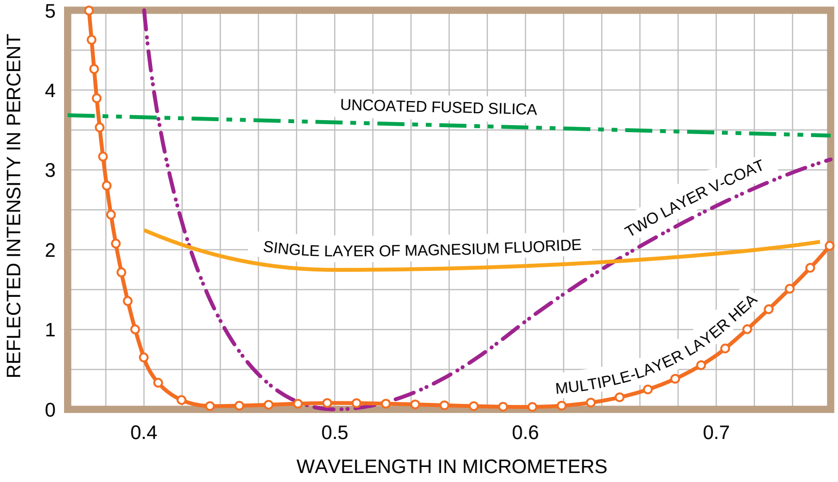
ANTIREFLECTION COATINGS

for Ultraviolet and Visible Applications

ANTIREFLECTION COATINGS

Whether an optical system consists of a single element or a complex array of optics, it is important to manage the transfer of energy through the system. Energy management usually includes maximizing the energy throughput of the system while minimizing the amount of scattered or stray energy. This is the task for which antireflection coatings are ideally suited.

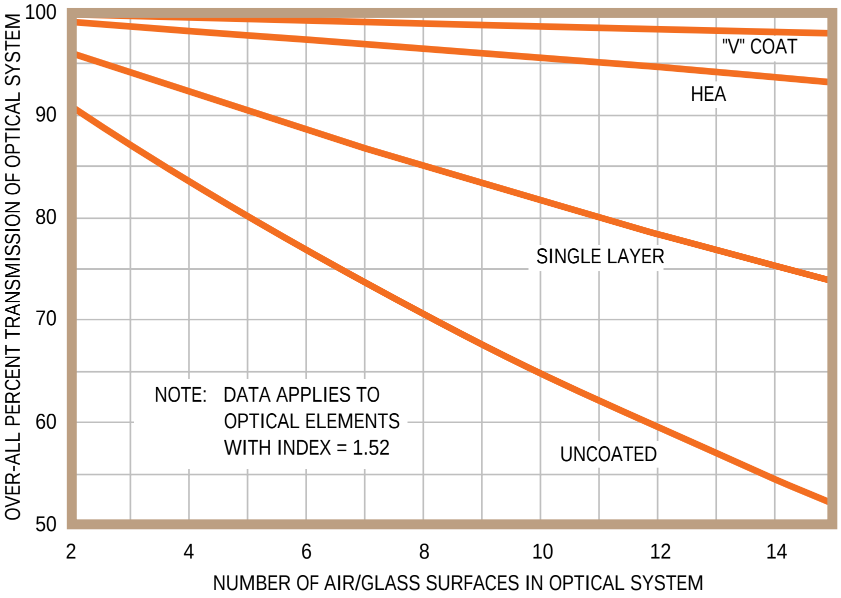
Antireflection coatings can be thought of as transformers which optimize the transfer of electromagnetic energy across the interface between two different media. Optimizing the transfer of energy at a single wavelength, or over a very narrow range of wavelengths, is relatively simple and can usually be accomplished with one or two coating layers. However, as the required bandwidth is increased, more coating layers are required and the difficulty of maintaining optimized energy transfer across the whole band progressively increases. The figure below compares the performance of three different antireflection coatings on the surface of fused silica substrate.



Performance of antireflection coatings on fused silica substrate. Broad band coatings with very low reflectance tend to be more complex than single layer coatings. Notice that the reflectance of fused silica changes with wavelength due to dispersion.

Reflected energy from a lens, window, or other transmissive optical component results not only in a loss of energy at the detector, but also a decrease in signal-to-noise ratio or, in the case of imaging systems, a degradation of image contrast. Since reflected energy can be any combination of specular and diffuse, depending on the texture of the reflecting surface, management of this energy can be very difficult. One of the most effective solutions is to reduce the surface reflections to such a level that further management of the remaining reflected signal is not necessary. Antireflection coatings are particularly effective because they reduce the diffuse reflectance as well as the specular reflectance from a given surface. For example, when an antireflection coating with a reflectance of 0.1% is applied to a glass surface with 4% specular reflectance and 0.1% diffuse reflectance, specular reflectance is reduced by a factor of 40. In most cases, diffuse reflectance will be reduced by nearly the same factor as the specular reflectance, down to 0.0025% in this example. In many optical systems, the corresponding improvement in signalto-noise and contrast ratio is at least as important as the increase in signal or image brightness.

Single and multilayer antireflection coatings developed by OCLI may be used for virtually all visible and ultraviolet transmitting materials, including various crown and flint glasses, fused silica, sapphire, and calcium fluoride. Of these, the most practical and frequently used substrate materials are borosilicate crown glass and fused silica.



Transmission of Multi-element Optical Systems

Glass Absorption Not Shown: Losses Due to Reflection Only

Single and multilayer antireflection coatings are designed to increase substrate transmission and reduce surface reflection over a specific wavelength range. Typical Fresnel reflectance losses for a multi-element optical system are shown by the graph above. If system requirements are such that transmission improvement is required for only a relatively narrow wavelength interval, single layer coatings may be sufficient. However, if uniformly higher transmission is desired over a wide wavelength interval, or if suppression of reflected energy is critical, multilayer antireflection coatings must be used.

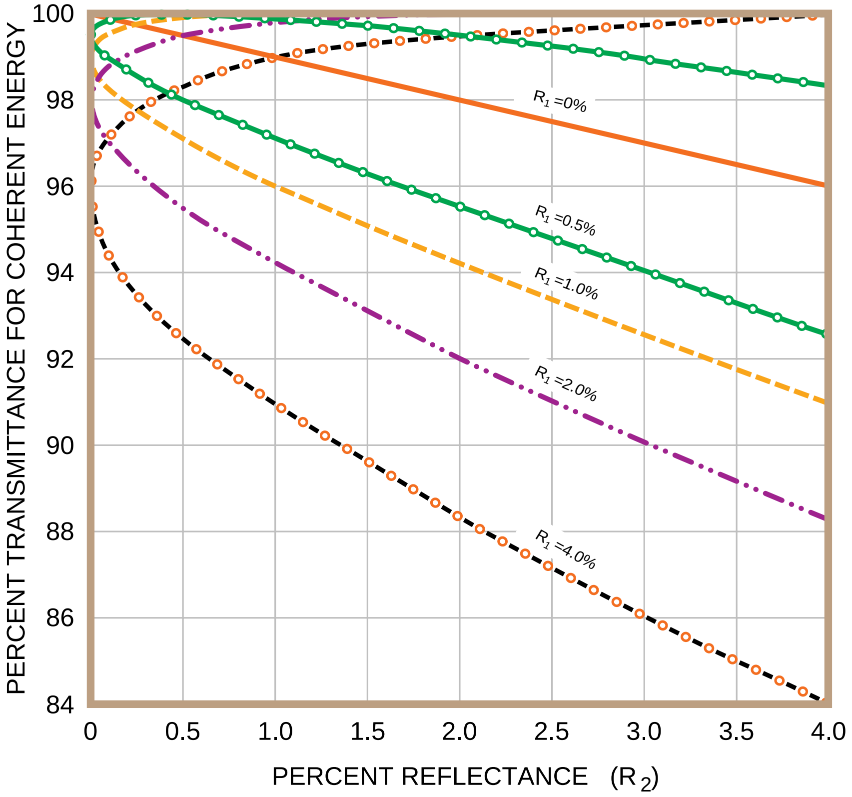
The simplest type of multilayer antireflection coating is the “V” coat, so-called because of the shape of its reflectance curve (see page 9). Although extremely efficient, because of its narrow bandwidth, it is best used in systems with with monochromatic sources such as lasers. When the energy source has a long coherence length compared with the thickness of an optical component, particular attention must be given to the reflectance levels from the entrance and exit surfaces of the component. In the case where the energy reflected from the entrance or front surface is colinear with the energy reflected from the exit or rear surface such as the case with a plane parallel window, the resulting transmittance of the component is a function of the optical path length between the entrance and exit surfaces. Depending on whether the optical thickness is an odd or even number of quarter waves the transmittance will vary between a minimum and maximum value.

The maximum transmittance can be 100% only when the amplitudes of the reflectance from the entrance and exit surfaces are equal. When the reflections are not equal, but they are both less than 4%, the following formulas can be used to predict the transmittance range.

$$T_{MIN} = 1 - \left(\sqrt{R_1} + \sqrt{R_2}\right)^2 \qquad T_{MAX} = 1 - \left(\sqrt{R_1} - \sqrt{R_2}\right)^2$$

where R_1 and R_2 are the reflected energies from the two surfaces of the component.

These formulas are shown graphically in the figure below. It is seen that, when the reflectance from one surface of a parallel window is



Maximum and minimum transmittance of coherent energy through a parallel window as a function of the reflectance from the entrance (R_1) and exit surfaces (R_2)

zero, there is only one value of transmittance, but, when the reflectance from neither surface is zero, the actual transmittance may be any value between the minimum and maximum values from the two equations above, depending on the optical thickness of the window. In order to avoid congestion of the graph in the transmittance range above 99%, maximum transmittance values have been completely plotted only for the cases where the first-surface reflectance is either 0.5% or 4.0%.

If the reflected energy from the first surface of an optical component is not colinear with the reflectance from the second surface (e.g., lenses or wedges), the component's transmittance will not be changed when the coherence length of the incident energy is changed. In this case, when surface reflectance is less than 4%, the approximate total reflectance is found by summing the reflections from the two surfaces.

Typical Performance of Antireflection Coatings

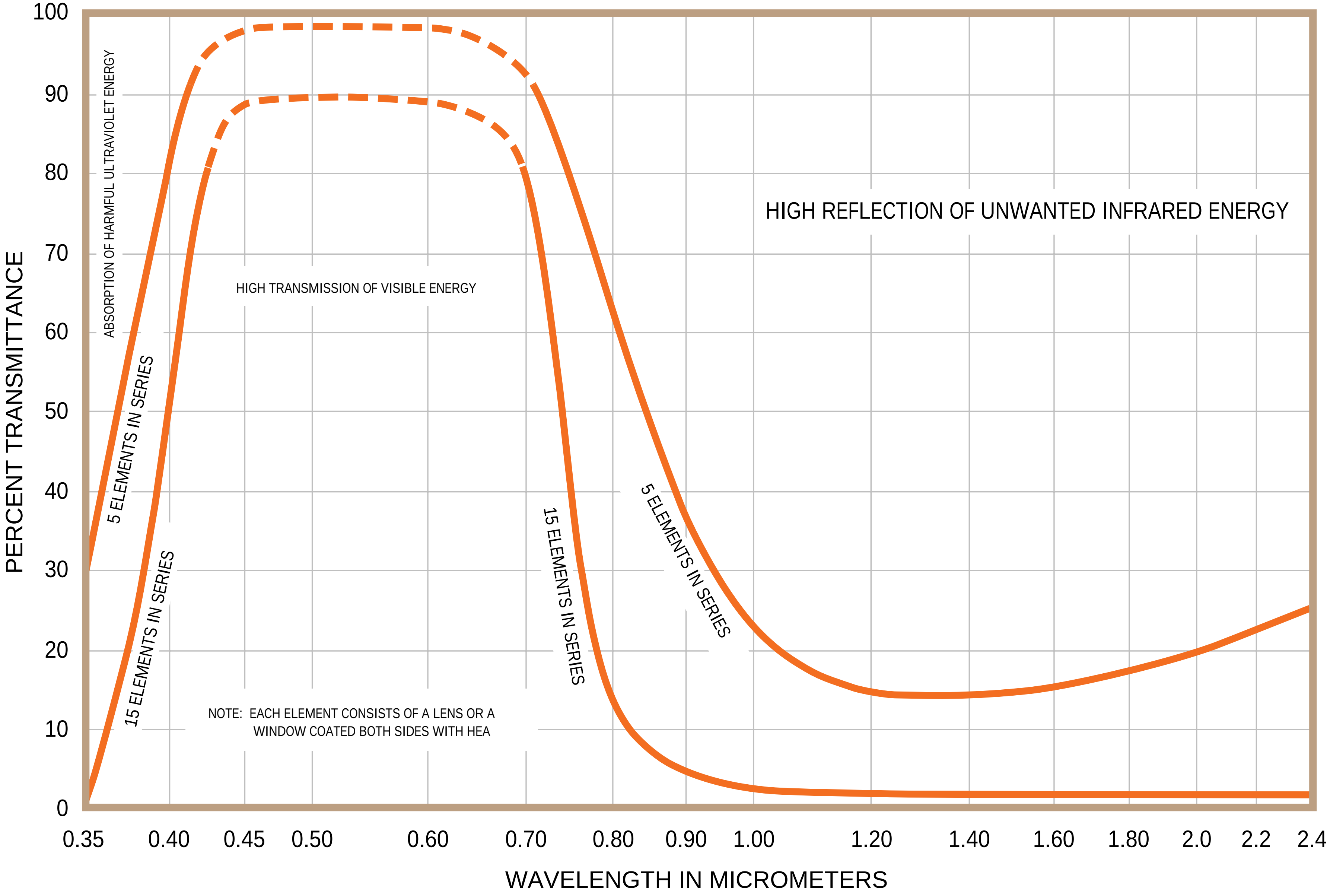
For broad band requirements, OCLI has designed a family of high efficiency antireflection (HEA®) coatings. They are used in such applications as photographic systems (both monochrome and color), cathode ray tube displays, laser ranging systems, spacecraft windows, low light level and night vision devices, edge-lit aircraft instrument cover glasses, bubble chamber optics, periscope systems, and other optical viewing systems. All coatings meet the physical and environmental requirements of MIL-C-14806.

HEA can be deposited on flat, convex, and concave surfaces with extremely good uniformity. Sizes range up to 1.8 meters in diameter.

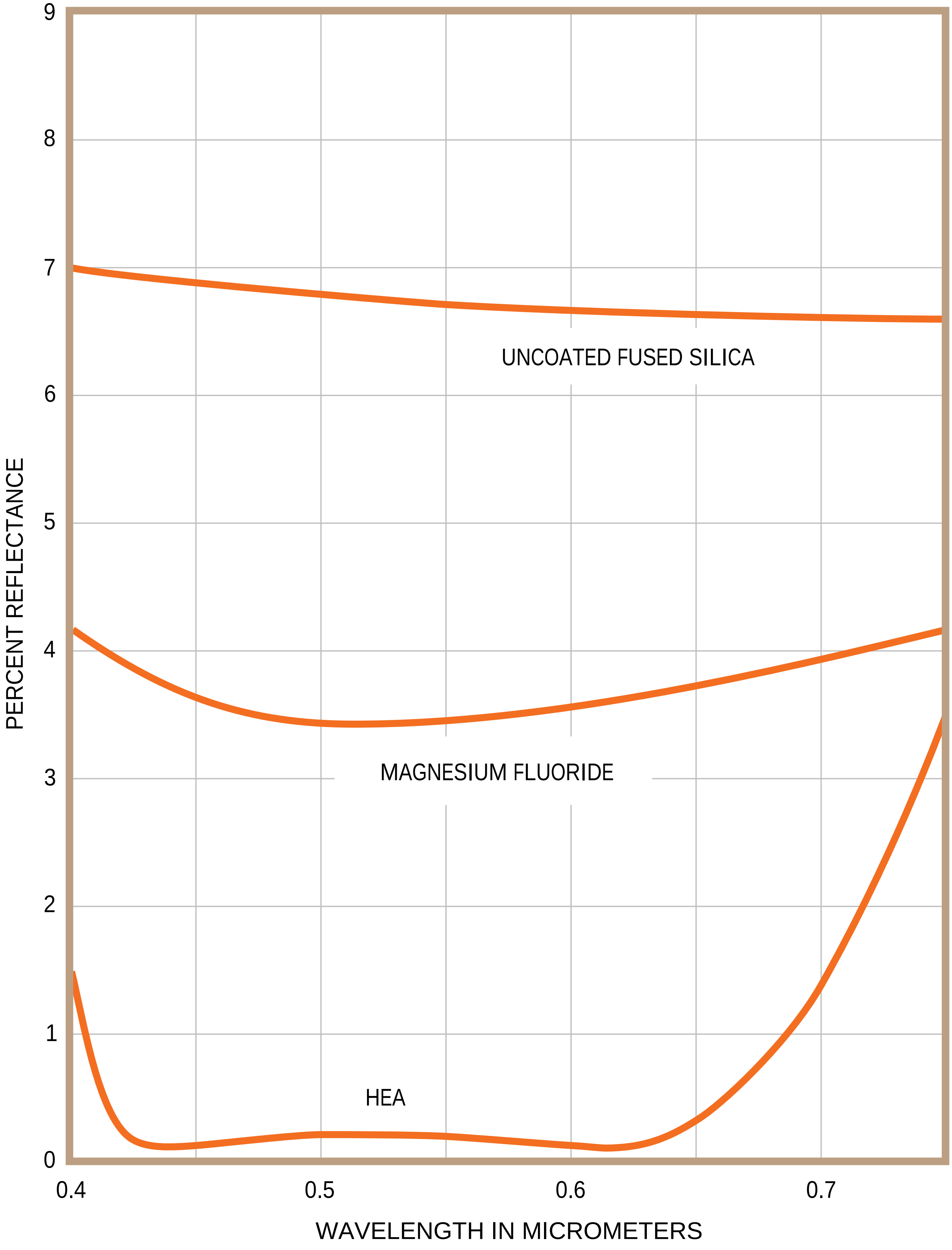
When using HEA in multi-element optical systems, the engineer must consider the bandwidth limits of the coating. The graph on page 6 shows that the useful bandwidth of OCLI's standard visual HEA is about 55% of the center wavelength, or 0.30 µm. For many photographic and viewing systems the limited bandwidth eliminates the need for additional infrared or ultraviolet blocking filters. However, systems which must operate over a wider wavelength range must use an antireflection coating with appropriately wider bandwidth. For example, a photograph taken with infrared film through the 15 element system indicated on page 6 would not produce satisfactory results.

Pages 7 to 13 show typical characteristics of several different HEA coatings designed to meet a variety of needs. Write or call OCLI for information concerning antireflection coatings for specific applications.

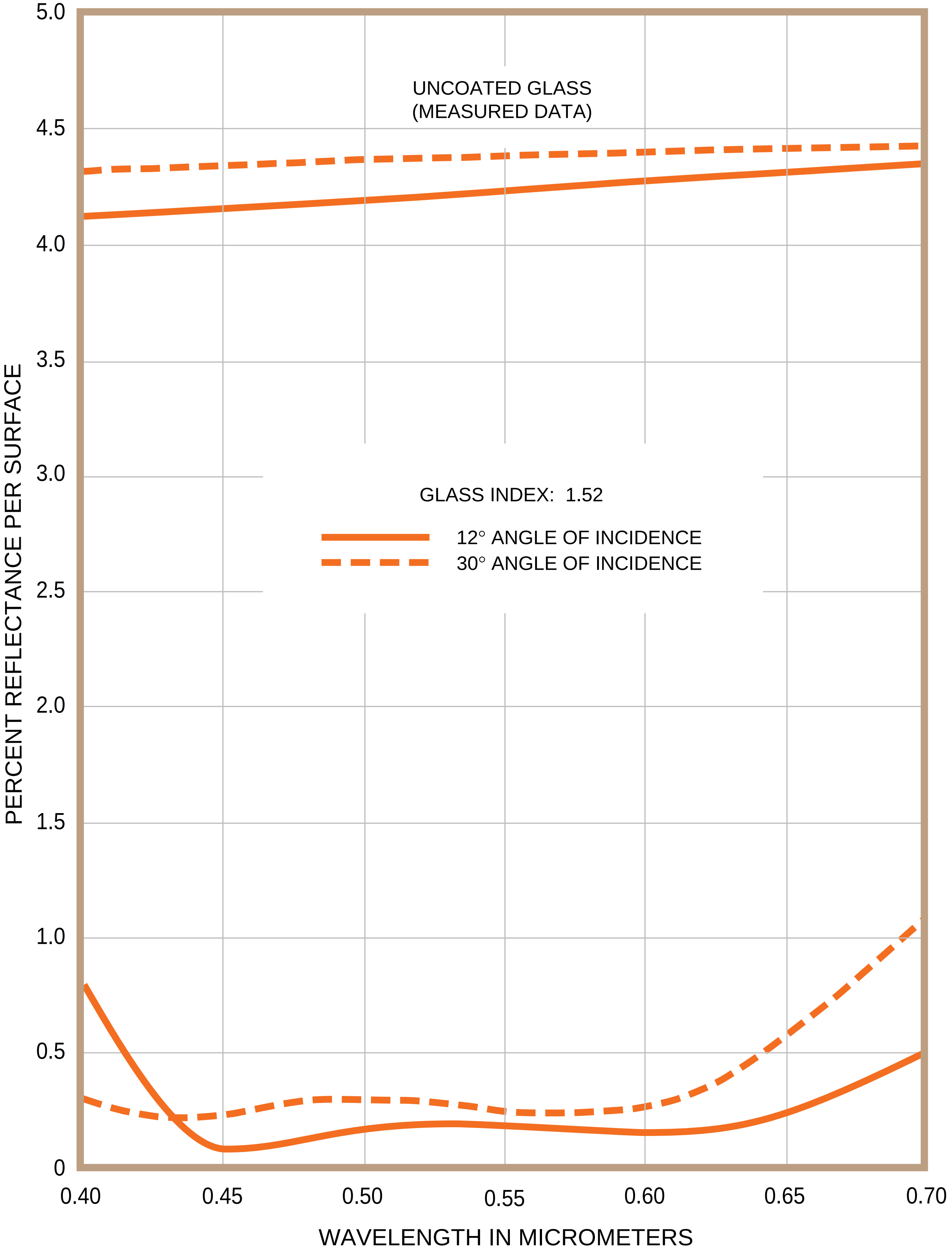
PROPERTIES OF HEA IN THE INFRARED AND ULTRAVIOLET SPECTRAL REGIONS

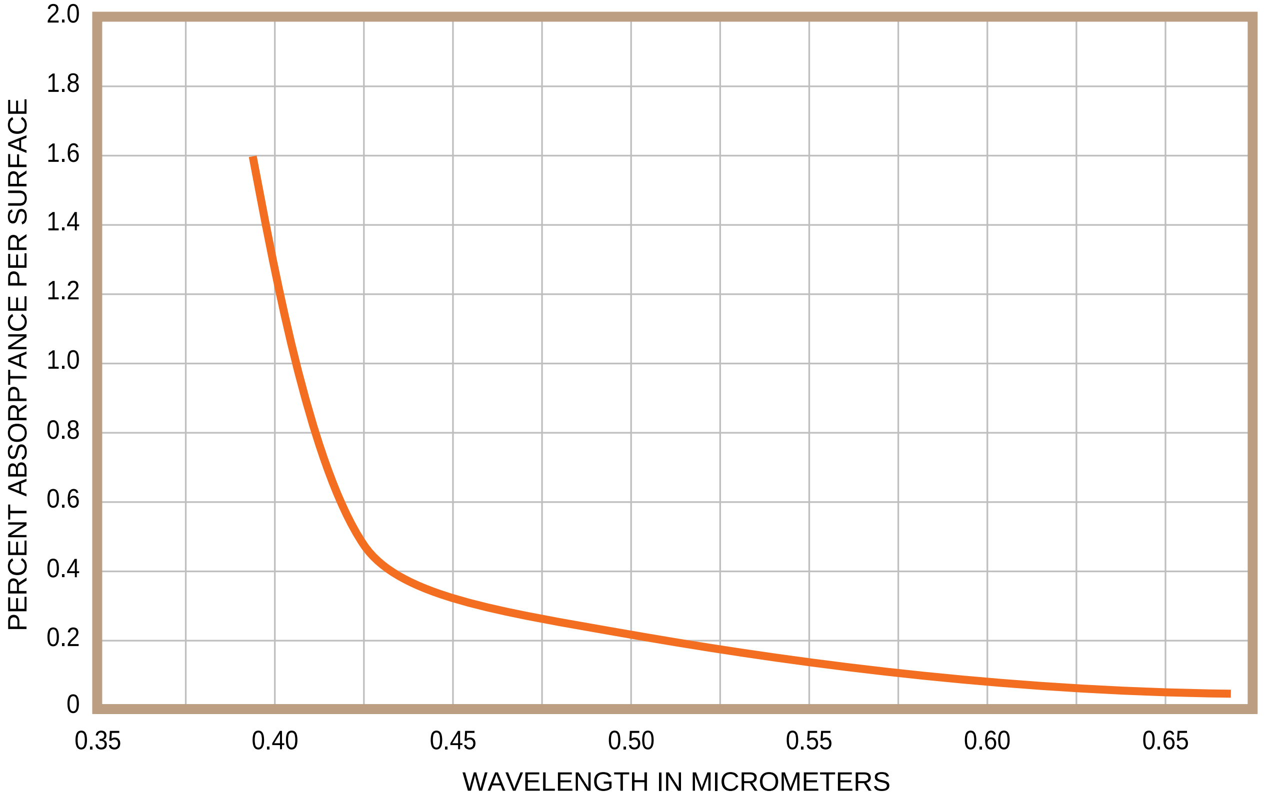


TOTAL REFLECTION FROM TWO SURFACES OF A WINDOW COATED WITH SINGLE LAYER AND MULTILAYER COATINGS

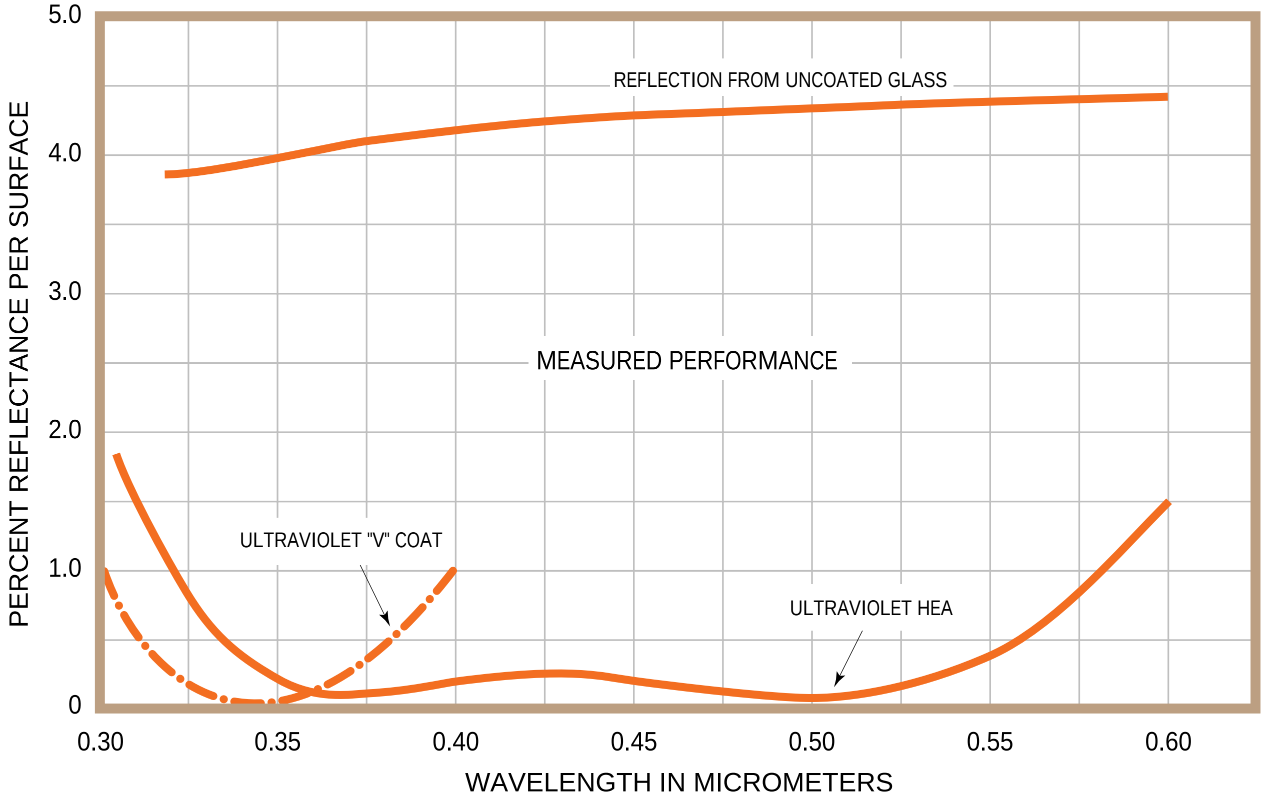


HEA FOR USE OVER AN ANGULAR RANGE FROM 0° TO 30°



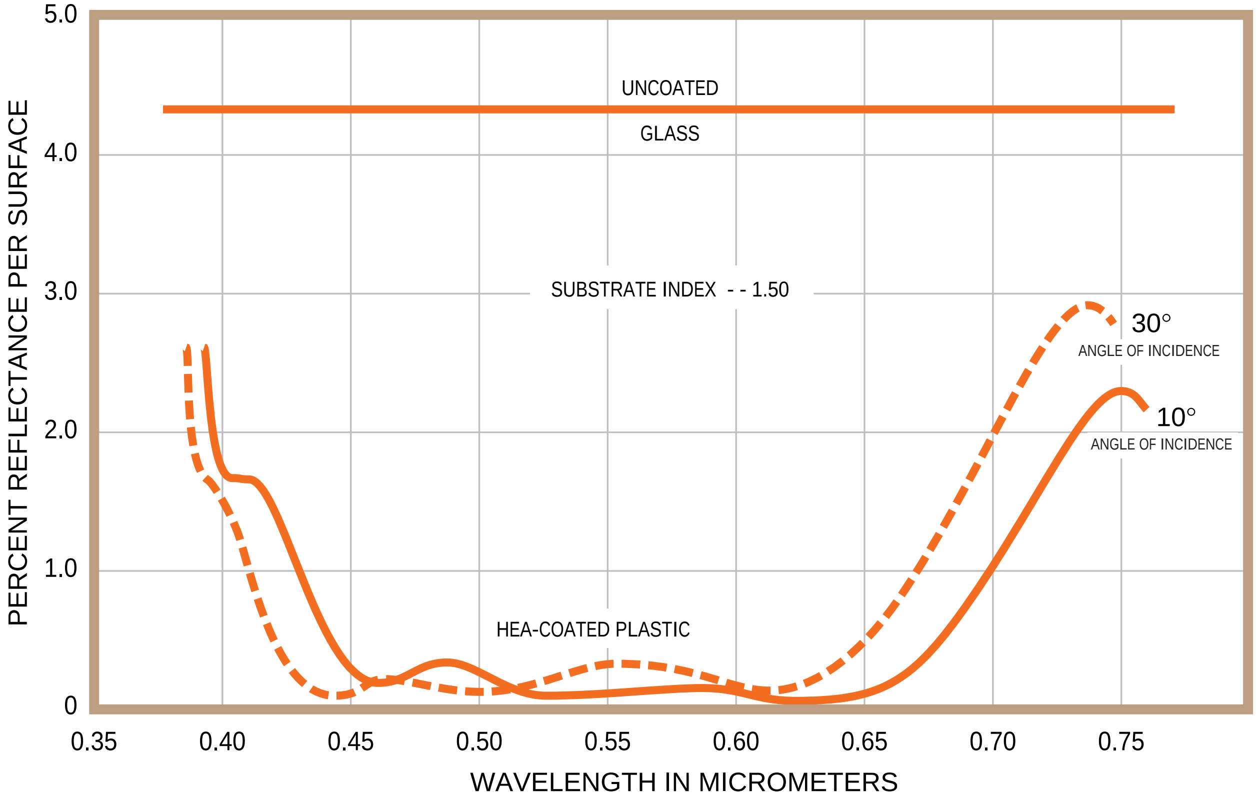


TYPICAL ABSORPTION LOSS FROM A STANDARD HEA COATING

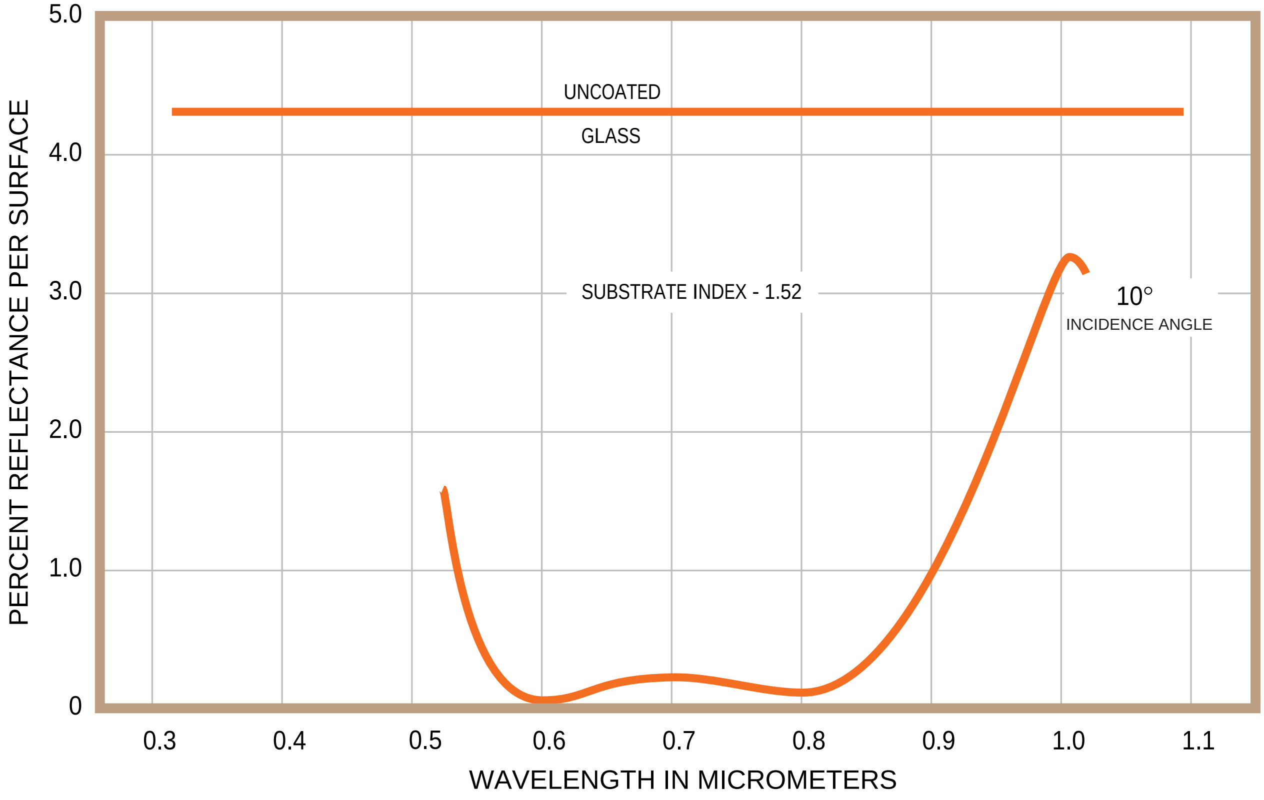


ULTRAVIOLET ANTIREFLECTION COATINGS

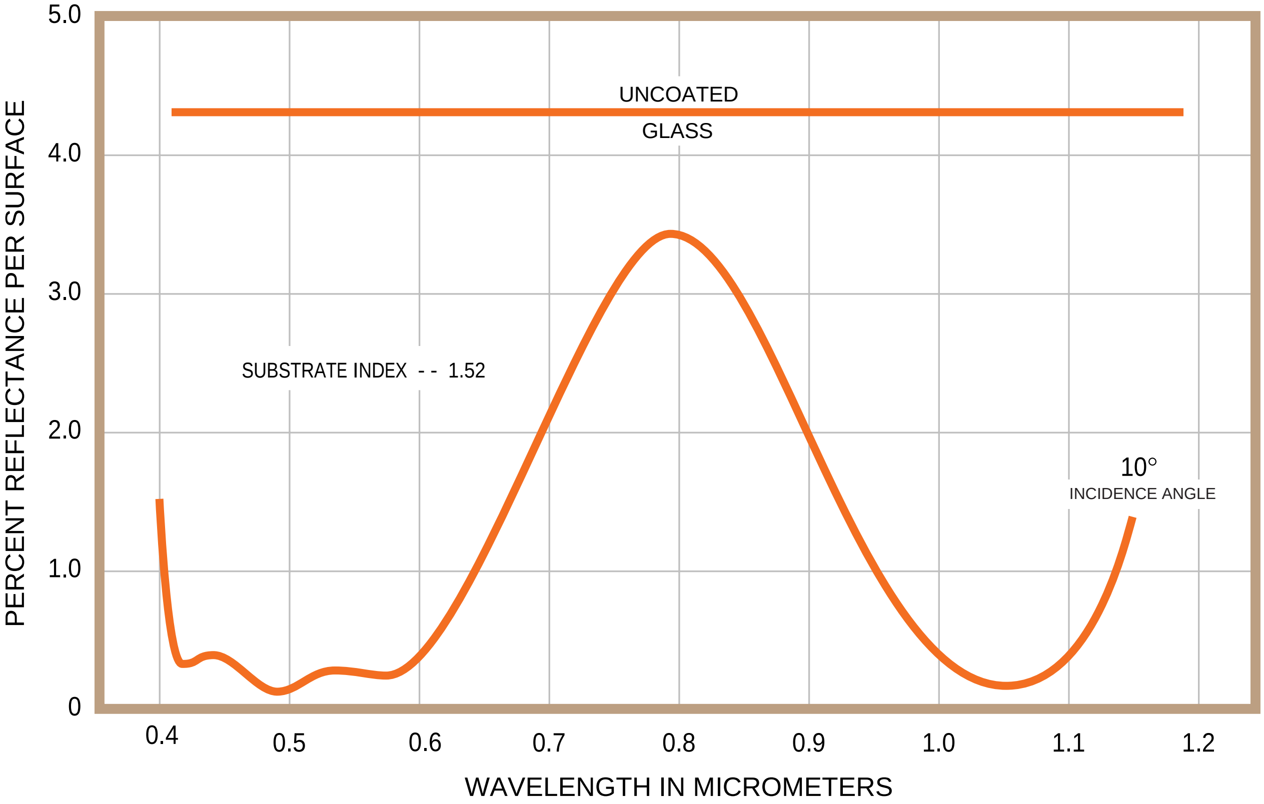
HEA COATING FOR USE ON PLASTICS



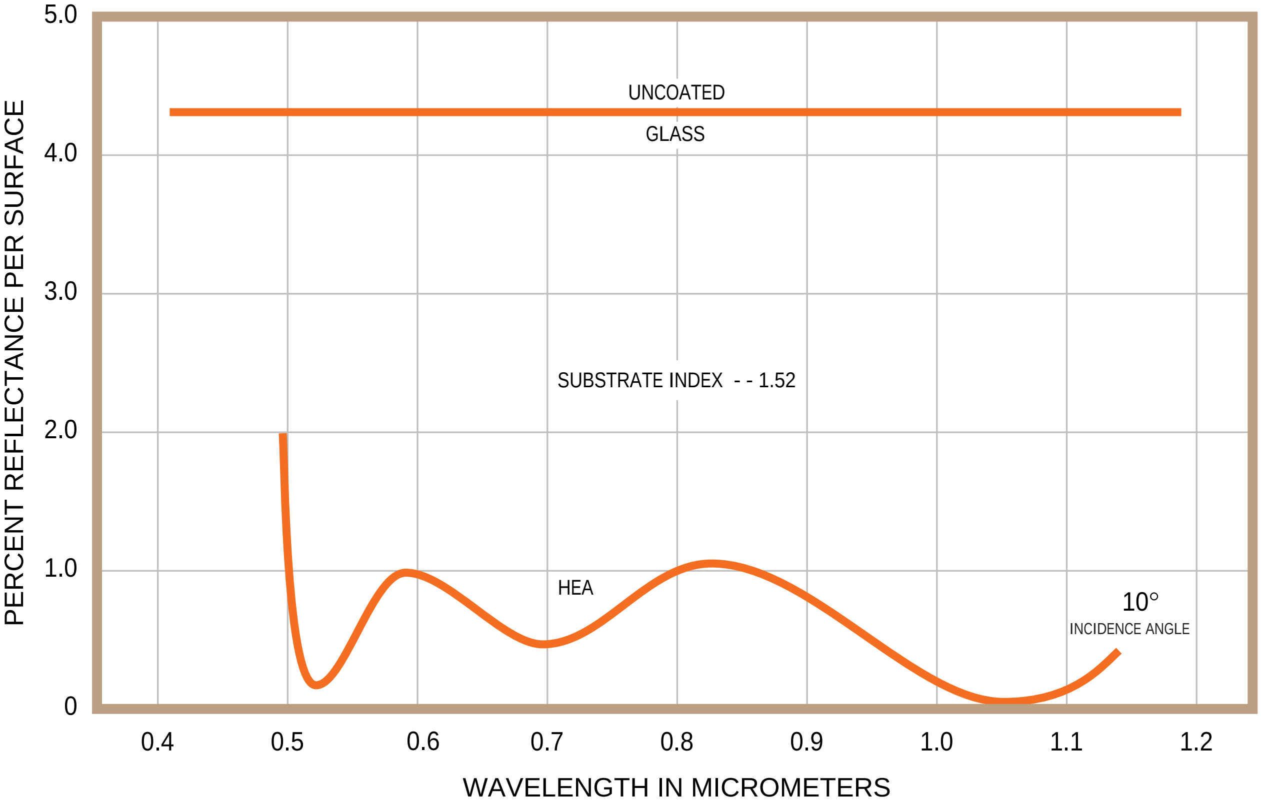
HEA FOR USE OVER THE SPECTRAL RANGE FROM 0.5 μm TO 0.85 μm



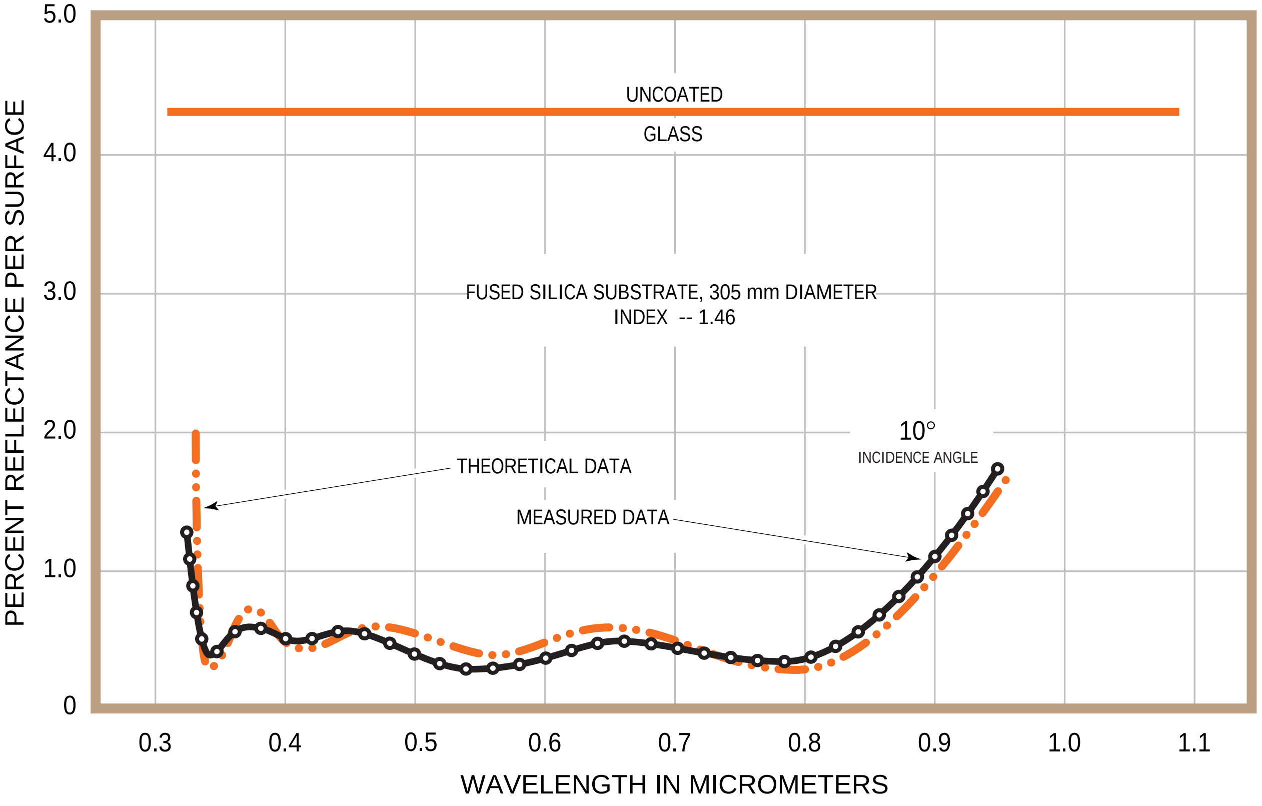
HEA FOR USE IN THE VISIBLE SPECTRUM & AT 1.06 μm



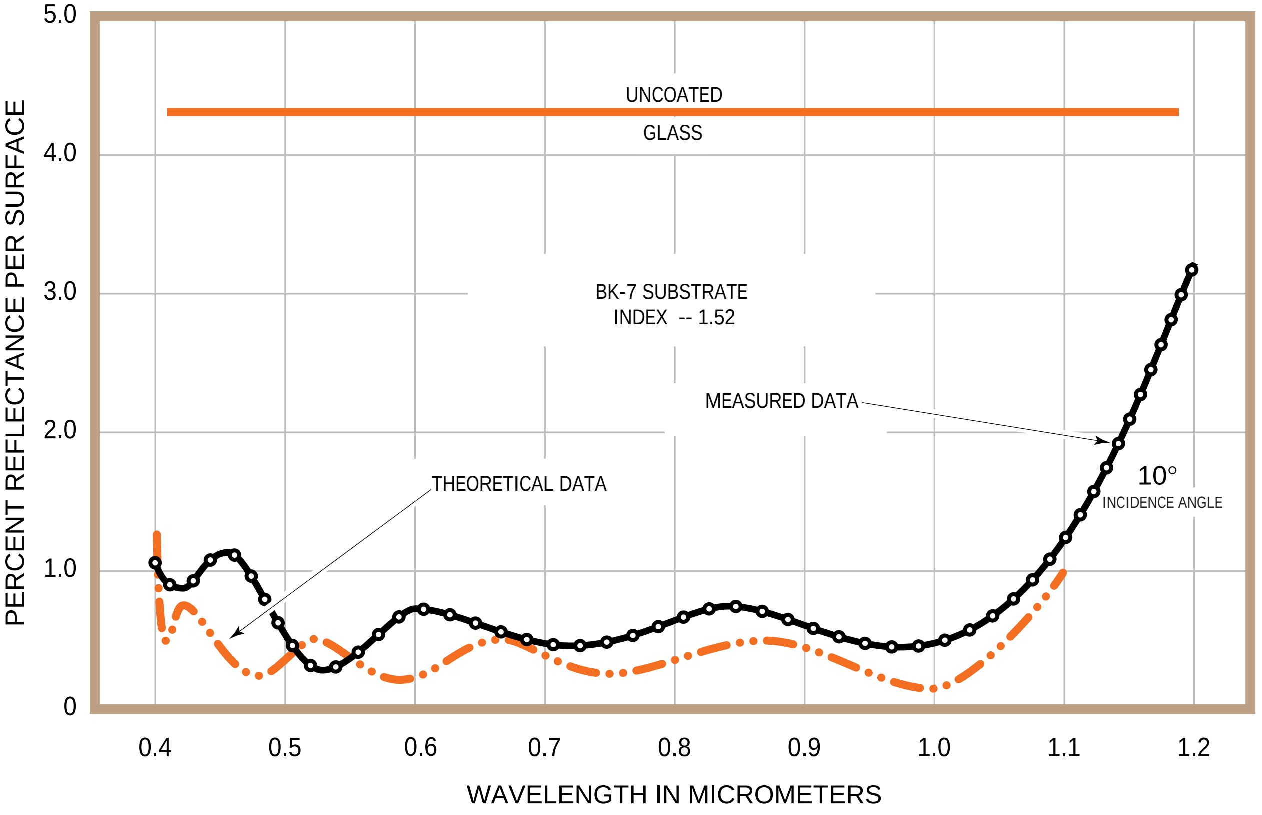
HEA COATING FOR USE FROM 0.5 μm TO 0.8 μm AND AT 1.06 μm



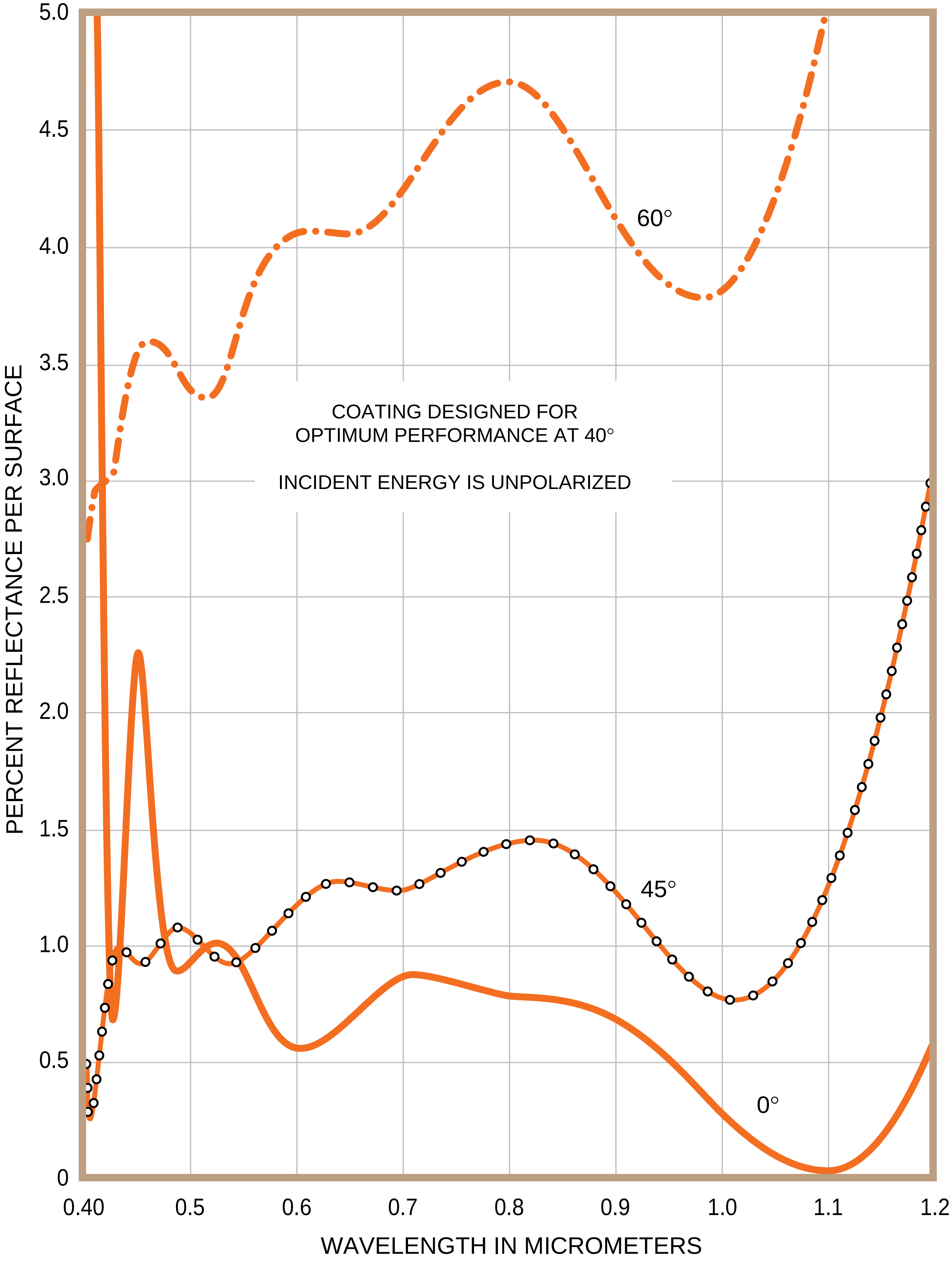
HEA COATING FOR USE OVER A 200% WIDE WAVELENGTH BAND



HEA COATING FOR USE OVER A 300% WIDE WAVELENGTH BAND



ANGLE SHIFT PROPERTIES OF A WIDE BAND HEA



COATING DESIGNED FOR
OPTIMUM PERFORMANCE AT 40°

INCIDENT ENERGY IS UNPOLARIZED