Long-Lived Optical Coatings

Optical thin-film coatings and filters are remarkably high in performance as well as long-lived products. From an efficiency perspective, optical filters can isolate a transmitted wavelength band with near unity transmission and at the same time, provide OD 8 attenuation of a broad background. From a lifetime perspective, they are assured of lasting multiple decades with minimal degradation. This is impressive, as the typical passband filter may have 200 plus layers of material at thicknesses of only tens of nanometers.

A message has been communicated regarding the relative lifetime longevity of surface and protected optical coatings, which is that hard surface coatings have a longer life than soft coatings that are protected by a fused silica cover. Although this may be the case in some applications, it is not an unequivocal contention.

Coatings of refractory oxides are the most common surface coatings, although some spectral regions such as the Far IR and Deep UV may be coated with surface materials of lesser hardness than the substrate. These oxide coatings have two potential failure mechanisms: The first is the inherent stress of a dense thin film deposited by an energetic process. The second is the porosity of a less dense coating.

In the case of the dense film (energetic process), the stress forces in the thin film can distort a substrate from a flat to a distorted surface. For an aspect ratio of less than 8, these forces can add 10s of waves of reflected distortion to the flattest starting substrate. If the thin film is not dense, the columnar structure is prone to absorption of moisture. This absorption causes the spectral profile to shift to the red. For optimum optical performance, the thin film needs to strike a balance between density that is adequate for stability and stress that neither distorts the substrate or in the worst case, shears free of it.

In the case of the protected coating, the thin film stress is dramatically reduced due to a much-reduced condensing energy. The film is then protected with a fused silica window that provides scratch resistance and environmental stability. The failure mechanism of protected coatings is the slow absorption of moisture by the optical laminate. Over decades, moisture can be trapped and absorbed by the film. The typical appearance is a haziness from the periphery, which encroaches upon the center of the optic.

Although unsightly, the performance impact of this aging is minor. For this report, I will evaluate a pair of filters, one in the visible and one in the deep UV. In both cases the appearance of the filter is far from specular, due to the scattering of light. (See images below)

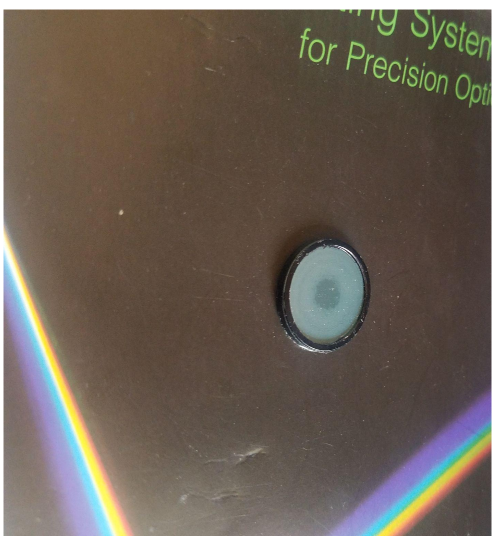

Image 1

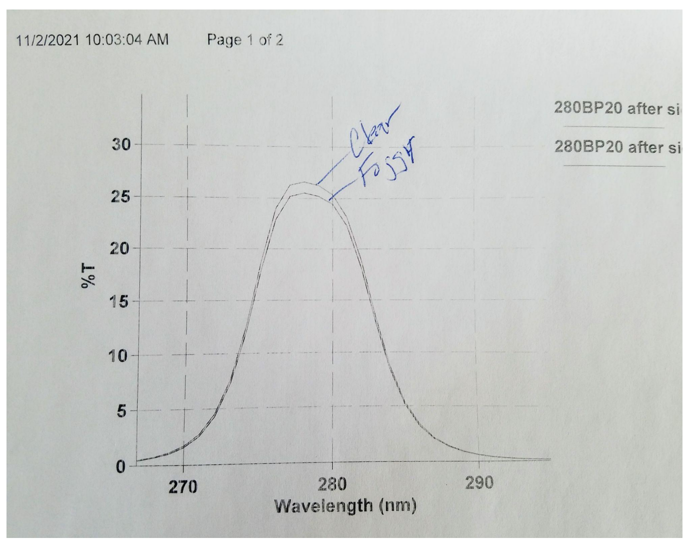

Image 2

The filter in image 1 was deposited 25 years ago and was of an extremely thick coating, operating in the 13th order of interference. This coating shows performance at the central “bullseye” that is effectively unaltered from original measurements and at the coating edge, about 10% lower transmission. The transmission is least impacted in the red and most in the blue, due to the decrease in performance being caused by scatter that increases as wavelength decreases. The degree of attenuation has decreased by 0.1 OD, and there has been a spectral shift of 0.02% or about 1 nm to the red.

Image 2 shows what happens with a “foggy” filter in the deep UV. This filter has shown severe scatter and granularity to a reflected image. Although the appearance of the coating is likely to raise concern regarding performance, the actual spectral performance is slightly better than when originally measured. This filter was exposed to a thermal shock of 400F for 2 hours, to exaggerate the degradation. The appearance of the coating became less spectacular, with a clear demarcation across the surface. Upon spectral scanning of the surface, the performance in transmission was found to improve by nearly 5% absolute, in the region of least scatter and remain unchanged in the region of most scattering. The filter showed no loss in out-of-band attenuation and no measurable shift in spectral profile.

The point of this note is to clarify the message on longevity of optical thin films. It is my observation over many years of study that the longevity of protected thin films is great. The degradation of protected thin films is gradual and minor, as contrasted to the typical failure of surface coatings which is more often catastrophic.