Thin Film Interference – A Study

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Abstract:-

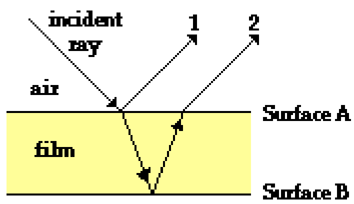
This paper seeks to understand the emphasis on thin film interference of this unit is to present some evidence that has historically supported the view that light behaves as a wave. The reflection, refraction and diffraction of light waves is one strand of evidence. The interference of light waves is a second strand of evidence. In the early nineteenth century, Thomas Young showed that the interference of light passing through two slits produces an interference pattern when projected on a screen. In this section of Lesson 1, we will investigate another example of interference that provides further evidence in support of the wavelike behavior of light.

Perhaps you have witnessed streaks of color on a car windshield shortly after it has been swiped by a windshield wiper or a squeegee at a gas station. The momentary streaks of color are the result of interference of light by the very thin film of water or soap that remains on the windshield. Or perhaps you have witnessed streaks of color in a thin film of oil resting upon a water puddle or concrete driveway. These streaks of color are the result of the interference of light by the very thin film of oil that is spread over the water surface. This form of interference is commonly called **thin film interference** and provides another line of evidence for the wave behavior of light.

Keywords:- **reflection, refraction, diffraction, light waves**.

Introduction:

Light wave interference results when two waves are traveling through a medium and meet up at the same location. So what exactly is causing this thin film interference? What is the source of the two waves? When a wave (light waves included) reaches the boundary between two media, a portion of the wave reflects off the boundary and a portion is transmitted across the boundary. The reflected portion of the wave remains in the original medium. The transmitted portion of the wave enters the new medium and continues traveling through it until it reaches a subsequent boundary. If the new medium is a thin film, then the transmitted wave does not travel far before it reaches a new boundary and undergoes the usual reflection and transmission behavior. Thus, there are two waves that emerge from the film - one wave that is reflected off the top of the film (wave 1 in the diagram) and the other wave that reflects off the bottom of the film (wave 2 in the diagram).

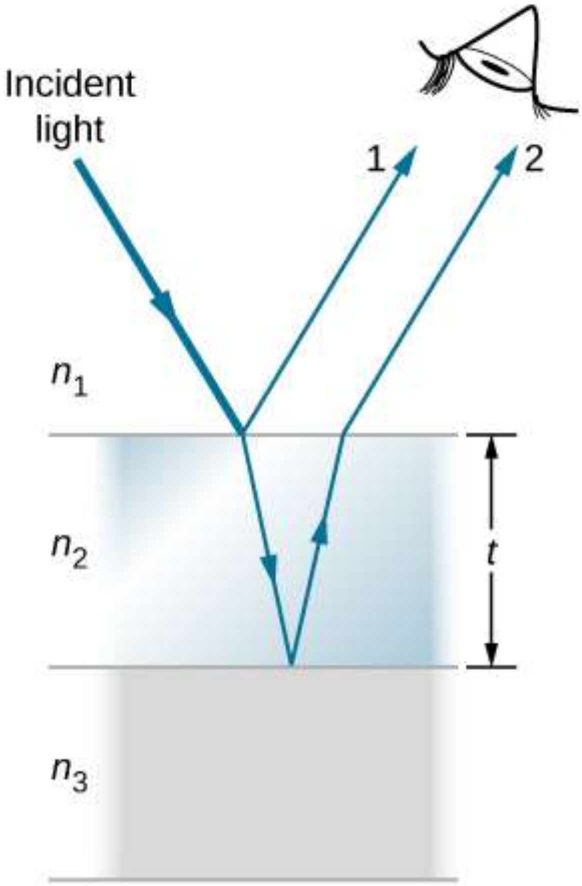


These two waves could interfere constructively if they meet two conditions. One condition is that the two waves must be relatively close together such that their crests and troughs can meet up with each other and cause the interference. To meet this condition, the light must be incident at angles close to zero with respect to the normal. (This is not shown in the diagram above in order to space out the waves for clarity sake.) A second condition that must be met is that the wave that travels through the film and back into the original medium must have traveled just the right distance such that it is *in phase* with the other reflected wave. Two waves that are *in phase* are waves that are always at the same point on their wave cycle. That is, the two waves must be forming crests at the same location and at the same moment in time and forming troughs at the same location and at the same moment in time. In order for the second condition to occur, the thickness of the film must be *just perfect*.

Objectives: This paper seeks to understand the emphasis of Lesson 1 of this unit is to present some evidence that has historically supported the view that light behaves as a wave. The reflection, refraction and diffraction of light waves is one strand of evidence

The bright colors seen in an oil slick floating on water or in a sunlit soap bubble are caused by interference. The brightest colors are those that interfere constructively. This interference is between light reflected from different surfaces of a thin film; thus, the effect is known as **thin-film interference.**

What causes thin-film interference? shows how light reflected from the top and bottom surfaces of a film can interfere. Incident light is only partially reflected from the top surface of the film (ray 1). The remainder enters the film and is itself partially reflected from the bottom surface. Part of the light reflected from the bottom surface can emerge from the top of the film (ray 2) and interfere with light reflected from the top (ray 1). The ray that enters the film travels a greater distance, so it may be in or out of phase with the ray reflected from the top. However, consider for a moment, again, the bubbles in Figure 3.5.13.5.1. The bubbles are darkest where they are thinnest. Furthermore, if you observe a soap bubble carefully, you will note it gets dark at the point where it breaks. For very thin films, the difference in path lengths of rays 1 and 2 in Figure 3.5.23.5.2 is negligible, so why should they interfere destructively and not constructively? The answer is that a phase change can occur upon reflection, as discussed next.



Light striking a thin film is partially reflected (ray 1) and partially refracted at the top surface. The refracted ray is partially reflected at the bottom surface and emerges as ray 2. These rays interfere in a way that depends on the thickness of the film and the indices of refraction of the various media.

Changes in Phase due to Reflection

We saw earlier (Waves) that reflection of mechanical waves can involve a 180° phase change. For example, a traveling wave on a string is inverted (i.e., a 180° phase change) upon reflection at a boundary to which a heavier string is tied. However, if the second string is lighter (or more precisely, of a lower linear density), no inversion occurs. Light waves produce the same effect, but the deciding parameter for light is the index of refraction. Light waves undergo a 180° or ππ radians phase change upon reflection at an interface beyond which is a medium of higher index of refraction. No phase change takes place when reflecting from a medium of lower refractive index (Figure 3.5.33.5.3). Because of the periodic nature of waves, this phase change or inversion is equivalent to ±λ/2±λ/2 in distance travelled, or path length. Both the path length and refractive indices are important factors in thin-film interference.

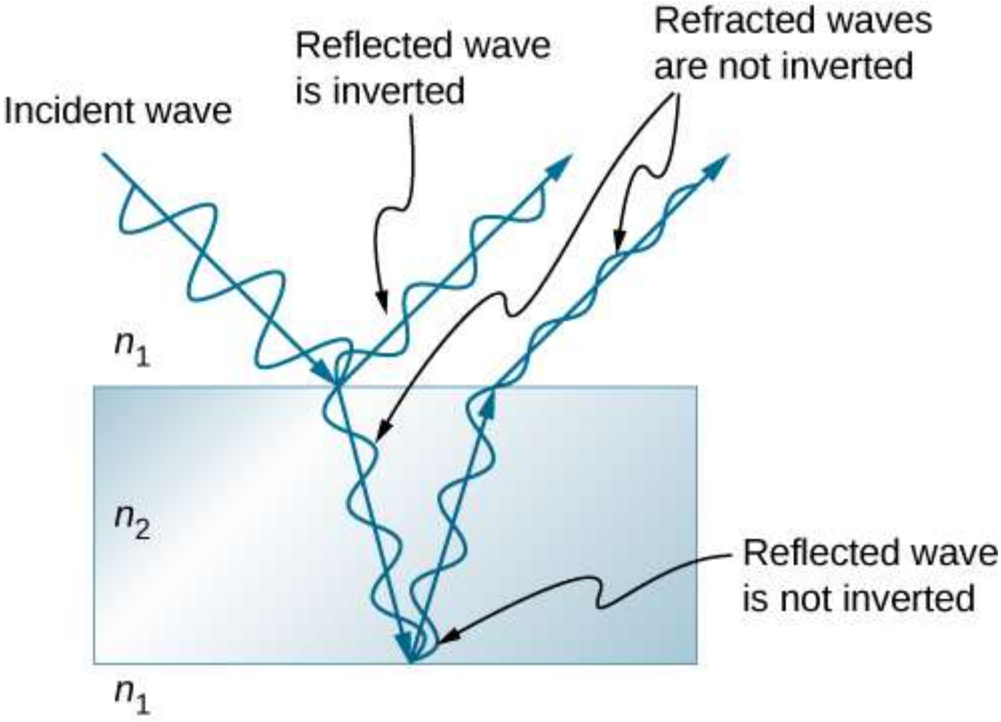


Figure 3.5.33.5.3: Reflection at an interface for light traveling from a medium with index of refraction n1n1 to a medium with index of refraction n2n2, n1<n2n1<n2, causes the phase of the wave to change by ππ radians.

Strategy

Refer to Figure 3.5.23.5.2 and use n1=1.00n1=1.00 for air, n2=1.38n2=1.38, and n3=1.52n3=1.52. Both ray 1 and ray 2 have a λ/2 shift upon reflection. Thus, to obtain destructive interference, ray 2 needs to travel a half wavelength farther than ray 1. For rays incident perpendicularly, the path length difference is 2*t*.

Solution

To obtain destructive interference here,

2t=λn222t=λn22

where λn2λn2 is the wavelength in the film and is given by λn2=λ/n2λn2=λ/n2. Thus,

2t=λ/n22.2t=λ/n22.

Solving for *t* and entering known values yields

t=λ/n24=(500nm)/1.384=99.6nm.t=λ/n24=(500nm)/1.384=99.6nm.

Significance

Films such as the one in this example are most effective in producing destructive interference when the thinnest layer is used, since light over a broader range of incident angles is reduced in intensity. These films are called **nonreflective coatings**; this is only an approximately correct description, though, since other wavelengths are only partially cancelled. Nonreflective coatings are also used in car windows and sunglasses.

Combining Path Length Difference with Phase Change

Thin-film interference is most constructive or most destructive when the path length difference for the two rays is an integral or half-integral wavelength. That is, for rays incident perpendicularly,

$2t=\lambda n,2\lambda n,3\lambda n,...or2t=\lambda n/2,3\lambda n/2,5\lambda n/2,...(3.5.1)(3.5.1)2t=\lambda n,2\lambda n,3\lambda n,...or2t=\lambda n/2,3\lambda n/2,5\lambda n/2,...$

To know whether interference is constructive or destructive, you must also determine if there is a phase change upon reflection. Thin-film interference thus depends on film thickness, the wavelength of light, and the refractive indices. For white light incident on a film that varies in thickness, you can observe rainbow colors of constructive interference for various wavelengths as the thickness varies.

Strategy

Use Figure 3.5.33.5.3 to visualize the bubble, which acts as a thin film between two layers of air. Thus $n1=n3=1.00n1=n3=1.00$ for air, and $n2=1.333n2=1.333$ for soap (equivalent to water). There is a $\lambda/2$ shift for ray 1 reflected from the top surface of the bubble and no shift for ray 2 reflected from the bottom surface. To get constructive interference, then, the path length difference ($2t$) must be a half-integral multiple of the wavelength—the first three being $\lambda n/2,3\lambda n/2\lambda n/2,3\lambda n/2$, and $5\lambda n/25\lambda n/2$. To get destructive interference, the path length difference must be an integral multiple of the wavelength—the first three being 0, $\lambda n\lambda n$, and $2\lambda n2\lambda n$.

Solution

a. Constructive interference occurs here when

$2tc=\lambda n2,3\lambda n2,5\lambda n2,...2tc=\lambda n2,3\lambda n2,5\lambda n2,...$

Thus, the smallest constructive thickness tctc is

$tc=\lambda n4=\lambda/n4=(650nm)/1.3334=122nm.tc=\lambda n4=\lambda/n4=(650nm)/1.3334=122nm.$

The next thickness that gives constructive interference is $t'c=3\lambda n/4tc'=3\lambda n/4$, so that

$t'c=366nm.tc'=366nm.$

Finally, the third thickness producing constructive interference is $t'c=5\lambda n/4tc'=5\lambda n/4$, so that

$t'c=610nm.tc'=610nm.$

b. For destructive interference, the path length difference here is an integral multiple of the wavelength. The first occurs for zero thickness, since there is a phase change at the top surface, that is,

td=0,td=0,

the very thin (or negligibly thin) case discussed above. The first non-zero thickness producing destructive interference is

2t′d=λn.2td′=λn.

Substituting known values gives

t′d=λ2=λ/n2=(650nm)/1.3332=244nm.td′=λ2=λ/n2=(650nm)/1.3332=244nm.

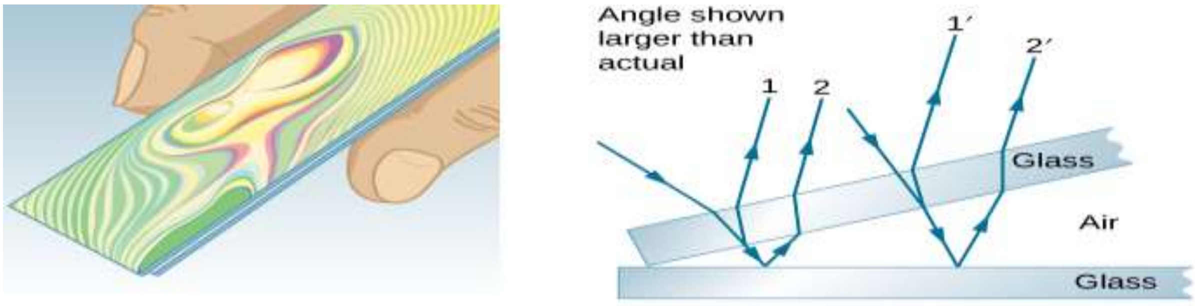
Finally, the third destructive thickness is 2t"d=2λn2t"d=2λn, so that

t"d=λn=λn=650nm1.333=488nm.t"d=λn=λn=650nm1.333=488nm.

Significance

If the bubble were illuminated with pure red light, we would see bright and dark bands at very uniform increases in thickness. First would be a dark band at 0 thickness, then bright at 122 nm thickness, then dark at 244 nm, bright at 366 nm, dark at 488 nm, and bright at 610 nm. If the bubble varied smoothly in thickness, like a smooth wedge, then the bands would be evenly spaced.

Another example of thin-film interference can be seen when microscope slides are separated (see Figure 3.5.43.5.4). The slides are very flat, so that the wedge of air between them increases in thickness very uniformly. A phase change occurs at the second surface but not the first, so a dark band forms where the slides touch. The rainbow colors of constructive interference repeat, going from violet to red again and again as the distance between the slides increases. As the layer of air increases, the bands become more difficult to see, because slight changes in incident angle have greater effects on path length differences. If monochromatic light instead of white light is used, then bright and dark bands are obtained rather than repeating rainbow colors.



(a) (b)

(c)

If wave 1 and wave 2 meet these two conditions as they reflect and exit the film, then they will constructively interfere. As will be learned in Lesson 2, light that is visible to our eyes consists of a collection of light waves of varying wavelength. Each wavelength is characterized by its own color. So a red light wave has a different wavelength than an orange light wave that has a different wavelength than a yellow light wave. While the thickness of a film at a given location may not allow a red and an orange light wave to emerge from the film *in phase*, it may be *just perfect* to allow a yellow light wave to emerge *in phase*. So at a given location on the film, the yellow light wave undergoes constructive interference and becomes brighter than the other colors within the incident light. As such, the film appears yellow when viewed by incident sunlight. Other locations of the film may be just perfect to constructively reinforce red light. And still others area of the film may be of perfect thickness for the constructive reinforcement of green light. Because different locations of the film may be of appropriate thickness to reinforce different colors of light, the thin film will show streaks of color when viewed from above.

Chemical depositi

edite, a fluid precursor undergoes a chemical change at a solid surface, leaving a solid layer. An everyday example is the formation of soot on a cool object when it is placed inside a flame. Since the fluid surrounds the solid object, deposition happens on every surface, with little regard to direction; thin films from chemical deposition techniques tend to be *conformal*, rather than *directional*.

Chemical deposition is further categorized by the phase of the precursor:

Plating relies on liquid precursors, often a solution of water with a salt of the metal to be deposited. Some plating processes are driven entirely by reagents in the solution (usually for noble metals), but by far the most commercially important process is electroplating. It was not commonly used in semiconductor processing for many years, but has seen a resurgence with more widespread use of chemical-mechanical polishing techniques.

Chemical solution deposition (CSD) or chemical bath deposition (CBD) uses a liquid precursor, usually a solution of organometallic powders dissolved in an organic solvent. This is a relatively inexpensive, simple thin-film process that produces stoichiometrically accurate crystalline phases. This technique is also known as the **sol-gel** method because the 'sol' (or solution) gradually evolves towards the formation of a gel-like diphasic system.

Langmuir-Blodgett method uses molecules floating on top of an aqueous subphase. The packing density of molecules is controlled, and the packed monolayer is transferred on a solid substrate by controlled withdrawal of the solid substrate from the subphase. This allows creating thin films of various molecules such as nanoparticles, polymers and lipids with controlled particle packing density and layer thickness.[2]

Spin coating or spin casting, uses a liquid precursor, or sol-gel precursor deposited onto a smooth, flat substrate which is subsequently spun at a high velocity to centrifugally spread the solution over the substrate. The speed at which the solution is spun and the viscosity of the sol determine the ultimate thickness of the deposited film. Repeated depositions can be carried out to increase the thickness of films as desired. Thermal treatment is often carried out in order to crystallize the amorphous spin coated film. Such crystalline films can exhibit certain preferred orientations after crystallization on single crystal substrates.[3]

Dip coating is similar to spin coating in that a liquid precursor or sol-gel precursor is deposited on a substrate, but in this case the substrate is completely submerged in the solution and then withdrawn under controlled conditions. By controlling the withdrawal speed, the evaporation conditions (principally the humidity, temperature) and the volatility/viscosity of the solvent, the film thickness, homogeneity and nanoscopic morphology are controlled. There are two evaporation regimes: the capillary zone at very low withdrawal speeds, and the draining zone at faster evaporation speeds.[4]

Chemical vapor deposition (CVD) generally uses a gas-phase precursor, often a halide or hydride of the element to be deposited. In the case of MOCVD, an organometallic gas is used. Commercial techniques often use very low pressures of precursor gas.

Plasma enhanced CVD (PECVD) uses an ionized vapor, or plasma, as a precursor. Unlike the soot example above, commercial PECVD relies on electromagnetic means (electric current, microwave excitation), rather than a chemical-reaction, to produce a plasma.

Atomic layer deposition (ALD), and its sister technique molecular layer deposition (MLD), uses gaseous precursor to deposit conformal thin films one layer at a time. The process is split up into two half reactions, run in sequence and repeated for each layer, in order to ensure total layer saturation before beginning the next layer. Therefore, one reactant is deposited first, and then the second reactant is deposited, during which a chemical reaction occurs on the substrate, forming the desired composition. As a result of the stepwise, the process is slower than CVD, however it can be run at low temperatures, unlike CVD.

Conclusion:

In molecular beam epitaxy (MBE), slow streams of an element can be directed at the substrate, so that material deposits one atomic layer at a time. Compounds such as gallium arsenide are usually deposited by repeatedly applying a layer of one element (i.e., gallium), then a layer of the other (i.e., arsenic), so that the process is chemical, as well as physical; this is known also as atomic layer deposition. If the precursors in use are organic, then the technique is called molecular layer deposition. The beam of material can be generated by either physical means (that is, by a furnace) or by a chemical reaction (chemical beam epitaxy).

Sputtering relies on a plasma (usually a noble gas, such as argon) to knock material from a "target" a few atoms at a time. The target can be kept at a relatively low temperature, since the process is not one of evaporation, making this one of the most flexible deposition techniques. It is especially useful for compounds or mixtures, where different components would otherwise tend to evaporate at different rates. Note, sputtering's step coverage is more or less conformal. It is also widely used in optical media. The manufacturing of all formats of CD, DVD, and BD are done with the help of this technique. It is a fast technique and also it provides a good thickness control. Presently, nitrogen and oxygen gases are also being used in sputtering.

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