Optics: Thin Film Interference and Coatings

Computational Science Templates

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1 Introduction

Thin film interference creates colors in soap bubbles and enables anti-reflection coatings, high reflectors, and narrow-band filters. This analysis computes reflectance and transmittance spectra for single-layer and multi-layer thin film structures using Fresnel equations and the transfer matrix method, with applications in optical coating design.

2 Mathematical Framework

2.1 Fresnel Equations

At normal incidence, the amplitude reflection coefficient:

$$r_{ij} = \frac{n_i - n_j}{n_i + n_j} \tag{1}$$

For oblique incidence:

$$r_s = \frac{n_i \cos\theta_i - n_t \cos\theta_t}{n_i \cos\theta_i + n_t \cos\theta_t} \tag{2}$$

$$r_p = \frac{n_t \cos\theta_i - n_i \cos\theta_t}{n_t \cos\theta_i + n_i \cos\theta_t} \tag{3}$$

2.2 Single Layer Reflectance

For a single layer on a substrate:

$$R = \left| \frac{r_{01} + r_{12} e^{2i\delta}}{1 + r_{01} r_{12} e^{2i\delta}} \right|^2 \tag{4}$$

where $\delta = \frac{2\pi n_1 d \cos\theta_1}{\lambda}$ is the optical phase thickness.

2.3 Transfer Matrix Method

For a layer with refractive index n and thickness d:

$$M = \begin{pmatrix} \cos\delta & \frac{i\sin\delta}{\eta} \\ i\eta\sin\delta & \cos\delta \end{pmatrix} \tag{5}$$

where $\eta = n\cos\theta$ for s-polarization and $\eta = n/\cos\theta$ for p-polarization.

3 Environment Setup

4 Single Layer Anti-Reflection Coating

5 High Reflector (Dielectric Mirror)

6 Narrow-Band Filters

7 Angle Dependence and Polarization

8 Soap Bubbles and Natural Thin Films

9 Results Summary

10 Statistical Summary

- **Uncoated glass reflectance**: **??**%
- **Minimum AR coating reflectance**: **??**%
- **Quarter-wave AR thickness**: **??** nm
- **Optimal coating index**: $n = \sqrt{n_{glass}} =$ **??**
- **High reflector peak (16 pairs)**: **??**%
- **Stop band width**: $\approx$ **??**% of λ_0
- **Brewster angle (glass)**: **??**°

11 Conclusion

Thin film interference enables precise control of optical properties through constructive and destructive interference. A single quarter-wave MgF_2 layer reduces glass reflectance from 4% to below 1% at the design wavelength. Multi-layer stacks can achieve reflectances exceeding 99.99% for high-power laser mirrors. The transfer matrix method provides an efficient algorithm for analyzing arbitrary layer structures. Angular dependence causes blue-shifting of spectral features and polarization splitting, exploited in polarizing beam splitters. These principles underpin technologies from camera lenses to laser mirrors, interference filters, and optical telecommunications components.