Progress Toward Roll Processing of Solar Reflective Material

Russell Smilgys and Steve Wallace
Science Applications International Corporation
McLean, VA

Cheryl Kennedy
National Renewable Energy Laboratory
Golden, CO

Presented at Solar Forum 2001
April 23, 2001

NREL/PR-550-40031

Presented at the 2001 Solar Energy Forum: The Power to Choose held on April 21-25, 2001, in Washington, D.C.

Disclaimer and Government License

Goal:

Demonstrate that it is possible to cost-effectively produce high performance solar reflective material using vacuum deposition techniques.

high performance:

Specular reflectance above 90% for at least 10 years

cost effective:

$10.8 per square meter ($1 per sq ft.)

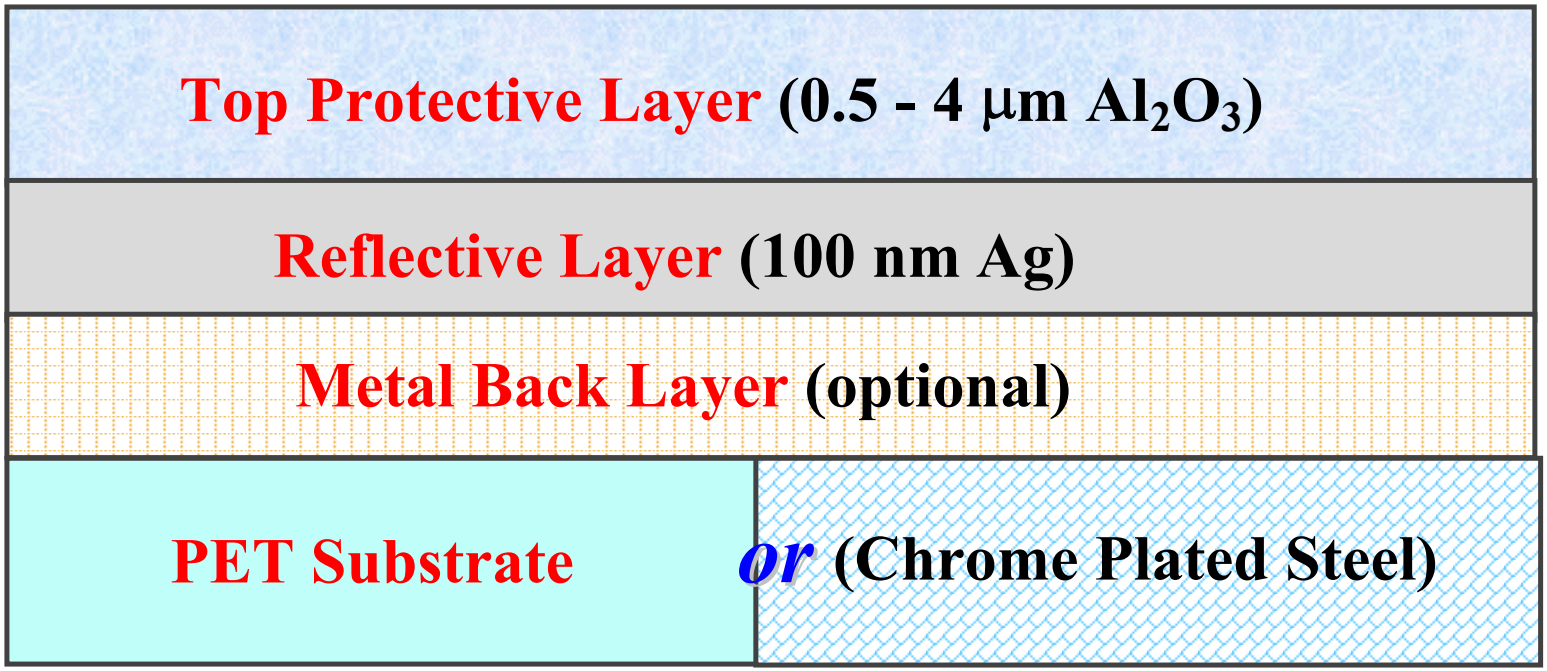
Approach:

Develop roll coating process for a first surface silver mirror with a protective alumina coating.

Focus on increasing durability and lowering production costs.

SAIC
An Employee-Owned Company

First Surface Mirror under Development to Replace Thin Glass



- Vacuum evaporate metal layers
- Deposit alumina coating by EB-PVD technique called ion beam assisted deposition
- Process compatible with roll coating for efficient production

SAIC
An Employee-Owned Company

Possible Application for Material: Dish/Engine System

Mirrors arrayed on a dish concentrate sunlight onto Stirling engine

Pictured system was designed and built by SAIC (Golden, CO)

Concentrator:

- stretched-membrane faceted dish
- 90 square meters
- 1 mm thick silvered thin glass
- 90% reflectivity

Issues:

- Individual panes of glass are cut and glued to stainless steel membrane- very labor intensive

-Reduction in cost of complete system possible if steel membrane could be supplied with mirror finish

SAIC
An Employee-Owned Company

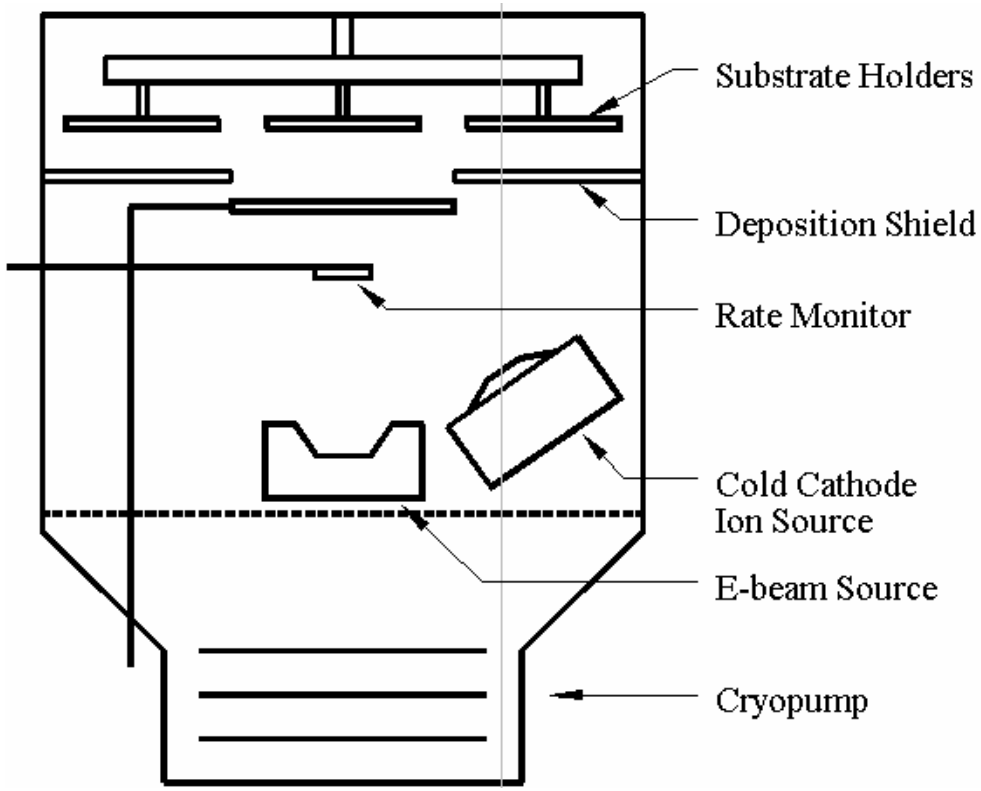
Outline of Program

1994	First sample of solar reflector material produced at Armstrong World Industries.
1995	Start of funding by NREL to make samples on PET with coating 0.5 to 5.6 microns thick using small box coater.
	Prepare analysis of cost to produce material in roll coater.
1997	Build large coating system at SAIC.
1998	Increase alumina deposition rate from 1 nm/s to 10 nm/s.
1999	Increase alumina deposition rate to 20 nm/s.
2000	Build web-handling machine and integrate into SAIC coating system.
2001	Produce solar reflector material on 12 foot long strips of chrome-plated steel web (underway).

SAIC
An Employee-Owned Company

First Test Samples Produced in Small Box Coater

- 66 cm wide box coater
- Electron beam evaporator
- Cold cathode ion source
- 8 kW power supply
- Quartz crystal rate monitor/ controller
- No direct cooling of substrates



Box coater located at Armstrong World Industries, then Penn State University

SAIC
An Employee-Owned Company

Typical Deposition Procedure

1. 6”x6” PET sheets stretched over shim stock holder, mounted on rotating planetary holders.

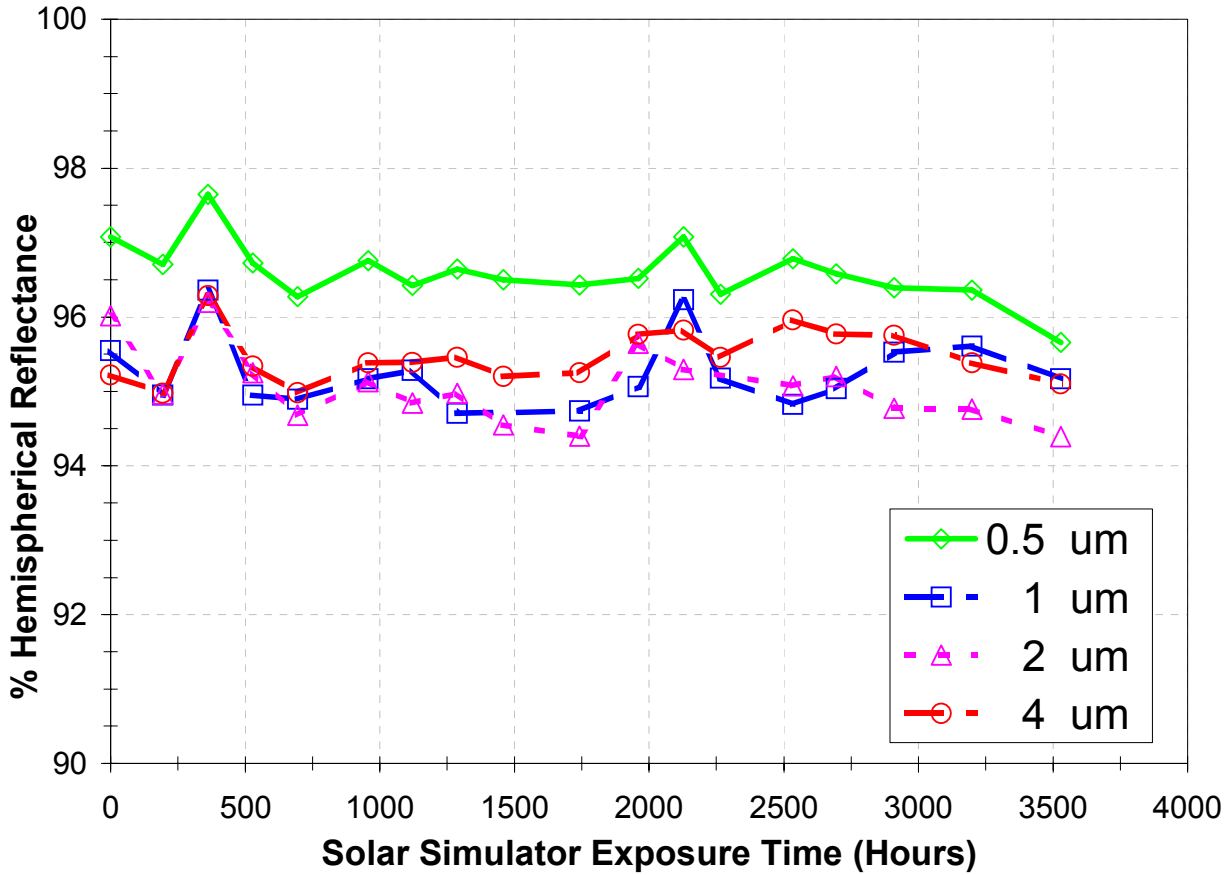
2. Sputter clean PET with argon ion beam for 5 minutes

3. Evaporate copper, 50 nm thick @ 1 nm/s

4. Evaporate silver, 100 nm thick @ 1 nm/s

5. Evaporate alumina, 0.5-4 μm thick @ 1 nm/s

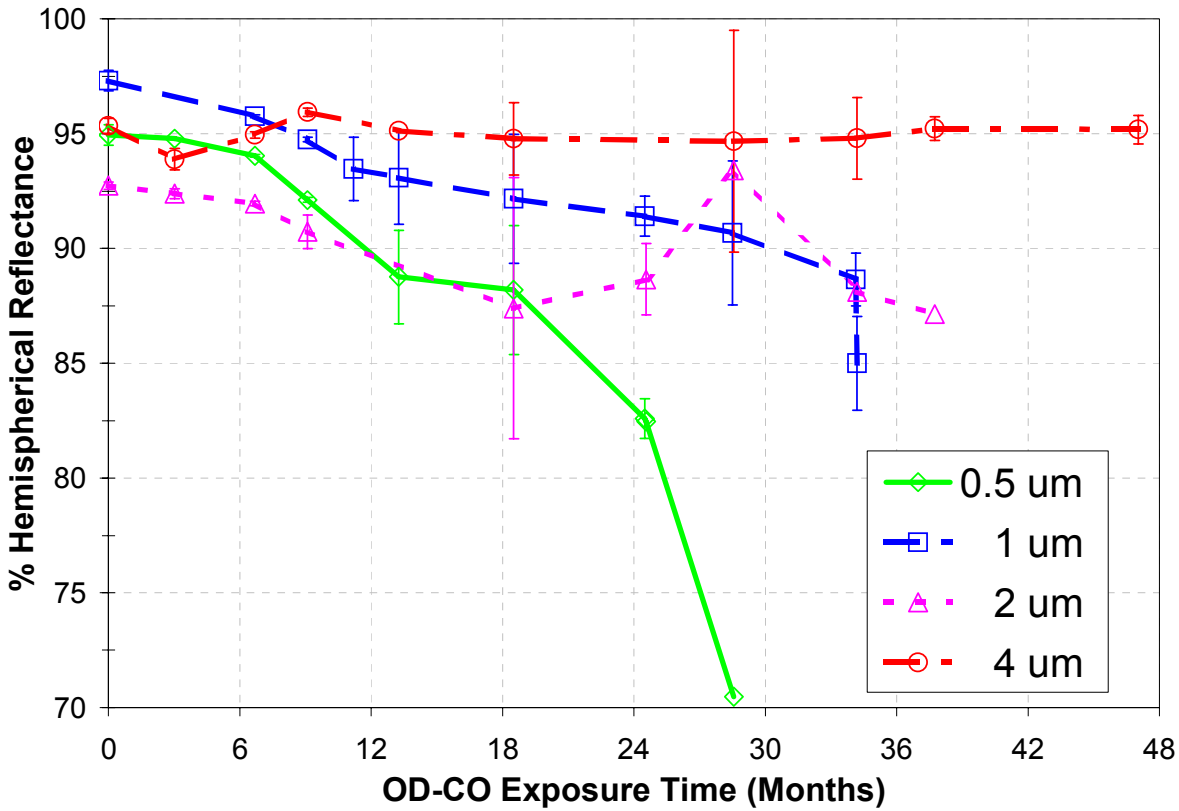
Solar Simulator Data of First Surface Mirrors with Alumina Coating (1nm/s deposition rate)



Longest durability in solar simulator of any first surface mirror

SAIC
An Employee-Owned Company

Outdoor Colorado Exposure Data of First Surface Mirrors with Alumina Coating (1 nm/s deposition rate)



Sample with 4 micron coating lasts 4 years outdoors

SAIC
An Employee-Owned Company

Cost Model to Produce Solar Reflective Material in Roll Coater (circa 1995)

Geometry

Web length	2400 ft
Web width	3.5 ft
Web diameter	12 inches

Evap Process

Capital Equipment	$1M
Web line speed	80 ft/hr
Cycle time/web	30 min
Workers	1 @ 100%

IBAD Process

Capital Equipment	$1.19M
Cycle time/web	83.4 hr @ 32 nm/s
Workers	2 @ 100%

Plant Operation

300 days/yr
3 shifts/day
8 hr/shift
15% capital recover cost
5% capital recovery period
$35 wage rate
$0.10 electricity/kW-hr

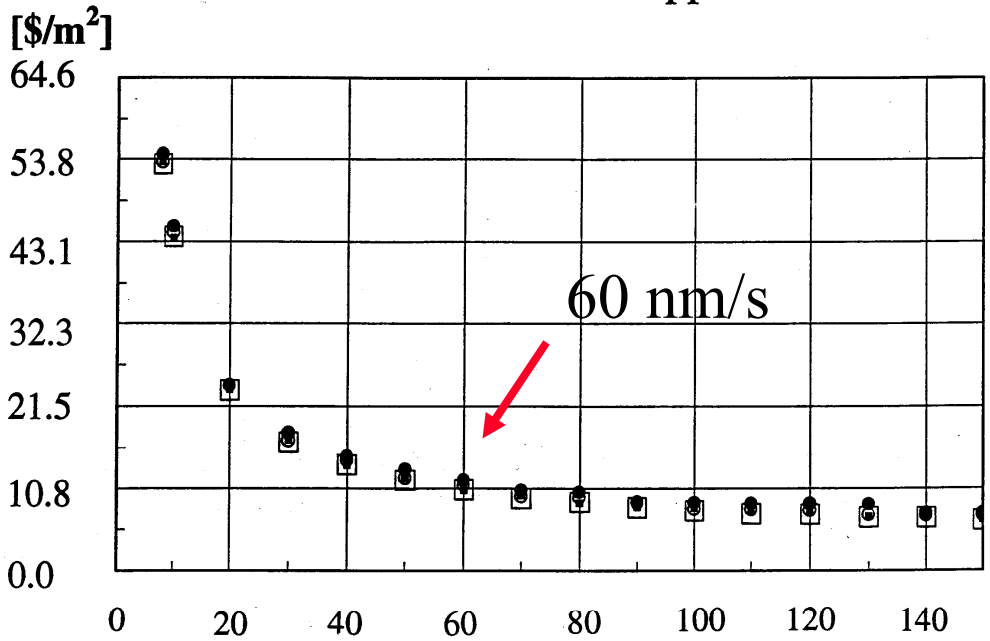
Materials Cost

Alumina	$12/lb
Silver	$200/lb wire
Copper	$2.5/lb wire
PET	$1.5/lb

SAIC
An Employee-Owned Company

Result of Cost Model to Produce Solar Reflective Material in Roll Coater

Structure: alumina/silver/copper/PET substrate



$1/sq.ft. →

Maximum Production Volumes for Available Equipment

Film Thickness: Al_2O_3 4 µm, Cu&Ag 200 nm

When alumina coating is 4 micron thick, need 60 nm/s rate for $1/sq.ft.. (Assumes production volume one million sq. meters per year.)

SAIC
An Employee-Owned Company

Build Bigger Coating System at SAIC to Increase the Deposition Rate

- Vacuum system walk-in sized
  - cylinder 7 ft diameter, 12 ft long
  - Stokes 412 roughing pump
  - three CTI-10 cryopumps

- Evaporators
  - rod fed source (2” OD)
  - 4 pocket source (each 60 cc)
  - 14 kW Temescal power supply

- Ion source
  - 16 cm CSC gridded, high output
    1.25 A @ 1000 V

SAIC
An Employee-Owned Company

Increase Alumina Deposition Rate + Sheet Size

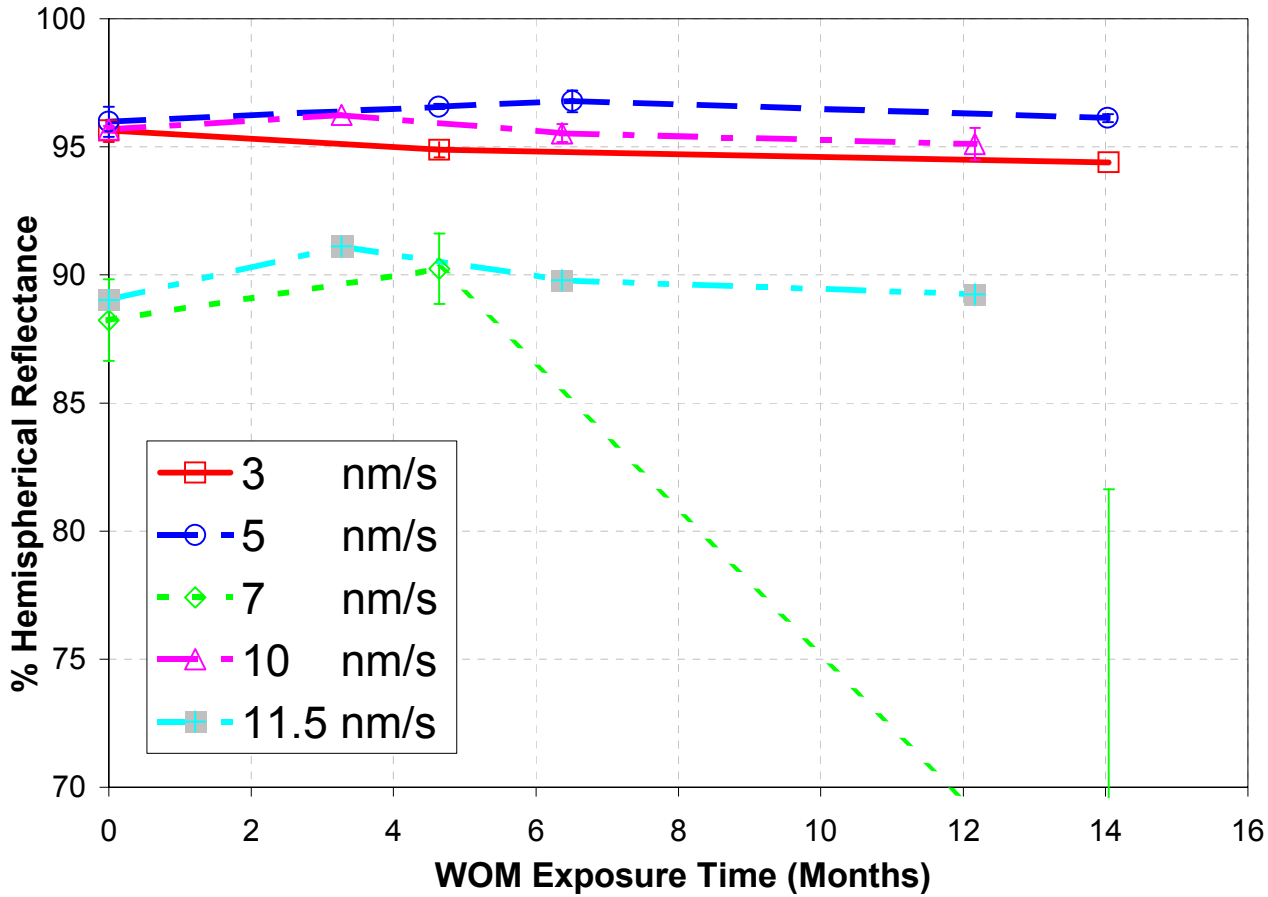
Cooled Al plate mounts sheets 7”x25”

Cooled Al plate in chamber

Evaporators and ion source located at bottom of chamber

SAIC
An Employee-Owned Company

WOM Data of First Surface Mirrors with Alumina Coating (higher deposition rate)



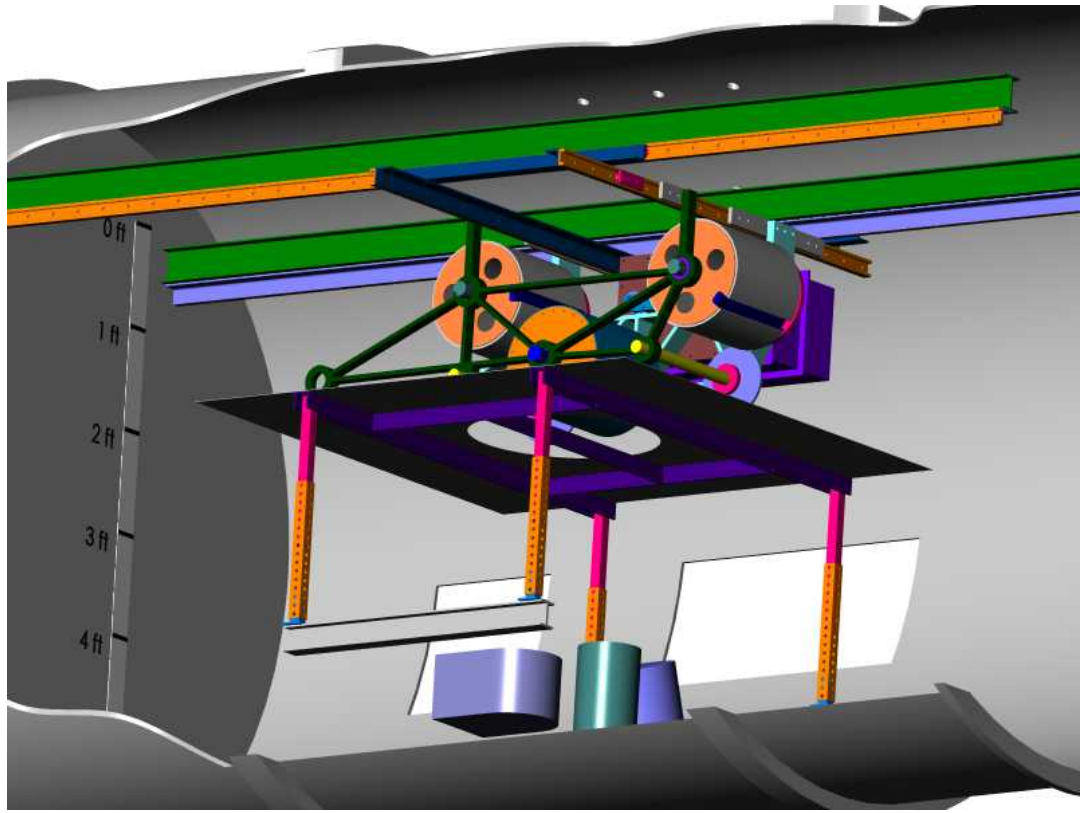
Samples with 10x increase in deposition rate still durable.

SAIC
An Employee-Owned Company

Roll Coater Design

Specifications

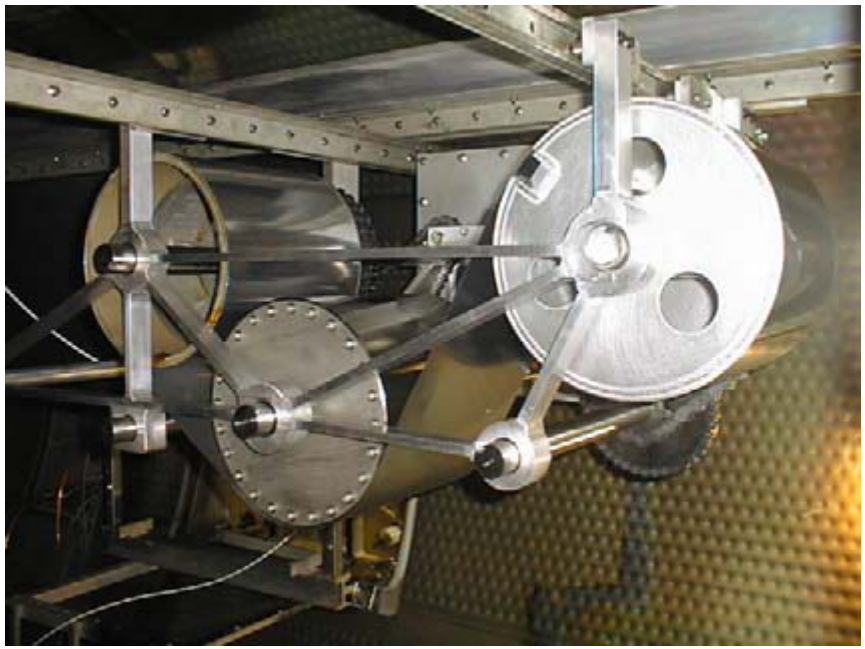
Web width 30.5 cm
Web speed 1-89 cm/min
Web tension 1-189 N
Reel ID 30.5 cm
Drum temperature > 77 K



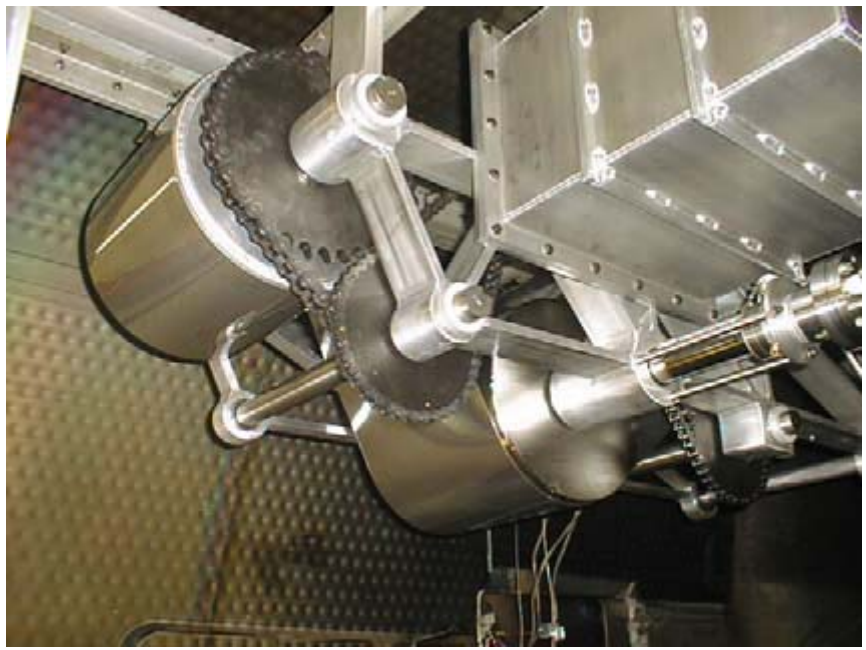
Intended web is chrome-plated steel strip, 12” wide, 8 mil thick

SAIC
An Employee-Owned Company

Roll Coater at SAIC (McLean, VA)



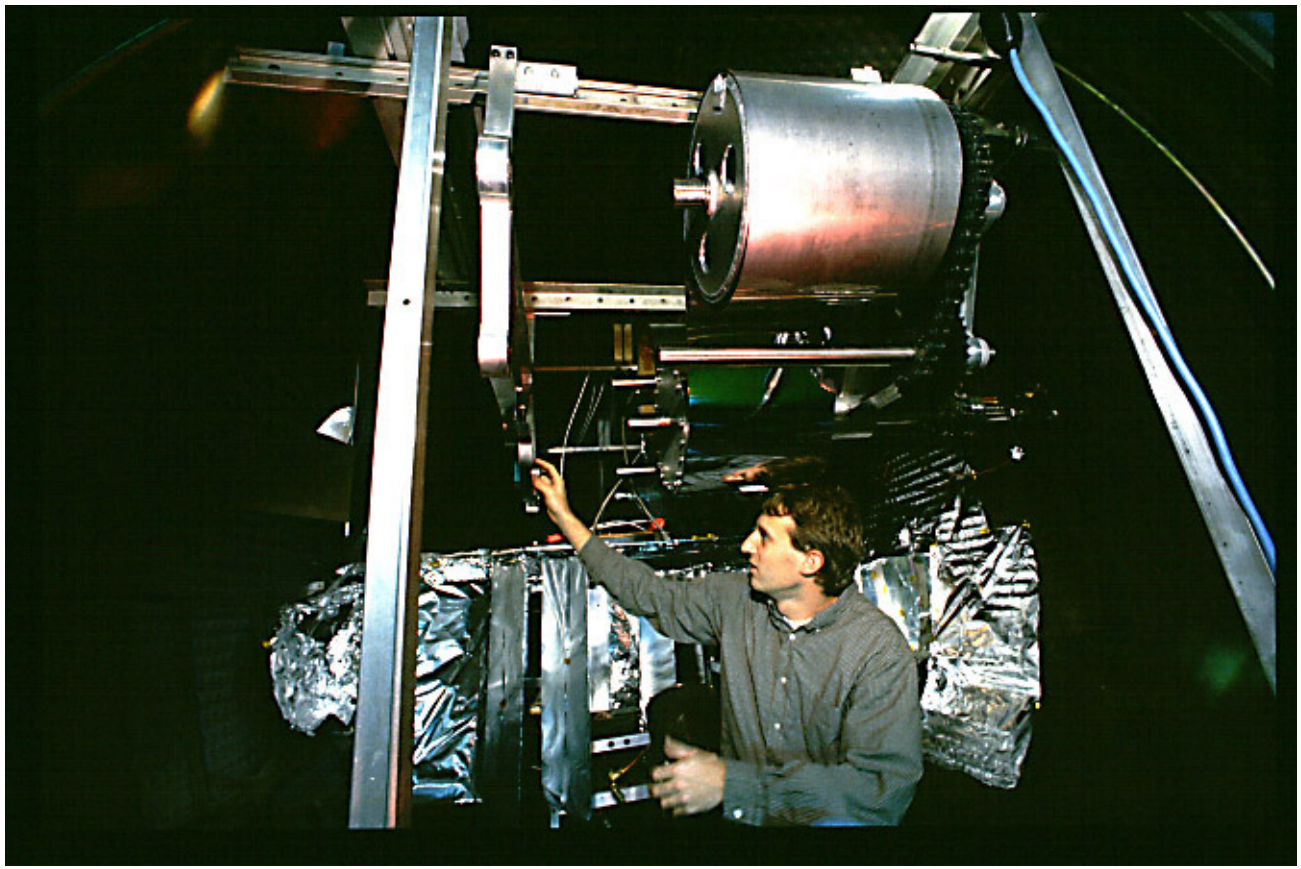
Front view showing steel web advanced over 12” drum



Rear view showing chain drive

SAIC
An Employee-Owned Company

Roll Coater at SAIC (McLean, VA)



SAIC
An Employee-Owned Company

Development Path to Commercial Application of Solar Mirror

Current Work:

- Transition coating process from PET to chrome-plated steel web (12” wide).
- Produce solar reflective material on 12’ long strips of chrome-plated steel.

Future Work:

- Produce 280 lineal feet of solar material for field trials.
- Increase the alumina deposition rate beyond 20 nm/s.

Acknowledgments

Northeastern University
Dr. Jackie Isaacs

Armstrong World Industries:
Dr. J. S. Ross

Penn State University:
Prof. Singh
Tom Medill
Dale Donner

SAIC
An Employee-Owned Company