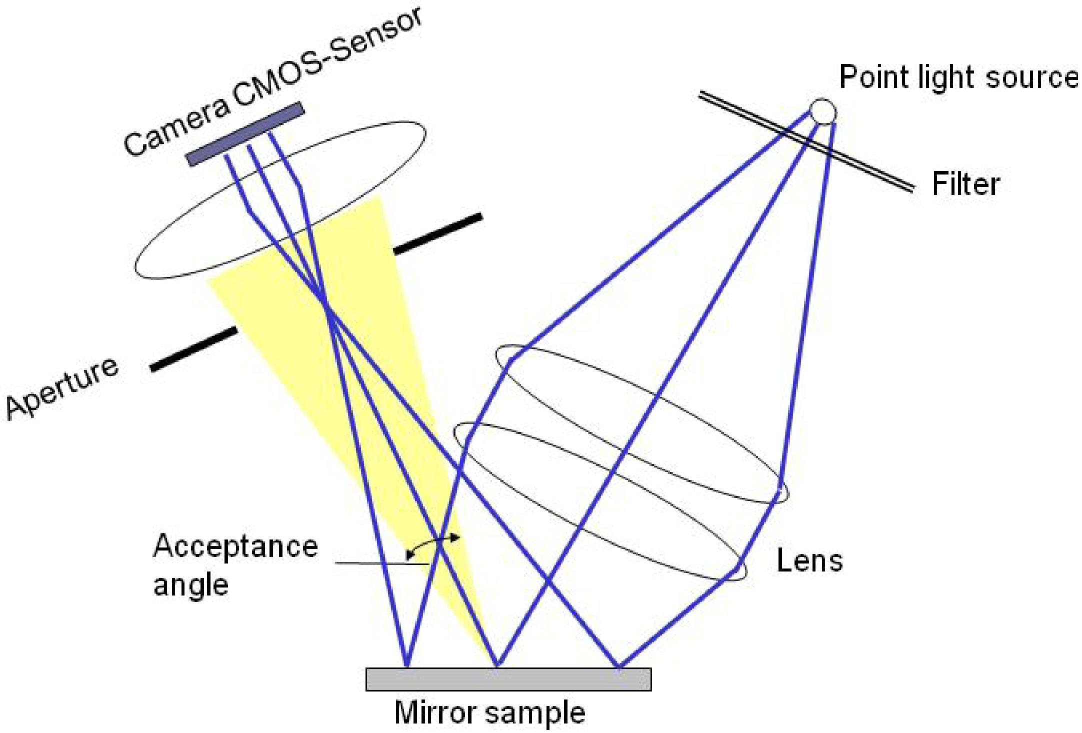
Mirror Characterization & Durability Testing

- FY10 – Design & build *Space Resolved Specular Reflectometer* $(SR)^2$ to measure:
  - growth rate of corrosion spots
  - specular reflectance of corrosion spots
  - specular reflectance of non-corroded area
- Develop accelerated test procedure to reproduce outdoor corrosion observed in anodized aluminum mirrors

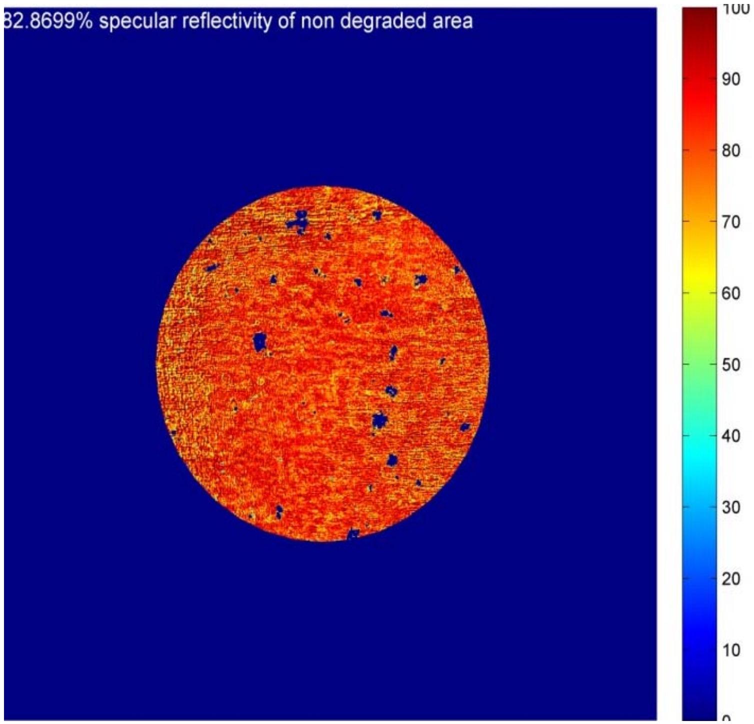




(SR)² - Basic principle



Pristine MiroSun sample:
D&S 25 mr: r = 85.8%
(SR)² 25-mr: r = 84.5



Mirosun w/ 46 corrosion spots:
Total 25-mr loss = 1.19%
Ave 25-mr = 31.6%

- Light incidence angle is 15°
- (SR)^2 calibrated and matches *D&S* measurements

Corrosion Mechanism

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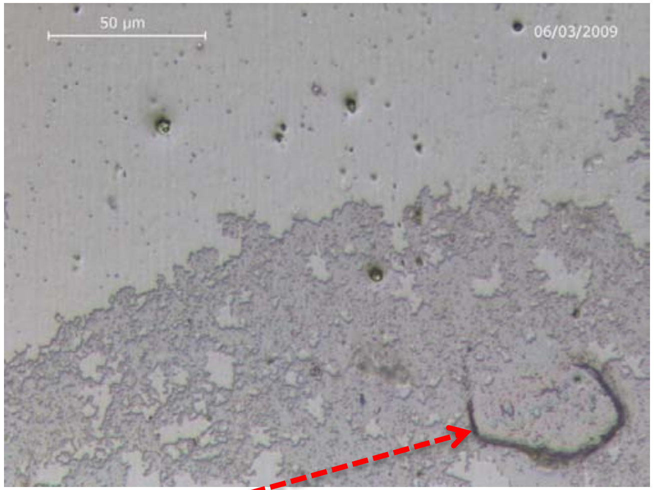
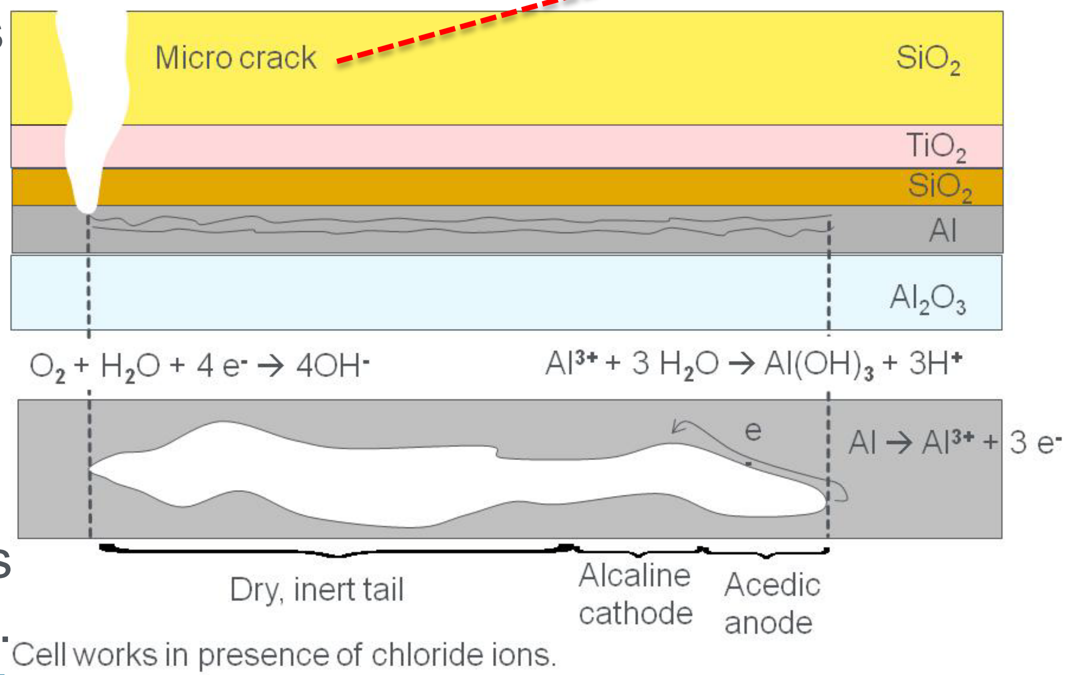
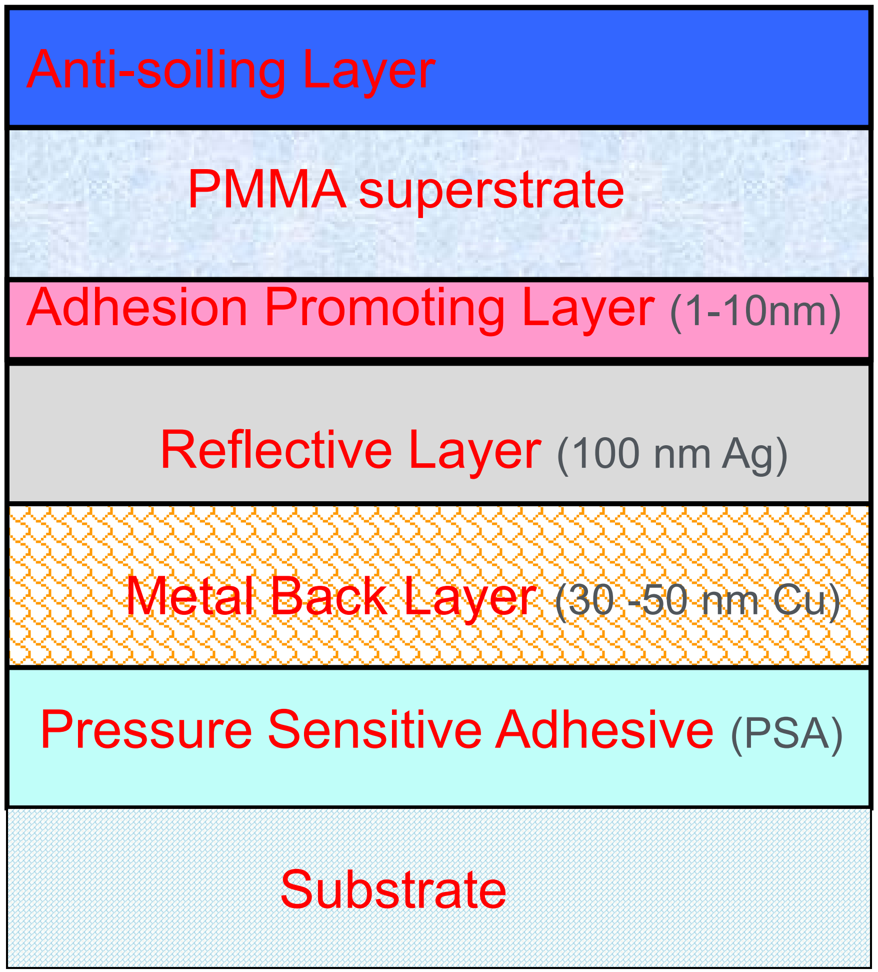
- Corrosion starts at coating defects
  - micro cracks
  - coating break outs
  - pinholes
- SIMS analysis showed corrosion occurs at pure Aluminum layer.
- Once corrosion starts at coating defect it propagates underneath protective film. Effect is known as filiform corrosion.
- Alanod built in-house sol-gel capability to deposit improved nanocomposite SiO_2 protective coating.
- Thus new MiroSunA (11/09) has improved specular reflectance & significantly fewer coating defects resulting in fewer corrosion spots.





Development of Improved 3M Polymer Mirror

- Based on prior 3M/NREL collaborations



- 3M restarting 3M ECP-305++
  - after 15 yr hiatus
  - rebranded Solar Reflector 1000
- Antisoiling/hardcoat (FOA)
- Adhesion promoting layer
  - NREL DDRD
- Provide laminated to substrate and heat treated
- Built on:
  - Joint NREL/3M subcontract
  - NREL patent lead to ECP-305+
- Service Lifetime Prediction (SLP) Methodology developed under DDRD on 3M ECP-300, 305, 305+

3M Metallized Polymer Films

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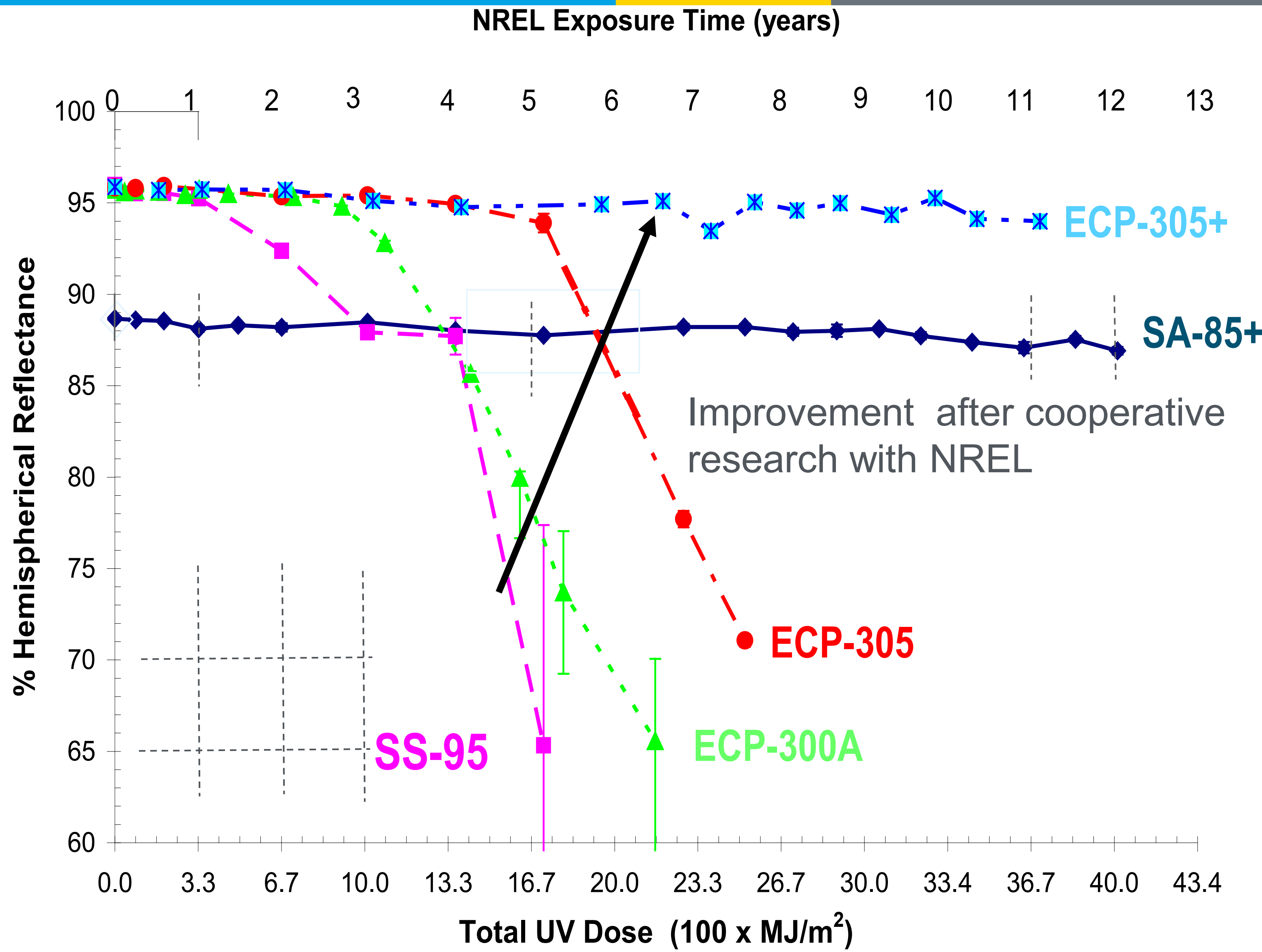
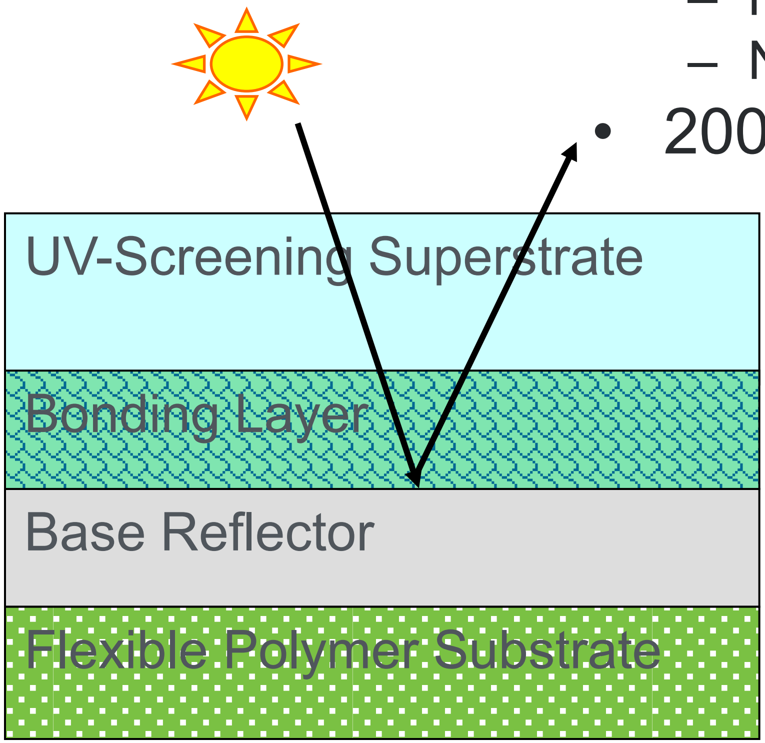


Development of Improved Polymer Mirror

- Based on prior NREL advanced reflector research & collaborations
  - Built on:
    - Joint NREL/ReflecTech patent
    - NREL/ReflecTech subcontract
    - NREL Scientist in Residence at SkyFuels
  - 2009 R&D 100 award



ReflecTech

Front Surface Solar Reflector Architecture

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- Abengoa Solar (CSP FOA)
  - commercialize NREL / SAIC IBAD Al_2O_3 ASRM subcontract

Anti-soiling Layer (100 nm TiO_2)

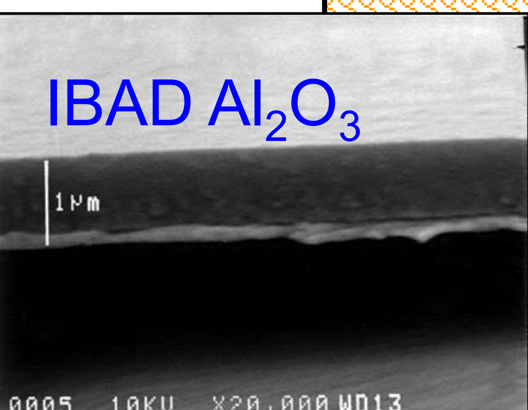
Top Protective Layer (1-4µm Al_2O_3)

Adhesion Promoting Layer (APL) (1-10nm)

Reflective Layer (100 nm Ag)

Metal Back Layer (30 nm Cu —optional)

Substrate (PET) | (Chrome Plated Steel, Leveled Stainless Steel, or Aluminum)



Spectral Reflectance after 104 months of outdoor exposure in Phoenix, AZ

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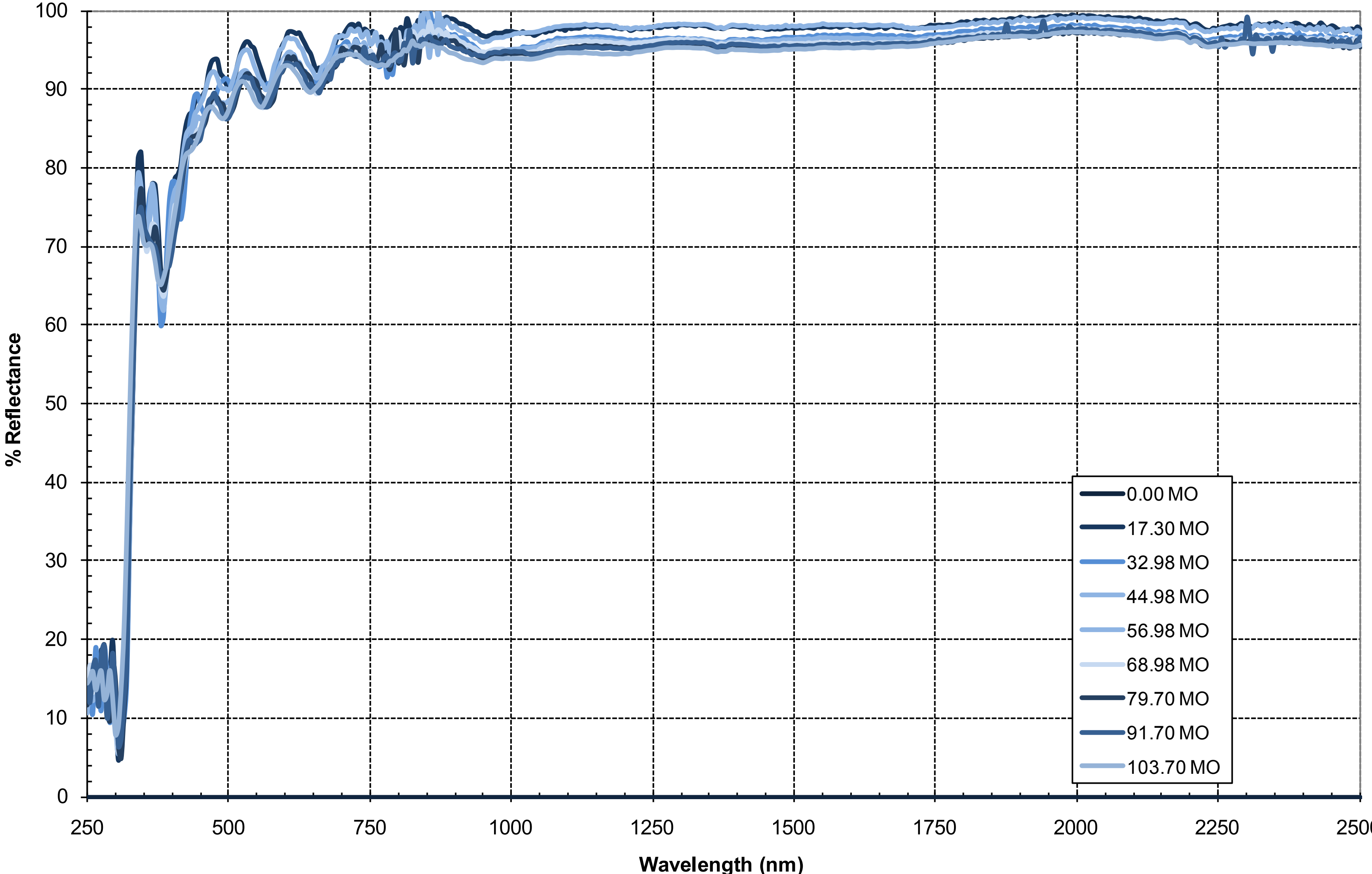

Cost Analysis

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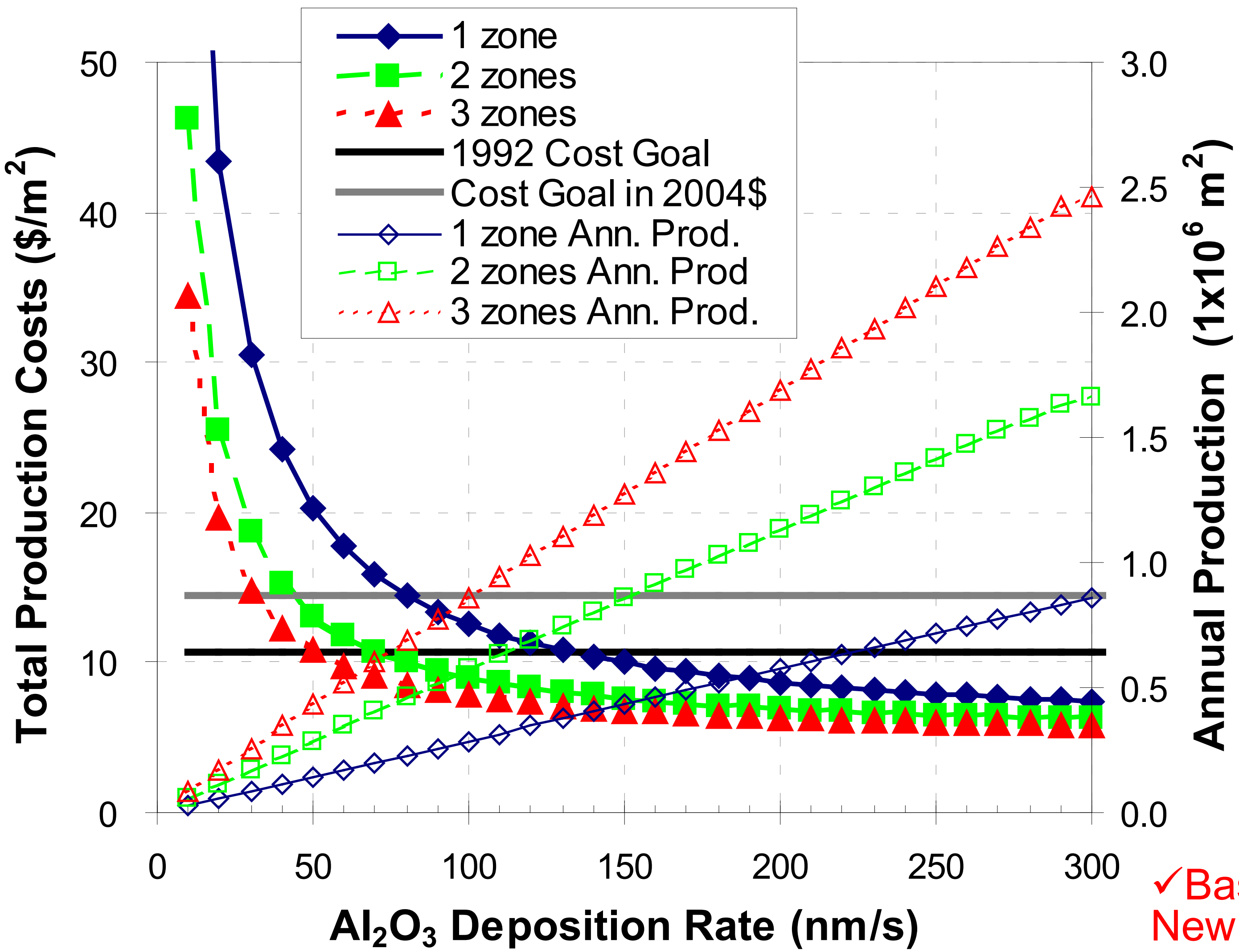

- 30% yield
- Coating 79% time
- 10 to 200 nm/s rate
- Machine cost: $2M-$4.1M
- Loan%/length: 12% for 5 yrs
- PET substrate
- 1-µm Al_2O_3
- Modified ASRM
- $200/h machine burden
- 1200-mm web
- High-purity High-volume (i.e.,$200/kg) Al_2O_3
- 1 vs. 2 vs. 3 zones in 1 machine

✓Basis for Abengoa FOA
New cost analysis even more interesting

Service Lifetime Prediction (SLP)

- Predicting outdoor lifetime based on AET risky because AET failure mechanisms must directly replicate those observed OET.
- All commercial & prototype solar mirrors have had major changes to chemistry & structure in last 5 yrs.
- None of commercial solar reflectors available have been in test long enough to demonstrate 10-yr or 30-yr lifetime goal, outdoors in real-time.
- SLP methodology developed in 1995 under NREL DDRD project with 3M ECP-300, 305, & 305+ correctly predicted mirror lifetime
- SLP methodology will be replicated with 3M's new improved "Solar Reflector 1000" 3M/NREL CRADA, including 250 hrs on-sun ultra-accelerated natural sunlight testing.
- SLP methodology will be expanded to other silvered polymer, glass, anodized Al, & front surface mirrors.
- Leverages SLP activities proposed by DLR as area for cooperation with NREL under auspices of SolarPACES and NREL/DLR MOU.

Accomplishments / Progress / Results

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Service Lifetime Prediction (SLP)

FY09

- Exposure in high humidity chamber (dark/ 85C°/ 85%RH) replicates corrosion observed outdoors and accelerates it by as much as 25% for *glass mirrors*. Other types solar mirrors put into test.
- 3M/NREL CRADA proposal written and executed 8/09.
- Proposal written to expand Advanced Optical Materials Laboratories & purchase new equipment ($1,079,967) for DOE National Laboratories Research projects FOA under American Recovery and Reinvestment Act (ARRA).

FY10

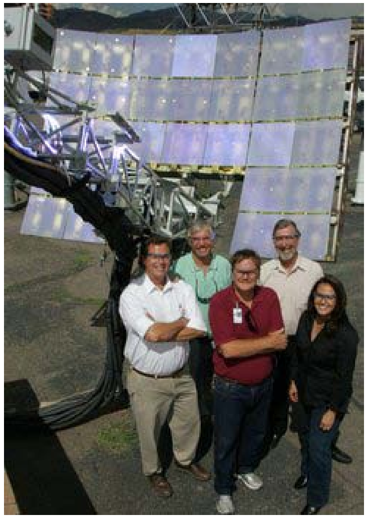
- 3M/NREL kick-off meeting 10/09
- New AET equipment installed & brought on line 2/10
- ARRA approved for new solar simulators & EMMAQUA; specifying equipment
- Initiation of SLP testing waiting on receipt of new 3M samples, including 250 hrs on-sun
- Hosted DLR visiting scientist to research accelerated corrosion mechanisms

Ultra-Accelerated UV Outdoor

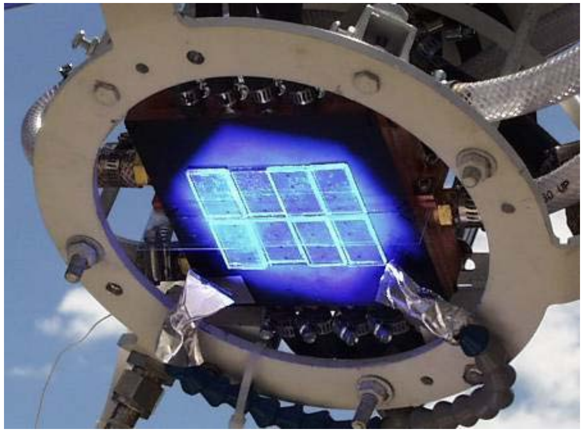
Original dish 100X < 500 nm; 10 years of operation

2009 R&D 100 Award

- **Developed in collaboration with Atlas**



New UV dish includes environmental chamber; same 100X < 500 nm, but 4x size



Accelerated aging of materials

EMMAQUA: Phoenix, AZ X7 to 8 cooled—near ambient sprayed w/ DI H_2O 8 min /nat. sun hr

Advanced Reflector Coatings

Develop advanced mirrors incorporating:

- Higher specular reflectance, longer durability, and lower cost
- Incorporate lessons learned from NREL previous Front Surface Mirror (FSM) research
- Technology advances in:
  - Adhesion promoting interlayers
  - Hardcoats
  - Barrier coatings
  - Integrate antisoiling top coatings
  - Levelized stainless steel and polymer substrates

Advanced Reflector Coatings

FY09

- Proposal written to expand Advanced Optical Materials Laboratories & purchase new equipment ($1,079,967) for DOE National Laboratories Research projects FOA under American Recovery and Reinvestment Act (ARRA).

FY10

- Contact with several polymer manufacturers including Celplast Metalized Products, Dow Corning, Dunmore, DuPont, Evonik, GE (see Supplemental Slides)
- ARRA approved for upgrading deposition systems; specifying equipment
- Initial design of advanced front surface mirror

Antisoiling Coatings & low-to-no H_2O Cleaning

FY09

- Proposal written and Team #19 selected for University of Colorado, Boulder (UCB) Senior Mechanical Engineering design project. Statement of Work written and contract paperwork submitted.

FY10

- NREL provided technical support, SAM training, and review of air-knife design to UCB Team #19.
- UCB team designed & built air-knife & table-top parabolic trough. First air-knife tested resulting in modification of air-knife design.
- NREL characterized specular reflectance improvement after table-top parabolic trough soiled with Arizona Road dust and cleaned with modified air-knife.
- UCB Team #19 demonstrated air-knife design and submitted final report 4/10 (6/10 milestone)
- Contact with Harvey Mudd, CSM, UCB; proposals drafted for FY11

Antisoiling Coatings and low-to-no H_2O Cleaning

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FY11: Plan a combination of in-house research and sponsoring University projects or teams on:

- Fundamental research into soiling mechanisms
- Water capture and reuse from parabolic trough mirror cleaning operations
- Develop accelerated soiling tests, determine soil properties and soiling rates at outdoor sites
- Develop antisoiling coatings including TiO_2 and alternative antisoiling layers
- Explore replaceable vs. permanent and low vs. high surface energy coatings
- Alternative low-to-no H_2O mirror cleaning concepts

Solar Mirrors - Standards Issues

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- No standards for solar glass mirrors
- Qualification tests for indoor mirrors being used
  - Resistance to damp heat constant atmosphere:
    - 480 hours @ 60°C without defects per ISO 6270-1 or ASTM D1735
  - Resistance to salt spray test
    - 480 hours without defects per ISO 9227 NSS or ASTM B117
  - Resistance to cooper-chloride-acetic acid-salt spray fog tests (CASS)
    - 120 hours without defects per ISO 9227 CASS or ASTM B368
  - Aging/weather exposure test:
    - 5 weeks weather exposure test per ISO 21207, test type “B” or 480 h G1173-03 with no softening of the mounting element adhesive, separation of protective coatings, or defects
- Few warranties given
  - e.g., Limited 3 y warranty until mounted in use
- But aggressive warranties being requested
  - e.g., <1% after 30 y

Solar Mirror Reflectance Measurements & Durability Standards Development

FY09

- Participated in SolarPACES Standardization Workshop at NREL Feb 09.
- Participated in DOE Glass work
- Chaired & presented at SolarPACES Task III Standards reflectance, Durability, and Receiver Testing Working Groups at SolarPaces Meeting in Berlin, Sept 09.

FY10

- Participated in organizational meetings for ASTM E44.20 Solar Glass standard.
- Documented NREL's reflectance measurement procedures and form census protocols with DLR & Ciemet to form basis of SolarPaces CSP testing standards (3/10 milestone)
- Collected round robin commercial mirror samples for Round Robin measurements with DLR & Ciemet (3/10 milestone)

Advanced Reflector & Baseload FOA

FY09

- Provided technical support and Go/ NoGo review.
- Characterized samples and performed durability testing for 3M, Abengoa, Alcoa, & PPG

FY10

- Continued technical review, optical characterization, and durability testing
- Purchased and installed scrub abrasion tester. Developed test protocol. Abengoa samples scrubbed for equivalent of 30 yrs.
- VSHOT testing performed on Alcoa collector at Alcoa site.
- Alcoa collector mounted and tested on 2-axis tracker (3/10 milestone)
- Provided support to DOE with review of proposals submitted under advanced baseload power systems FOA. On May 7 DOE Secretary Chu announced 3 projects will share up to $62 million over 5 yrs to research, develop, & demonstrate CSP systems.

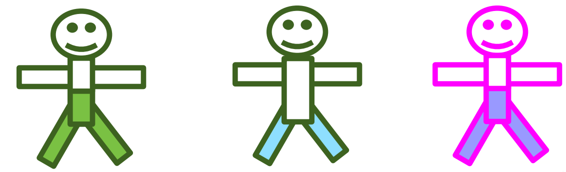
Optical Materials Laboratories

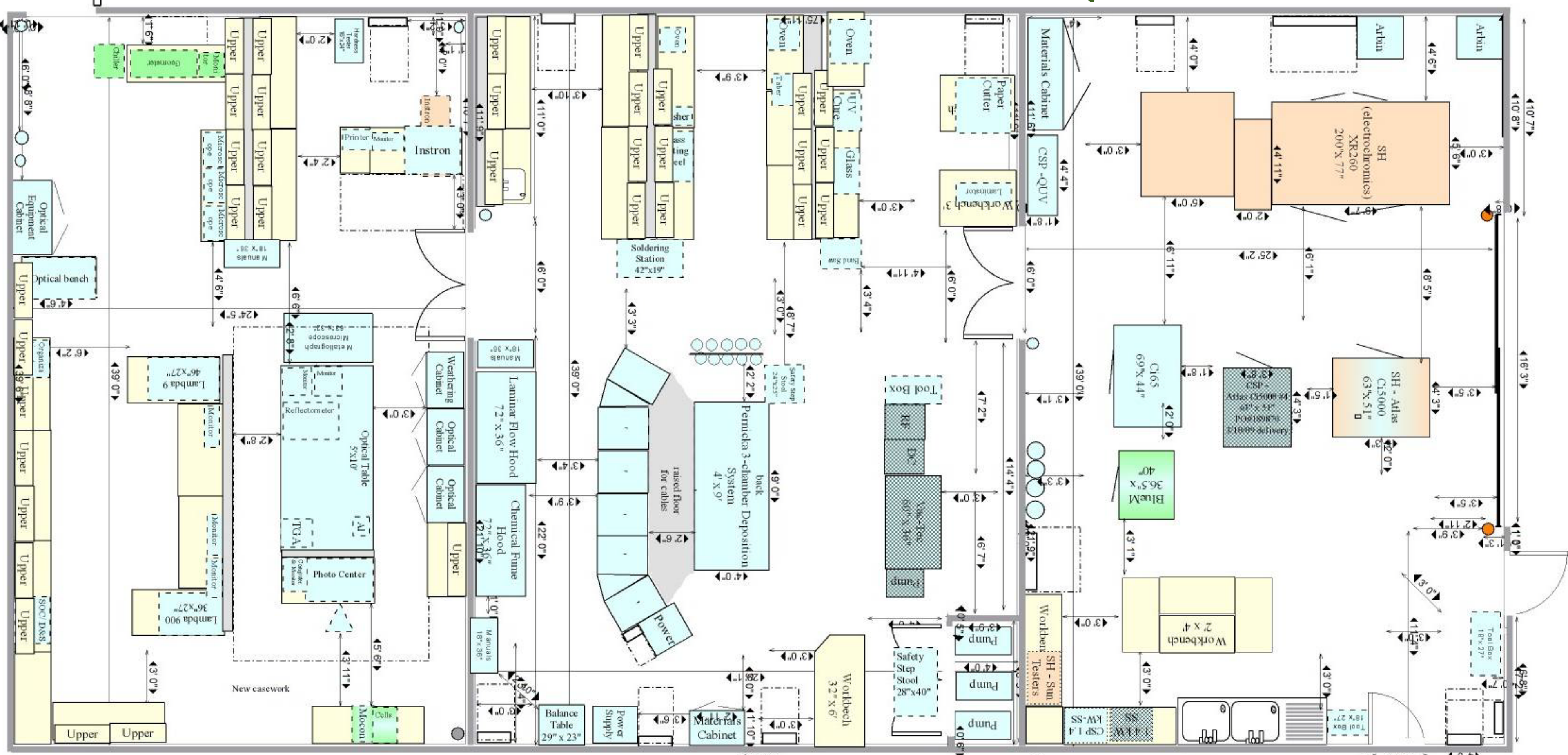
- After > 5 yrs of very low budgets capabilities severely degraded

FTE

Temporary

Scientist Technician Intern





Optical Materials Laboratories

- Began building up capabilities in FY08

FY09

- 1 Research Technician and 4 interns hired & trained
- Ci5000 WOM (rain) and Tenney Cyclic chambers purchased & delivered
- One Ci5000 (1^{st} std [2x/60°C/60%RH]) & BlueM (dark/85°C/85%RH) installed
- Perkin-Elmer 1050 w/150-mm integrating sphere software developed
- Proposal written to expand Advanced Optical Materials Laboratories and purchase new equipment ($1,079,967) for DOE National Laboratories Research projects FOA under American Recovery and Reinvestment Act (ARRA).

FY10

- Principal scientist rejoined project with ½ his time devoted to project. Hired 2 Research Technicians (1 FTE & 1 Leased worker); reviewing resumes for Material Scientist & Post-doc
- Installed all equipment purchased in FY09. $(SR)^2$ complete, SSR being built.
- ARRA approved, specifying new equipment submitting PR

Optical Materials Laboratories

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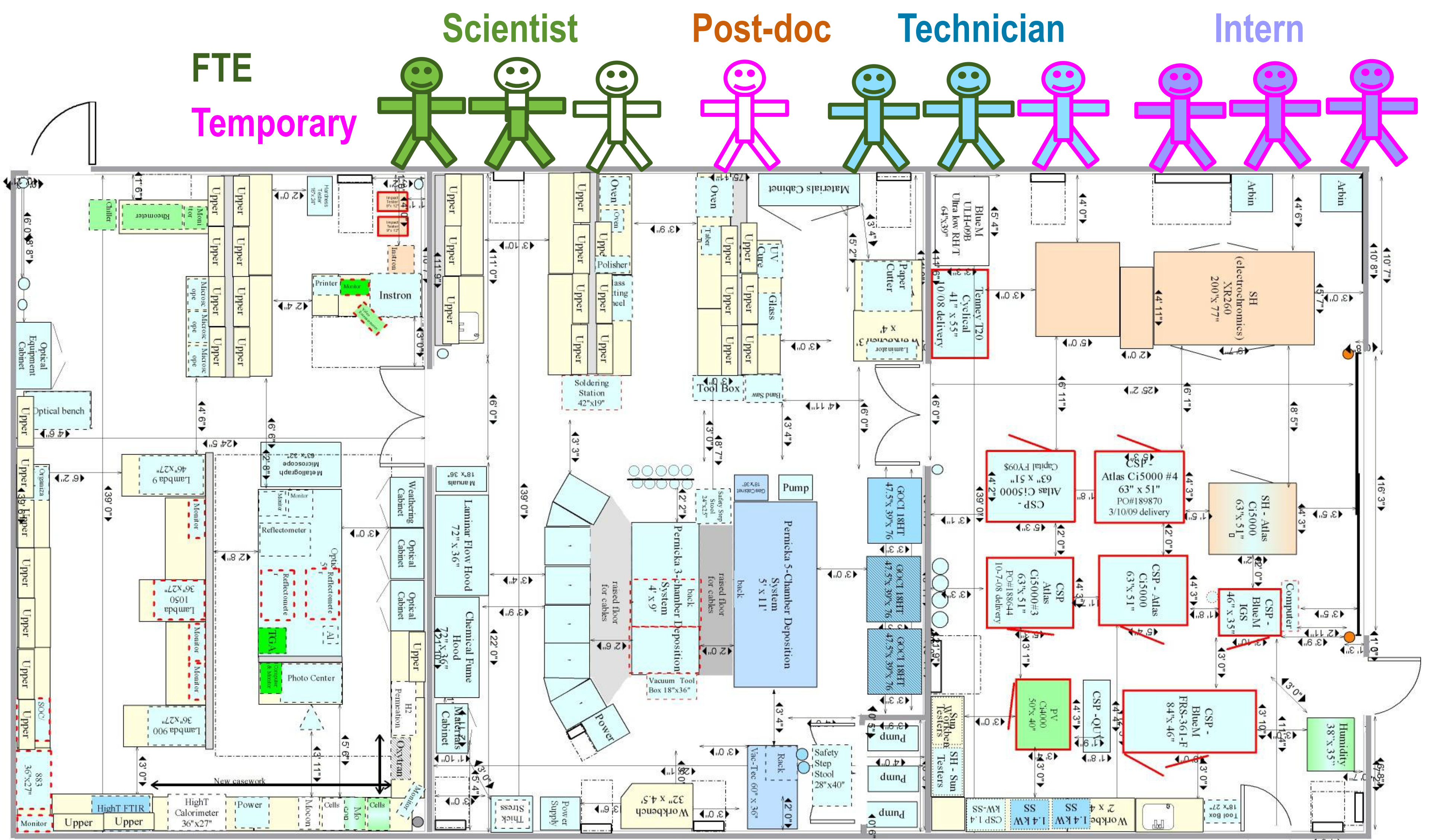

Future Plans

FY2010 (balance)

- Perform optical measurements of FOA & industry supplied solar mirrors and report (milestone)
- Hire Material Scientist & Post Doc to support optical materials development (increasing staff)
- Order ARRA accelerated weathering equipment (increasing capabilities)
- Deposit prototype front surface mirror with high barrier properties & characterize
- Complete consensus of Round-robin reflectance measurement protocols and perform round-robin of commercial solar reflectors (milestone)
- Begin 250 hours of on-sun ultra-accelerated natural sunlight testing of the Solar Reflector 1000 (milestone)

FY2011

- Provide optical characterization and durability support to NREL, SNL, FOA, & industry reflector materials
- Apply SLP methodology to silvered glass, anodized aluminum, and front surface mirrors
- Sponsor low-to-no H_2O cleaning design projects on improved low-no-H_2O cleaning methods (e.g., improved air knife), H_2O reclamation & reuse, antisoiling coatings, fundamental soiling study
- Complete installation and activation of ARRA equipment
- Deposit initial design of advanced front surface mirrors & characterize property improvements
- Continue development of reflectance measurement and durability standards for solar mirrors with SolarPaces and ASTM E44.20

Solar Mirror Suppliers

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Thick Glass	Thin Glass	Laminated Glass	Silvered Polymer	Anodized Aluminum	Front Surface
Flabeg Germany US	**AGC** EU (Glaverbel) Thailand Malaysia	**Guardian**	**ReflecTech**	**Alanod**	**Abengoa (FOA)**
AGC Japan US	**Flabeg** (Naugatuck)	**Veridian**	**3M (FOA)** Solar Reflector 1000 (improved ECP-305+)	**Alcoa (FOA)**	**JDSU**
PPG (FOA)			**GE**	**Alcan**	
RioSolar Spain Portugal			**Evonik**	**Alubond**	
Saint Gobain				**Alucbond**	
				Aluminum Coil Anodizing (ACA)	

Broad Industry Collaboration/Interactions

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- Mirrors from have been provided by:
  - Solar mirror suppliers
  - Float glass from 1-mm to 5-mm manufacturers around the world
  - Independent glass mirror fabricators
  - Glass mirror coating providers
  - Anodized aluminum manufacturers
  - Deposition Companies
  - Roll-to-Roll coaters
  - Polymer manufacturers

- See Supplemental Slides for Complete list

Summary

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- Research activities are a balance of long-term fundamental research and near-term industry optical materials support priorities in line with CSP Roadmaps
- LCOE reductions in range of 0.3 – 1.6 ¢/kW-h
- Reflector research directed at glass, silvered polymer, anodized aluminum, and front surface mirrors with enhanced specular reflectance and long lifetimes
- Upgrades to Optical Materials Laboratory to support new advanced mirrors and solar selective coating materials development at laboratories, universities and industry
- Began initiative to develop advanced front surface mirrors with coatings that have high barrier, reflective enhancing, and antisoiling properties with specular reflectance >98% and >30 year lifetimes.
- Began initiative to develop antisoiling coatings and low-to-no H_2O cleaning methods
- Collaboration with international community on solar mirror standards