Sputtered Coatings for Space-Based Optical Systems Including Gold Induced-Transmission Filters

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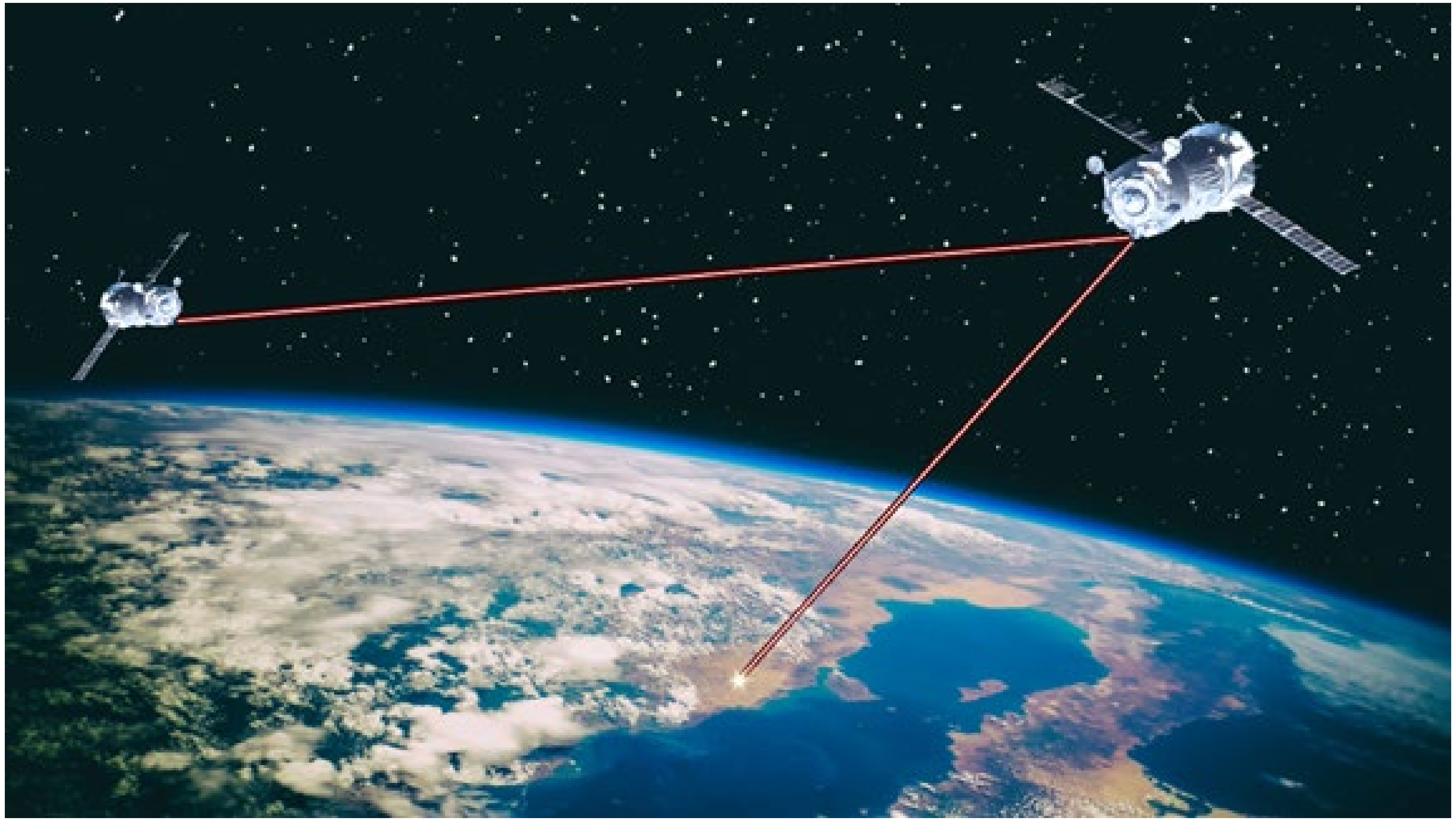


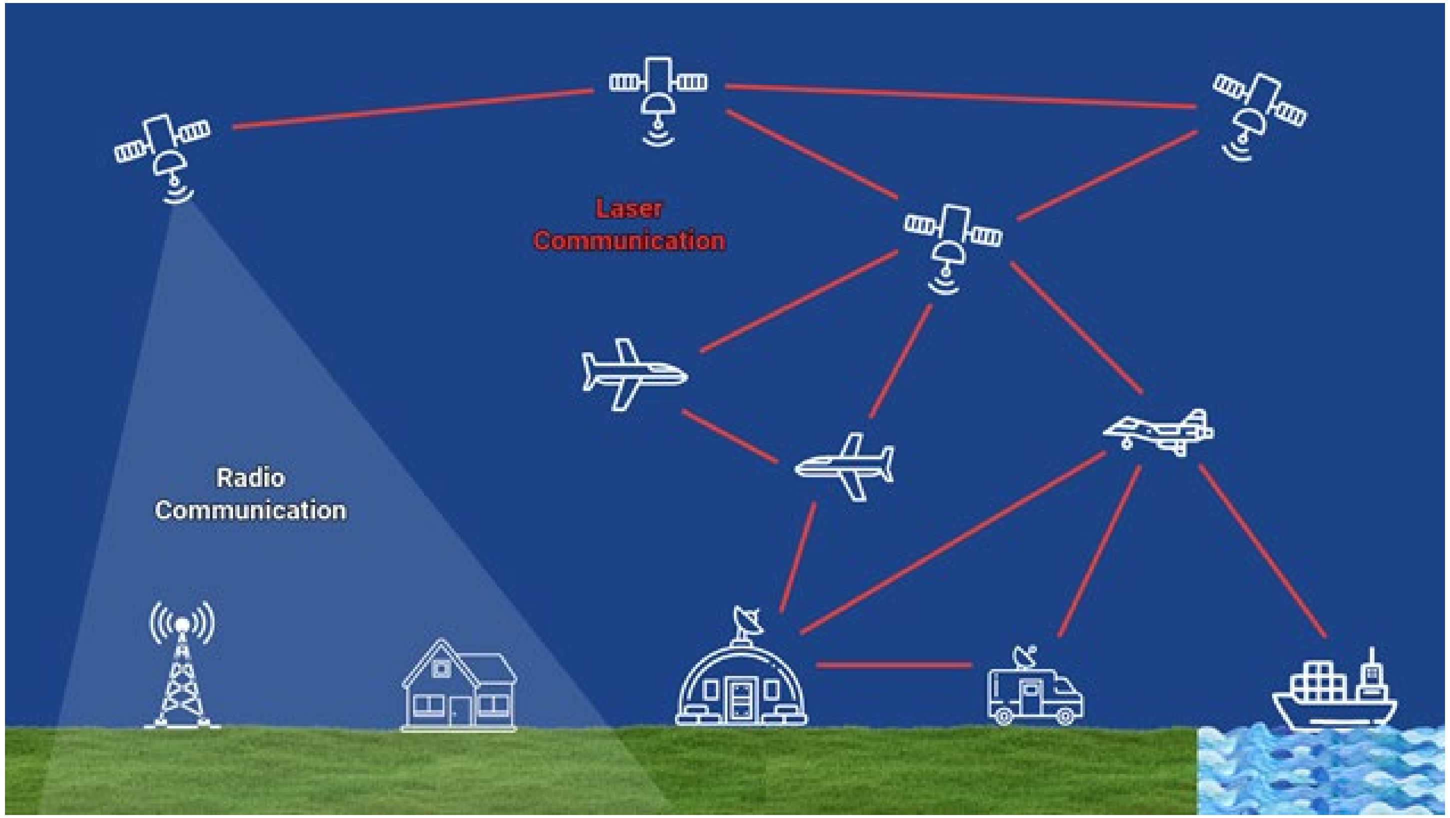
Overview

- Space-based applications for optical filters
- Sputtering basics
- Optical filters for free-space laser satellite communications
- Gold Induced-transmission filters

Space-based applications for optical filters

"Satcom" Free-space Optical (FSO) Laser Communications

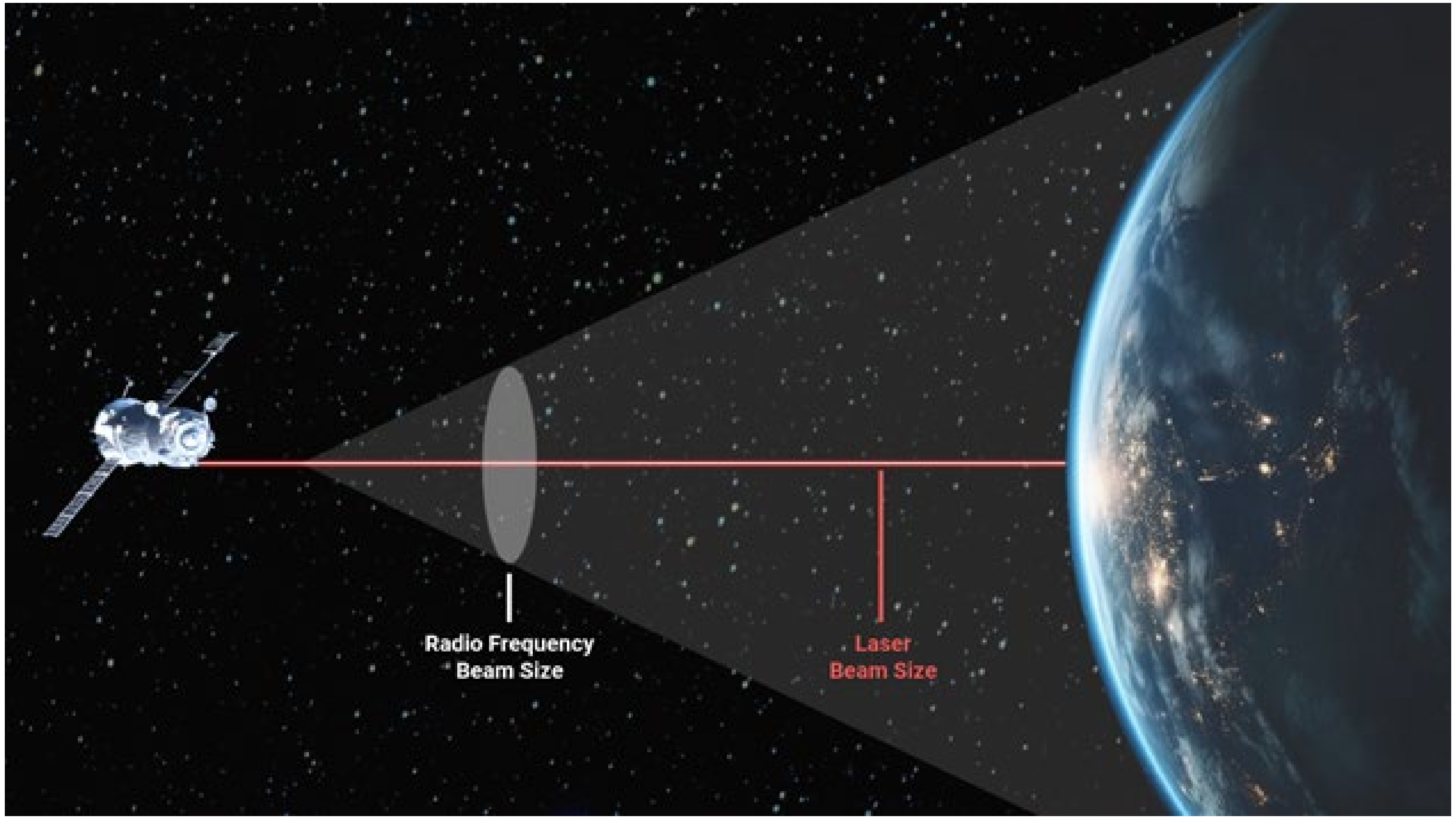
- Satellite constellations
- Inter-satellite link
- Space-ground link



Space-based applications for optical filters

Advantages Over Radio Frequency

- More secure
- Higher-speed
- Lower cost



Space-based applications for optical filters

“Satcom” Free-space Optical (FSO) Laser Communications

- Satellite constellations
- Inter-satellite link
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Space-based applications for optical filters

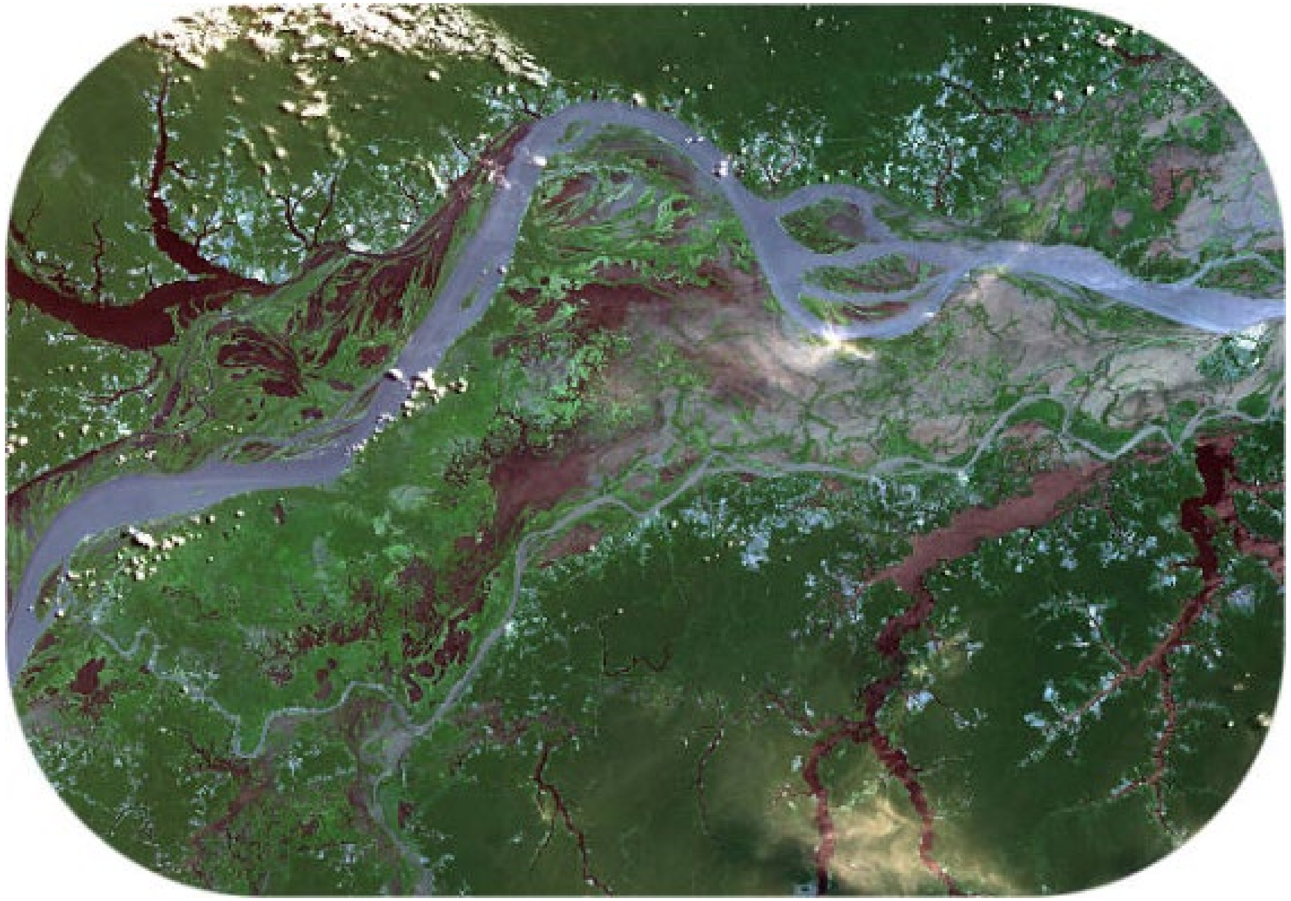
Optical Filter Challenges

- High-precision
- Durability to withstand harsh conditions / longevity
- Incorporates SWIR λ's
- Full spectrum blocking
- Every photon counts
- Polarization/phase control

Space-based applications for optical filters

Remote sensing

- Earth observation
- Environmental monitoring
- Agricultural inspection / smart farming

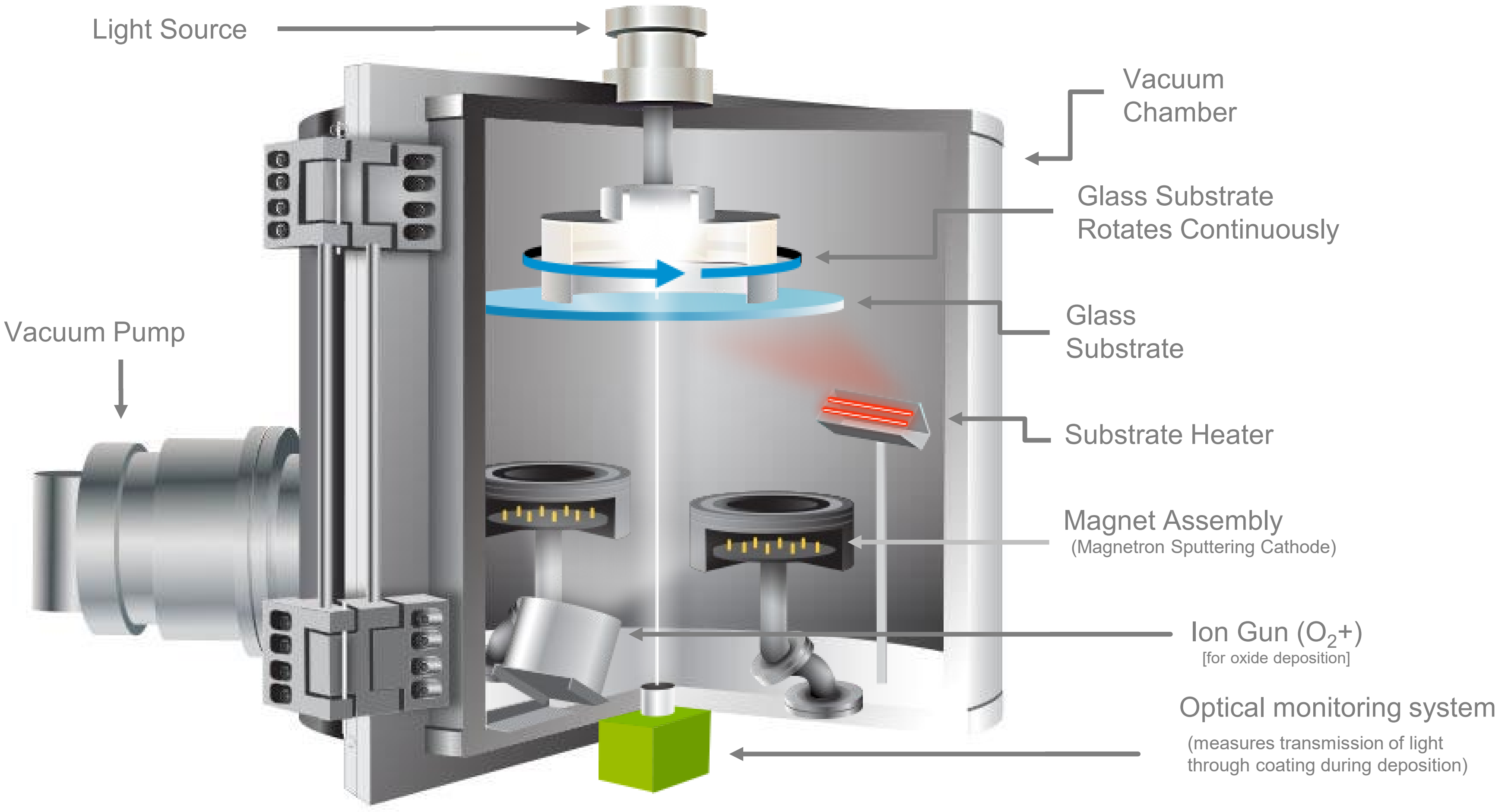


Space-based applications for optical filters

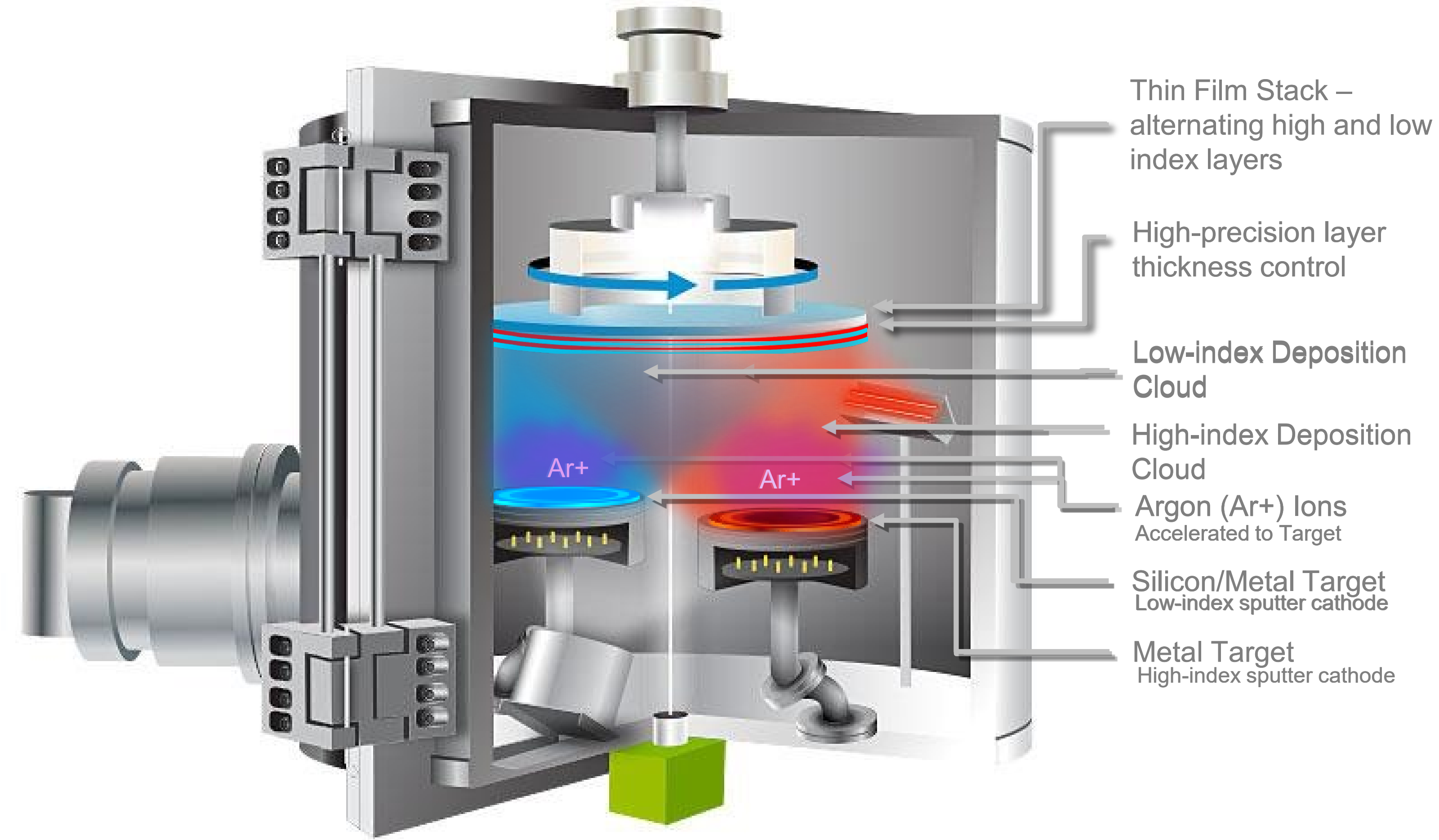
Optical Filter Challenges for Remote sensing

- High-precision
- Durability to withstand harsh conditions / longevity
- Full spectrum blocking
- Incorporates SWIR/MWIR λ's
- Highlighly optimized
- Cost sensitivity

Sputter Coating Process - Main Components



Sputter Coating Process – Deposition Components



Sputter Coating Process – Sputtering Basics

With **reactive sputtering**, oxide coatings can be made by introducing oxygen gas which reacts with the metal/semiconductor during deposition.

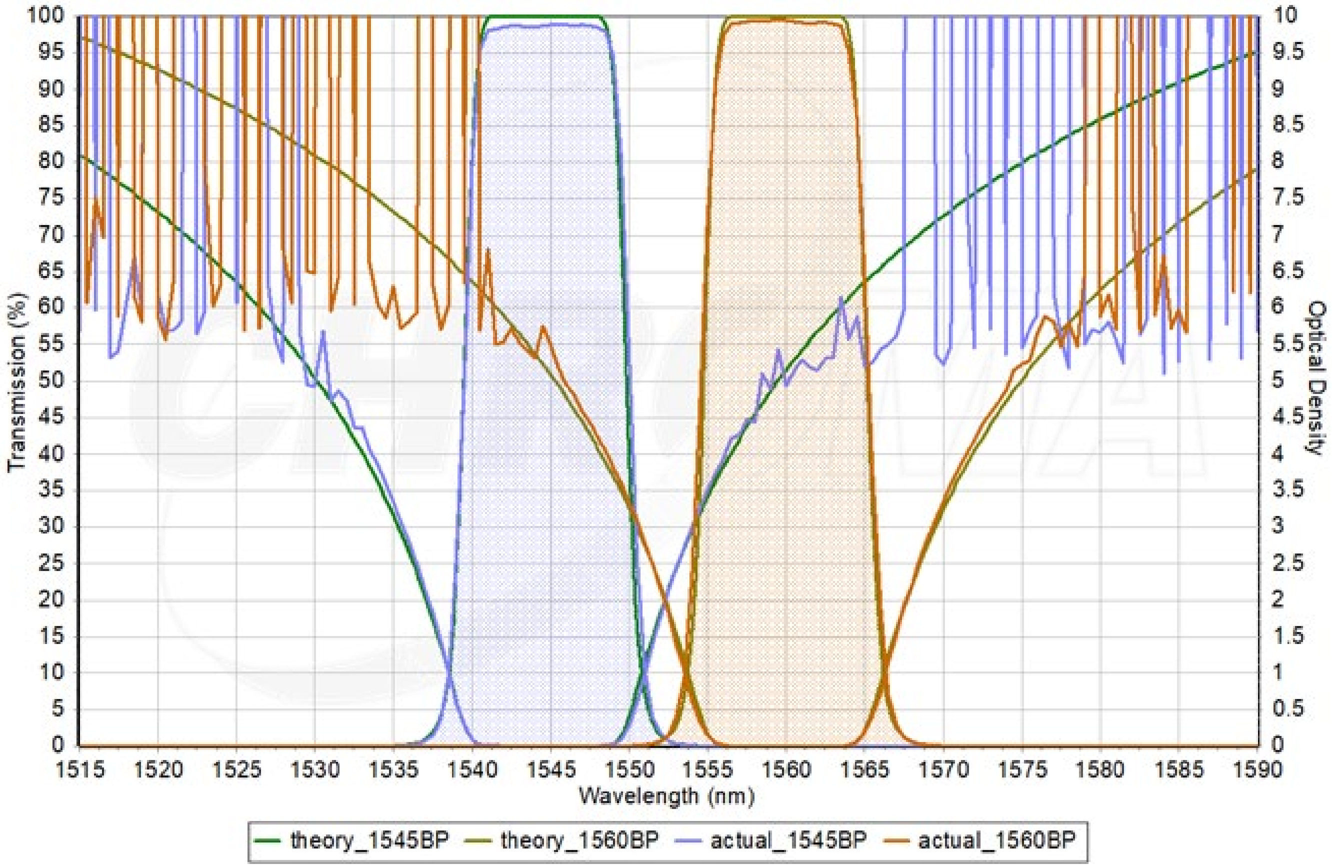
Ion-assist is used to enhance the reactivity of ionized oxygen (for oxide deposition), and deliver energy to the growing film in order to promote void-free growth and enhance film durability.

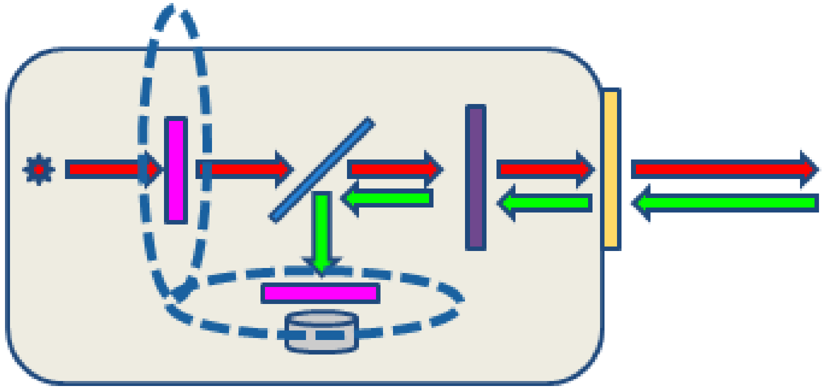
A negative high voltage is applied to the metal target and ionized argon gas is accelerated toward the target thereby dislodging metal material.

Vacuum chamber pressure/pumping performance, gas flows, temperature, cathode currents and voltages, and ion-gun operation are all critical parameters for repeatable coating execution, stable refractive index, and consistent film structure.

Filters for Satcom

Tx and Rx bandpass filters (clean-ups)



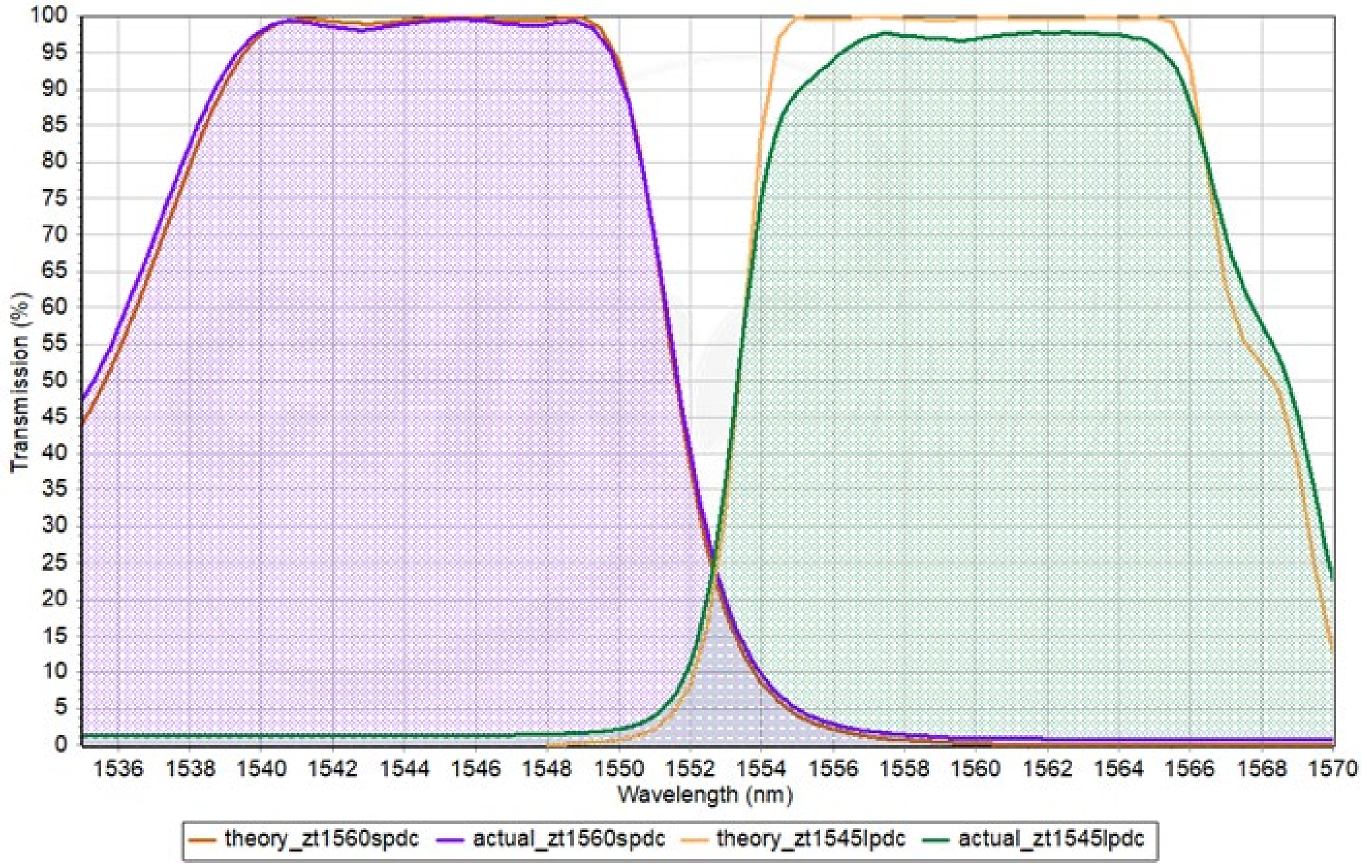


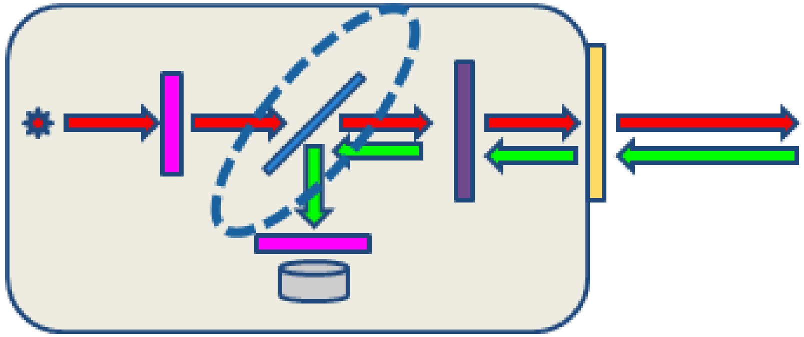
Features:

- Steep
- Narrow
- Tight CWL tolerances
- Very high transmission

Filters for Satcom

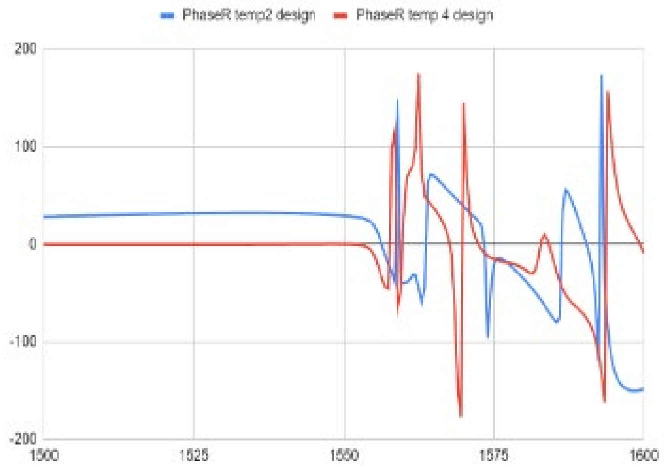
Tx and Rx beam-splitters





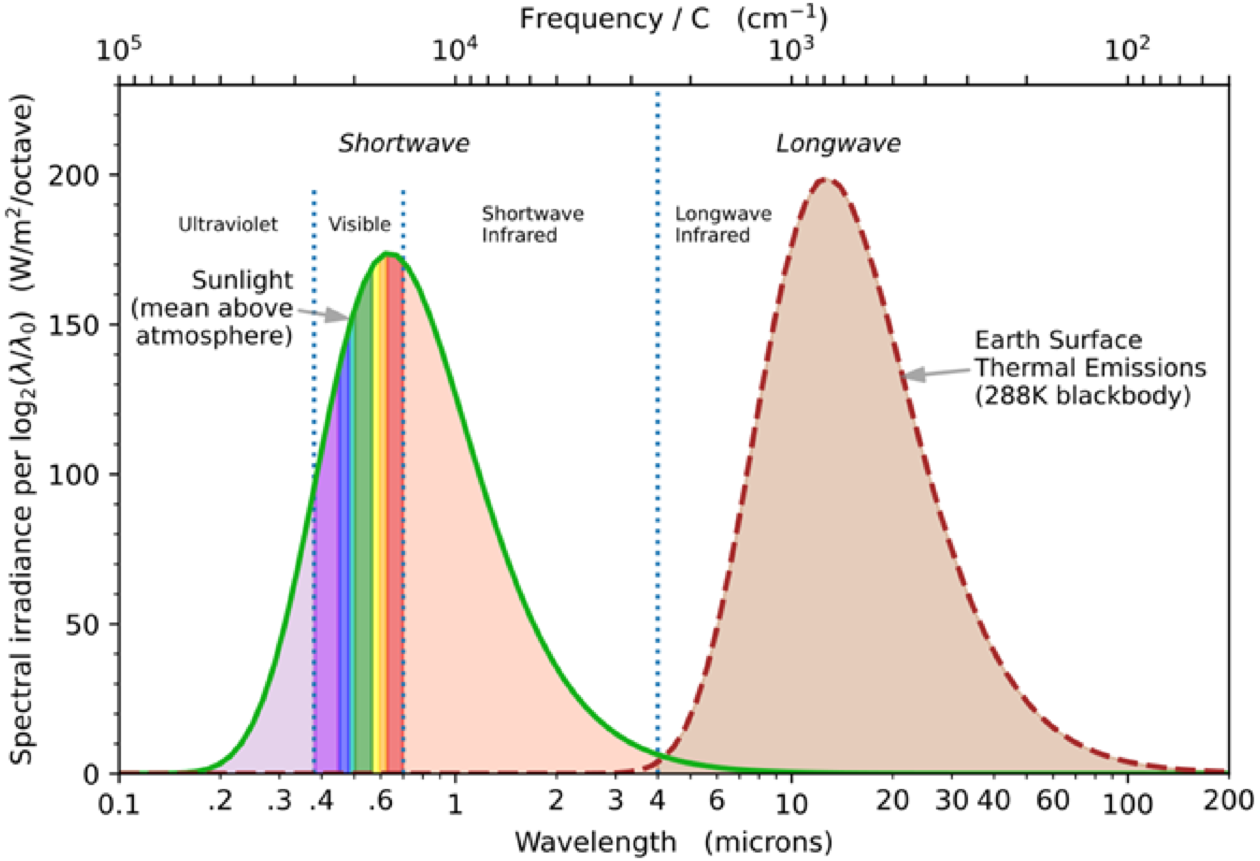
Features:

- Steep
- Tight cut-on tolerances
- Very high transmission
- Flatness, TWD
- Polarization control / low phase retardance



Filters for Satcom

Solar filters



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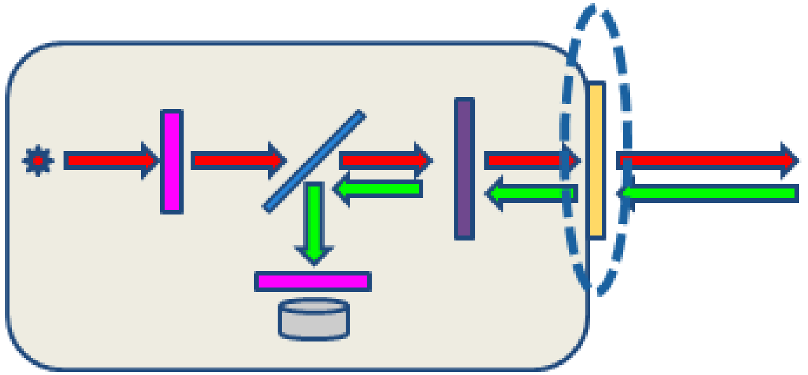


Features:

- Wide-angle (90deg HCA),
- Very wide-band rejection/high reflection, of heat (thermal energy from Sun, and also in some cases the Earth which radiates well into the deep IR)
- High-transmission
- TWD

Solar Filter

Challenge:

High transmission in C-Band, with wide range of reflection extending into IR

Basic Design:

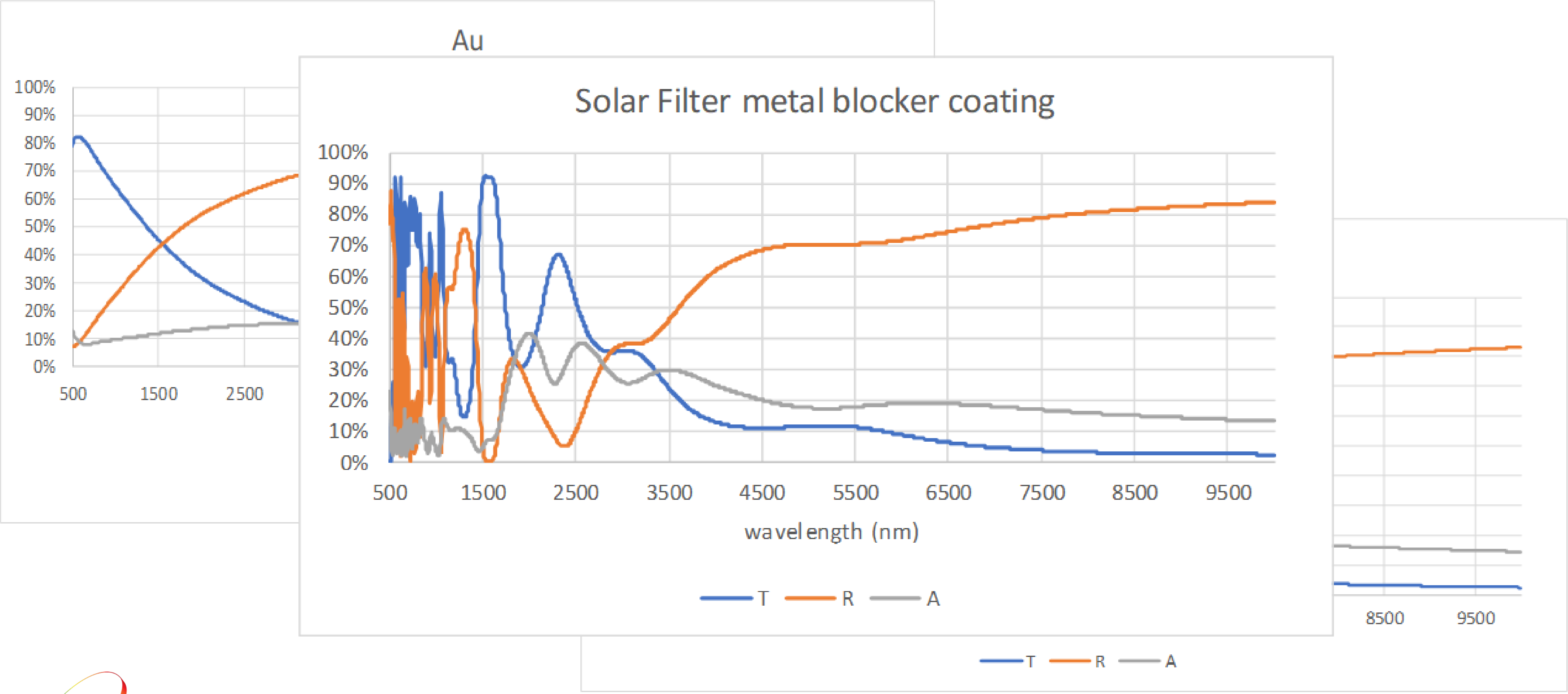
BP Filter (dielectric/a-Si:H) : glass : induced transmission filter (metal/dielectric)

Induced transmission filters[1,2] : **Metal layer provides wide range of reflection**

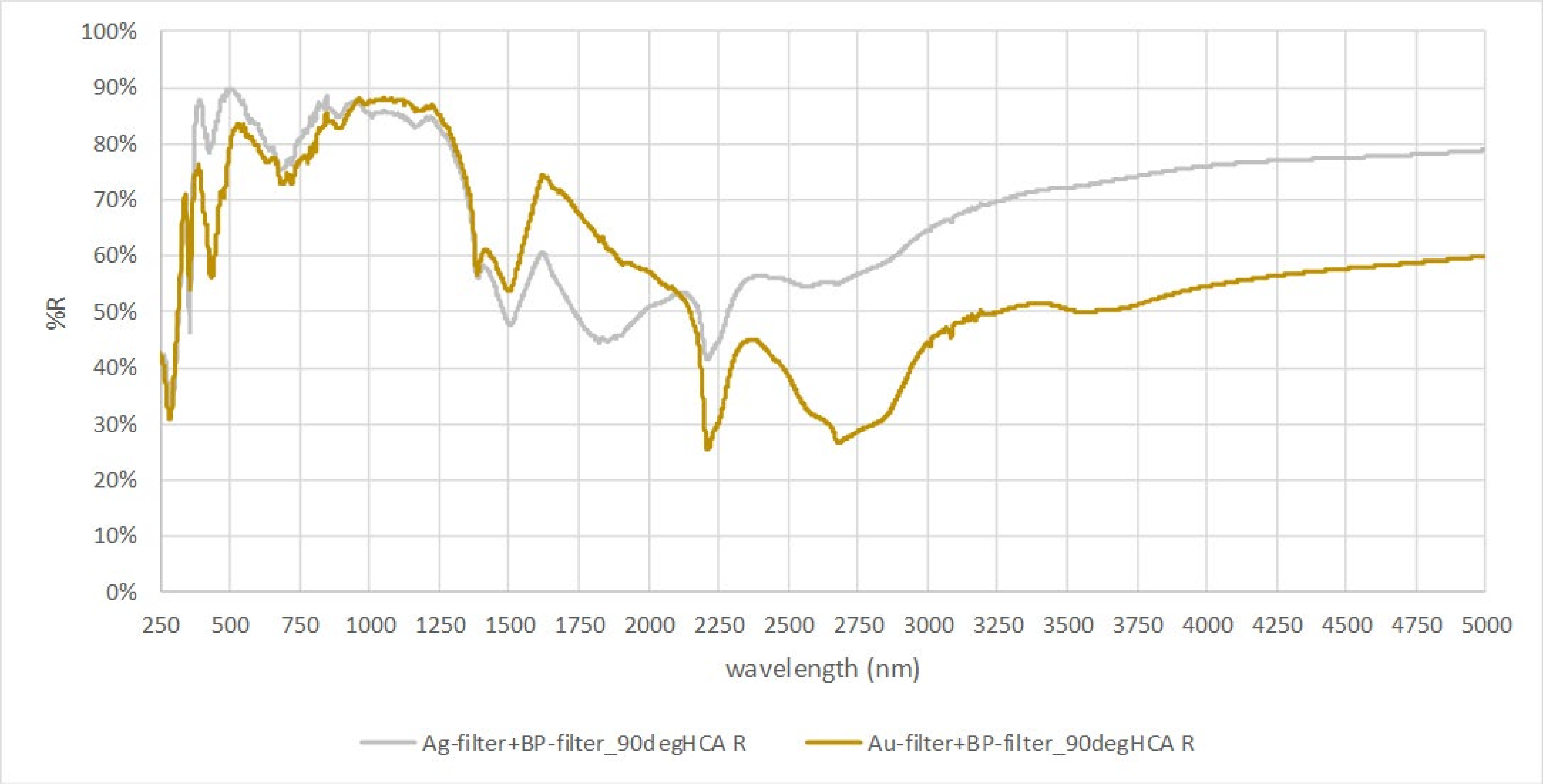
- However, metal also has significant absorption - too thick a metal layer would not allow for high %T
- Silver (Ag) provides higher IR reflection …
- … but Gold (Au) films more robust, so can go thinner and get higher %T
- Overcoat of dielectric still needed for robustness and to “AR” the metal
- Too thick a dielectric overcoat would absorb instead of reflect IR
- Thin metal optical constants don’t agree with bulk, or even “normal” thickness metal layers

1.Peter H. Berning and A. F. Turner, "Induced Transmission in Absorbing Films Applied to Band Pass Filter Design," J. Opt. Soc. Am. 47, 230-239 (1957)
2.R. J. Holloway and P. H. Lissberger, "The Design and Preparation of Induced Transmission Filters," Appl. Opt. 8, 653-660 (1969)

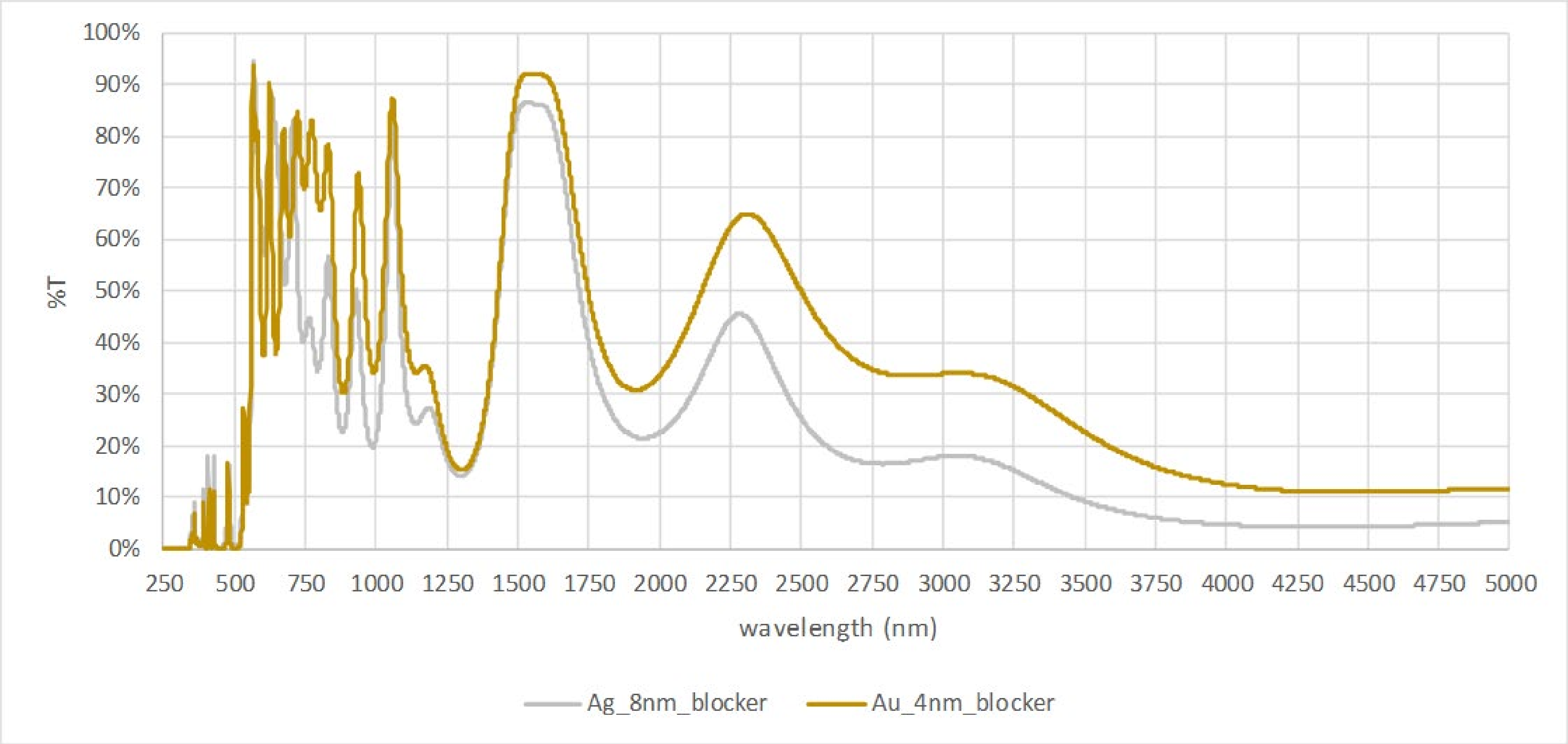
Solar Filter - Transmission, Reflection, Absorption



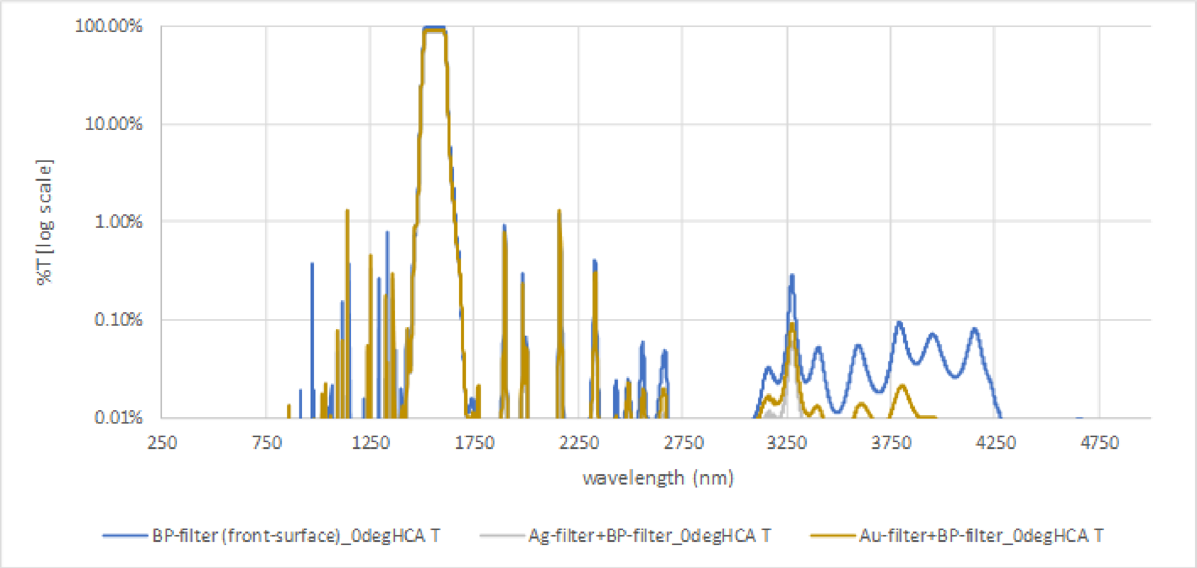
Solar Filter - Reflection, Full Half-cone Angle

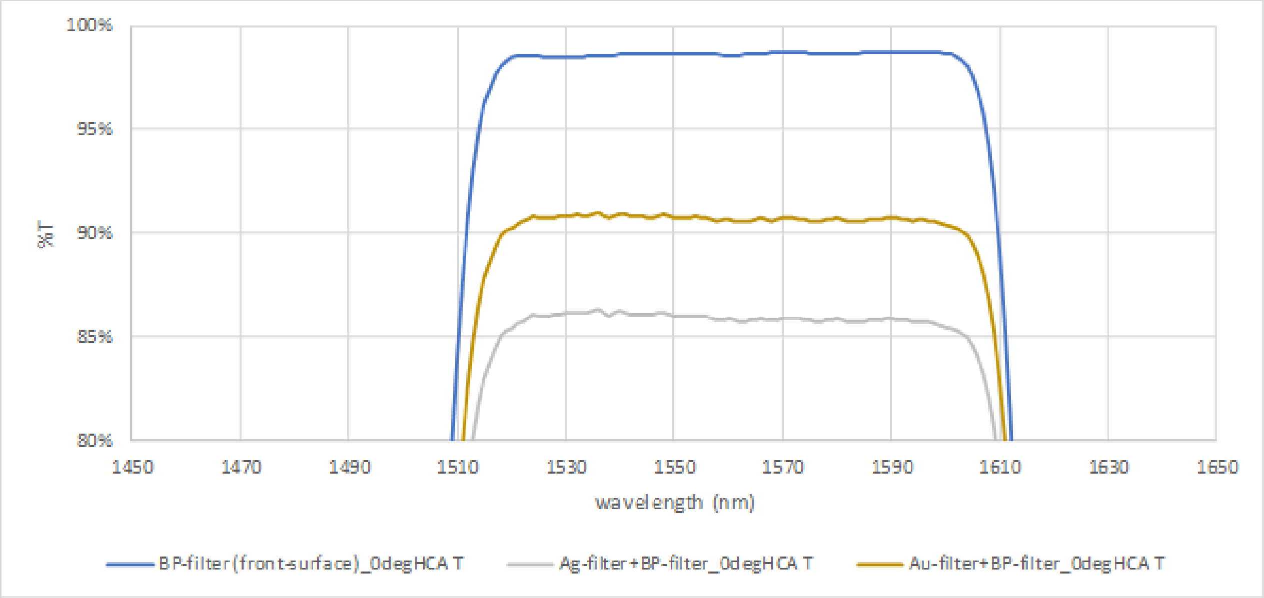


Solar Filter - Transmission, 0 deg AOI, Metal Blockers



Solar Filter - Transmission, 0 deg AOI, Solar Filter





Solar Filter - Gold Nano-layer Optical Properties

Deposited ultra-thin (< 10nm) metal layers have different optical properties (n, k) from bulk or even from that of more typical thickness thin films (10-100nm)

In addition, film structure also changes as material is deposited

- Upon deposition, depending on temperature, metal atoms form "islands" (aggregation) and these only coalesce at sufficient thicknesses;
- Until coalescence, optical properties are different than expected for a thin continuous film.

To achieve continuous films but very thin layers (~4nm based on design), etch-back process used

- Ar+ ion gun etching – low voltage end-hall source; metals etch easily (< 200V)
- Process optimized for etch uniformity across ~150mm diameter

1.Riera, B. Baloukas, O. Zabeida, and L. Martinu, "Optimizing the Deposition of Sputtered Gold Island Films with Time Derivative Surface Reflectance," in Optical Interference Coatings Conference (OIC) 2019, OSA Technical Digest (Optica Publishing Group, 2019), paper TA.9.
2.Dmitry I. Yakubovsky, Aleksey V. Arsenin, Yury V. Stebunov, Dmitry Yu. Fedyanin, and Valentyn S. Volkov, "Optical constants and structural properties of thin gold films," Opt. Express 25, 25574-25587 (2017)

Solar Filter - Gold Nano-layer Optical Properties

Empirically adjusting optical constants

- Modeling was conducted to get the optical properties using single layers w/ known materials
- Subsequent deposition used optical monitoring to find target transmission based on modeling
- At thinner layers, n and k converge

Further exploration done to find compatible dielectric material on either side of Au

- Diffusion potential, durability considerations

The outer layer is optimized to get target of 92%T in C-Band via induced transmission while maintaining %R in the long-wave IR. (Effect of layer absorption is reduced %R)

1.Riera, B. Baloukas, O. Zabeida, and L. Martinu, "Optimizing the Deposition of Sputtered Gold Island Films with Time Derivative Surface Reflectance," in Optical Interference Coatings Conference (OIC) 2019, OSA Technical Digest (Optica Publishing Group, 2019), paper TA.9.
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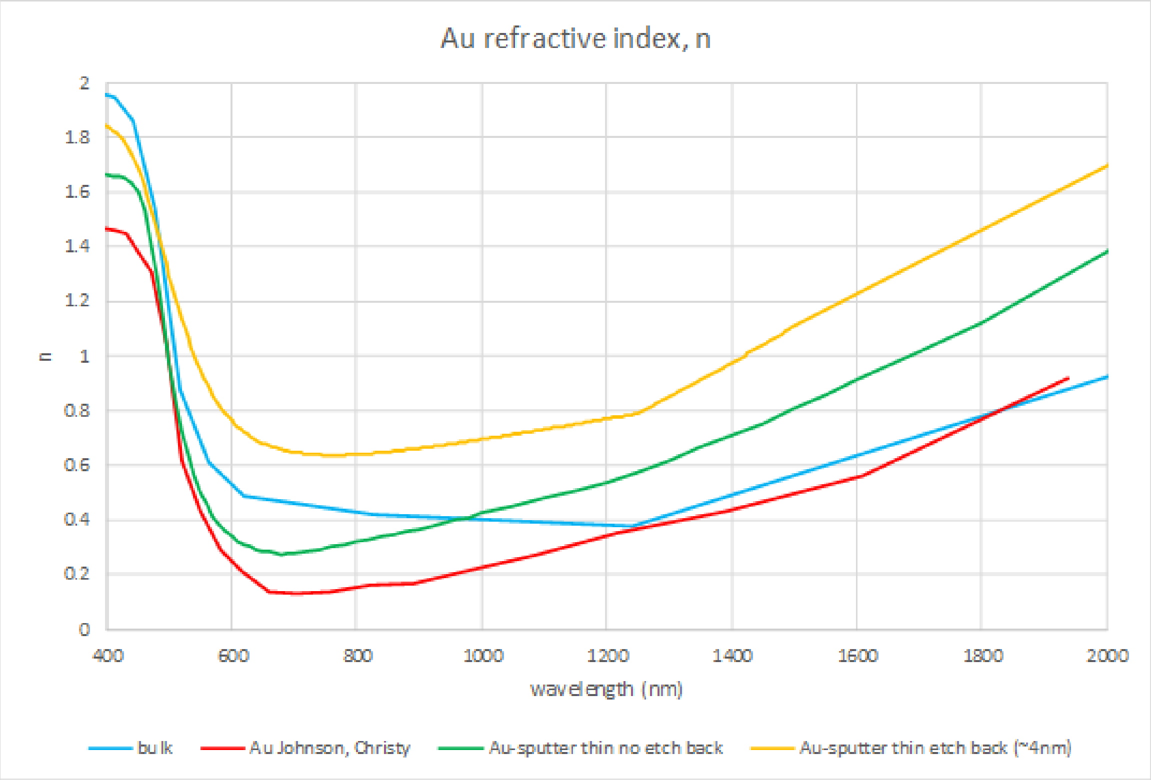
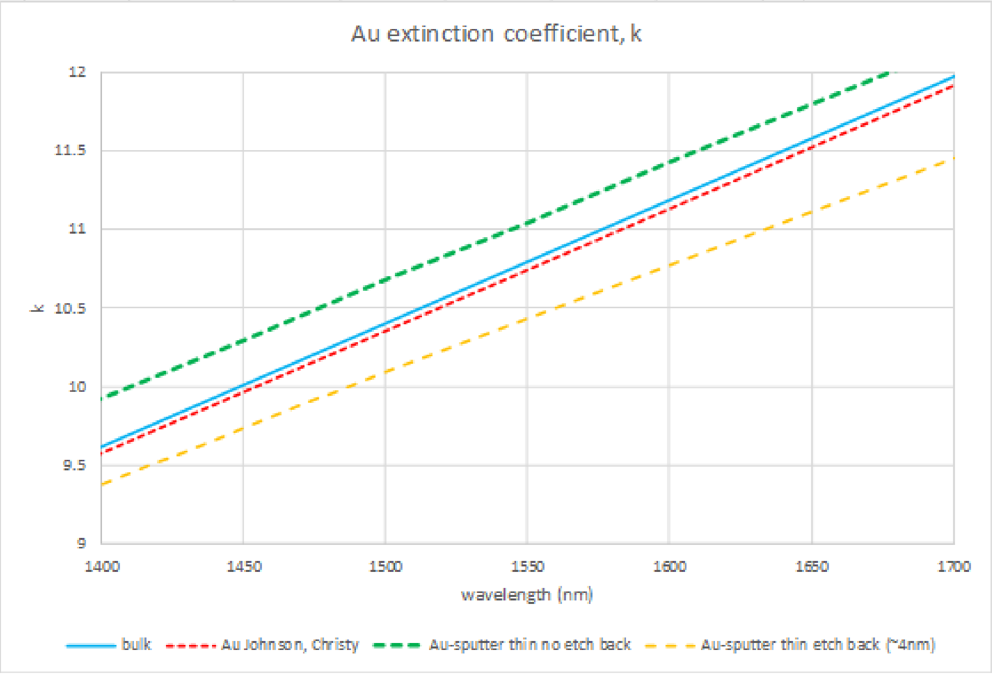
Solar Filter





P. B. Johnson and R. W. Christy. Optical constants of the noble metals, Phys. Rev. B 6, 4370-4379 (1972)

Results

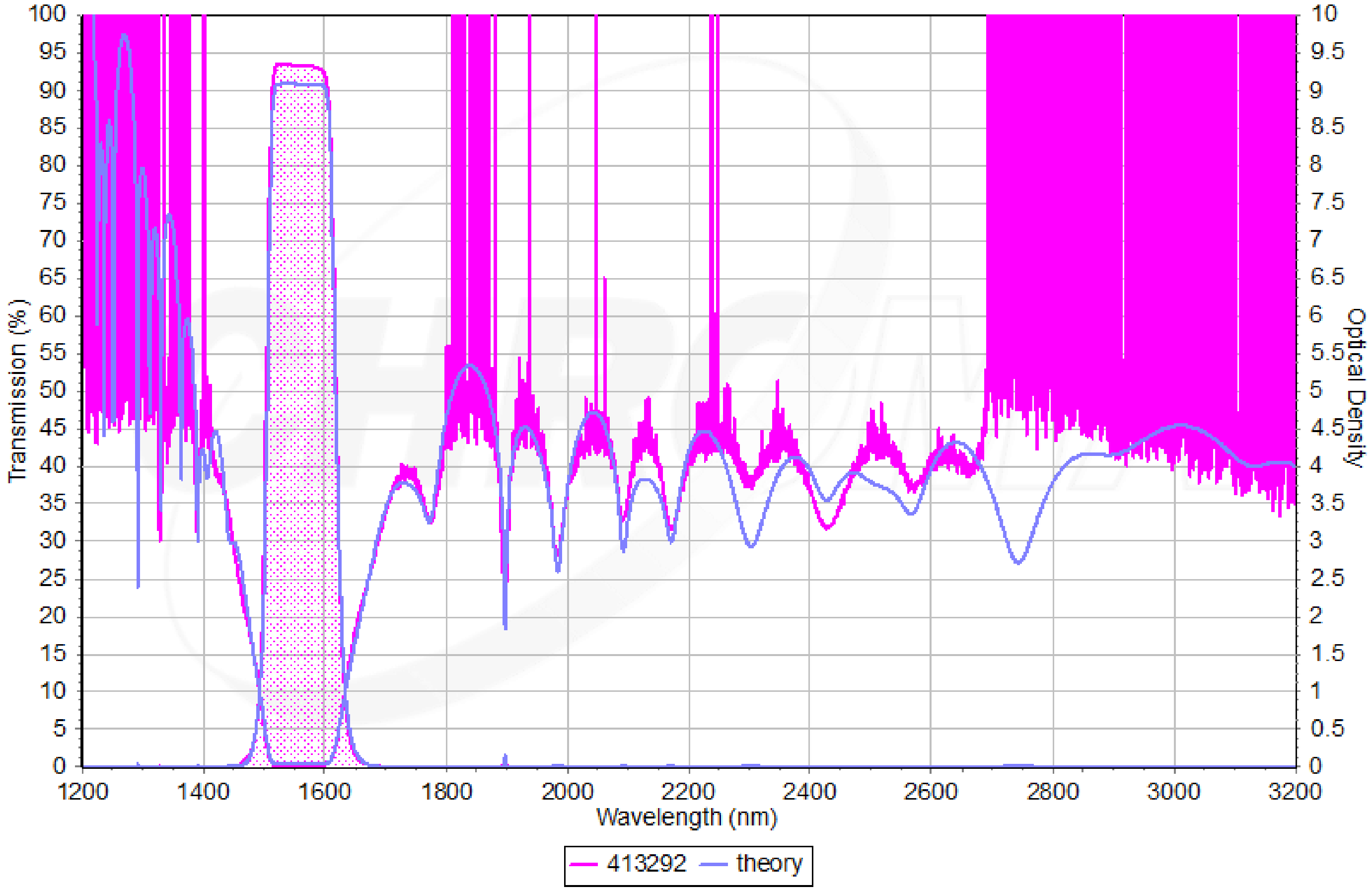
Spectra:

Excellent match with theory, but achieved higher %T!

Durability:

Passed tape/adhesion and cheesecloth abrasion tests:

- ISO 9211-4-01-01, MIL-C-48497A 4.5.3.3
- ISO 9211-4-02-02, MIL-C-48497 4.5.3.1



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