THIN FILMS

One way to produce two coherent sources is to bounce light from a single (monochromatic) source from the front and the back of a reflecting surface. This will produce fringes. Since the coherence length of light is short, the film must be thin, otherwise coherence is lost over the pathlength of the light.

ANTI-REFLECTION COATINGS

An anti-reflective coating (AR coating) is used to reduce reflections at the air-glass interfaces in optical instruments, and sometimes in glasses. Those reflections can produce annoying ghost images in glasses and degrade image contrast in optical instruments. The coating works by setting up wave trains at front and back which interfere destructively.

Figure 1 shows how this works. A wave is incident on a thin film of index n' and thickness t as in the top of the figure. Waves reflected from the air-coating and coating-glass interfaces are coherent and, if t and n' are properly selected, interfere destructively. In the lower diagram on the next page, these two reflected wavefronts completely cancel one another, thus eliminating all reflections at the interface and allowing all of the incident light to be transmitted.

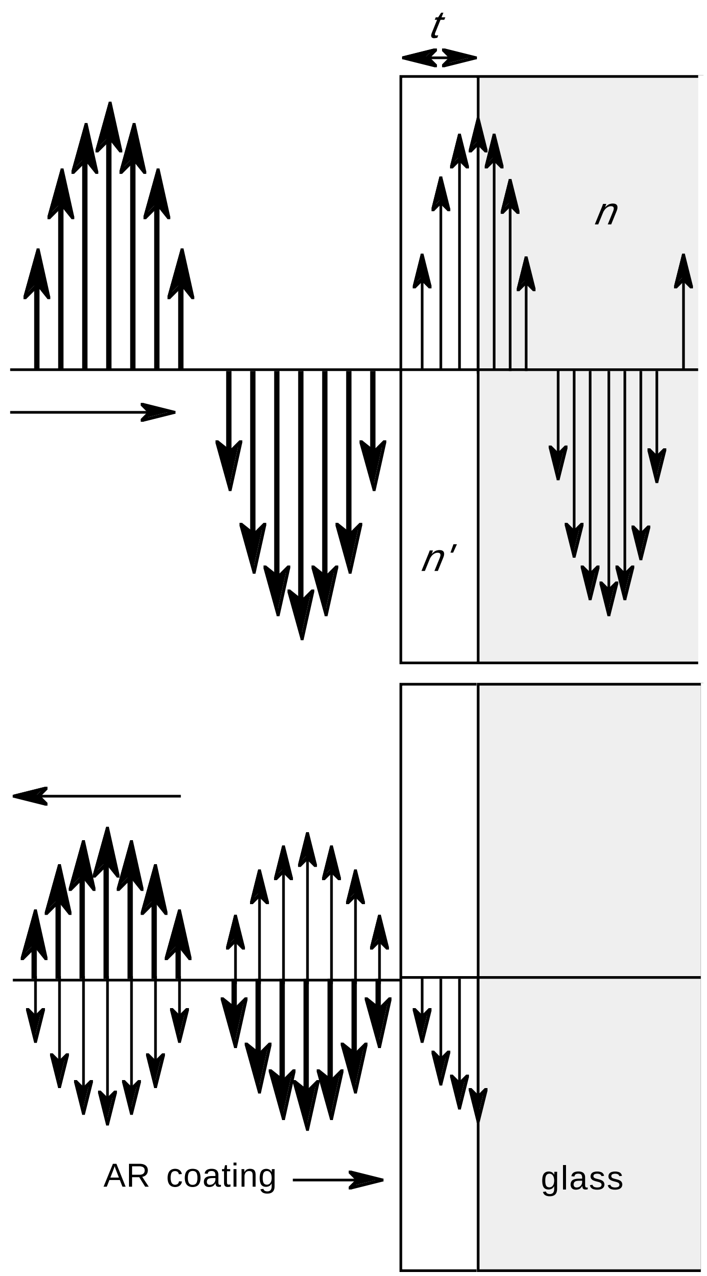

Figure 1. Waves incident on (top diagram) and reflected from (bottom diagram) a perfect anti-reflective coating.

Let's calculate the thickness of coating to get total cancellation of the reflected wave. Let the indices of air, the coating, and glass be 1, n', and n where $1 < n' < n$. Let t be the thickness of the coating. The difference in phase between the waves from the front and back surface is

$$\alpha = (2\pi/\lambda)(2n't).$$

The factor n' has to be inserted before t because the physical pathlength t isn't what's seen by the light, but rather the optical pathlength, $n't$. For destructive interference the phase factor must be

$$\alpha=180°=\pi \text{ radians}$$

so, combining the last two equations,

$$\pi=(2\pi/\lambda)(2n't)$$

and finally,

$$t=\lambda/4n'.$$

This is the phase condition. Note that adding a whole wavelength circuit to the thickness will not change the phase of the wave from the coating-glass interface when it leaves the front surface. Thus we can add a factor $\lambda/2n'$ to the above for the more general solution,

$$t=(\lambda/4n')(1+2m), \quad m=0,\ 1,\ 2,\ 3,\ ... \tag{1}$$

To get complete destructive interference, the two amplitudes should be equal, as well. Recall Fresnel's law, which says the amplitude of a wave reflected normally from a surface is

$$R=[(n-n')/(n+n')]E$$

where n' and n are the indices of the two media and E the amplitude of the incident electric vector. At the first surface,

$$R_1=[(1-n')/(1+n')]E_1 .$$

At the second surface,

$$R_2=[(n'-n)/(n'+n)](E_1-R_1)\cong[(n'-n)/(n'+n)]E_1.$$

Equating the amplitudes $R_1=R_2$,

$$(1-n')/(1+n')=(n'-n)/(n'+n)$$

Solving,

$$(1-n')(n+n')=(n'+1)(n'-n),$$

$$n'n+n'^2-n-n'=nn'+n-n^2-n',$$

$$2n'^2=2n,$$

or finally,

$$n'=\sqrt{n}. \tag{2}$$

This last equation is the amplitude condition. Consider a typical case. For Crown glass, n=1.523, $n'=\sqrt{1.523}$=1.234. Such low indices are hard to find. The standard material used is MgF_2 which has n'=1.38. This is vacuum-deposited on a lens.

A single anti-reflective coating for a spectacle lens is deposited to a thickness which cancels out yellow light near the peak sensitivity of the visual system, about 550 nm. The effects of coatings on reflectance are shown in the graphs of figure 2. As the figure indicates, short wavelength and long wavelength light are reflected from the coating the most and these combine to give a magenta tint to the reflections. To further decrease reflections, multiple coatings may be deposited, each cancelling a different wavelength.

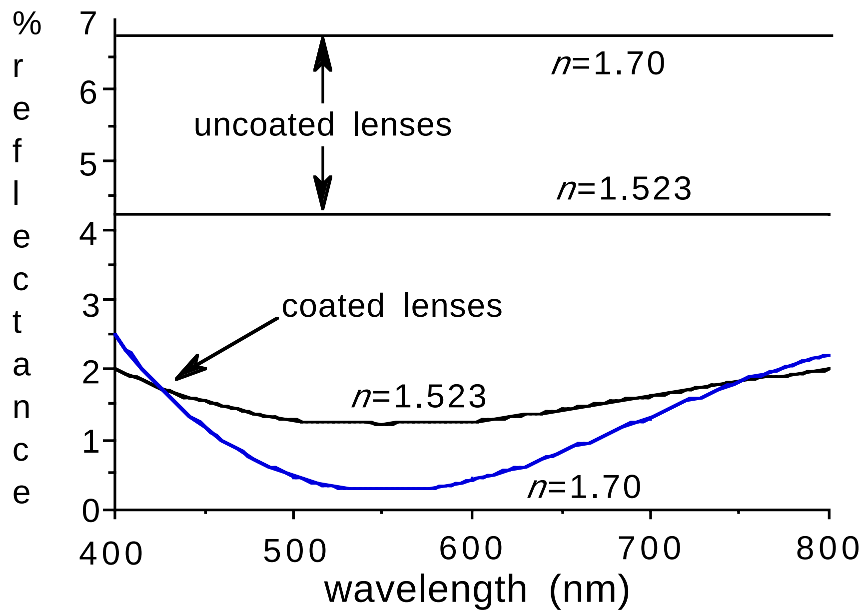

Figure 2. Reflectance from Crown glass, index n=1.523, and flint glass, index n=1.70, with and without a magnesium fluoride AR coating.

INTERFERENCE FILTERS

In a variety of applications, most notably fluorescein angiography, it is important to have very monochromatic light. Filters can be used to produce a monochromatic beam from a white light beam. But ordinary gel filters have too wide a band pass. An alternative is the interference filter which uses thin film interference to get a very narrow wavelength band.

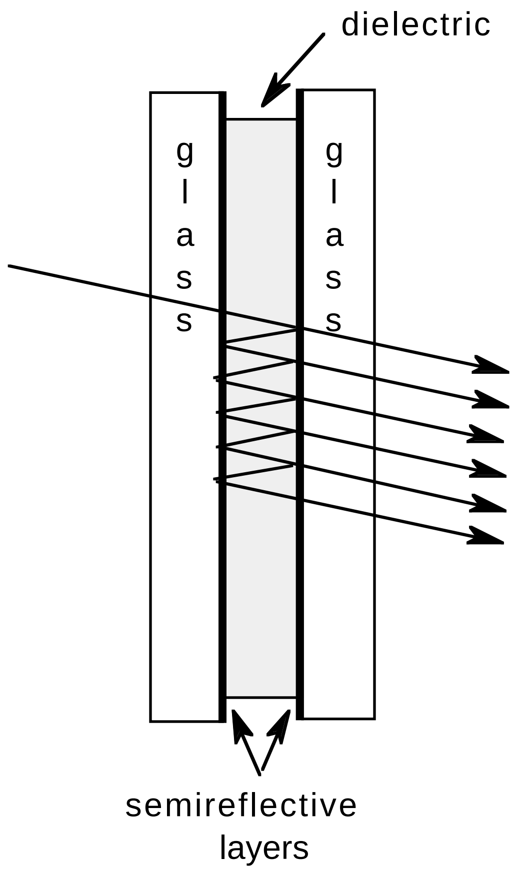

Figure 3. Interference filter cross section

Interference filters consist of a spacer layer of dielectric sandwiched between two reflective coatings. Coatings and spacer are vacuum-deposited. The separation between the two coatings is usually one-half of the wavelength desired, or a multiple thereof. Wavelengths at or near the desired wavelength will be reinforced. Otherwise there will be destructive interference.

COLORED PATCHES

If white light is bounced off a film of irregular thickness, swirling patterns of color are seen where light of different wavelengths reflected from the front and back layers of the film reinforce. This accounts for the appearance of gasoline patches on water puddles. Similar patterns can be seen in human tears under high magnification, and Josephson has suggested that these might be useful in predicting contact lens success.

Lens Testing

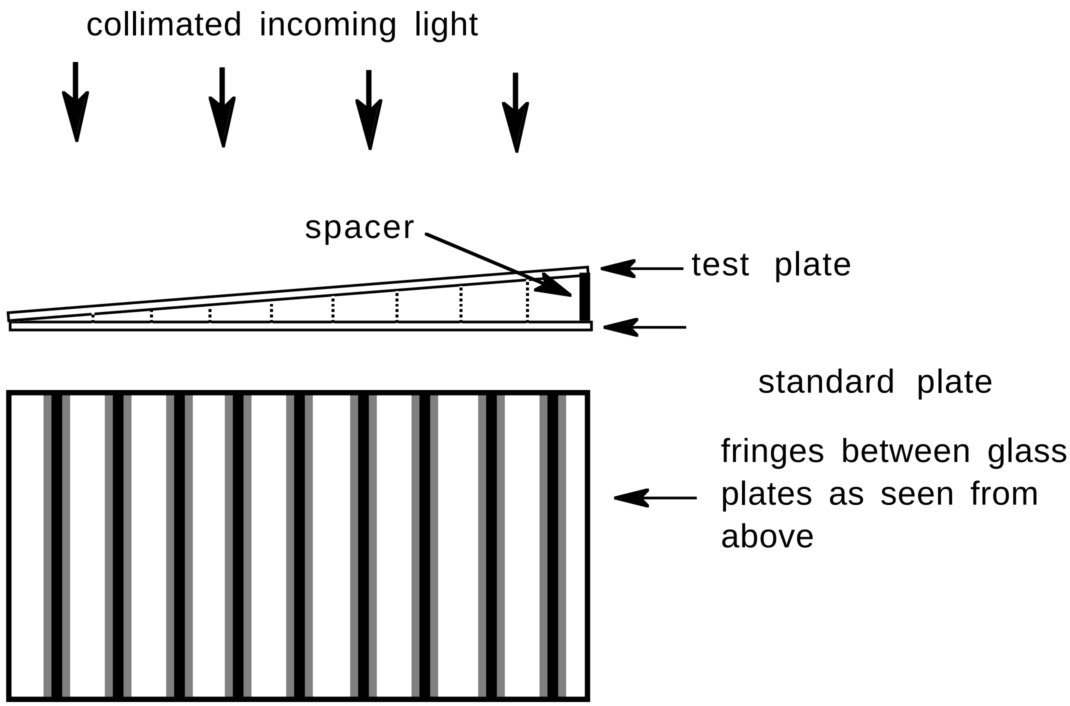

Figure 4. Interference fringes formed between flat glass plates.

In testing optical flatness, one observes the regularity of fringes produced between a flat plate and the tested plate, the plates slightly separated at one side by a spacer. Where the distance between the plates is a half integer number of wavelengths, as at the positions indicated by dotted lines in the diagram above, the wavefront reflected from the top plate will be in phase with the wavefront reflected from the bottom plate and there will be positive reinforcement producing the fringe pattern of the diagram. If the fringes are straight and regularly spaced, the test plate is flat.

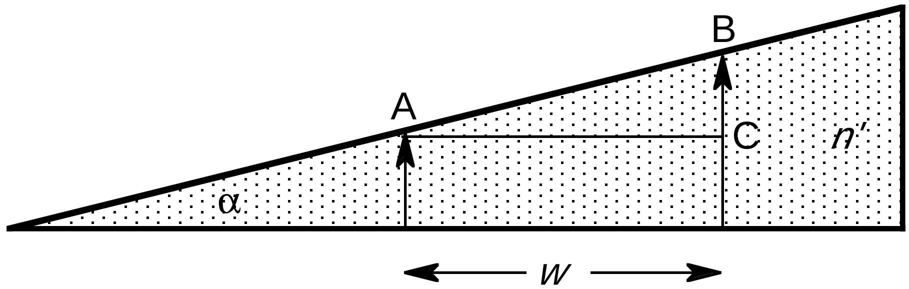

Figure 5. Calculating fringe separation in a dielectric wedge.

This is a special case of calculating the spacing of fringes in a dielectric wedge. The more general case is shown in figure 5 where the wedge has angle α and index n'. Assume a bright fringe occurs at A. A bright fringe will also occur at B if BC=$\lambda/(2n')$. The 2 in the denominator comes from the wave's traversing BC once coming and once going, and the n' adjusts for optical path length. From triangle ABC, $\tan\alpha = BC/w = [\lambda/(2n')]/w$. Solving for w gives

$$w = \lambda/(2n'\tan\alpha) \tag{3}$$

<u>Newton's rings</u> can be used similarly to detect the regularity of a curved surface. Classically they are formed by the interference between a collimated beam of light reflected from a curved surface and a standard plate. Nowadays, however, it's easier to demonstrate Newton's rings by simply shining laser light on a lens. The long coherence of laser light makes it possible for the light beam reflected from the two surfaces of the lens to interfere with one another.

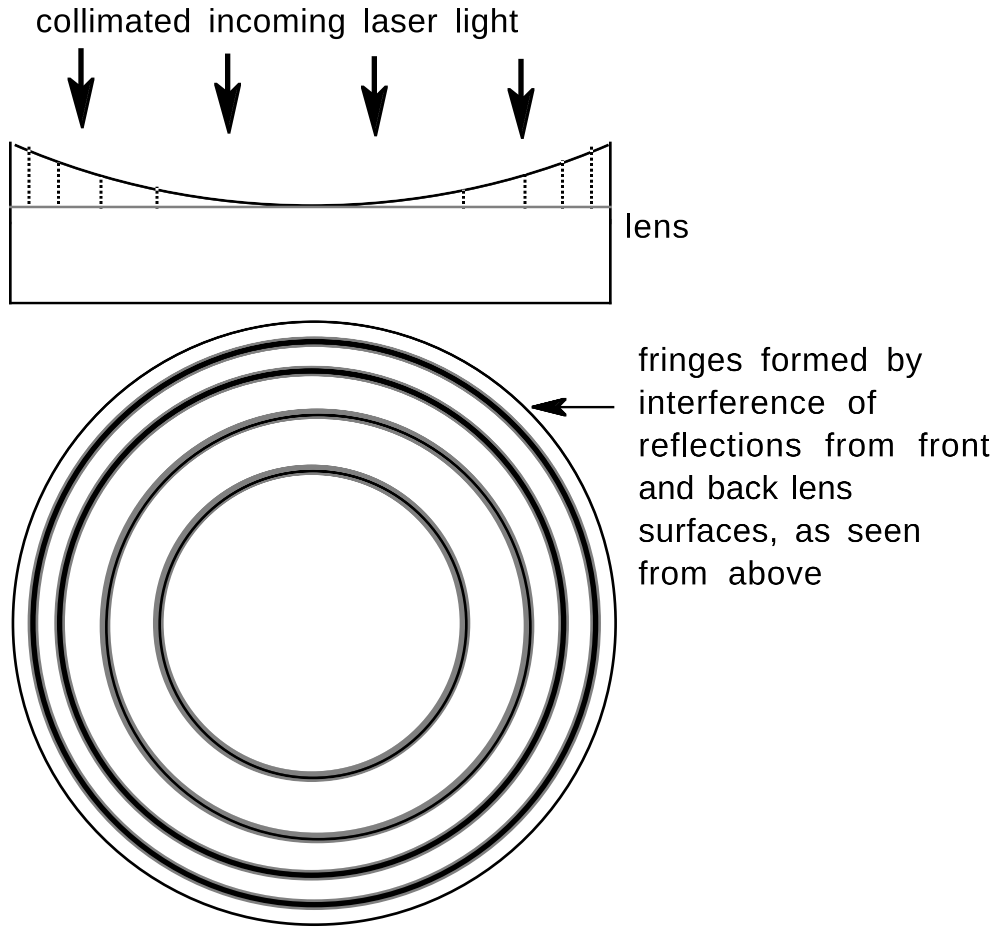

Figure 6. Formation of Newton's rings.

In effect, Newton's rings define equithickness contours. What shape rings would be produced if the test lens were toric?

Amateur astronomers used to use Newton's rings to confirm that they were polishing spherical curves on their lenses. If the rings are perfectly round and regular, the surface is at least rotationally symmetric.

The explanation above assumes that the coherence length of the light is longer than twice the lens thickness. This is true for laser light which is commonly used to demonstrate Newton's rings in teaching labs, nowadays.