

Broadband Mirrors for Solar Applications



Figure 1. Layouts of concentrating solar (parabolic dish from Sterling Energy Systems)

Concentrating solar applications require the use of high-quality, robust, high-reflectivity mirrors to focus the solar energy onto a cell or a heat-transfer liquid. Figure 1 shows a number of geometries and implementations of this concept, ranging from parabolic troughs employed exclusively in photothermal applications, to relatively small parabolic mirrors used in concentrated photovoltaics to large arrays of flat mirrors that direct many beams towards a central tower. The tower employs a combination of photovoltaic (for direct energy conversion) and photothermal (for indirect conversion) technologies. The common feature in these systems is that the entire solar spectrum (roughly 350-1800 nm- Figure 2) is utilized for photovoltaics, photothermal or both.

Most outdoor commercial mirrors used in solar applications are second-surface metal mirrors, whereas in controlled or laboratory environments, first-surface mirrors are more common. First surface mirrors reflect off the top of the glass, while in second surface mirrors, the incoming light first hits the glass and is reflected off a metal layer on the underside (Figure 3). **The disadvantage of the “second surface” is that there are multiple reflections at the glass surface, first as the light enters the mirror and again as it leaves.** The reflections at each surface are roughly 4% of the incident light level. They cause ghosting of the image and difficulties focusing in certain geometries. Furthermore, because the refractive index difference between glass and metal is not the same as between air and metal, the reflectivity of the metal surface itself is different. The cover glass can be anti-reflected, but the AR-coatings tend not to be very durable to the elements.

Many deployed PV/PT systems use Silver coated directly on the cover glass with protective paints on the backside, or a reflective metal sheet (stainless steel, aluminum or silvered metal) bonded to the cover glass with an optically transparent adhesive or epoxy layer. Epoxies and adhesives used in the assemblies absorb certain wavelengths and degrade over time due to photochemical damage and oxidation. The backside is usually composed of a series of materials with various properties including paints, epoxies, metals and/or another piece of glass.

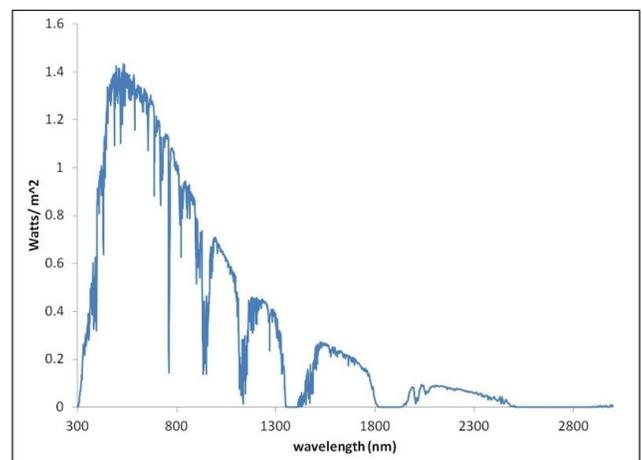
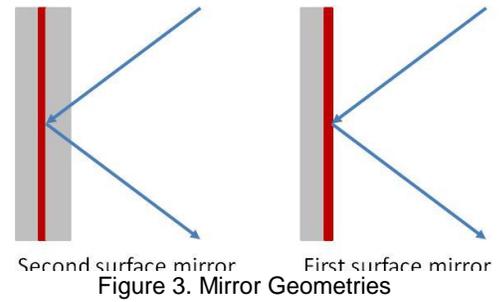


Figure 2. Solar Irradiance versus wavelength

Inexpensive mirrors have also been developed using metalized polymer films and laminations. Like epoxies, many polymers become yellowed and brittle with age and are not as resistant to oxygen and moisture penetration as glass.

There are several disadvantages of metal mirrors:

1. They absorb some of the light and heat up
2. Unless well-protected, they degrade over time due to photodegradation, water and air infiltration
3. The reflectance cannot be optimized for a specific wavelength performance



Another approach is to employ rugged first-surface mirrors. **Unlike the metal coatings which often degrade over time, dielectric interference mirrors are made of thin layers of oxide materials, similar to glass.** By tuning the thicknesses of the layers, specific wavelengths or ranges of wavelengths can be made to be transmit or reflect light. In Figure 4, the reflectance of three first surface mirrors are displayed. The Aluminum and Silver mirrors are protected with thin layers of Magnesium Fluoride and Silicon Dioxide respectively, while the Ultra-wide band dielectric mirror is composed of layers of Silicon Dioxide and Niobium Pentoxide.

As illustrated in Figure 4, the dielectric mirror is comparable or better in reflectivity to a new protected silver mirror in the 350-1800 nm range. The average reflectance of the dielectric mirror in this range is >99.5 % (NIST) while fresh, unprotected silver is in the 98-99% range. Aluminum is quite a bit lower (in the 85-90% range). However, after a full 5-day temperature and humidity cycling test (MIL810E), the Silver reflectivity decreases significantly, as does the Aluminum to a lesser extent. The dielectric mirror does not change within the sensitivity of our spectrometer.

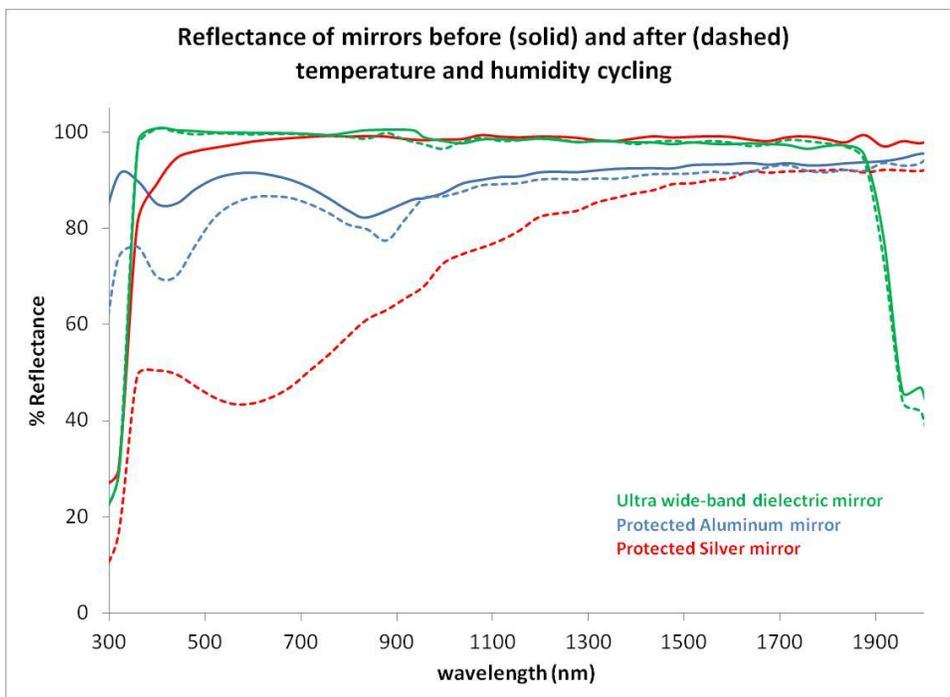


Figure 4. Reflectance of first-surface mirrors with the Cary 5 spectrometer

The oxide materials do not absorb light in the 350-1800 nm region, so they do not heat up with intense illumination. The light that is not reflected does get absorbed by the glass substrate at low wavelengths (<340 nm or so) and is transmitted through the part at higher wavelengths. The transition between transmission and reflection can be optimized by changing the number and thickness of the individual layers for various effects. For instance, light of some wavelengths can be directed to a solar cell with one spectral response, while the remaining light can be captured by a different cell with another spectral response in spectral splitting applications.

Dielectric mirrors have many advantages in concentrating photovoltaic applications. They exhibit high durability, extremely high reflectance over the desired wavelength range and the reflectance can be optimized to the cell's spectral response.