METALLIC COATINGS FOR LASER AND ASTRONOMICAL APPLICATIONS
FRONT SURFACE SILVER MIRRORS

BROADBAND SILVER MIRRORS FOR THE VIS AND NIR

![Graph](image1)

**Optical properties:**
- \( R > 98 \% \) throughout the specified wavelength range (except type b).
- \( R = 94 \% … 97 \% \) in the VIS outside the specified wavelength range.
- \( R > 97 \% \) in the NIR outside the specified wavelength range.

**Special features:**
- Silver has the highest reflectance of all metals in the VIS and NIR.
- Sputtered protective layers yield very stable optical parameters.
- Lifetime of more than 10 years in normal atmosphere has been demonstrated although unprotected silver is chemically unstable.
- The high atomic density of sputtered coatings guarantees that even very thin protective layers (= 20 nm) provide a good protection against the atmosphere.
- The thickness of the protective layer can be used to optimize the reflectance of the mirrors for different wavelength ranges (see fig. 1).
- Sputtered silver mirrors show extremely low scattering losses. (total scattering TS = 30 ppm in the VIS and NIR).
- Silver mirrors with defined transmittance (e.g. \( T = 0.01 \% \)) on request. (see page 86)
- Mechanical stability of protected silver mirrors is tested according to MIL-M-13508C § 4.4.5.
- Maximum diameter: 600 mm, especially for astronomical applications.

Figure 1: Reflectance spectra of three standard types of protected silver mirrors:
- a) Optimized for 600 – 1000 nm with \( R > 98 \% \)
- b) Optimized for 600 – 2000 nm, 600 – 750 nm with \( R > 96 \% \), 750 – 2000 nm with \( R > 98 \% \)
- c) Optimized for 1000 – 10000 nm with \( R > 98 \% \)

SILVER MIRRORS FOR USE IN FEMTOSECOND LASERS

![Graph](image2)

**Figure 2:** Reflectance and GDD spectra of a silver mirror optimized for use with fs-lasers in the wavelength range 600 – 1000 nm (AOI = 45°)
- a) Reflectance vs. wavelength
- b) GDD vs. wavelength

Silver mirrors are ideal in femtosecond laser systems because of their extremely broad low-GDD reflectance band.
For more examples see pages 86 – 87.
The reflectance of silver mirrors can be enhanced for selected wavelengths or wavelength regions by a dielectric protective coating. Figures 3 – 6 show examples for silver mirrors with enhanced reflectance. Such mirrors combine very high reflectance at the wavelengths of interest with a relatively high reflectance throughout the VIS which makes them ideal for use in conjunction with alignment lasers.

Figure 3: Reflectance spectra of an enhanced silver mirror which shows R ≥ 98 % throughout the visible spectral range:
   a) AOI = 0°
   b) AOI = 45°, unpolarized light

Enhanced silver mirrors of this type are useful for applications in astronomical devices.

Figure 4: Silver mirror with enhanced reflectance at 425 and 850 nm (R > 99.5 %)

Figure 5: Silver based turning mirror for 1030 nm with R > 80 % for any alignment laser in the red spectral range

The mirror in figure 5 is a cost effective alternative for all dielectric mirrors for high power Yb:YAG- or Nd:YAG- lasers.

Figure 6: Reflectance spectra of a silver based scanning mirror for laser diodes in the NIR:
   HRu (22° – 58°, 805 – 940 nm) > 99.3 %
   + Ru ( 22° - 58°, 630 – 670 nm) > 50 %

For more information on enhanced silver mirrors see pages 56, 86 – 87 and 108 – 109.
FRONT SURFACE ALUMINUM MIRRORS

BROADBAND MIRRORS FOR THE UV, VIS AND NIR

**Optical properties:**

Unprotected aluminum:
- \( R > 80 \% \) at 193 nm
- \( R = 92 \% \) at 248 nm
- \( R > 85 \% \) from 200 nm to 950 nm
  \( (R > 90 \% \) from 230 nm to 600 nm)\n- \( R > 90 \% \) for \( \lambda > 1 \mu m \).

Standard mirror:
- \( R = 82 \% \ldots 92 \% \) from 240 nm to 550 nm
- \( R = 85 \% \ldots 92 \% \) from 550 nm to 950 nm
- \( R > 92 \% \) for \( \lambda > 1 \mu m \).

Aluminum is the metal with the highest reflectance in the UV spectral range. Besides this, aluminum has a high and relatively constant reflectance in the VIS and NIR. The minimum in the reflectance curve around 800 nm is due to a phonon resonance and can only be overcome by a dielectric protective coating. The reflectance in the VIS and UV spectral range can be influenced by the coating technologies. In case of protected aluminum mirrors, the positions of the minima and maxima of the reflectance depend on the design of the protective layer system and on the angle of incidence (AOI). Please specify AOI and the wavelengths of interest so that reflectance may be optimized as much as possible.

Fig. 1: Reflectance spectra of unprotected aluminum and of a standard protected aluminum mirror

Fig. 2 shows the reflectance spectra of a mirror optimized for high reflectance at 266 nm, 400 nm and 800 nm at AOI = 45°.

*Special features:*
- High reflectance in the wavelength range specified
- Extremely low scattering losses of protected aluminum mirrors (total scattering TS < 100 ppm at 633 nm, TS < 1000 ppm at 248 nm, TS < 5000 ppm at 193 nm).
- Standard mirrors can be cleaned using ethanol or acetone and are resistant to moderate abrasion (tested according to MIL-M-48497A § 4.5.4.2 and § 4.5.3.3).
- All mirrors are resistant to humidity (tested according to MIL-M-13508C §4.4.7).
- Highly stable optical parameters because of sputtered SiO₂ protective layer.

ALUMINUM MIRRORS FOR MULTIPLE WAVELENGTH AND FEMTOSECOND APPLICATIONS

**Figure 2:** Reflectance and GDD spectra of an aluminum mirror optimized for \( R > 85 \% \) at 266 nm, 400 nm and 800 nm (AOI = 45°)

- a) Reflectance vs. wavelength
- b) GDD vs. wavelength

**Figure 3:** Reflectance and GDD spectra of aluminum mirrors with different designs for enhanced reflectance for the third harmonic of the Ti:Sapphire laser (AOI = 0°)

- a) Reflectance vs. wavelength
- b) GDD vs. wavelength
PROTECTED AND ENHANCED ALUMINUM MIRRORS FOR THE DUV AND VUV

Optical properties:
Special coating design depending on the wavelengths of interest.
Optimized for 157 nm: R = 74 % … 78 % for 157 nm (R > 70 % from 150 to 200 nm).
Optimized for 193 nm: R = 75 % … 80 % for 193 nm.
Optimized for 248 nm: R > 90 % for 248 nm.

- Reflectance at 157 nm can be further improved by dielectric protective coatings (up to R > 94 %).
- Reflectance in the VIS: R = 60 … 80 %. This can be used for an alignment laser.
- Especially mirrors with R = 85 … 90 % can be used at a wider range of AOI than all dielectric mirrors of this reflectance.
- Reflectance at 193 nm can be improved up to R > 95 %.
- This kind of mirrors can also be used as scanning mirror for AOI = 45° – 50° with Ru > 93 %.
- Reflectance in the VIS: R = 60 … 80 %. This can be used for an alignment laser.
- VUV optimized mirrors should be treated with extreme care.

Figure 4: UV optimized aluminum: reflectance spectra of aluminum mirrors optimized for 157 nm and 193 nm (AOI = 0°)

Figure 5: Reflectance spectra of two types of enhanced aluminum mirrors for 157 nm: a) R > 80 % for AOI = 0° … 45°
b) R > 94 % at AOI = 0°

Figure 6: Reflectance spectra of an aluminum mirror with enhanced reflectance for 193 nm (AOI = 45°, Ru > 95 %)
SPECIAL METALLIC COATINGS

CHROMIUM COATINGS FOR OPTICAL APPLICATIONS

Chromium coatings are used for lithographic processes and other special optical applications. LAYERTEC offers chromium coatings with extremely low pinhole density on mask blanks and silicon wafers. Typical substrates sizes are 6 inch x 6 inch, but uncommon sizes up to diameter 600 mm are also possible.

LAYERTEC uses specialized sputtering processes for very efficient industrial production. These processes are optimized for:

- Low pinhole density
- High optical density
- Low mechanical stress
- High electrical conductivity.

Besides high volume coating manufacturing, LAYERTEC still maintains its capabilities for flexible production of small volumes such as OEM components or components for research and development. Do not hesitate to contact LAYERTEC regarding your special request.

BROADBAND NEUTRAL DENSITY FILTERS FOR THE NIR

- Nearly constant transmittance for broad wavelength range from 1 μm to 10 μm.
- Substrate: BaF₂.
- Other transmittance values on request.

Figure 1: Transmittance spectra of broadband neutral density filters with different transmittance values.

![Transmittance spectra of broadband neutral density filters](image)
SOLDERABLE COATINGS

Soldering is one of the most important mounting techniques for optics which require excellent thermal contact to a heat sink. LAYERTEC has developed several coating designs containing gold and other metals which can be used for soldering of the optics.

A very special problem is solder coatings on components for high power applications. As an example figure 2a and 2b show a pump mirror which is coated with a solder layer system on the top side and with dielectric coatings on the front and rear surfaces. Extreme care must be taken to avoid metallic contaminations on the optical surfaces. Nevertheless, the solder coating has to cover the whole top surface of the substrate.

Figure 2: Pump mirror which is coated with a solder layer system on the top side

GOLD MIRRORS FOR THE NIR SPECTRAL RANGE

Gold coatings with a thickness of 10 nm to 50 nm can be used as partial reflectors or attenuators in the NIR spectral range. Fig. 5 shows transmittance spectra of gold layers with different thickness. Moreover, thin gold layers are also useful for non-optical applications. An example of such an application is the generation of single electron pulses. Thin metallic layers are irradiated with femtosecond laser pulses. This results in the release of electrons. These electron pulses are generated with the repetition rate of the femtosecond laser. Recent investigations have shown that the pulse length of these electron pulses can be compressed to the attosecond range using a microwave cavity 1, 2.

Magnetron sputtering allows the manufacture of partially transmissive gold layers in the mentioned thickness range. The optical parameters of these coatings are very stable because gold is chemically inert. Please note that gold layers are soft and can be easily damaged mechanically.

Figure 3: Reflectance spectra of protected and unprotected gold mirrors

Optical properties:
Unprotected gold: \( R > 97\% \) from 700 nm to 1 \( \mu \)m
\( R > 98\% \) for \( \lambda > 1 \) \( \mu \)m.

Protected: \( R > 96\% \) from 700 nm to 2 \( \mu \)m
\( R > 98\% \) for \( \lambda > 2 \) \( \mu \)m.

Special features:
- Extremely low scattering losses (total scattering \( TS < 100 \) ppm at 633 nm).
- Gold mirrors are chemically stable and can be used without protective layer.
- Unprotected gold is soft and scratches easily.
- Protected mirrors can be cleaned (tested according to MIL-M-13508C § 4.4.5).

Figure 4: Gold mirror on plano-concave substrate

PARTIALLY TRANSMISSIVE GOLD LAYERS FOR OPTICAL AND NON-OPTICAL APPLICATIONS

Soldering is one of the most important mounting techniques for optics which require excellent thermal contact to a heat sink. LAYERTEC has developed several coating designs containing gold and other metals which can be used for soldering of the optics.

A very special problem is solder coatings on components for high power applications. As an example figure 2a and 2b show a pump mirror which is coated with a solder layer system on the top side and with dielectric coatings on the front and rear surfaces. Extreme care must be taken to avoid metallic contaminations on the optical surfaces. Nevertheless, the solder coating has to cover the whole top surface of the substrate.

Figure 2: Pump mirror which is coated with a solder layer system on the top side

Gold coatings with a thickness of 10 nm to 50 nm can be used as partial reflectors or attenuators in the NIR spectral range. Fig. 5 shows transmittance spectra of gold layers with different thickness. Moreover, thin gold layers are also useful for non-optical applications. An example of such an application is the generation of single electron pulses. Thin metallic layers are irradiated with femtosecond laser pulses. This results in the release of electrons. These electron pulses are generated with the repetition rate of the femtosecond laser. Recent investigations have shown that the pulse length of these electron pulses can be compressed to the attosecond range using a microwave cavity 1, 2.

Magnetron sputtering allows the manufacture of partially transmissive gold layers in the mentioned thickness range. The optical parameters of these coatings are very stable because gold is chemically inert. Please note that gold layers are soft and can be easily damaged mechanically.

Figure 5: Transmittance of partially transparent gold coatings on sapphire

Literature:
2) M. Aichelsburger, F.O. Kirchner, F. Krausz and P. Baum; PNAS vol.107 no.46 19714-19719