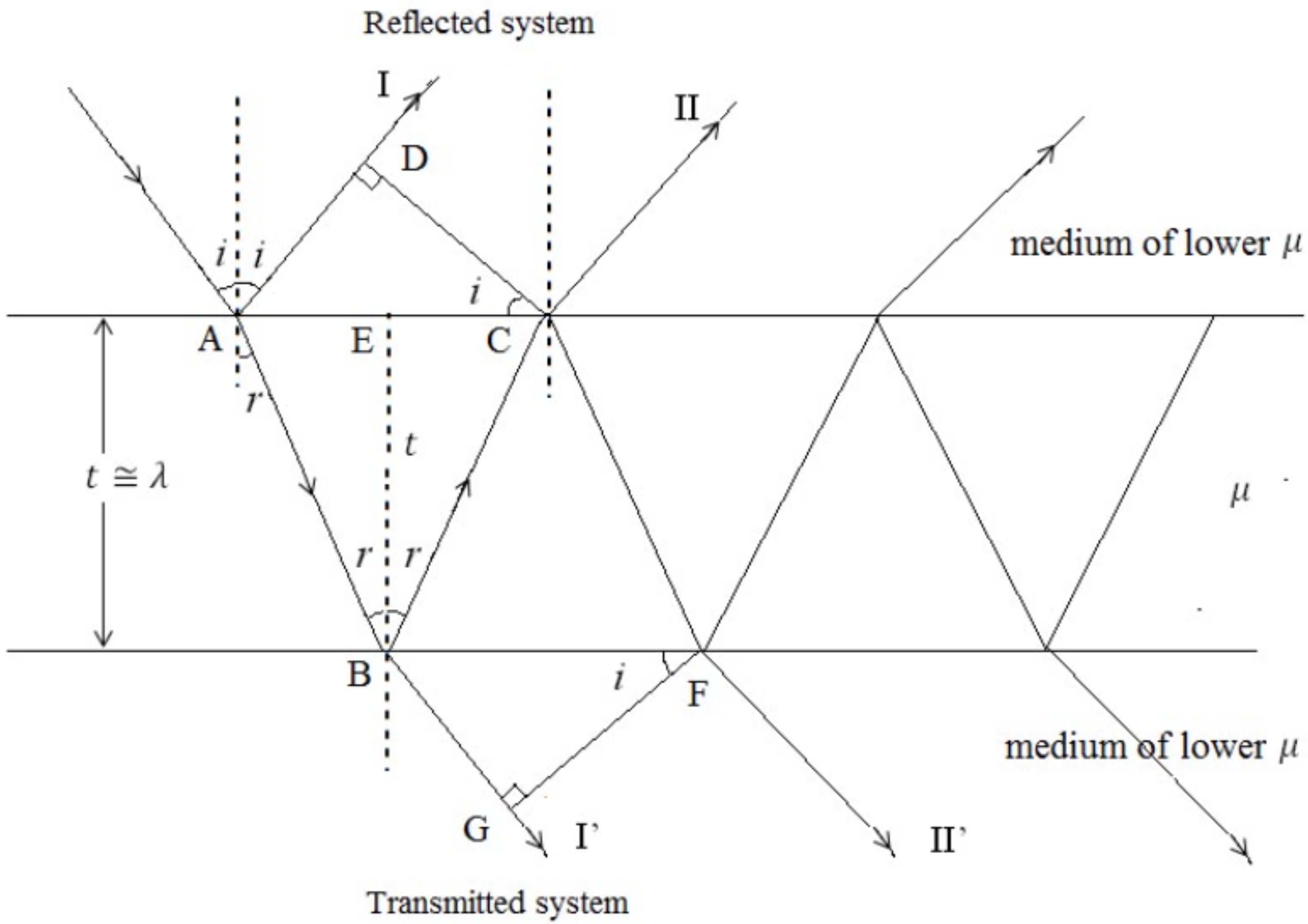
Interference

Thin film

- Film thickness is nearly equal to wavelength of light
- Average wavelength of visible light 5500Å (0.55μm)
- Example
  - Oil films on the road during rainy days
  - Soap bubble
- Applications
  - Anti-reflection coating on camera lens, Solar cell
  - Interference filters
  - Anti transmission coating on invisible glass


Reflected system
I
II
D
medium of lower μ
i
i
i
A
E
C
r
t
$t \cong \lambda$
μ
r
r
B
i
F
medium of lower μ
G
I'
II'
Transmitted system

Explanation:

t--- Uniform thickness of the thin film
μ--- Refractive Index of the thin film

A monochromatic light of wavelength λ is incident on thin film at the point A, at an angle of i and is reflected at i itself.
During refraction, it enters into a denser medium at an angle of r.

On the second interface at point B, the ray is incident at r and is reflected at r itself.
Such reflections and refractions continue within and outside the film as shown in the Figure

Ray I and II (and consecutive rays) in the reflected as well as transmitted system are coherent as these are derived from the single ray.
This is amplitude division technique.

Now the interference of ray I and II will decide the intensity of the point A.

Point A will appear bright if I and II interfere constructively and it will appear dark if destructive interference takes place.

As we know, the nature of the interference is essentially governed by the path difference between the interfering rays.

Content

- Thin Parallel film (P D ,conditions maxima, minima, wedge shaped film, and fringe width (without derivations),
- Newton’s rings Formation
- Applications of Newton’s rings
- Antireflection (high transmission) coating
- Anti- transmission (high reflection coatings)

Ray I travels a distance of only AD

Ray II, before it arrives at C, travels a distance of AB + BC,

Additionally, as the distance traveled by the ray II is through the denser medium, it becomes slower and spends more time in the medium depending upon μ.

Thus the geometrical path (*AB* + *BC*) should be converted in to an optical path μ(*AB* + *BC*).

In the other words, ray II suffers a decrease in the wavelength as it travels through the denser medium.
The decrease is depend on μ.

Thus the optical path of ray II with respect to the line CD is larger than ray I.

Thus Path Diffrence Between Ray I andII is given by

$$\boxed{PD_{R,I,II} = 2\mu t\cos r \pm \frac{\lambda}{2}}$$

$$Optical\ path = \mu \times Geometrical\ path$$

Stoke’s Law

“When a light wave is reflected from the surface of an optically denser medium, it suffers a phase change of π (Path diffrence of $\lambda/2$) but it suffers no change in phase when reflected at the surface of optically rarer medium”

Characteristics of thin film interference

1. The interference patterns of the reflected side and transmitted side of the thin film are always complimentary

As t and μ are assumed to be same throughout, the geometry of the triangles ABC and BCF and triangles ACD and BFG is same.

Thus the geometrical path difference between reflected rays I and II and transmitted rays I' and II' is same.

We Know that, optical energy is conserved during interference

Therefor, the occurance of interference patterns from the reflected side and the transmitted side must complement witheach other.

for transmitted rays

$$PD_{I',II'} = 2\mu t \cos r$$

In the transmitted system,

ray I' does not undergo any phase reversal, as it is just transmitted at point A and B.

Ray II' is reflected at B and C and transmitted at F.

As the reflection at B and C is due to rarer medium, there is no phase reversal.

Thus both I' and II' do not undergo phase reversal

The term λ/2 is absent in the transmitted system.

If a point appears bright at a given angle in the reflected system, then it appears dark at the same angle in the transmitted system and vice varsa

Sarrounding medium of thin film is rarer then,

Condition :

For constructive interference

$$2\mu t cosr \pm \frac{\lambda}{2} = 2n\frac{\lambda}{2}$$

For destructive interference

$$2\mu t cosr \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

2. An extremely thin or extremely thick film cannot produce interference pattern

If $t<<\lambda$ then tends to 0

All point on thefilm has same path diffrence ($\pm\lambda/2$ or 0)

Thus all points on reflected system appears dark and bright in transmitted system (or vice varsa)
This is not an interference pattern

If $t>>\lambda$ then path diffrence $>>\lambda$

For every λ, there exist some path difrence is an even and odd multiple of $\lambda/2$

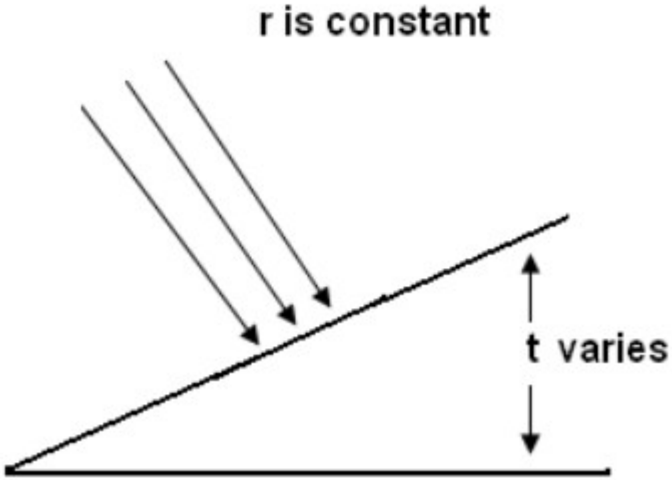
Thus at every point constructive as well as destructive interference is possible

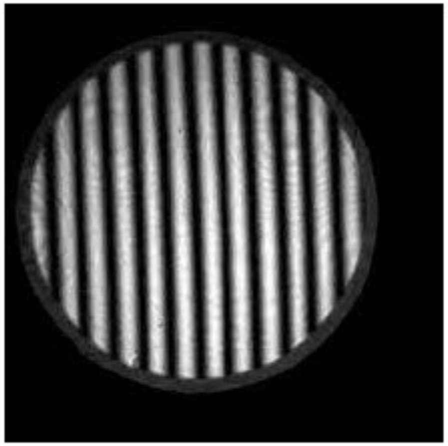
Therefor interference pattern will not be observed

3. Fizau's Fringes and Haindinger's fringes

Fizau's Fringes

Here thickness varies gradually, wavefronts parallel and angle refraction r is same





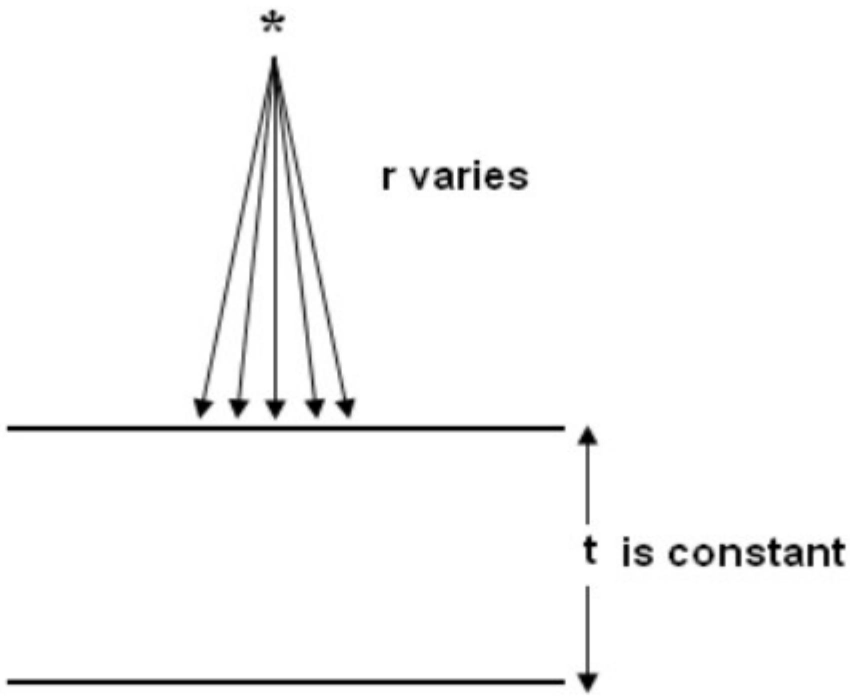
As the variation of the t occurs in horizontal (X)direction, the P.D. and the change in the intensity of the fringe occurs in horizontal (X) direction.

As the thickness gradually increases, the p.d. gradually acquires the values starting from $\lambda/2$, $2\lambda/2$, $3\lambda/2$, $4\lambda/2$....
Correspondingly dark and bright fringes occurs alternatively.

These fringes, which are parallel to the edge of the film, equidistant, and in the horizontal plane, are referred as Fizau's fringes.

Haidinger’s Fringes

r varies, t constant



Consider point source, it emits a spherical wavefront and thus the rays are incident on the film along various cones.
Thus, for each cone, r remains constant over a circle.

Thus PD remains constant over a circle.

Owing to this circular symmetry, if observed from the top, the fringes will appear concentric and circular.
This are referred as Haidenger’s

4. Color of a thin film

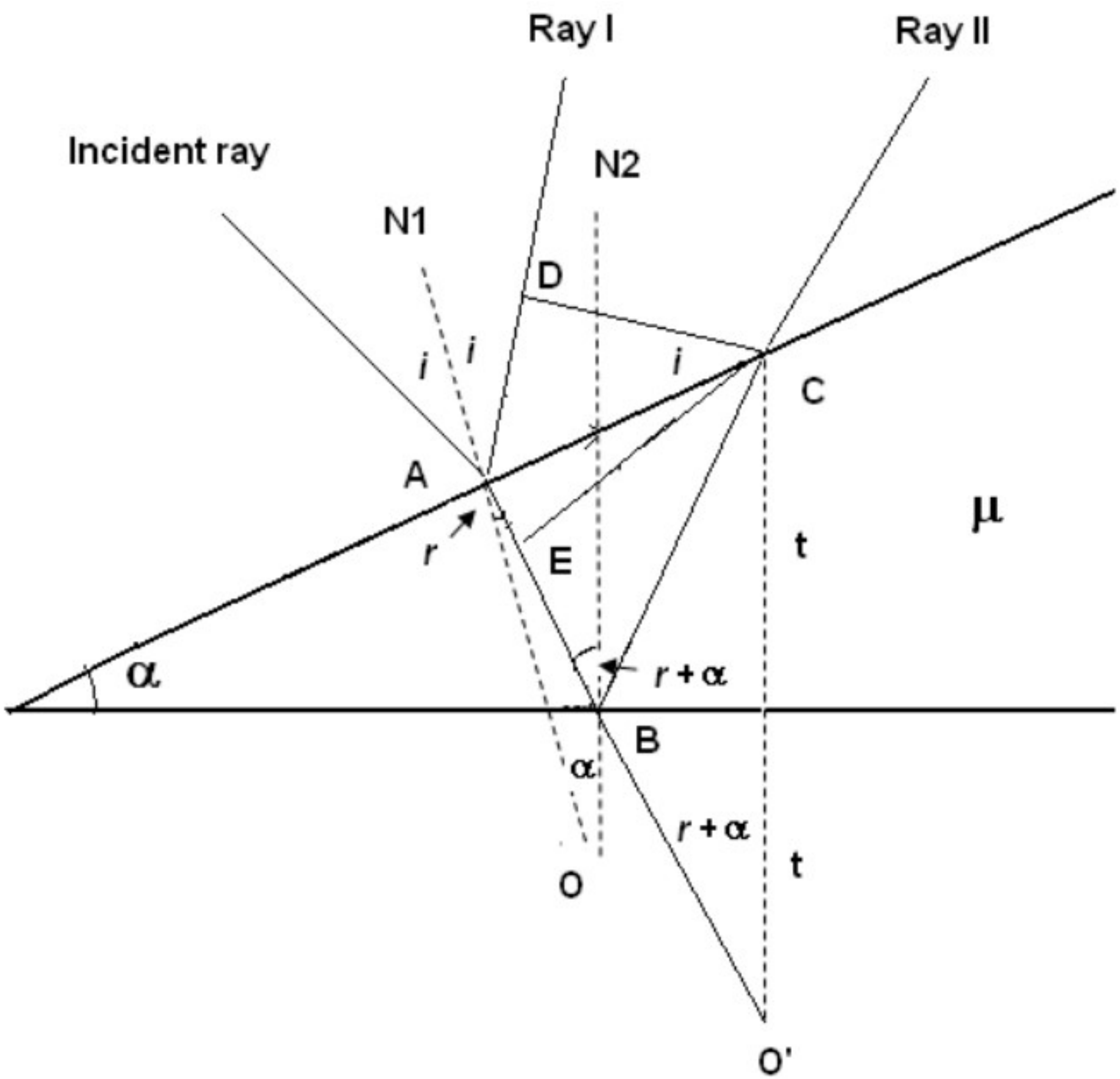
Oil films spread on the road in rainy days or the soap bubbles appear colored. Such films are exposed to the ambient polychromatic light.

The parameters like t, r and μ vary randomly.
Thus the Path diffrence varies from region to region in a random manner.

If pathdifrence satisfies the conditions of constructive and/or destructive interference for different λ in the different regions in a random manner.

Thus some colors are enhanced in some regions and some are suppressed in the other regions.
We thus see a random distribution of colors.

WEDGE SHAPED FILMS



The P.D. between the reflected ray I and II can be shown to be equal to

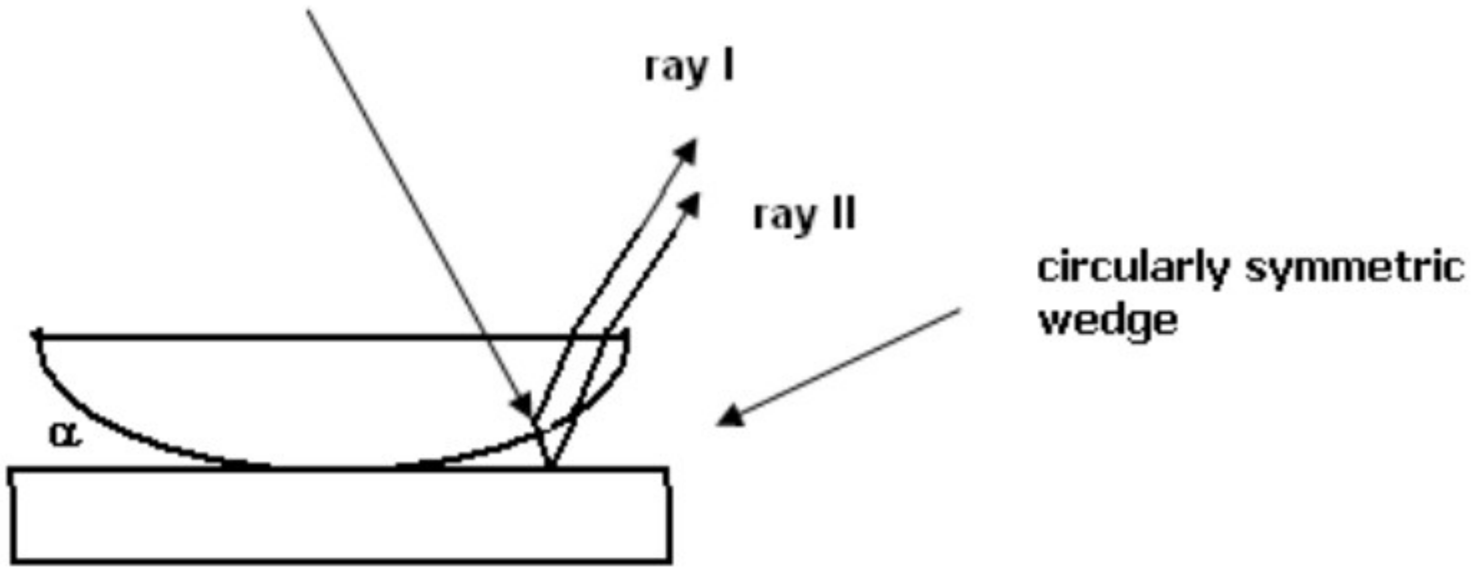
$$P.D._{W,R,I,II} = 2\mu t\cos(r+\alpha) \pm \frac{\lambda}{2}$$

The wedge shaped film produces straight fringes which are parallel to the edge of the film. The fringe-width of such fringes can be shown to be equal to

$$x_{n+1} - x_n = \frac{\lambda}{2\mu\tan\alpha\cos\alpha} = \frac{\lambda}{2\mu\sin\alpha} \approx \frac{\lambda}{2\alpha}(air)$$

NEWTON’S RINGS

Newton’s interferometer



When a parallel beam of monochromatic light is incident normally on a combination of a plano-convex lens and a glass plate, a part of each incident ray is reflected from the lower surface of the lens, and a part, after refraction through the air film between the lens and the plate, is reflected back from the plate surface. These two reflected rays are coherent, hence they will interfere and produce a system of alternate dark and bright rings with the point of contact between the lens and the plate as the center. These rings are known as Newton’s ring.

This is the case of the contours of constant thicknes and constant path diffrence from circles

Thus in this case, Fizau's fringes are circular and concentric
It is a special case of Wedge shaped film

Thus path diffrence

$$P.D._{I,II} = 2\mu t\cos(r+\alpha) \pm \frac{\lambda}{2}$$

Diameter of the ring

$$D_n^2 = \frac{4Rn\lambda}{\mu}$$

R--- radius of curvature
n--- Number of the ring
μ--- Refractive index of thin film
λ--- Wavelength of light

Radius of curvature (R)

$$R = \frac{\mu\left(D_m^2 - D_n^2\right)}{4(m-n)\lambda}$$

D_m --- Diameter of the m[th] ring

D_n --- Diameter of the n[th] ring

Refractive index μ

$$\mu = \frac{D_n^2}{D_n^{2'}}$$

$$\mu = \frac{D_m^2 - D_n^2}{D_m^{2'} - D_n^{2'}}$$

Characteristics of Newton's rings

1. **Newton's rings on reflected side are complementary to those on transmitted side**
2. **If the glass plate in the Newton's ring set up is replaced by the Mirror, then Newton's rings fade out and a uniform illumination is observed.**
3. **If the Newton's ring set up is illuminated by white light then a few colored rings near the center are observed.**
4. **When there is air gap at the center, the ring at the center may appear bright.**
5. **If the lens is gradually lifted up, then the Newton's rings are shifted outwards**
6. **If the monochromatic source in the setup is replaced by a source of higher wavelength, then the diameters of Newton's rings are increased.**
7. **If the planoconvex lens in the setup is replaced by the planoconvex lens of higher radius of curvature then the diameters of the rings will increase**
8. **If the lens or a glass slab used in the set up is imperfect then the Newton's rings are irregular.**

Anti reflection coatings

Non reflecting thinfilm coated on a transparent substrate

When light is transmitted, intensity of tranmitted light is reduced to some extent
This loss can be reduced by coating with suitable transparent dielectric maaterial whose refractive index is intermediate between air and glass

Thickness of the coated film plays very important role in reducing reflection

$$t_{ARC} = \frac{\lambda}{4\mu}$$

t_{ARC} --- Thickness of the anti reflection coating
At this thickness the reflected rays are in opposite phase, they cancel each other due to destructive interference

Coating Materials: MgF_2 (1.38), SiO_2 (1.46), Cryolite etc

Anti transmission coatings

Reflecting thin film coated on the substrate
Thin film should be denser than substrate
Constructive interference between the relected rays will make the film more reflective

Thickness of anti transmission coating

$$t_{HRC/ATC} = \frac{\lambda}{4\mu}$$

Coating Materials: TiO_2 (2.87), ZnS (2.36)

Reference : Concepts of Engineering Physics, Dr. N. L.Mathakari , MIT WPU

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