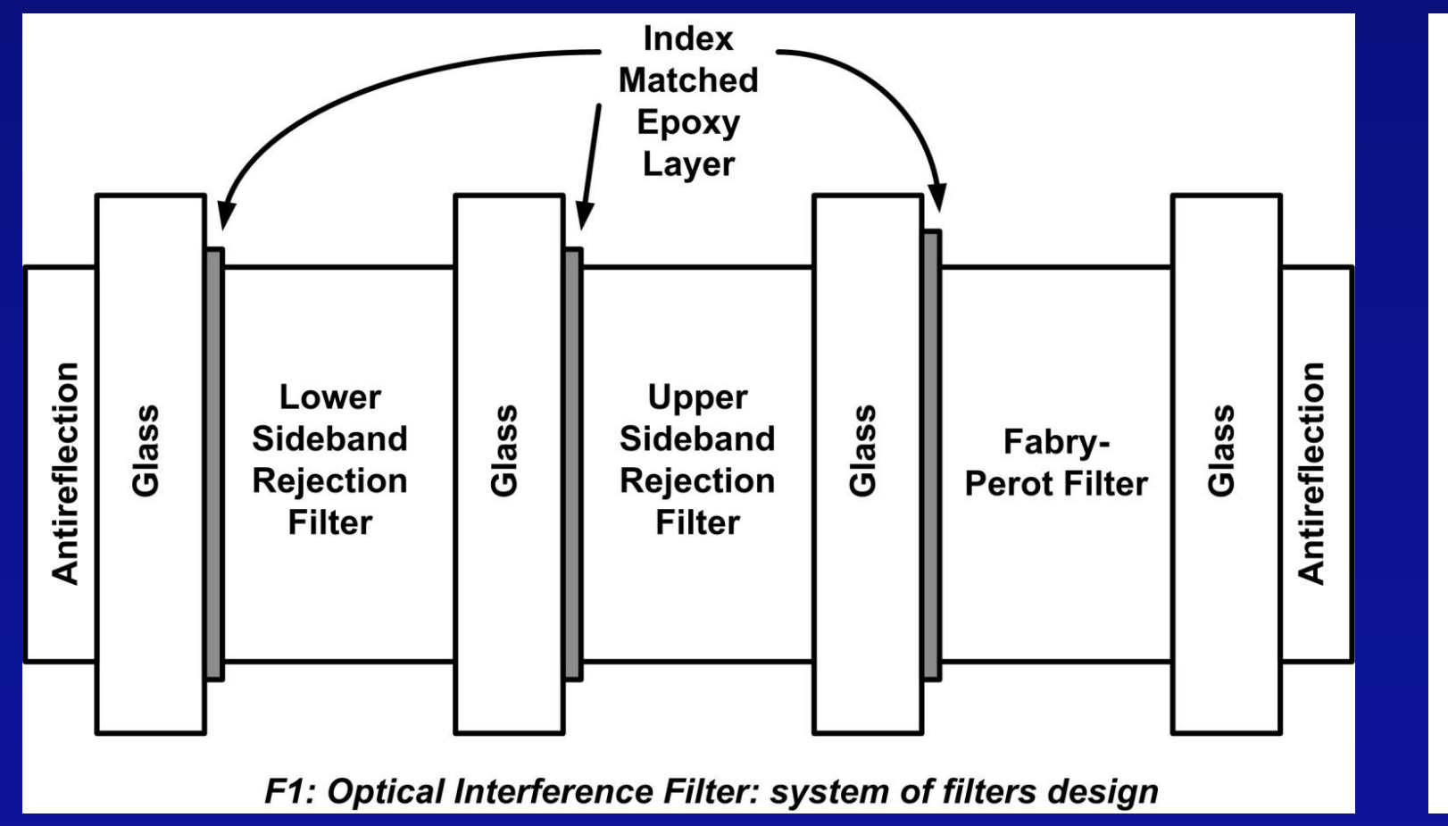
Metals for Induced Transmission Optical Filters

Scott W. Teare, P.Phys.

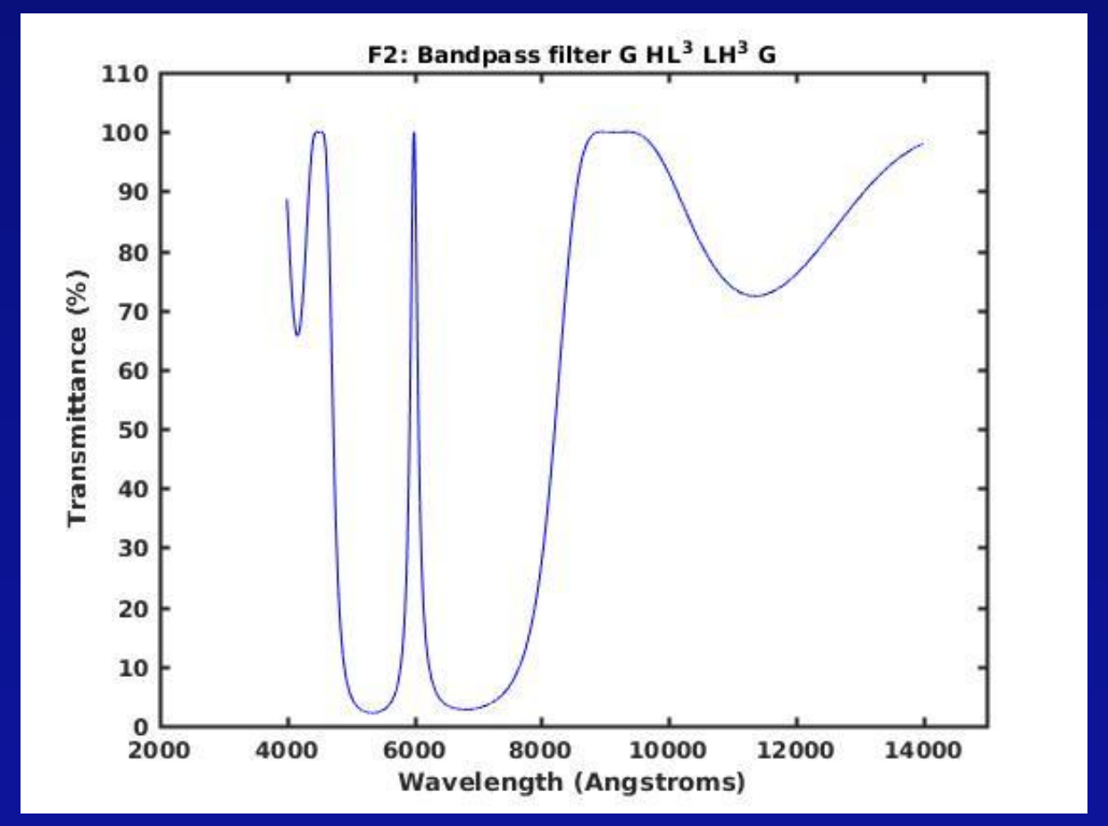
New Mexico Institute of Mining and Technology, Socorro NM USA.

Band-Pass Optical Filters

Band-pass optical filters are combinations of optical elements that block unwanted light while transmitting a narrow range of wavelengths. One design (F1) combines antireflection, high and low pass filters and a Fabry-Perot interference cavity. The transmission profile of a Fabry-Perot cavity (F2) constructed from dielectric thin films shows a designed peak at 600nm. Notice that there is a region around the band-pass that has lower transmission.



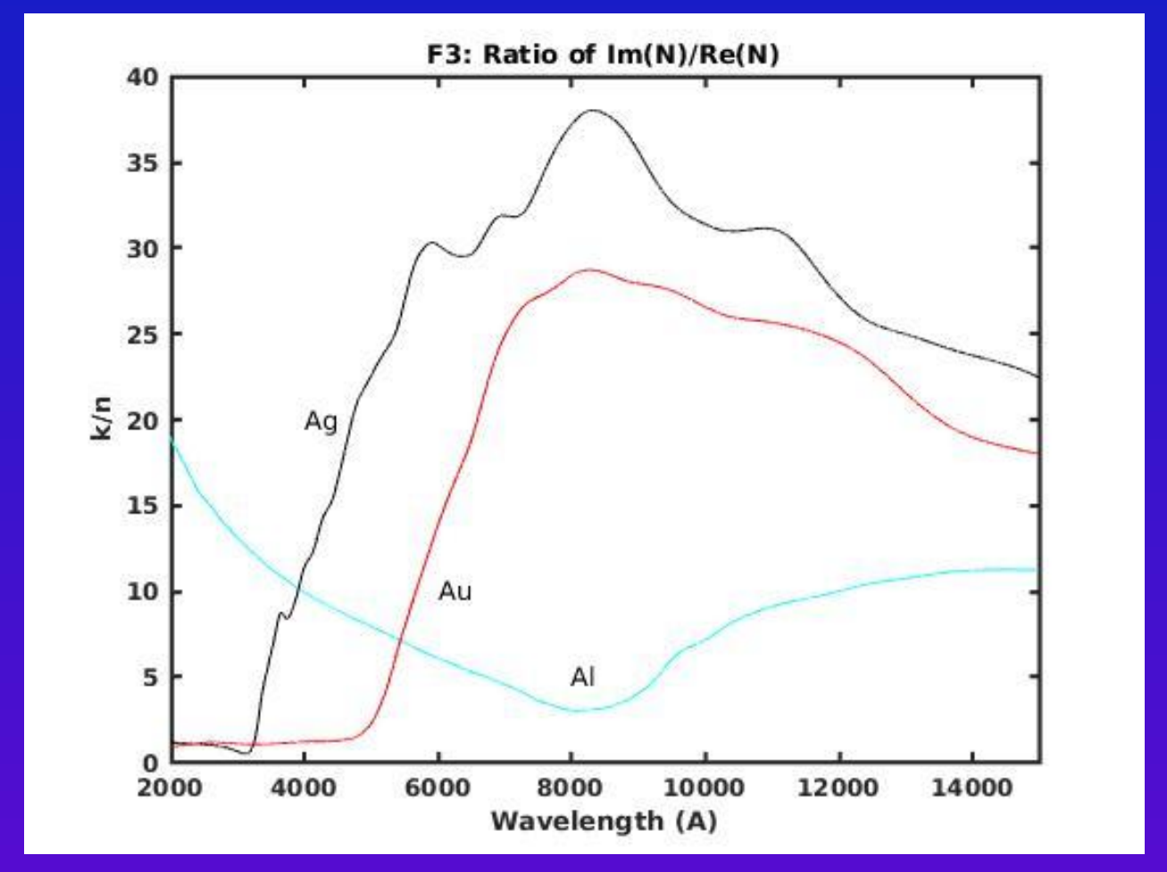
F1: Optical Interference Filter: system of filters design



F2: Bandpass filter G HL^3 LH^3 G

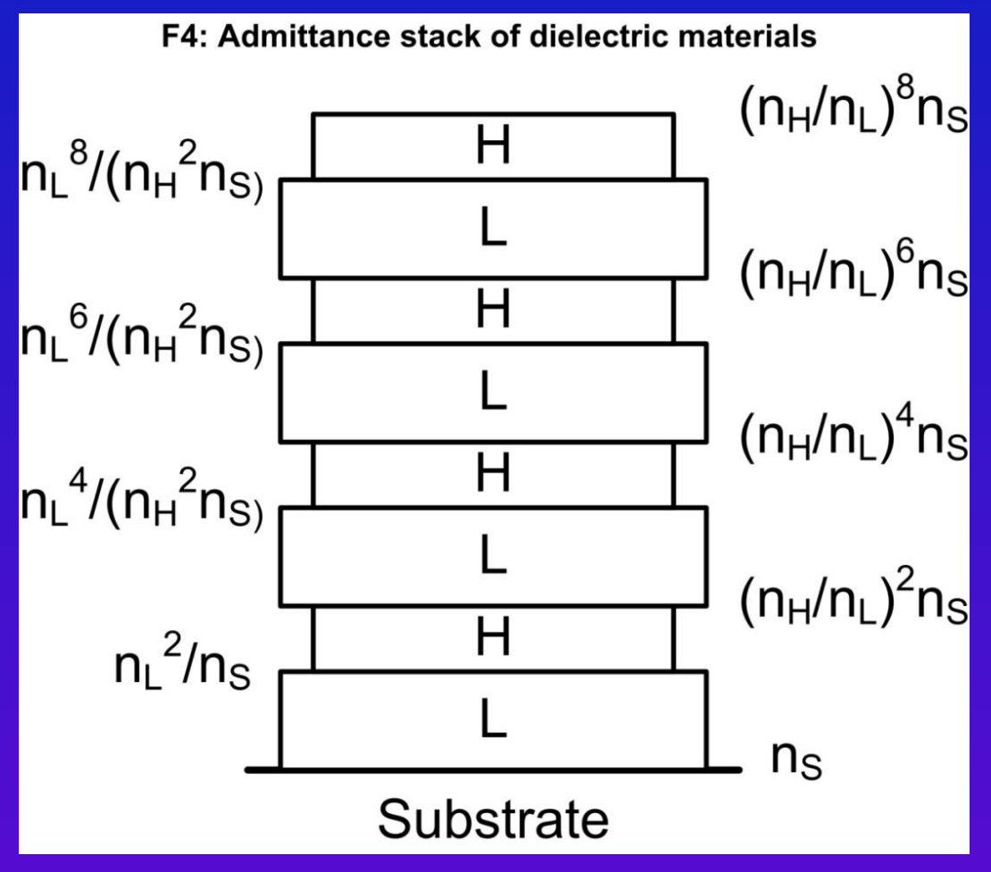
Blocking filters are required to suppress the unwanted light transmission in the side lobes on either side of the band-pass. These filters can be constructed using either absorbing or interference based approaches. However, advantage can be obtained in suppressing the off-band transmission by adding a thin metal layer to act as the cavity known as an induced transmission filter. Multilayer metal filters can also be realized which will improve suppression on the long wavelength side.

The metal layer of the induced transmission optical filter (ITOF) is matched to the incident and exit media using dielectric stacks of high and low optical index of refraction materials. Typically the incident and exit medium is a glass or air. The dielectric stack is made from ¼ wavelength optical thicknesses of alternating high and low index of refraction materials; where MgF_2 is an example of an L layer and ZnS is an example of an H layer.



F3: Ratio of Im(N)/Re(N)

F4: Admittance stack of dielectric materials



Three metals of interest for induced transmission filters are Al, Au, Ag (F3, www.filmetrics.com/refractive-index-database 5-1-17). The sensitive parameter for indicating a metal's performance is the k/n ratio of the metal. The complex index of refraction (N = n – jk) is required to describe the absorption in the metal layers. A dielectric stack (F4) is used to match the metal layer substrate to the incident medium. The closer the admittance can be matched the higher the transmission will be in the band-pass up to the Maximum Potential Transmittance, a limiting value.

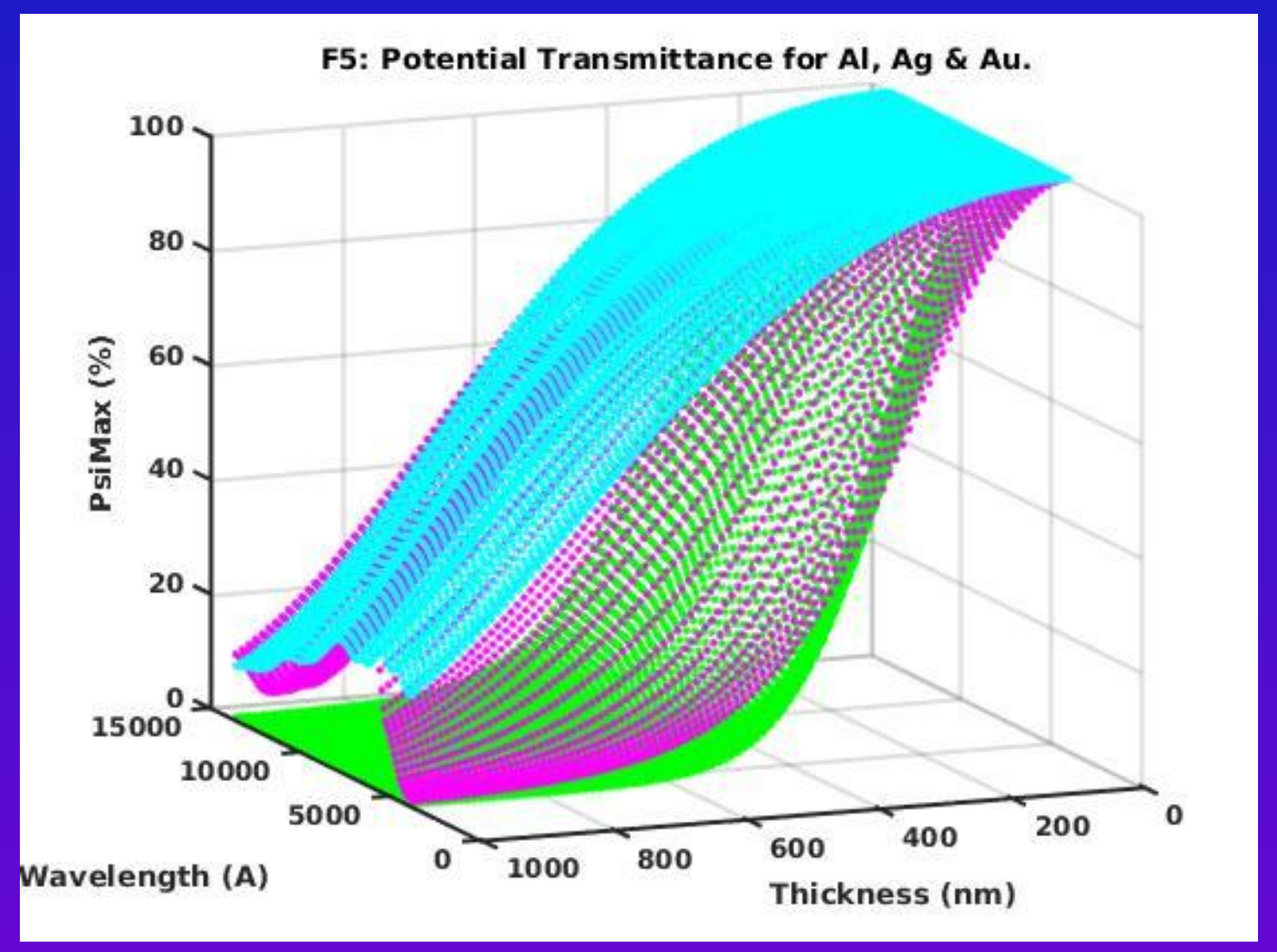
Abstract

Band pass optical interference filters can be constructed from simpler, stand-alone filter design components. Typically a peak centered in the filter's free spectral range is combined with low and high pass filters such that only a desired band pass remains over a wavelength range. The component filters can be either interference or absorption filters chosen such that there are no unwanted light leaks outside the band pass. Replacing the low pass filter with an induced transmission filter, one using embedded metal layers, can provide a better approach to suppressing long wavelength light leaks. This paper reports on simulations used to explore the performance of several easily vacuum deposited metals used in induced transmission filters.

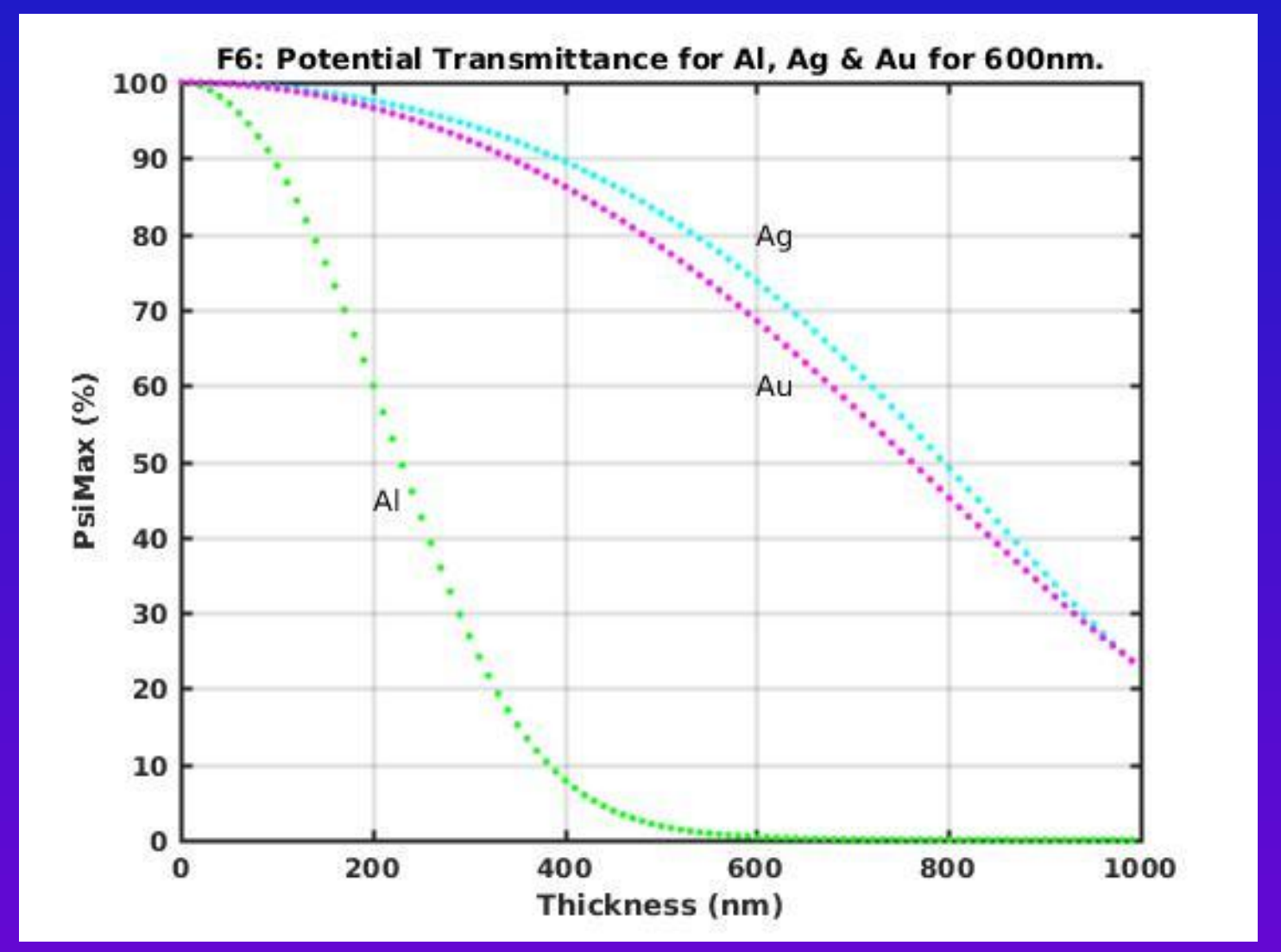
Bibliography

1) Macleod, H.A., Thin-Film Optical Filters, Third edition CRC Press (2001).
2) Fowles, G.R., Introduction to Modern Optics, Dover (1975).
3) Baumeister, P.W., Optical Coating Technology, SPIE Press (2004).
4) Wiley, R.R., Field Guide to Optical Thin Films, FG07, SPIE Press (2006).
5) Smith, W.J., Modern Optical Engineering, Third Edition, SPIE Press (2000)
6) Teare, S.W., Optics Using MATLAB, SPIE Press (2017).

Presented at the 2017 CAP Congress in Kingston, Canada.



F5: Potential Transmittance for Al, Ag & Au.



F6: Potential Transmittance for Al, Ag & Au for 600nm.

The Maximum Potential Transmittance for each metal can be calculated over a range of metal thickness and wavelengths (F5). By selecting a particular wavelength the range of available transmittances are shown (F6). The optical admittance of the metal layer for the thickness and central wavelength values is used to design the dielectric stack which must include an non ¼ wavelength layer on either side to make the complex index of refraction 'real' to match the substrate.

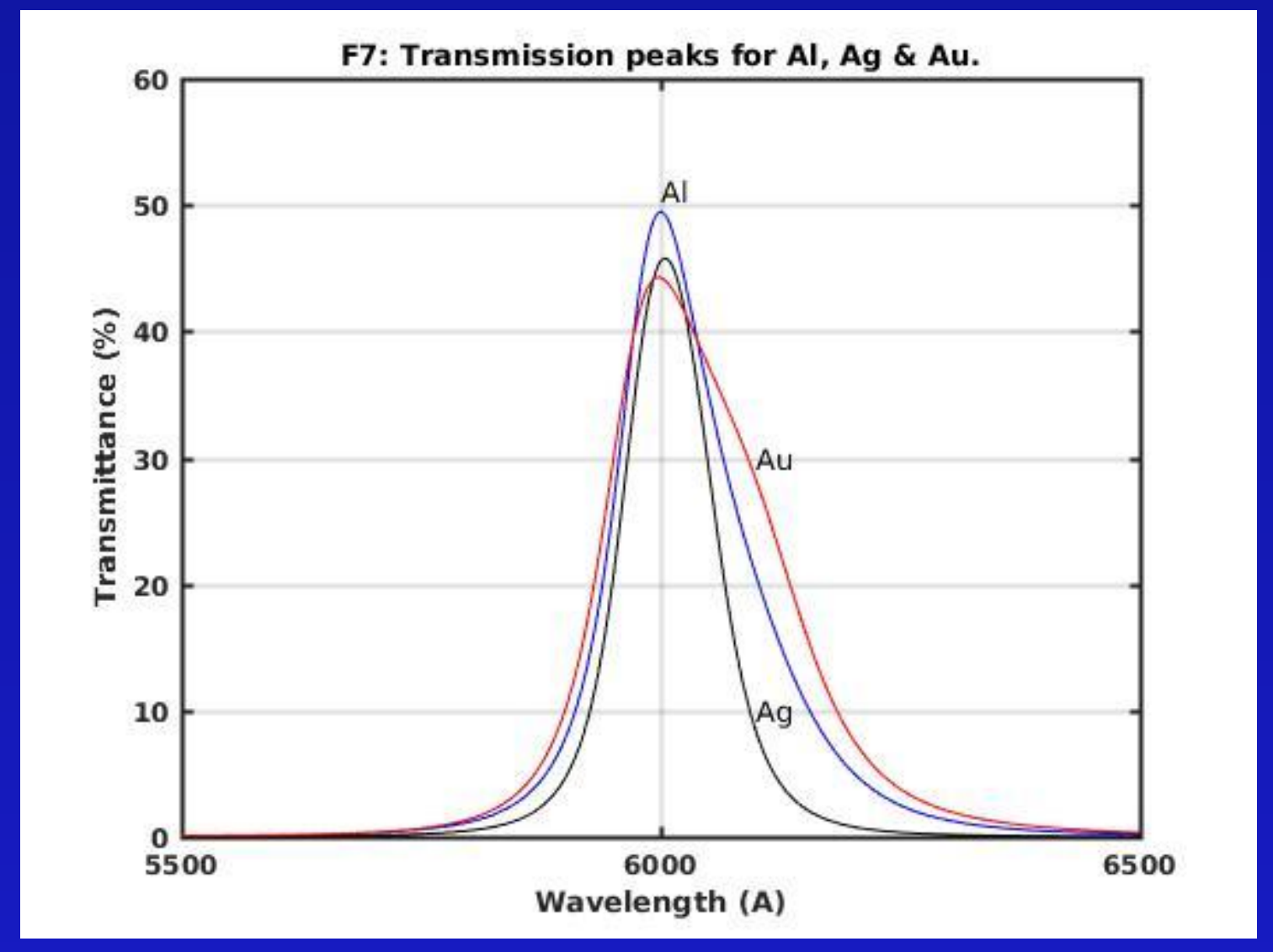
Wavelength suppression using ITOF

The value of the ITOF is to suppress the light leakage on the long wavelength side of the filter transmission curve. The ability of each metal to suppress light leaks in an ITOF was explored in a simulated filter for central wavelength of 600nm and transmission peak of 50% which sets the individual metal layer thickness.

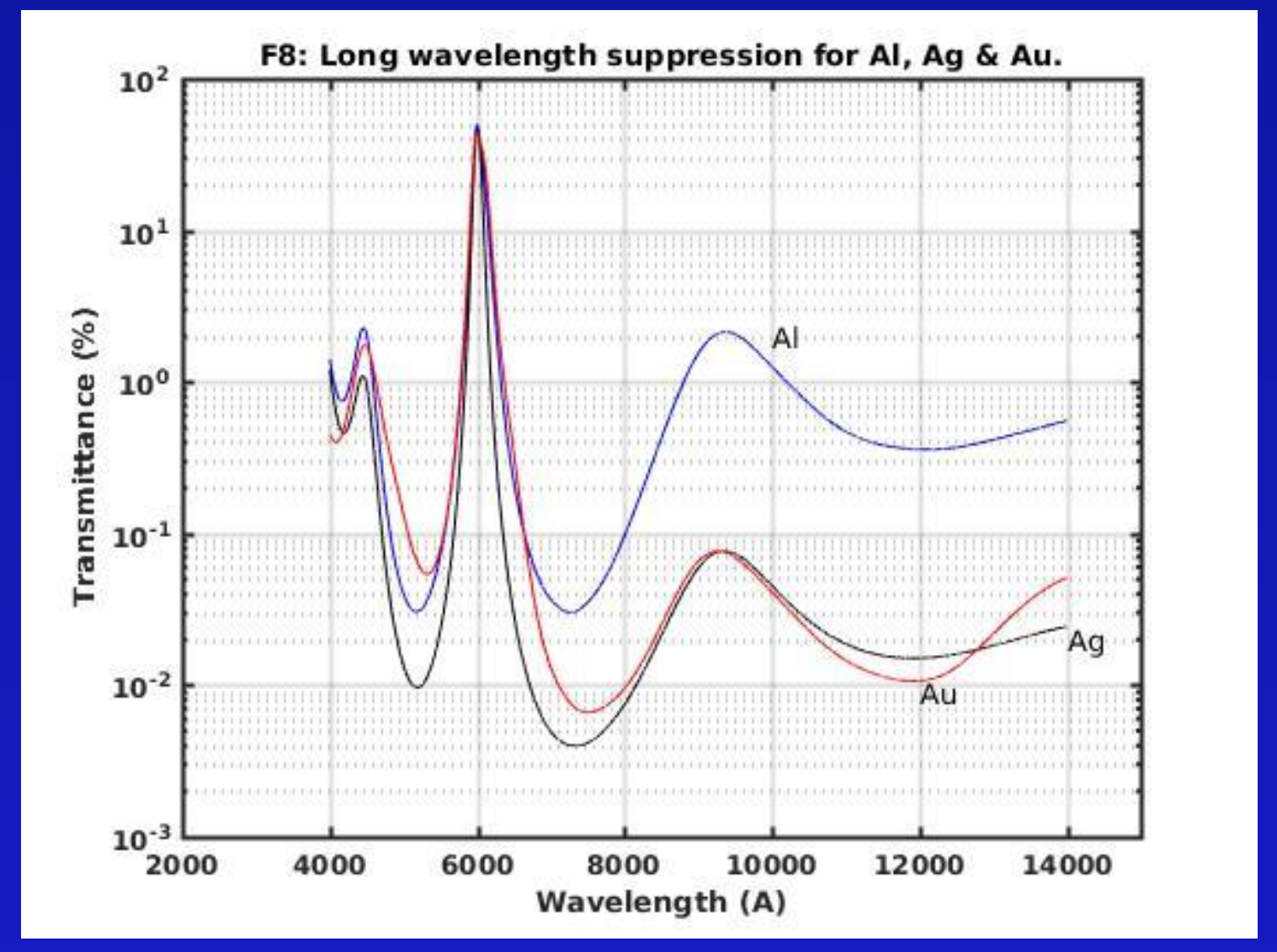
The shape of the metal cavity filter is often "not ideal" (F7) and may be broader than desired, requiring that a dielectric, narrow band-pass filter be used to define the width of the transmission band. The transmission profiles are plotted (F8) on a 'log scale' to show the relationship between the long wavelength side for each metal. The basic structure of the ITOF used here is:

$$G\ (HL)^3\ S\ M\ S\ (LH)^3\ G;$$

where H&L are ¼ wavelength layers of high and low index of refraction dielectrics; S is a non- ¼ wavelength layer of L material; M is the metal layer; G is the glass substrate.



F7: Transmission peaks for Al, Ag & Au.



F8: Long wavelength suppression for Al, Ag & Au.

Summary

Induced transmission optical filters were simulated for each of the Al, Au and Ag metal layers. The transmission profiles show transmission peaks close to 50%, with the differences being attributed to mismatches between the metal layer and the dielectric stacks. Each of the filters (F6) show reduced transmission in the long wavelength region (compare F2) at the cost of the transmission peak. Gold and silver were seen to perform better than aluminum. It is anticipated that the performance of the Al metal layers will improve when the transmission peaks are at shorter wavelengths as suggested in F3.

***About the Author:* Scott W. Teare received a PhD in physics from the University of Guelph, Canada, and is currently professor of Electrical Engineering at NMT. He is an RAS and SPIE Fellow and a senior member of IEEE. He holds 4 US patents and is currently writing his 5th book for SPIE.**