Polymer Glazing for Silver Mirrors

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Abstract

This paper reports on our evaluation and modification of polymeric glazings to protect silver mirrors. The mirrors were made using Corning 7809 glass as a substrate onto which a thin silver film is deposited. The modified polymeric films are then cast from solution onto the silver. The mirrors were characterized by measuring the hemispherical reflectance and the specular reflectance at 660 nm and selected acceptance angles (7.5 mrad or 3.5 mrad). The mirrors were exposed to environmental degradation using accelerated weathering devices and outdoor exposure. Empirical evidence has demonstrated that poly-methylmethacrylate is a stable polymer in a terrestrial environment, but the polymer does not provide adequate protection for the silver reflector. The crucial role in degradation played by ultraviolet (UV) light is shown by several experimental results. We have demonstrated that UV stabilizers added to the polymer improve the weatherability of mirrors. The relative effectiveness of different stabilizers will be discussed in terms of the weathering modes, retention of optical properties, and effectiveness of the additives. The process for silver deposition influences the reflectance of silver mirrors, and the optical properties depend on subtle relationships between the metallization and the dielectric (polymeric) films that are in contact with the silver.

Introduction

The importance of mirrors for solar energy applications is noted in a companion paper in these proceedings[1], where it is also shown that frequently the currently available polymer films do not provide adequate protection for silver reflective layers. Goals of this work are to establish the degradation effects of weathering on polymer/silver mirrors, to determine effective means for inhibiting such effects through modification of the polymer, and to prepare durable polymers or laminates that provide a basis for durable silver mirrors.

Empirical evidence has demonstrated that polymethylmethacrylate (PMMA) is a stable polymer in a terrestrial environment and that it can protect aluminum in that environment. Also, it is relatively inexpensive and has excellent optical characteristics. We have chosen to emphasize PMMA for silver mirrors, recognizing that unaltered PMMA probably will not protect silver for a sufficiently long time.[2]

For our tests, polymeric films are cast from solution onto a metallized substrate, usually glass. This process is a practical means for altering the PMMA films for laboratory testing. The basic configuration is represented by Figure 1.

Incident light

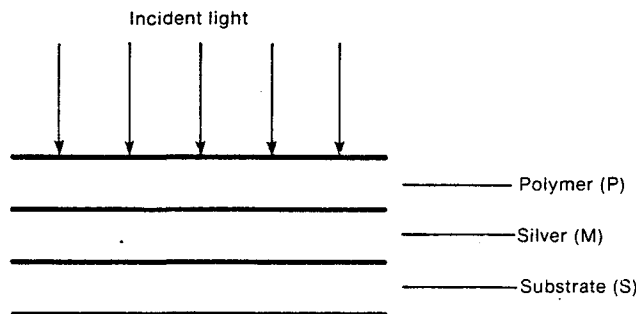005352

Polymer (P)

Silver (M)

Substrate (S)

Figure 1.   Test mirror configuration

Experimental procedure

Mirrors are made using Corning 7809 glass as a substrate onto which a thin, reflective silver film is deposited, and polymeric films are then cast from solution onto the silver. A series of additives (UV screens, quenchers, antioxidants, antipermeants) can

enhance the effectiveness of PMMA. We have identified a series of additives with first emphasis on UV screens that are being tested.

There are several possible silvering processes. We have used vacuum metallization by sputtering onto glass substrates and deposition by the wet-chemical process onto glass substrates as a precursor to casting polymeric films.

When the polymer formulations are being altered to improve durability, it is convenient to use the solution-casting technique to make the polymeric films. In this case, we coat the polymer onto the silver in contrast to the use of extruded films where we deposit the silver onto the polymer.[1] While solution casting may not be used in large-scale production, we have observed some factors that influence optical performance; the factors are all relevant for our tests, and they may be relevant where extruded films are used.

Mirrors are characterized for reflectance using a Perkin-Elmer 340 spectrometer and integrating sphere to obtain the hemispherical reflectance H as a function of wavelength. These data are used to calculate the solar-weighted (air mass 1.5) hemispherical reflectance. To save time in obtaining preliminary data, we integrate, in most cases, from 0.3 to 1 μm rather than from 0.2 to 2.6 μm, and hence H is lower than the true solar value.

For some applications specular reflectances S are relevant parameters that may be more sensitive to weathering degradation than hemispherical reflectances. Therefore, as work proceeded we included specular measurements at one wavelength (0.660 μm) and one acceptance angle (7.5 mrad). These measurements were made with a Devices and Services* instrument, which has now been altered to obtain S at a 3.5 mrad acceptance angle also. The acceptance angle is defined as half the apex angle of the right circular cone defined by the instrumentation.

After initial reflectance measurements, mirrors are exposed to environmental degradation using three techniques. Weather-Ometers** and QUV[†] accelerated weathering devices provide data for comparison with data from real-time, outdoor exposure (racks facing south with 45° tilt).

The Weather-Ometer specimens, as illustrated in Figure 1, are being subjected to UV or no UV, 60°C, and air at 80% relative humidity. A xenon arc lamp with filter cutoff to match the terrestrial solar spectrum supplies the UV light. The QUV test cyclically uses 4 hours of UV exposure (from fluorescent lamps) at 60°C and 4 hours of condensed water exposure at 40°C (ASTM, G53-77). The accelerated weathering devices are used for comparison purposes only; it is not possible to state, a priori, which device provides the harsher test for any particular mirror material.

Results and discussion

Reflectance data have been obtained for a series of silver/polymer mirrors as a function of environmental degradation and metallization methods.

Metallization effects

When silver is deposited onto glass by the wet-chemical process used to make household mirrors, the hemispherical reflectance of the silver at the silver/air interface falls from 96% to about 88% upon coating the silver with PMMA (note the silver/glass interface would be used if it were a "glass" mirror). A series of experiments demonstrates that the decrease in reflectance using wet-processed silver is not a chemical effect. When the PMMA film is redissolved with the same type solvent, the reflectance of the silver returns to its original value (Figure 2), and the transmittance measurements of the redissolved polymer compared to the original polymer solution are also unchanged.

Alternatively, we have also shown that when the silver is deposited by vacuum sputtering rather than the wet-chemical process, we obtain reflectances in the mid-90's, and this value remains when PMMA films are cast onto sputtered silver in the same way they were placed onto wet-processed silver.

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*Devices and Services Co., Dallas Tex.

**Weather-Ometer is a registered trademark of the Atlas Electric Devices Company, Chicago, Ill.

[†]QUV is a registered trademark of the Q-Panel Company, Cleveland, Ohio.

YELLOW FILM IDENTIFICATION

BEFORE
(1) ――――
    89.20

+PMMA
(2) ············
    77.80

-PMMA
(3) ― ― ―
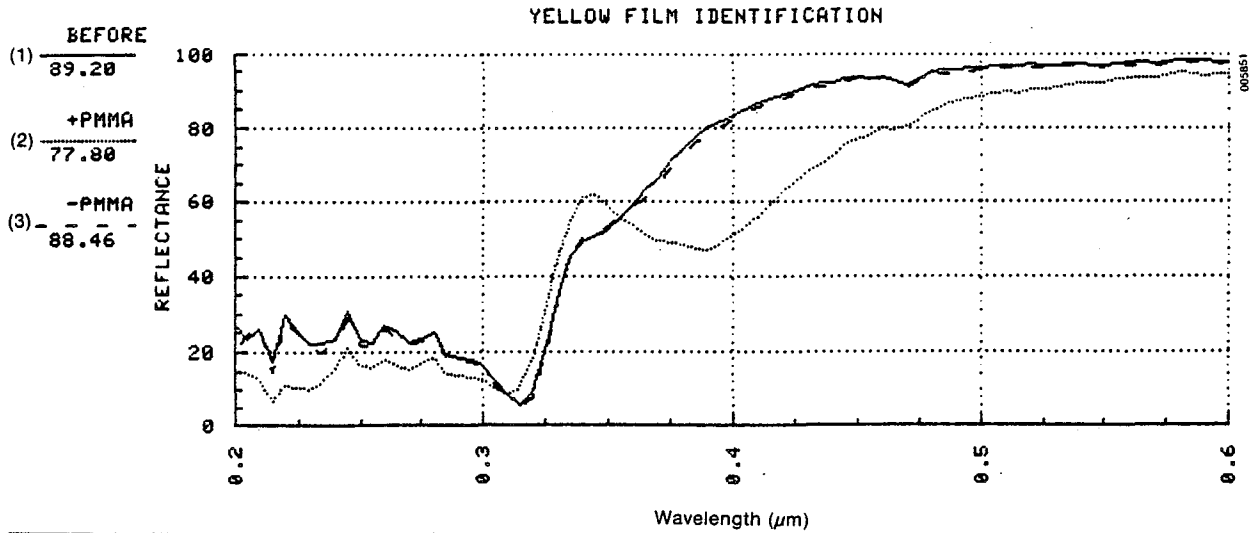   88.46

Wavelength (μm)

Figure 2.   Reflectance of wet-processed Ag/7809 glass mirrors: (1) before coating with
            PMMA. (2) after coating with PMMA, (3) after redissolving PMMA

The decrease of reflectance of PMMA-coated, wet-processed silver mirrors manifests itself
visually as a slight yellow hue that is not present when vacuum-sputtered silver is used.
The yellowing phenomenon is observed for different types of polymers or when a drop of
solvent (toluene) is deposited onto bare silver. The effect on reflectance is illustrated
in Figure 3, where the initial hemispherical reflectance of PMMA/Ag/7809 glass is shown as
a function of wavelength. The reflectance minimum at 0.4 μm is hardly discernable when
sputtered silver is used.[3,4]

Our measurements also show that thin silver films do transmit some UV light near
320 nm.[3] Although wet-processed silver seems to have a higher transmittance than sputtered
silver, a transmittance contribution to the dip in reflectance can be ruled out since
coating the silver surface with PMMA decreased the transmittance maximum of silver but did
not change the location of the transmittance maximum. The transmittance around 0.4 μm is
small.[3] Scanning electron microscopy studies have shown that the surface of wet-processed
silver is rougher than that of sputtered silver.[3] This surface roughness, together with
possible crystalline disorder in the silver surface, provides a coupling of incident light
to surface plasmons (collective electron excitations localized near the silver surface).[5]
Excitation of the surface plasmons in turn gives rise to increased absorption and scat-
tering in some wavelength regions.

Figure 4 demonstrates the reflectance decrease of a bare wet-processed mirror versus a
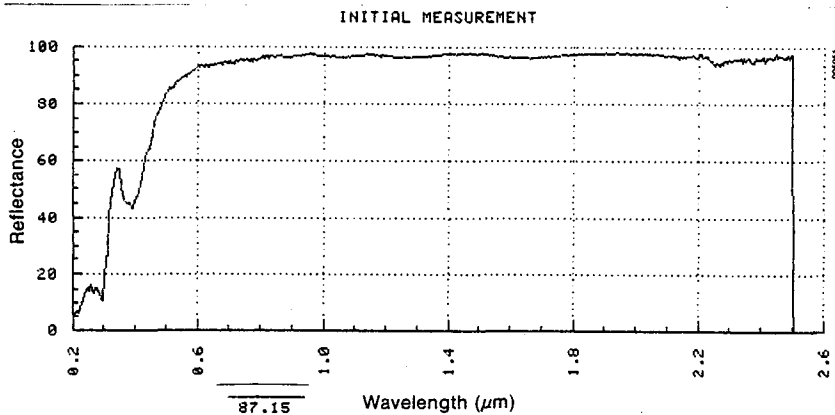
INITIAL MEASUREMENT

Wavelength (μm)

Figure 3.   Reflectance of PMMA/wet-processed AG/7809 glass
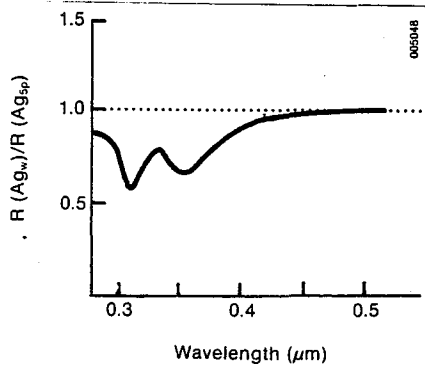

Wavelength (μm)

Figure 4. Comparison of
reflectance of wet-
processed and vacuum-
sputtered silver on 7809
glass

bare sputtered mirror that is due to the volume plasmon effect (λ_b = 0.32 μm) and is responsible for the increased transmittance of the wet-processed silver. The surface plasmon effect (λ_{sp} =0.36 μm) is responsible for the increased absorption and scattering of the rougher surface of the wet-processed silver.

These effects are enhanced by dielectric overcoating layers, which both increase the absorption and shift the surface plasmon peak to a longer wavelength. Also the volume plasmon absorption of PMMA-coated silver mirrors remains in position at 0.32 μm but is reduced in intensity, thus explaining the lower transmittance and higher reflectance in this wavelength region. A rigorous calculation of the wavelength location of the surface plasmon effect is quite complicated. Vitko et al.[6] calculated the infinite wavelength limit of λ_{sp} and compared the result to measured data for a variety of dielectric interfaces.[6] Table 1 presents their data and our experimental values. Calculated and experimental values of the surface plasmon wavelengths are in reasonable agreement and lend further support to the assignment of this feature to roughness-induced surface plasmon absorption. For optimum optical performance of silver surfaces in the visible and ultraviolet regions of the spectrum, it is essential that they have an absolute minimum of surface roughness and as undistorted a lattice structure as possible.

Table 1. Comparison of Calculated and Experimental Values of the Surface Plasmon Wavelength (λ_{sp}) as a Function of the Refractive Index (n_D) of the Dielectric Materials

| | n_D | λ_{sp} (μm) | | Ref. |
		Calculated	Experimental	
Ag/air	1.0	0.338	0.353	2
Ag/air	1.0	0.338	0.350-0.354	1
Ag_w/air	1.0	0.338	0.355	3
Ag/water	1.33	0.366	0.376	2
Ag/glass	1.52	0.374	0.384	2
Ag_w/PMMA	1.5	–	0.387	3
Ag_{sp}/PMMA	1.5	–	0.375	3

[1]Reference 5
[2]Reference 6
[3]SERI-in house data

The preceding discussion relates to the optical properties of the undegraded mirrors. Figures 5 and 6 show the normalized hemispherical reflectance curves of uncoated sputtered
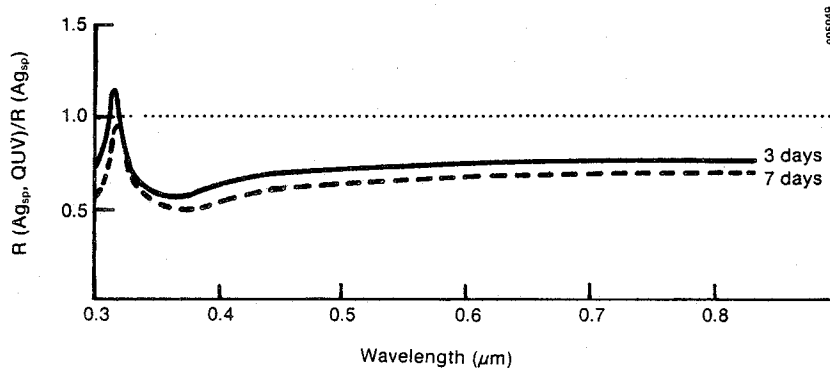
Figure 5. Normalized relfectivity at the air/Ag_s interface of mirrors exposed in the QUV for 3 and 7 days

and wet-processed mirrors exposed in the QUV-weathering device for 3 and 7 days. The spectra exhibit an increase in absorption and shift of the surface plasmon that can be attributed to changes in the surface roughness. The spectra in Figure 6 indicate that the changes occurring in the wet-processed mirror affect reflectance only in the bulk and surface plasmon regions but do not alter reflectance in the rest of the spectrum, which is in contrast to the behavior of sputtered mirrors. A similar behavior can be observed with mirrors aged for 1 hour in a vacuum oven at 100°C. The spectra shown in Figures 5 and 6
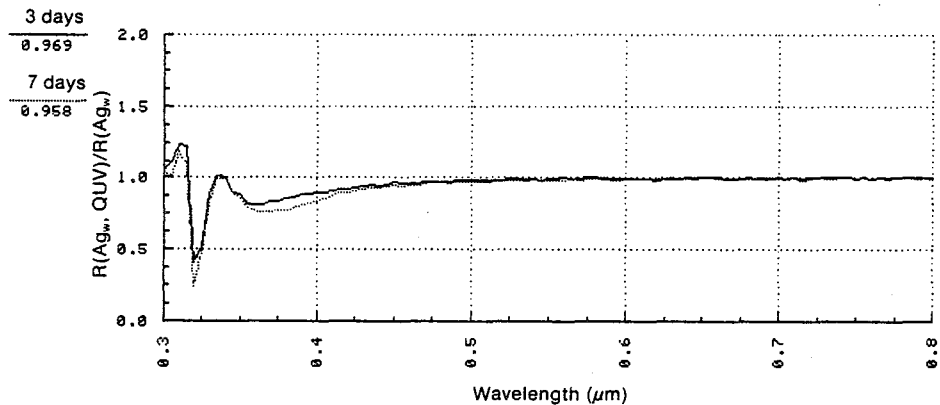
RATIOS

Figure 6. Normalized reflectivity of the air/Ag$_w$ interface of mirrors exposed in the QUV
for 3 and 7 days

indicate also that the reflectances in the spectral regions around both plasmon minima are
more sensitive to initial degradative changes in the silver. This also occurs due to the
UV contribution to the degradation of sputtered silver during a 3-day exposure in the
QUV.[3]   Thus, measurements of relative changes in reflectance especially around the
frequency of the surface plasmon may be of value to detect early degradation of the silver
layer.

<u>Preparation effects</u>

   The degradation of silver mirrors can be avoided or diminished by casting a modified PMMA
film onto the silver/glass substrate.   Polymeric films made this way are thin (500 to
10,000 nm) compared to extruded commercial films, and it is not expected that they neces-
sarily weather as well as thicker films.   Tests performed with these thin films are meant
to guide later formulations for extruded, thick films.

   Variations in solution-casting procedures have been investigated and resulted in the con-
clusion that drawing a silver mirror from a polymer solution (10 w % PMMA) with a constant
speed provided better control of coating thickness than a solution flow mode onto the
silver mirror.   The latter was used for the R9-169 series (Tables 2 and 3).   Other vari-
ables have been drawing speed, flow rate of nitrogen in the drying step, and drying time.

Table 2.   Stabilizer Additives Incorporated Into PMMA Coatings on Wet-Processed Silver

SERI Sample Number	Additives to PMMA	Film Thickness (nm)
R9-169-1	1.5% Tinuvin P	3800
-2	1.5% Tinuvin P + 1% Tinuvin 292	2200
-3	1.5% Tinuvin P + 1% Tinuvin 292 + 1% Irganox 1010	1600
-4	3% National Starch	8000
-5	3% National Starch + 1% Tinuvin 292	6000
-6	3% National Starch + 1% Tinuvin 292 + 1% Irganox 1010	8200
-7	1.5% Uvinul 408	1000
-8	1.5% Uvinul 408 + 1% Tinuvin 292	3000
-9	1.5% Uvinul 408 + 1% Tinuvin 292 + 1% Irganox 1010	3600
-10	1.5% Givsorb UV2	3800
-11	1.5% Givsorb UV2 + 1% Tinuvin 292	5200
-12	3% National Starch + 1% Goodrite UV3034	4800
-13	3% National Starch + 1% Goodrite UV3135	4000
-14	No Additive	-

The thickness of the coatings as measured with a surface profiler varied with changes in
these parameters from 450 nm to 4600 nm. For coating thickness up to 1000 nm a motor with
a variable speed control up to 10.5 cm/min could be used, but for thicker films (1000 to
4600 nm) fast manual dipping of the mirror was the method of choice. Thicker films (up to
10,000 nm) have also been prepared by multiple dipping of dried, coated silver mirrors.[3]

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Table 3. Commercially Available Stabilizers

Product	Manufacturer	Type[a]
Tinuvin P 2 (2'-hydroxy-5'methylphenyl) benzotriazole	Ciba-Geigy	UVA
Uvinul 400 2,4-dihydroxy-benzophenone	BASF-Wyandotte	UVA
Uvinul 408 2-hydroxy-4-n-octoxybenzophenone	BASF-Wyandotte	UVA
Givsorb UV2 N-(p-ethoxycarbonylphenyl)-N'-ethyl-N-phenylformamidine	Givaudan	UVA
National Starch 78-6121 developmental copolymer of a benzophenone	National Starch	UVA
Tinuvin 292 bis (1,2,2,6,6 pentamethyl-4-piperidinyl) sebacate	Ciba-Geigy	HALS
Irganox 1010 tetrakis [methylene (3,5-di-tert-butyl-4-hydroxyhydrocinnamate)] urethane	Ciba-Geigy	AO
Goodrite UV 3034 1,1'-(1,2-ethanediyl) bis (3,3,5,5-tetra-methylpiperazinone)	Goodrich	HALS
Goodrite UV 3125 3,5-di-tert-butyl-4-hydroxyhydro cinnamaic acid triester with 1,3,5-tris(2-hydroxyethyl)-S-triazine-2,4,6 (1H,3H,5H)-trione	Goodrich	AO

[a]UVA = ultraviolet absorber; HALS = hindered amine light stablizer; AO = antioxidant.

Visual inspection of the thinner coatings (450 to 1000 nm) showed small imperfections (pinholes, bubbles). These imperfections serve as nucleation centers for silver degradation during subsequent weathering. Surface profile measurements indicate a vertical growth of about 200 nm for the corroded, opaque silver spots that causes the polymer film to crack and wash away together with the corroded silver area during the dew cycles of the QUV, producing a transparent spot on the mirror. The corrosion patterns of silver mirrors with relatively thin coatings (450 to 1000 nm) can be avoided or diminished by using thicker polymer films.[3]

Variations in casting procedures can produce surface waviness, which limits specularity. This is not intrinsically due to the polymer systems but more a processing artifact. We also have evidence that dust generated, for example, during cutting of larger silvered mirror panels to smaller sizes, cannot be removed by physical means (blowing, brushing) without damaging the silver surface. These small dust particles seem to function also as nucleation centers for degradation after mirrors are coated with the polymer and weathered. Reflectance changes in the spectral regions around both plasmon minima were again most sensitive to these degradative changes.

Usually, when PMMA is solution-cast onto silver it is allowed to dry under nitrogen in a glove box, followed by a drying period under vacuum overnight. We have observed that incomplete drying (without vacuum drying) can influence reflectance because of the presence of residual solvent. The reflectance at frequencies near both plasmon minima was especially sensitive to the drying time.

Stabilized cast polymeric films

Pure PMMA is highly resistant to UV degradation, but laboratory-pure PMMA is not encountered in commercial production processes. Impurities and some additives enhance UV absorption at λ > 285 nm and accelerate degradation of the polymer and the silver. Impurities at the silver/PMMA interface also cause polymer degradation as well as silver degradation; chlorine has been specifically identified, and it enhances the polymer degradation rate by factors in excess of 1000.[7]

The characteristics of photodegradation permit application of methods to prevent such degradation by involving both photon absorption and transfer of energy. Generally, photo-stabilizers for polymers are classified according to their mode of action: UV light absorbers, excited state quenchers, antioxidants, and hydroperoxide decomposers.[8] Widely used UV absorbers are 2-hydroxy-benzophenones, 2-hydroxy- benzotriazoles, and phenylsalicylates. Quenchers currently in use are hindered amines and complexes or

chelates of transition metals. Typical antioxidants are hindered amines and hindered phenols. Hydroperoxide decomposers include phosphites and organic sulfides.

Since the photodegradation process is a multistep one, a synergistic system that combines a variety of stabilizing mechanisms may provide the best protection. Many stabilizers are multifunctional, and the application of stabilizers still comprises a series of problems, such as compatibility of the stabilizer with the polymer, diffusion of the stabilizer out of the polymeric matrix, and photodecomposition of the stabilizer.

A series of additives (Table 3) has been identified and incorporated into PMMA to enhance its effectiveness. The initial emphasis has been on using UV absorbers, and combinations of UV absorbers and hindered amine light stabilizers or antioxidants.

Mirror performance has been found to depend also on the weathering mode. The series R9-169 (Tables 2 and 4) serves as an example with representative results to demonstrate the effect of different weathering modes on reflectance. None of the samples degraded significantly during short-term tests outdoors (42 weeks) and in the accelerated QUV tests (42 weeks) as determined by comparing hemispherical reflectances (H). The specular reflectance values are most sensitive to outdoor exposure and need more study. The low initial S values for pure PMMA (R9-169-14) are undoubtedly due to casting procedure variations. Two samples (R9-169-3, R9-169-10) may be essentially unchanged within the expected error of measurement.

Table 4. Hemispherical Reflectance (H) and Specular Reflectance (S) at 7.5 mrad of Solution Cast Films onto Wet-Processed Silver after Outdoor and QUV Exposures

| SERI Sample Number | H(%) Weeks | | | | S--7.5 mrad(%) Weeks | | | |
| | Outdoors | | QUV | | Outdoors | | QUV | |
	0	42	0	42	0	42	0	42
R9-169-1	83.7	83.6	83.6	d	96	85	96	d
-2	77.0	78.6	78.0	d	87	46	87	d
-3	82.9	82.9	82.8	d	91	87	91	d
-4	85.1	d	85.1	85.5	48	d	48	d
-5	85.4	d	85.3	83.3	22	d	22	d
-6	85.5	d	85.7	84.1	39	d	39	d
-7	83.4	85.2	82.6	84.5	95	89	95	64
-8	80.4	80.7	80.1	85.0	91	88	91	77
-9	82.4	83.6	82.0	85.1	96	88	96	71
-10	83.2	85.8	83.1	83.5	93	89	93	73
-11	82.9	83.2	82.9	85.8	95	58	95	71
-12	85.0	d	85.2	82.9	34	d	34	d
-13	85.9	d	85.9	86.0	38	d	38	d
-14	84.1	85.6	84.4	86.0	75	56	75	d

d = discontinued

In contrast to the above-mentioned degradation modes, accelerated Weather-Ometers tests (Table 5) demonstrate an enhanced degradation of unstabilized PMMA/silver mirrors (Figure 7), while stabilizers added to PMMA impede the degradation. Figure 8 shows the decrease in reflectance at a selected wavelength (500 nm) as a function of time for the R9-169 series. Analysis of these data identifies Tinuvin P as a leading stabilizer for PMMA/silver mirrors. Several other combinations are comparable to it based on these Weather-Ometer results: Givsorb + Tinuvin 292, National Starch + Goodrite 3034, and National Starch + Goodrite 3125. There is evidence that a synergistic protection mechanism becomes operable whenever a hindered amine stabilizer and an antioxidant are added together with a UV screen to the polymer. No degradation was observed for samples shielded from the UV light except for unstabilized PMMA.

Permanence of polymer additives

The permanence of the stabilizer in the PMMA film is another important factor for preventing long-term degradation of PMMA/silver mirrors. The change in the absorption maximum of UV-screening additives was chosen to monitor this factor. The concentration of the selected UV screens in the polymer does not change during 16 weeks of testing in the Weather-Ometer if the samples are shielded from the UV light source. If exposed to UV light during these tests, a complete loss of the Givsorb stabilizer is observed, whereas the other stabilizers show little (Tinuvin P) or no loss from the polymer matrix during this time interval. Photodegradation of the stabilizer may be a possible reason for the

loss observed in the case of Givsorb and Tinuvin P.   The outdoor test data confirm a similar trend during a 30-week exposure period.

Table 5. Hemispherical Reflectance (H) of Solution Cast Films onto Wet-
Processed Silver after Weather-Ometer Exposures

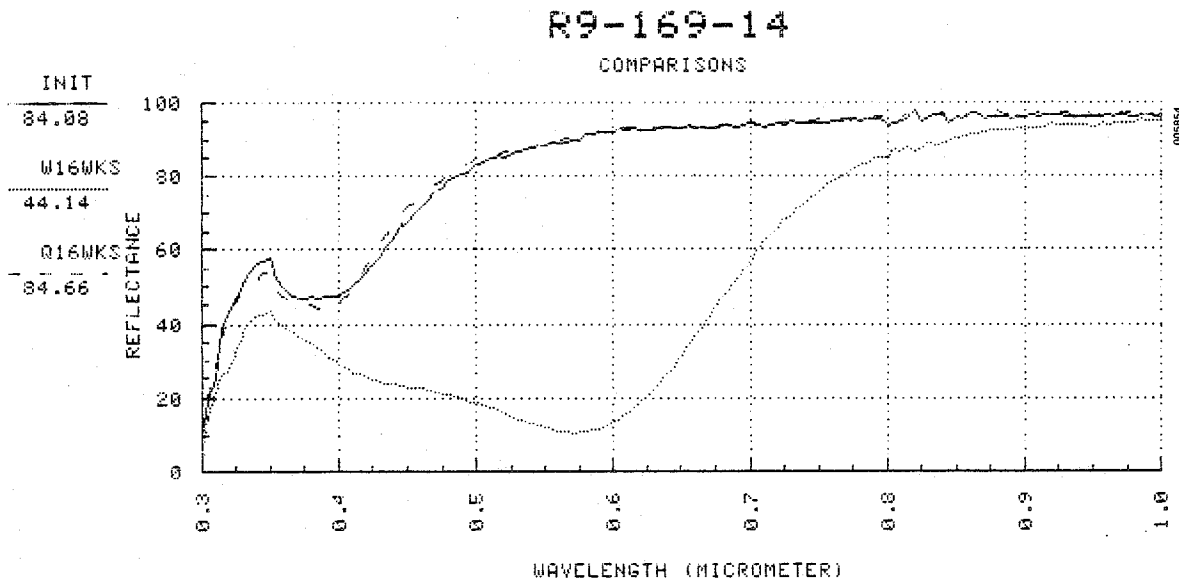| SERI Sample Numbers	H (%) Weeks				
	0	9_{UV}	$9_{No\ UV}$	16_{UV}	$16_{No\ UV}$
R9-169-1	83.4	85.0	84.5	83.9	84.3
-2	77.9	76.6	79.4	74.3	78.8
-3	81.9	82.5	83.1	82.5	83.0
-4	85.7	81.4	86.2	36.8	84.8
-5	85.4	66.3	83.1	55.1	85.0
-6	85.3	68.9	84.7	67.1	84.5
-7	83.7	48.2	83.1	45.5	83.0
-8	81.0	63.7	83.3	64.6	83.1
-9	83.1	69.8	84.1	66.0	84.0
-10	83.6	79.8	84.4	72.6	85.5
-11	82.5	85.3	84.2	85.4	84.4
-12	84.5	82.9	85.3	83.1	85.3
-13	85.7	86.7	86.6	86.3	86.4
-14	84.7	45.3	80.5	44.1	81.2

Figure 7. Reflectance of mirror R9-169-14 as a function of wavelength after 16 weeks of weathering in a Weather-Ometer (W) and QUV (Q)

Quite different results are obtained with the QUV exposure mode, which includes a repetitive condensation of water on the mirror samples. Severe stabilizer losses, probably due to a "washing out" effect, are observed after only 8 weeks of exposure, with Givsorb and Uvinul 408 showing the strongest decrease in absorber concentration, followed by National Starch. Tinuvin P demonstrates the best performance, showing a higher performance than the polymeric National Starch stabilizer. This phenomenon is not understood, but may be due to different homogeneous stabilizer distributions in the polymer matrix caused by solubility differences and the preparation technique of the polymer glazings.

Supplementary extraction experiments under different temperature conditions have been performed on the same stabilized mirror samples over 13 days in distilled water. In one series, mirrors were exposed to a constant volume of water at room temperature in

Erlenmeyer vessels. After one week, it was observed that the unstabilized PMMA film lifted completely off the mirror surface with the silver staying attached to the <u>glass</u> substrate.

All the stabilized PMMA films were still attached to the silver/glass with only the edges of the films lifting, where subsequently corrosion of the silver started. After 13 days,
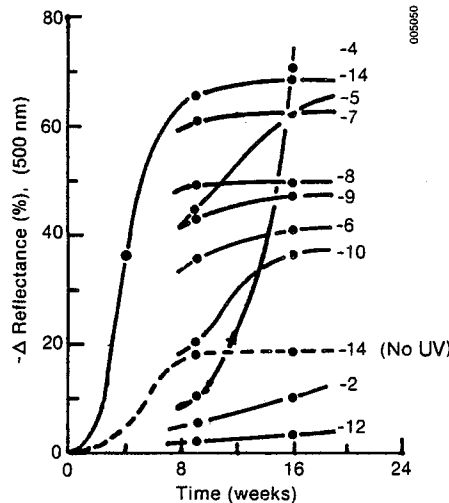

Figure 8.   Decrease in hemispherical reflectance at a selected wavelength (500 nm) as a function of time for the R9-169 series (samples -1, -3, -11, and -13 did not exhibit any change)

all stabilized films, except the one with Tinuvin P, had lifted off the glass substrate with the corroded silver layer attached to the <u>polymer</u> film. The corroded silver subsequently dissolved in the water. Transmission measurements of the polymer films provided some evidence on the permanence of the stabilizer: Tinuvin P > National Starch > Uvinul 408 > Givsorb.

In Weather-Ometer studies, samples can be mounted so that half of each sample is shielded from UV light while the whole sample is exposed to the temperature and humidity conditions. The sample portions exposed to UV usually degrade optically more rapidly than the half protected from UV. Since UV is known to degrade silver and PMMA, it is evident that the role of the stabilizer has been to diminish, if not eliminate, the problem. The challenge is to be able to incorporate a UV stabilizer that is also nondegradable without altering the desired reflectance properties of the silvered PMMA. With the QUV exposure mode, sample portions exposed to UV also degrade more rapidly than the half protected from UV, but by orders of magnitude less than in the Weather-Ometer. Although Tinuvin P proved to be more permanent than the other investigated stabilizers, a noticeably higher loss is observed in the UV-exposed portion versus the half protected from UV. This could indicate a photodecomposition contribution to the loss of Tinuvin P, assuming the same extractive loss contribution in both sample positions. These results from QUV studies are also confirmed by Weather-Ometer studies, where a small loss of Tinuvin P as a function of the time has also been observed under nonextractive exposure conditions.

Conclusions

   The most significant results are:
   ● Optical properties of the polymer/silver mirrors depend on subtle relationships between the metallization and the dielectric (polymeric) films that are in contact with the silver.
   ● Specularity of the mirrors is a function of the preparation procedures.
   ● UV light plays a crucial role in the degradation of silver mirrors.
   ● Degradation of silver mirrors can be avoided or diminished by casting modified PMMA films onto the silver/glass substrates.
   ● UV stabilizers added to the polymer impede the degradation of the polymer/silver mirrors.
   ● Mirror performance and the permanence of UV stabilizers have been found to depend on the weathering mode.

- Synergisms of various stabilizer combinations have been observed to improve the mirror protection.
- A benzotriazole UV stabilizer has performed best in PMMA/silver mirrors.

Acknowledgments

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