Integrated Target Reflectivity Analysis

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ARIES Project Meeting

March 8-9, 2001

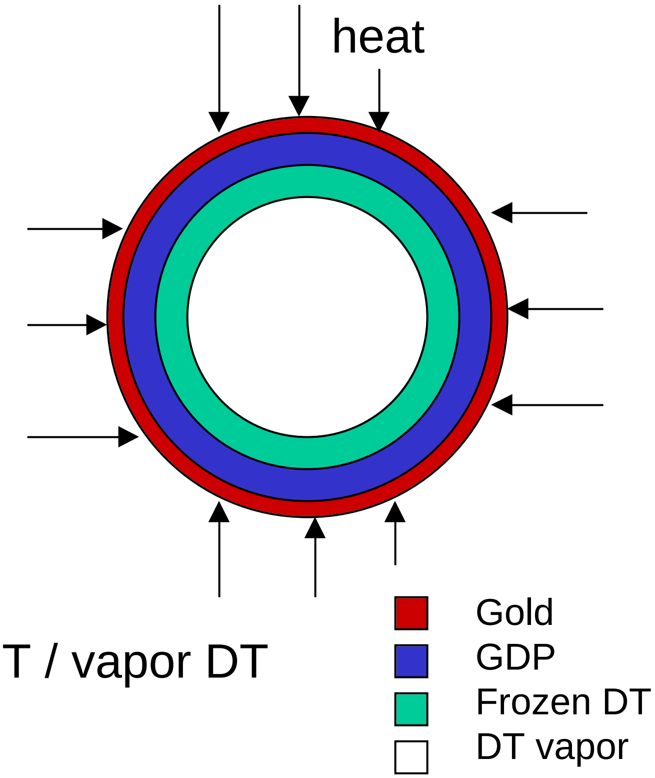
Livermore, California

UCSD

OUTLINE

- Motivation
- Modeling Approach
- Results for four metal films (Au, Ag, Pd, Pt)
- Frequency and temperature dependence of optical properties of metal films
- Future Plans

Motivation for Target Reflectivity Calculations



- Target heat reflectivity is computed at UCSD to provide input to target heating analysis carried out at General Atomics.

- Before irradiation by the driver beam, the target must be protected from external heat so that:

  T_{fuel} < DT triple point (21 K)

- Proposed target composition : Au / GDP / solid DT / vapor DT

- Sombrero study showed :

  Radiation heating from chamber wall
  \>> Convective heat transfer from chamber gas

Modeling Approach

- Objective is to calculate inertial fusion target reflectance of heat radiated from chamber wall.

- Assume incident radiation spectrum to be blackbody.

- Use four-layer (vac/film/polymer/DT) Fresnel model to calculate intensity reflectivity for each wavelength and angle of incidence.

- Include both S- and P-polarization components. Assuming random polarization mix, we have for reflectivity:

$$R(\lambda,\theta) = 0.5\,(R_S + R_P)$$

- Calculate reflectivity averaged over incident angle by

$$R(\lambda)_\theta = 2\int_0^{\pi/2} d\theta\, R(\lambda,\theta)\sin\theta\cos\theta$$

- Integrate over radiation spectrum to obtain total reflectivity:

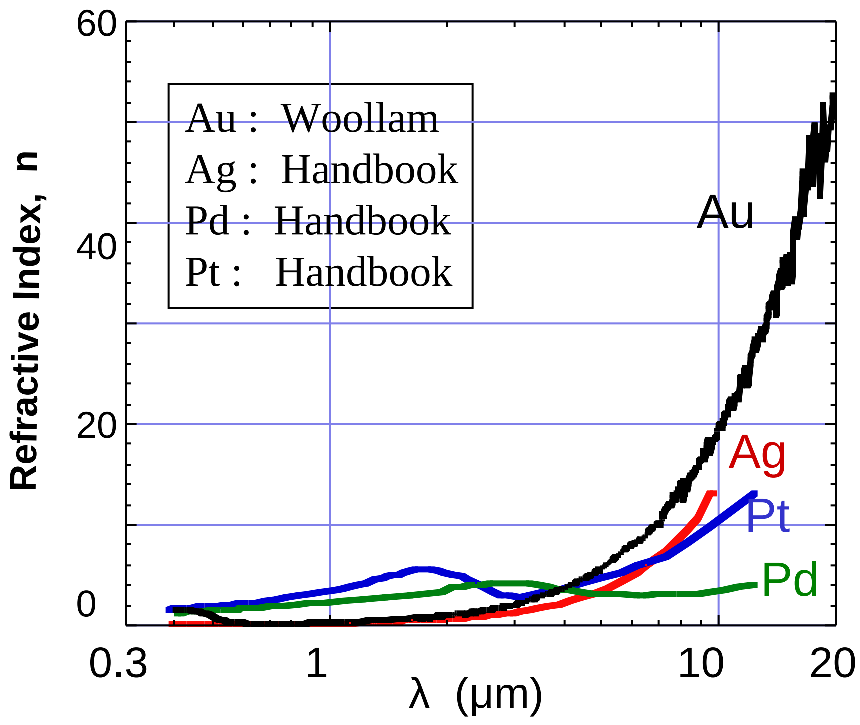
$$(T) = \pi\int_0^\infty d\lambda \langle R(\lambda)\rangle_\theta\, i'_{\lambda b}(\lambda,T) \Big/ \sigma T_W^4$$

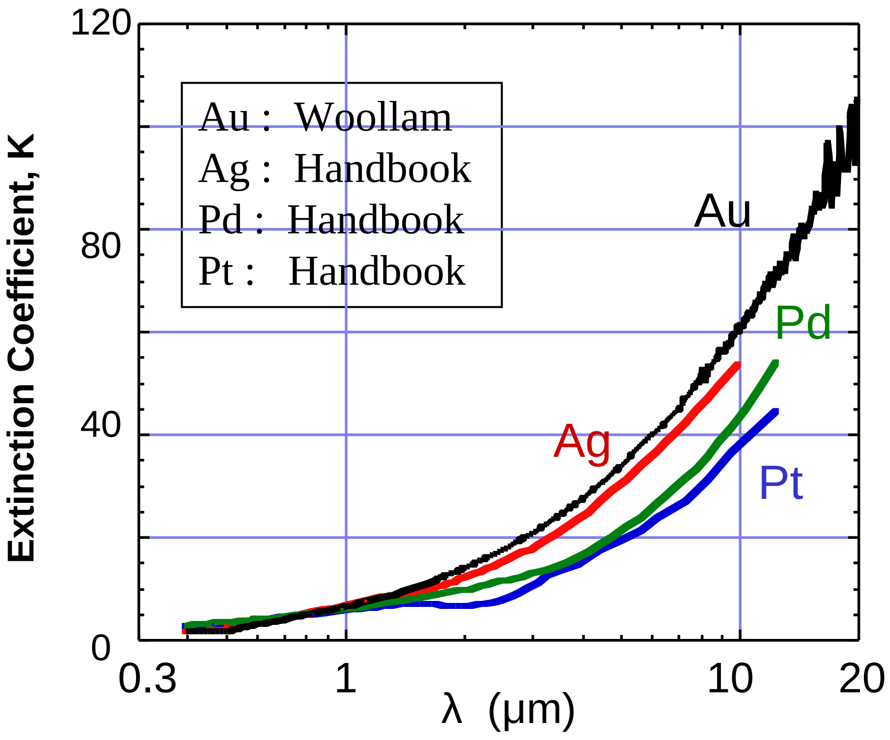
Optical Properties for Four Coating Materials

- Complex refractive index : $n = n + i\,k$
- Gold data are from Woollam Co. ($0.4 < \lambda < 20$ μm)

  Silver, Palladium and Platinum data are from Handbook of Optical Constants of Solids ($0.4 < \lambda < \sim 10$ μm)

  - Search for data into FIR regime.
- Target reflectivity is obtained by integrating over available spectrum.





Optical Properties of Polymer and DT Ice

- Polymer (GDP):

  - Visible spectrum : $n(\lambda) = A_n + B_n \lambda^{-2} + C_n \lambda^{-4}$ (Cauchy)

    $k(\lambda) = A_k \exp\{1.24B_k(1/\lambda - 1/C_k)\}$ (Urbach)

    The fitting coefficients are supplied by Woollam Co.

  - Infrared spectrum : Multiple oscillator model (More info from Woollam)

    Extend Cauchy/Urbach fit

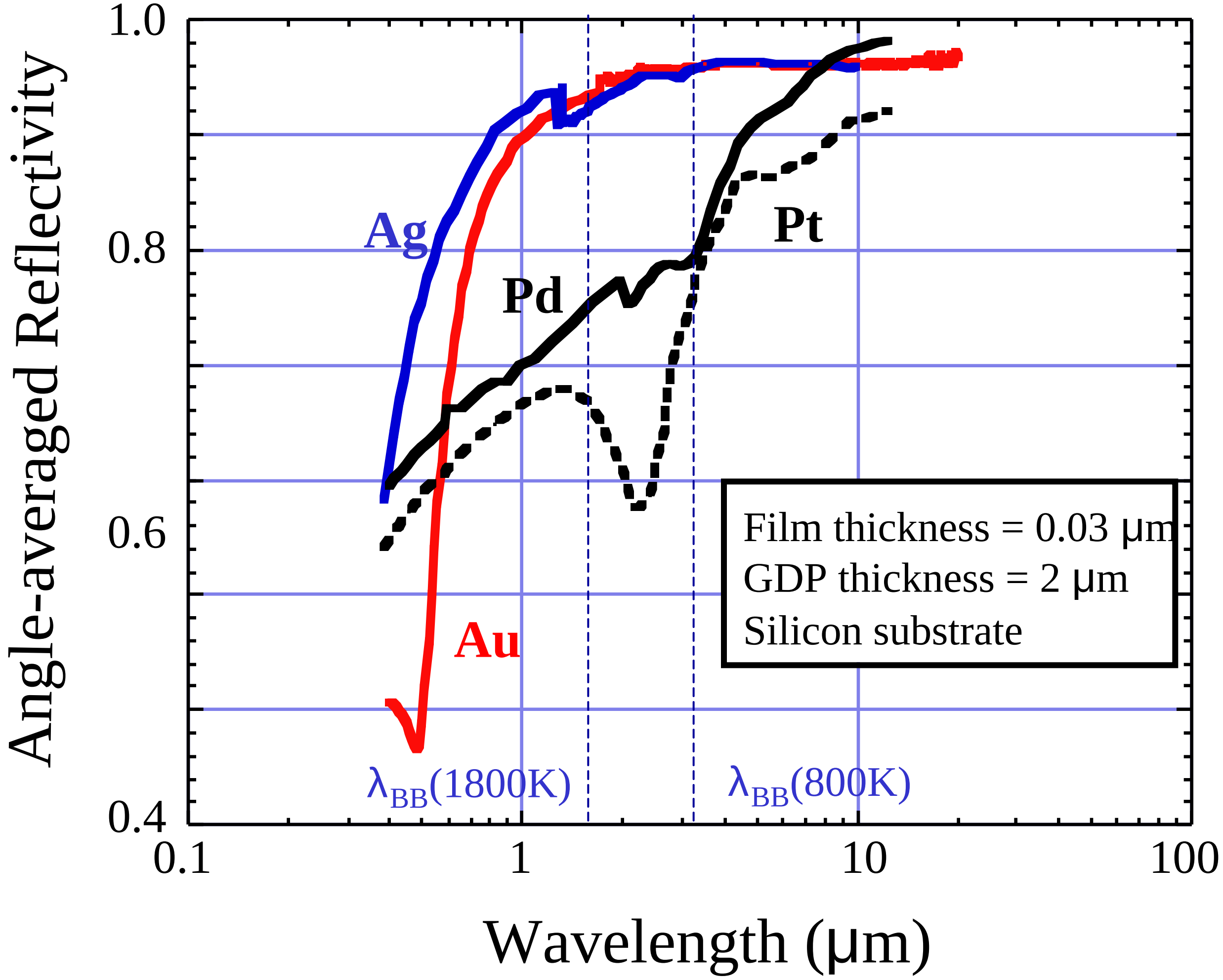
- DT Ice:

  - Have not uncovered any optical database yet.

  - Assume substrate to be Silicon with $n = 4.47$, $k = 1.12$.

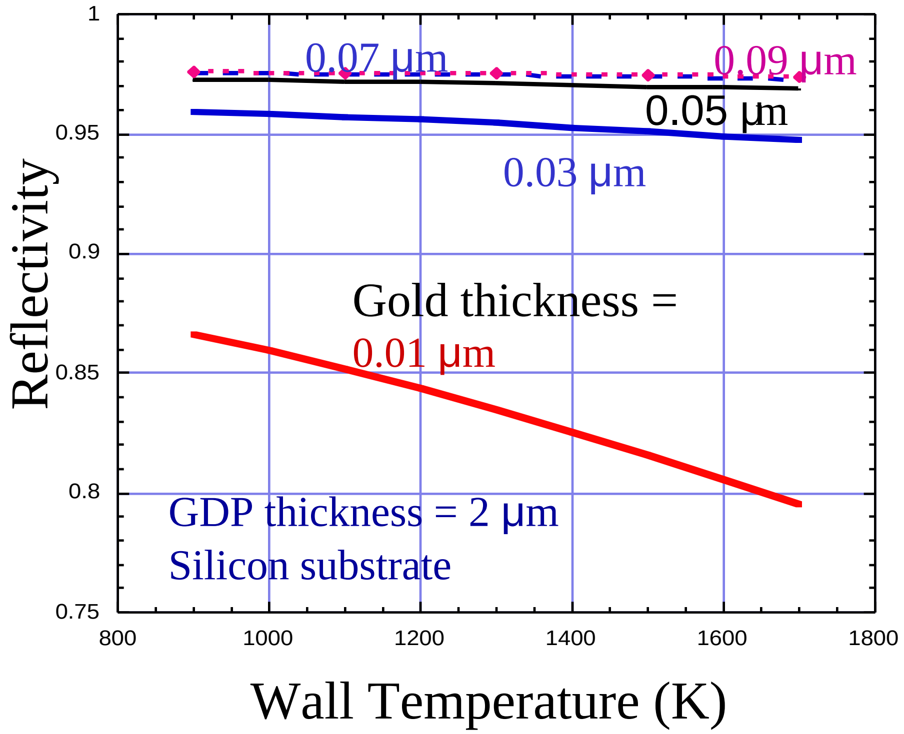
Angle-averaged Reflectivity for Four Metal Films

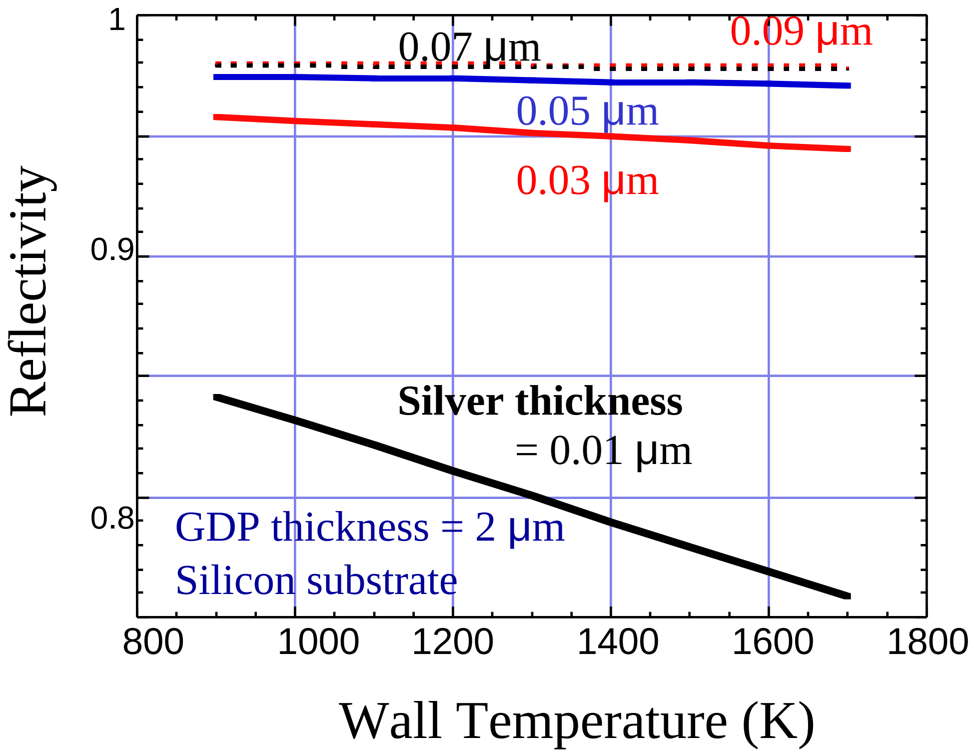
- Both gold and silver show sharp decrease in reflectivity $< R(\lambda) >_\theta$ towards visible range of wavelengths.



Gold and Silver Films Provide High Reflectivity

- Gold and silver films have very similar reflectivities (integrated over database spectrum).
- Reflectivity decreases with wall temperature, as peak radiated wavelength moves towards visible regime.
- Maximum reflectivity (~ 0.98) is reached when film thickness ≥ 0.07 µm.

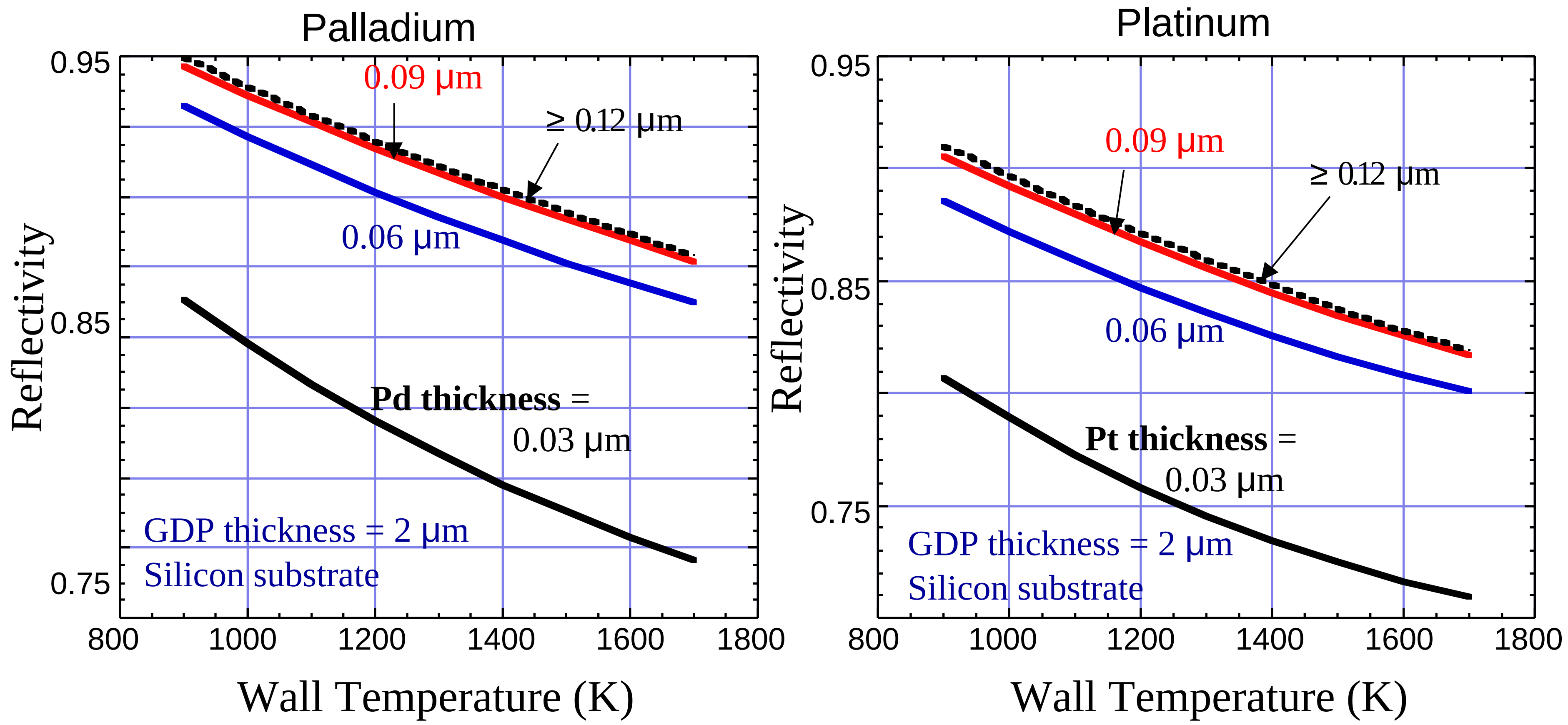




Palladium and Platinum have Poor Reflective Properties

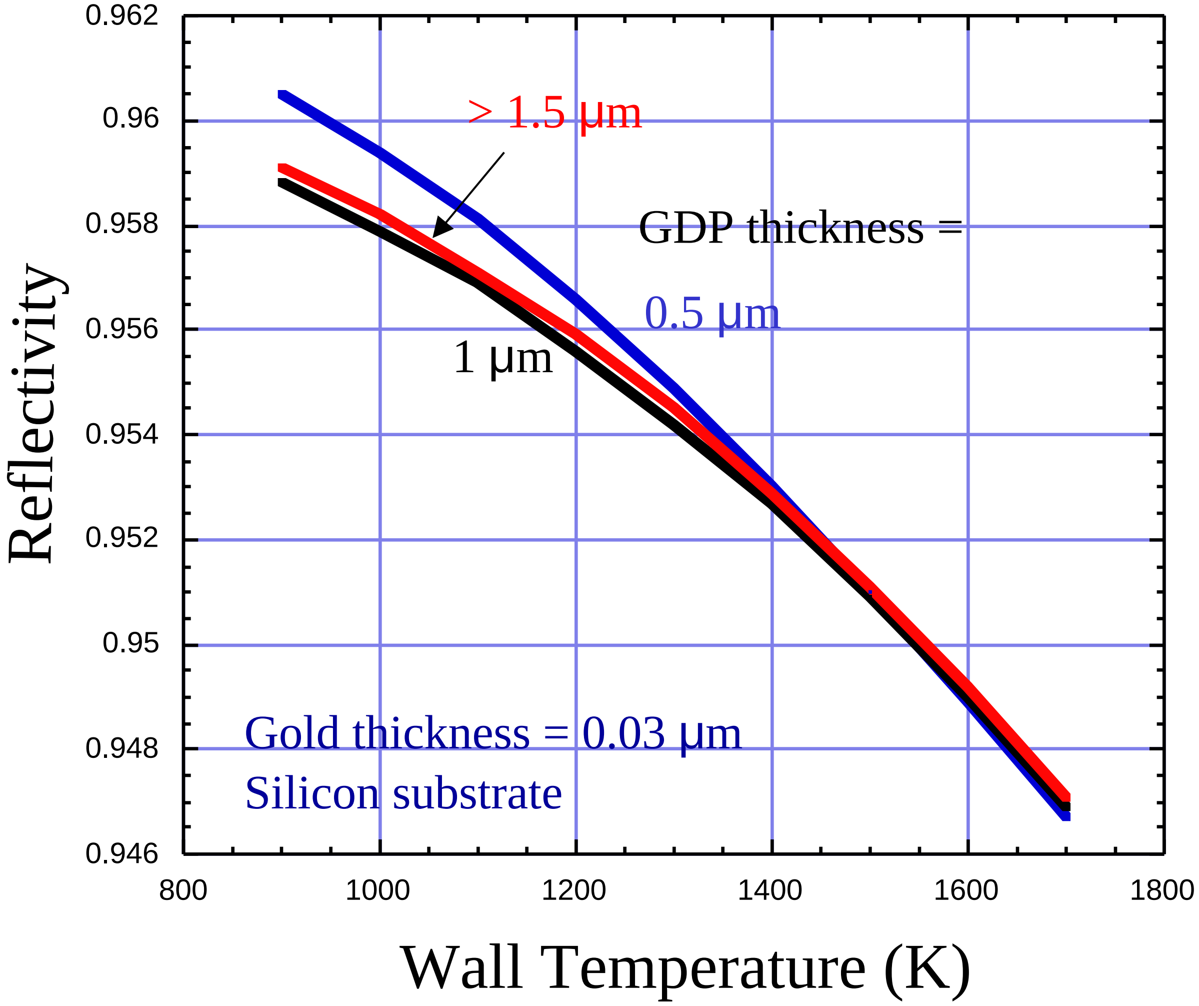
- Reflectivities for Palladium and Platinum films are much lower than Gold or Silver for the same thickness.

- Spectrum-integrated reflectivity is much more sensitive to wall temperature.



Target Reflectivity is Insensitive to Plastic Shell Thickness

- At low wall temperature, there is a ~ 0.2% variation of R with GDP thickness; no variation at higher temperature, for 0.03 µm film thickness.



Temperature and Frequency Dependence of Reflectivity

- For a conductor, dielectric response to external EM field is dominated by "free" electrons, and $n = n\,(1 + i\,\kappa)$ [κ : attenuation index]

  $n^2\,(1 - \kappa^2) = \mu\varepsilon$

  $n^2\kappa = 2\pi\mu\sigma / \omega$, where $\sigma = Ne^2 / [m(\gamma - i\,\omega)]$

  and $\gamma = 1 / \tau$, τ is time between collisions. Typically, $\gamma \sim 10^{14}\ s^{-1}$.

- For low frequencies (FIR), $\gamma << \omega$, σ is the dc conductivity, and is real.
  - Transition of optical properties into FIR range.

- For high frequencies (uv and visible) , $\gamma >> \omega$, and assuming $\mu = 1$,

  $n^2\,(1 - \kappa^2) \sim 1 - (\omega_p / \omega)^2$

  $n^2\kappa \sim 0.5\,\gamma\,\omega_p^{\,2} / \omega^3$

- Temperature dependence:
  - Low frequencies: dependence of σ_{dc} on temperature
  - High frequencies:
    (1) At low temperature, γ is determined by impurities and imperfections
    (2) At ordinary temperature, γ is dominated by electron-phonon scattering, *i.e.*, electron interaction with lattice vibrations.

FUTURE PLANS

- Incorporate Fresnel multi-layer model into target heating calculations at General Atomics
  - Use results as a heating source term
  - Extend spectrum to FIR range
  - Local heat deposition calculations (to verify assumptions made).
- Continue search for optical properties of solid DT
- Extrapolate results to lower temperatures
  - n and κ values at room temperature have been used