Optics of Thin Films

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1: Anti-reflection coating

(1) We want to make an anti-reflection coating for a glass substrate ($n = 1.5$) in air ($n = 1$). The substrate will be coated with a single layer of MgF_2 ($n = 1.38$). We want to minimize reflection at $\lambda = 580$ nanometers, assuming the light is incident normal to the surface. Determine what the thickness d of the layer should be.

2: Testing the design of an anti-reflection coating design: Instructions

For these problems, you will make use of the simulations at PhotonicsRT: Wave Propagation in Multilayer Structures. (You might also want to use them to check your answers to the previous problems) Note that you will need to create a free account on NanoHUB to use this.

1. Select "TE Polarization." (This just means that when the light hits the interface its electric field vector is in the same plane as the interface.)
2. Enter the angle that you want the incoming ray to make with the axis normal to the interface.
3. Click on "Layers."
4. Leave "Number of interpolation points" alone at the default setting (100).
5. Leave "Min" at the default setting (400nm) but change "Max" to 700 nm. These numbers define the range of wavelengths that we'll study.
6. For the number of layers, leave it at 1 (for now).
7. For the front, leave it as air.
8. Click on the tab labeled "Layer 1." Set it to be "Magnesium Fluoride." (There's a drop-down menu with a choice of materials.) Set the thickness to whatever thickness you got for problem 7-15 in Pedrotti. (This is a good chance to check your work and see if you really do get minimal reflectance at 580 nm under normal incidence!)
9. Click on the tab labeled "Back" and choose "Glass BK7".
10. Click "Calculate." You'll see several curves that don't mean much. From the drop-down menu at the top select "Reflectance (R), Transmittance (T), and Absorbance (A)."

11. Click on the purple arrow to the right of the plot to show the side bar. Uncheck the Transmittance and Absorbance. Then, on the left of the plot, click on the axis and change the scale so that the maximum is somewhere around 0.05. Now you can actually see a curve with a dip!

So, now you know how this works. Let's see how robust the design of the anti-reflection coating is.

Effects of incident angle:

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(1) For normal incidence, what wavelength(s) would you have to go to (longer and/or shorter) to increase the reflectance by 25% as compared to the reflectance at 580 nm?

(2) Now change the angle of incidence to 10 degrees. How much has the reflectance increased at 580 nm?

(3) For that 10 degree incident angle, what wavelength(s) would you have to go to (longer and/or shorter) to increase the reflectance by 25% as compared to the reflectance at 580 nm?

(4) Increase the angle of incidence to 45 degrees. What wavelength(s) would you have to go to (longer and/or shorter) to increase the reflectance by 25% as compared to the reflectance at 580 nm?

Questions on film thickness:

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(1) Again, for normal incidence, what wavelength(s) would you have to go to (longer and/or shorter) to increase the reflectance by 25% as compared to the reflectance at 580 nm?

(2) Increase the film thickness to 3/4 of the wavelength (inside the coating) and redo the previous question.

(3) Which of the two coatings (part 1 or part 2) is more useful? Why?

(4) What happens if we go to an even thicker film (but one that still minimizes reflectance at 580 nm)? What is the qualitative trend that you are noticing as film thickness increases?

(5) Now decrease the film thickness from part 4 by 10%. Now what wavelength gives the minimum reflectance? What is the percentage difference between this wavelength and 580 nm? What does this tell you about the relationship between the film thickness and the reflectance minimum?

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Robustness against additional layers:

Sometimes it is necessary to put a thin coating of silicon dioxide on the surface of the film (air-MgF_2 interface) and then put a thin layer of organic molecules on the air side of that. This is done to make the surface hydrophobic, so it won't absorb water. (See US Patent 6783704 for an example.) Let's see how this changes the functioning of the film. Use the following parameters in this part:

- Light incident at zero degrees.
- Consider wavelengths between 400 and 700 nanometers.
- Front = Air
- Layer 1 = Hexachloromethane (it's one of the few small organic molecules that this application can simulate)
- Layer 2 = Silicon dioxide
- Layer 3 = Magnesium Fluoride (same thickness as in your answer to the very first question in this assignment)
- Back = Glass (BK7)

Set the silicon dioxide layer thickness to 5 nm, and the hexachloromethane layer thickness to 2 nm.

(1) At what wavelength is the reflectance a minimum? You might have to zoom in on the vertical scale to see this. What is the percentage difference between this wavelength and 580 nm? Did the coating have a significant effect?

(2) If you increase the thickness of the hexachloromethane layer in steps of 5 nm, how much does it have to increase to increase the reflectance at 580 nm by 0.02?

(3) Would you characterize the organic layer as having a minor or significant effect on the optical performance of this film?