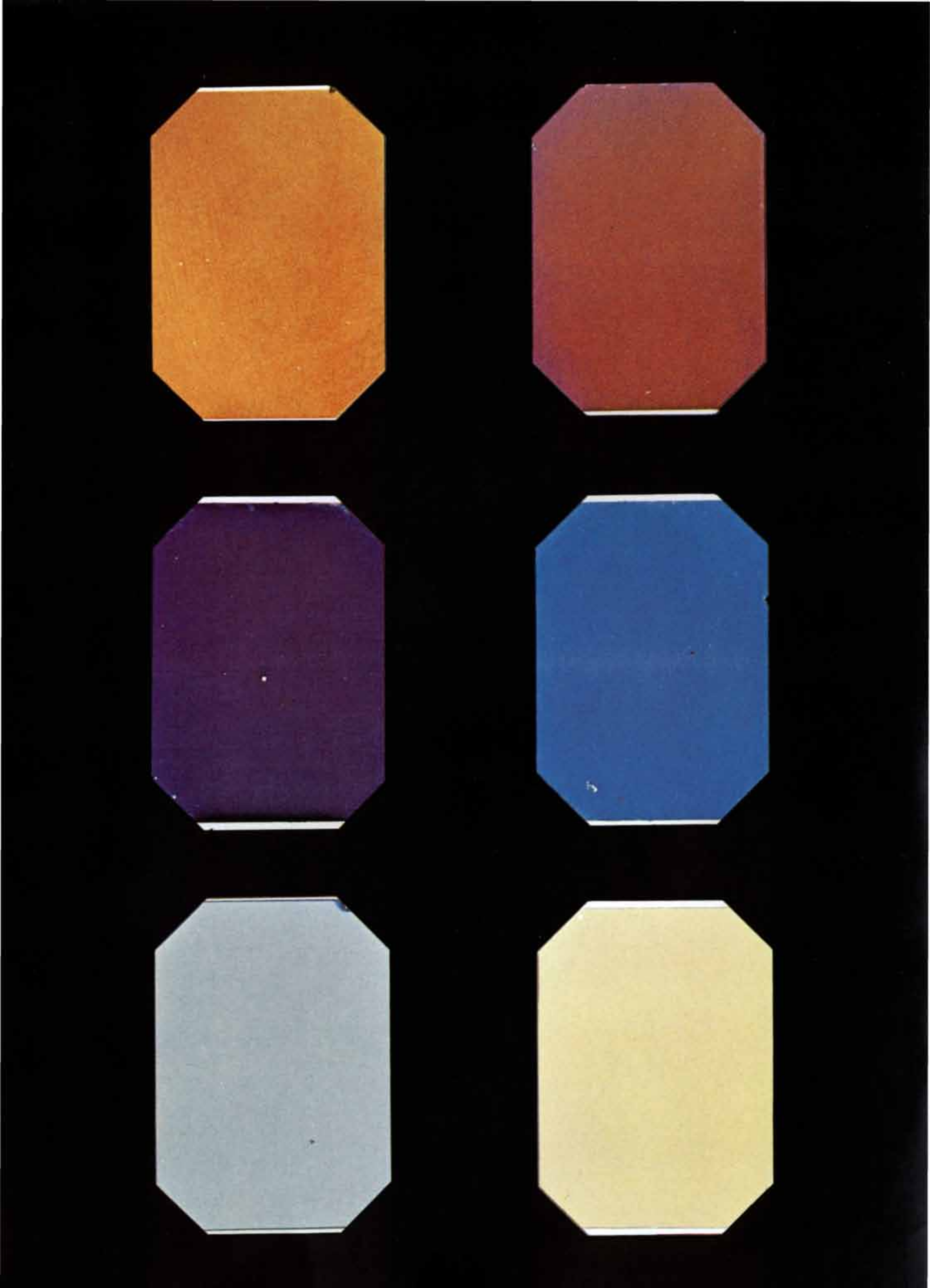


Optical Interference Coatings

The same phenomenon that is responsible for the iridescence of various natural surfaces, including peacocks' tail feathers, is exploited to produce a host of modern optical components

by Philip Baumeister and Gerald Pincus

What do oil slicks, soap films, oyster shells and peacock feathers have in common? The familiar iridescent patterns of color reflected from all these surfaces are natural manifestations of the same phenomenon: optical interference in a thin layer. Although the principles of optical interference have been understood for more than a century, it has been only in the past few decades that this knowledge has been exploited for technological ends. The oldest, simplest and still the most common application of an optical interference film is as a single-layer antireflection coating, such as those used to reduce the reflectance of camera lenses.

In recent years more complicated optical interference coatings have been developed in which many layers of different materials are deposited on an optical surface. Stacks of such films are used not only as antireflection coatings but also as filters, polarizers, beam-dividers and highly reflecting mirrors. These coatings are indispensable components of not a few modern optical systems, such as lasers, color television cameras and infrared missile-guidance systems. This article explains the rudiments of optical interference and discusses in detail a number of current devices that make use of this phenomenon.

Optical interference in a thin film can be explained in terms of the wave theory of light. When a light wave traveling in a certain medium, say air, encounters a medium with a different refractive index, say glass, a portion of the incident wave is reflected at the interface [*see top illustration on next page*]. The amplitude of the reflected wave, which is equivalent to the electric-field strength, is computed from an equation developed in 1816 by the French physicist Augustin Jean Fresnel. The equation yields a value called the amplitude-reflection coefficient, which depends on the ratio of the refractive indexes of the two mediums; in the case of air and glass, for example, the amplitude of the reflected wave is .203 (or about 20 percent) of the amplitude of the incident wave.

The human eye and most other photodetectors do not respond to the amplitude of a light wave directly but rather to its intensity, which is equal to the square of the amplitude; thus the intensity of the reflected wave in the foregoing example is $(.203)^2$, or 4.1 percent, of the intensity of the incident wave. This is the ordinary reflection that occurs at each surface of a pane of window glass.

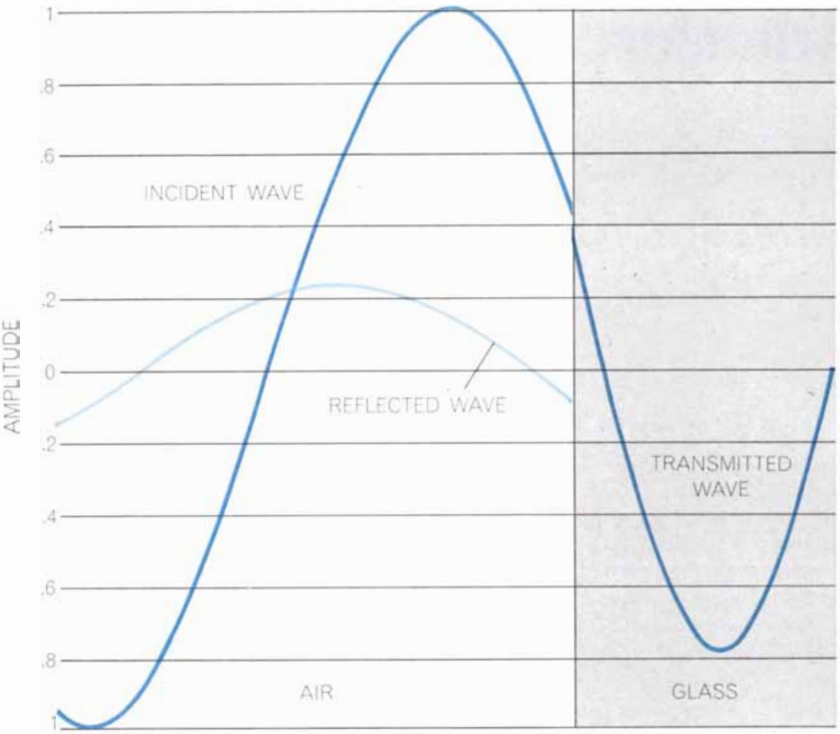
Now, suppose one wishes to reduce this reflectance by coating the glass surface with an antireflection coating, say a single layer of magnesium fluoride [*see bottom illustration on next page*]. A portion of the incident wave is then reflected at each of the two interfaces. There is a difference in the phase of the two waves because of the time it takes for the wave to penetrate the film, reflect from the film-glass interface and emerge into the air again. This phase difference depends on the film's thickness (measured in wavelengths of the incident light) and also on the film's refractive index. It is convenient to express the phase difference in terms of the "optical thickness" of the film, which is defined as the product of its physical thickness times its refractive index.

When a film's optical thickness is a quarter of a wavelength, the phase difference between the two reflected waves is 180 degrees; in other words, they are completely out of phase. This means that the net amplitude of the reflected wave is a minimum because, to use the language of physical optics, the two waves add destructively. The amplitude of the wave reflected from the air-film interface is .16 and the amplitude at the film-glass interface is .048. The net amplitude of the reflected wave is approximately .16 minus .048, or .11, and its intensity is $(.11)^2$, or .012, which is equivalent to 1.2 percent of the incident wave.

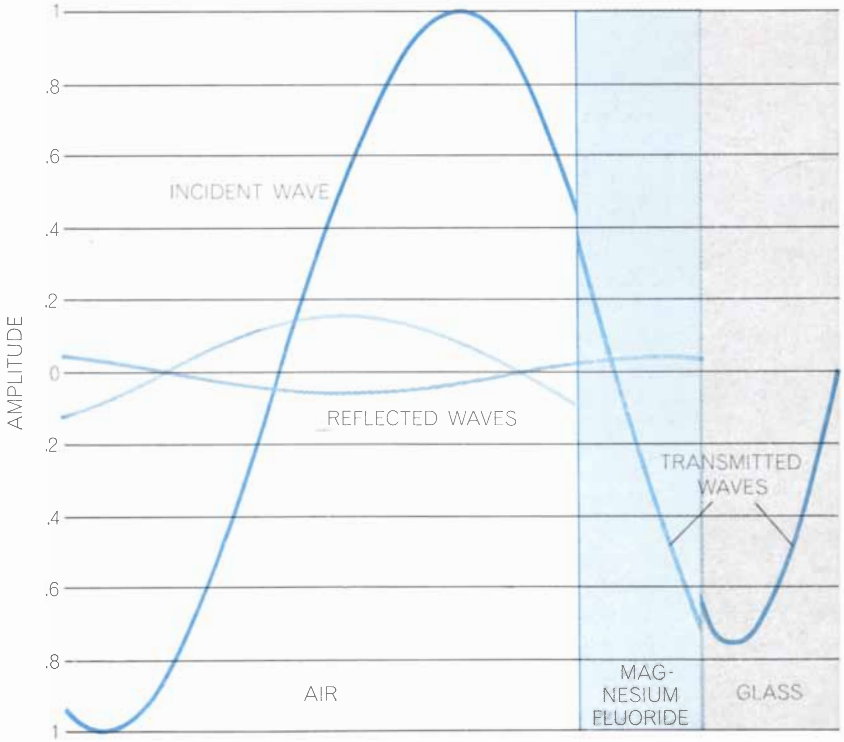
This minimum reflectance is attained at only one wavelength. At wavelengths shorter than the minimum the reflectance increases until the film's optical thickness is a half-wave. At this point the phase difference is 360 degrees and the waves that reflect at the two interfaces of the film add constructively, or in phase, to produce a maximum amplitude. Thus the net amplitude of the reflected wave is approximately .16 plus .048, or .208. At other wavelengths the reflectance lies between the minimum and the maximum value.

The wavelength at which the minimum reflectance occurs depends on the thickness of the film. For example, if its optical thickness is a quarter-wave in the green portion of the spectrum, the reflectance is a minimum there. Such coatings appear purplish in reflected

SINGLE-LAYER ANTIREFLECTION COATINGS consisting of varying thicknesses of magnesium fluoride are responsible for the distinctly different colors reflected from the glass plates in the photograph on the opposite page. The thicknesses of the magnesium fluoride coatings are .073 micron (*top left*), .086 micron (*top right*), .098 micron (*middle left*), .123 micron (*middle right*), .180 micron (*bottom left*) and .220 micron (*bottom right*). The coated plates are used as references to gauge the thickness of magnesium fluoride coatings applied to a variety of optical surfaces by comparing their colors in reflected light.



UNCOATED GLASS SURFACE reflects a portion of an incident light wave at the interface between the air and the glass. The amplitude of the reflected wave, which is equivalent to the electric-field strength, is dependent on the ratio of the refractive indexes of the two mediums; in this particular case the amplitude of the reflected wave is .203 (or about 20 percent) of the amplitude of the incident wave. The wavelength of the transmitted wave is shorter inside the glass because the wave's velocity there is less than it is in the air.



COATED GLASS SURFACE is covered by a single antireflection layer of magnesium fluoride with an optical thickness equal to a quarter of a wavelength of the incident light. The reflectance is reduced because the two reflected waves are exactly out of phase. The amplitude of the wave reflected from the air-film interface is .16 and the amplitude at the film-glass interface is .048. Hence the net amplitude of the reflected wave is approximately .16 minus .048, or .11, which is equivalent to 11 percent of the amplitude of the incident wave.

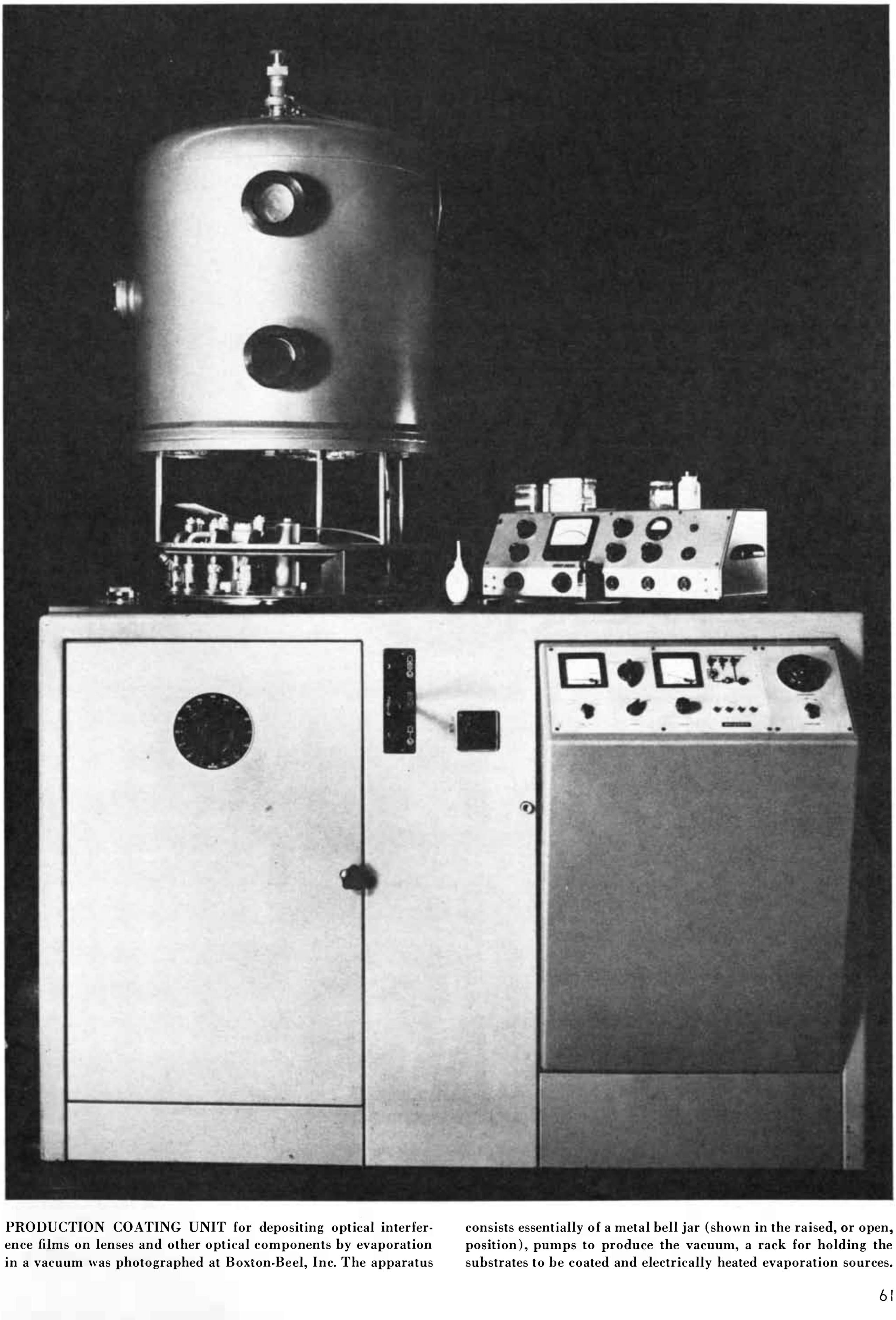
light and are deposited on camera lenses for use with black-and-white film. If the lenses are to be used for color photography, then the magnesium fluoride layer is made slightly thinner so that the reflectance minimum is in the blue part of the spectrum. These coatings have an amber hue in reflected light.

The single layer of magnesium fluoride reduces the reflectance to low values, but not to zero. The minimum reflectance depends on the refractive index of both the glass and the film. If the film's index is the square root of the index of the glass, then the waves that reflect from each interface of the film are equal in amplitude and they exactly cancel. This would require that the refractive index of the film equal $\sqrt{1.51}$, or 1.23. Unfortunately it is not possible to deposit durable films with such a low refractive index, and thus magnesium fluoride represents a compromise: a film with a fairly low refractive index (1.38) that is hard and durable.

In the foregoing discussion only the reflectance of the coating was considered. How is the transmittance determined? Although there are equations by which the transmittance can be computed, it can also be found by noting that if the coating is nonabsorbing, then the reflectance and transmittance must add to 100 percent. This follows from the conservation of energy. For example, the minimum reflectance of the coated glass mentioned above is 1.2 percent. Since the absorptance of the coating is negligible, its transmittance is 100 percent minus 1.2 percent, or 98.8 percent.

This method of computing the coating's reflectance by adding the waves that are reflected at each interface is called "vector addition of amplitudes." Although the method is used here to compute the reflectance of a single layer, it can be extended to two or more layers. Its advantage is that it furnishes an intuitive and simple model of how the coating functions. The disadvantage is that it is an approximation that becomes less and less accurate as the number of layers increases and also as the differences in the refractive indexes get larger. How good an approximation is the method in the case of the magnesium fluoride coating? We can obtain some estimate of its accuracy for this material, since it can be rigorously shown that when the optical thickness of the layer is a half-wave, the reflectance is the same as that of the bare substrate. By vector addition of amplitudes one obtains a reflectance of $(.208)^2$, or 4.3 percent, in contrast to the exact result of 4.1 percent.

The commercial production of opti-



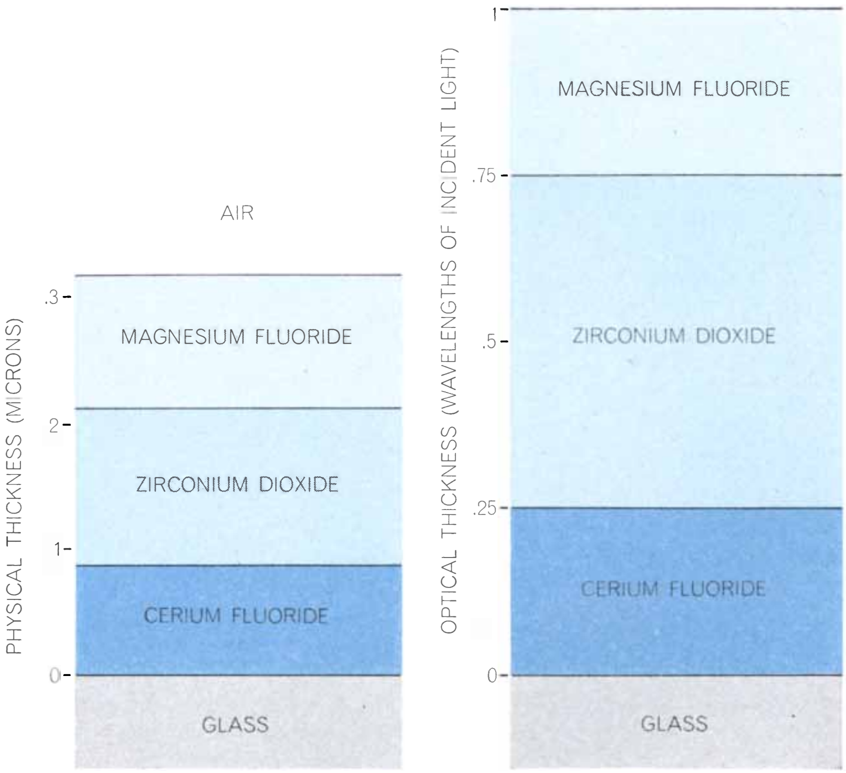
PRODUCTION COATING UNIT for depositing optical interference films on lenses and other optical components by evaporation in a vacuum was photographed at Boxton-Beel, Inc. The apparatus consists essentially of a metal bell jar (shown in the raised, or open, position), pumps to produce the vacuum, a rack for holding the substrates to be coated and electrically heated evaporation sources.

cal interference coatings was not undertaken until the 1930's, when suitable pumps and vacuum materials were developed for depositing the films by evaporation in a vacuum. The problem is to deposit these thin layers in a uniform thickness over a substrate, which in some instances is as much as several meters across. The film should be hard and durable and its thickness should be controlled to an accuracy of within 5 percent. Although it is possible to produce such films by chemical deposition or by the process called sputtering, the most widely used method is evaporation in a vacuum.

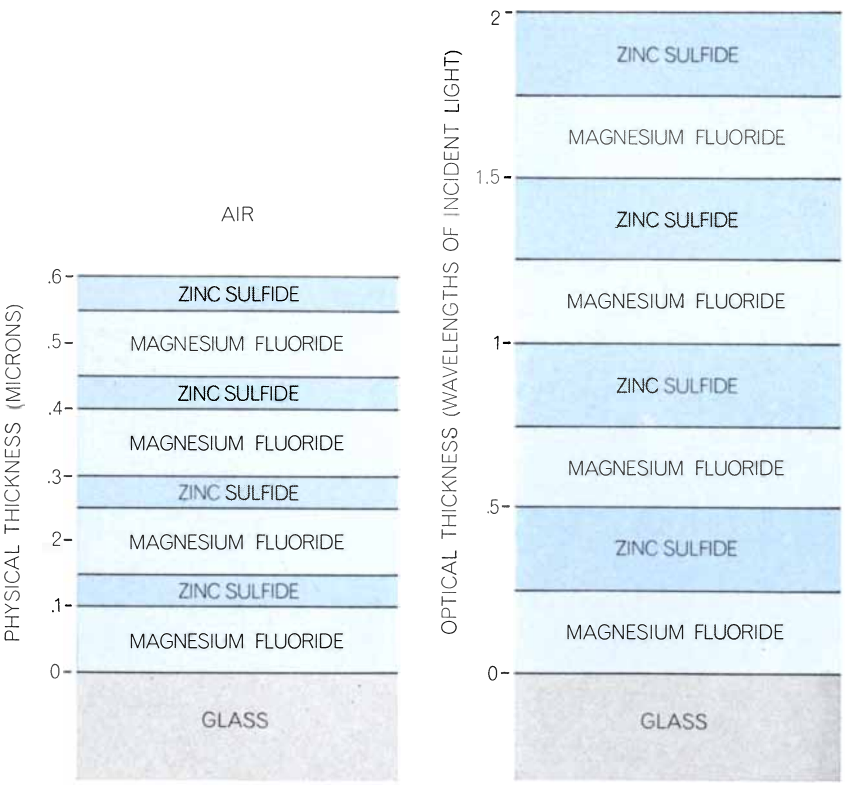
The apparatus for the deposition of these films consists of a metal bell jar, a rack for holding the substrates that are to be coated and an electrically heated evaporation source [*see illustration on preceding page*]. In addition there is a heater above the substrates so that they can be heated during the deposition of the film. Attached to the bottom of the chamber is an oil diffusion pump and a mechanical pump that exhaust the air from the enclosure.

Let us follow the steps for depositing a magnesium fluoride film on a batch of camera lenses. First, the lenses are washed to remove grease and other contaminants from the surface. Then they are loaded into the rack in the bell jar, which typically holds 40 lenses. The pumps remove the air from the chamber until the pressure is less than 1/7,600,000 of atmospheric pressure. This pressure can also be expressed as 100 microtorr; one microtorr is a millionth of the pressure of a mercury column one millimeter in height. While the chamber is being exhausted, the heaters are warming the substrates so that they reach a temperature of 150 degrees Celsius by the time film is deposited. This deposition onto a heated substrate produces a film that is very durable.

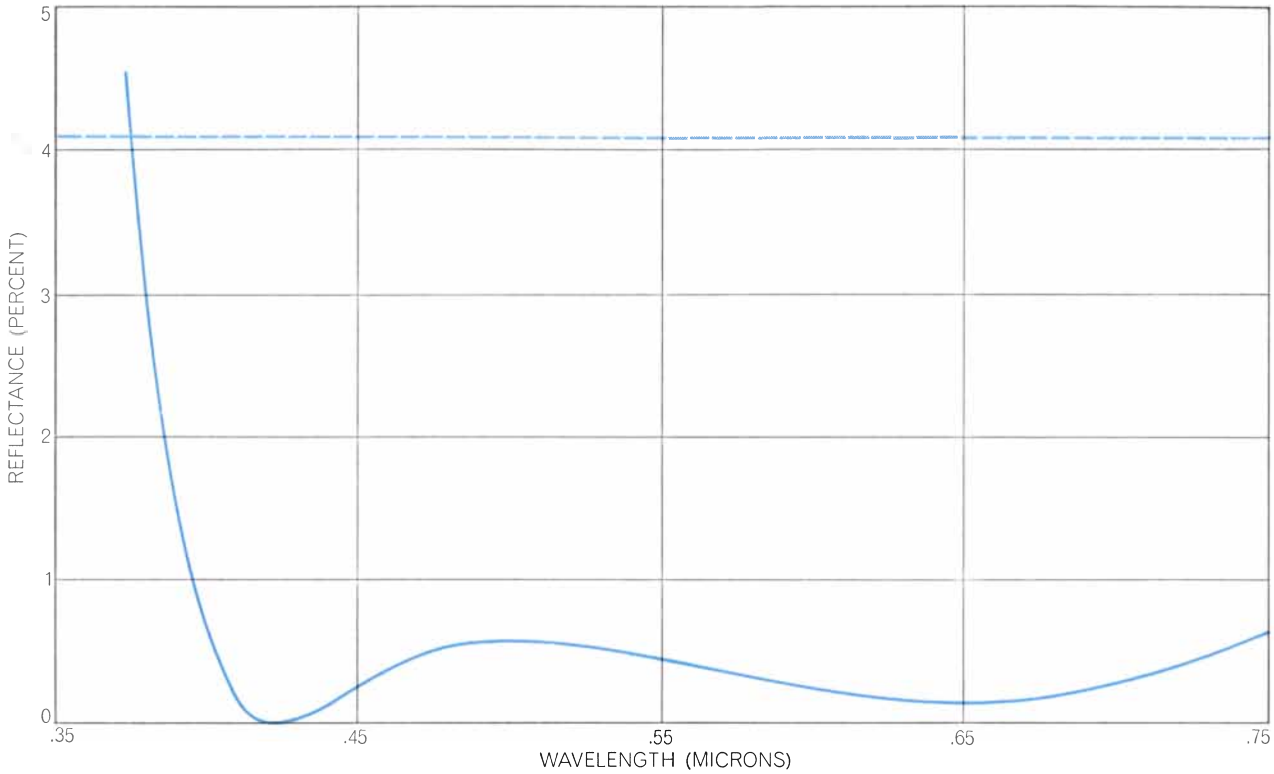
Depending on the speed of the pumps, it typically takes 10 minutes to reach a pressure of 100 microtorr. The operator then turns on the evaporation source and the magnesium fluoride evaporates when it reaches the proper temperature. At this pressure the mean free path of a molecule (the average distance it travels before it collides with another molecule) is greater than the dimensions of the bell jar. This means that most of the molecules of the vapor travel directly from the source to the substrate without colliding with any of the residual gases in the chamber. As these molecules hit the substrate, some stick and sublime (change directly from a vapor into a sol-



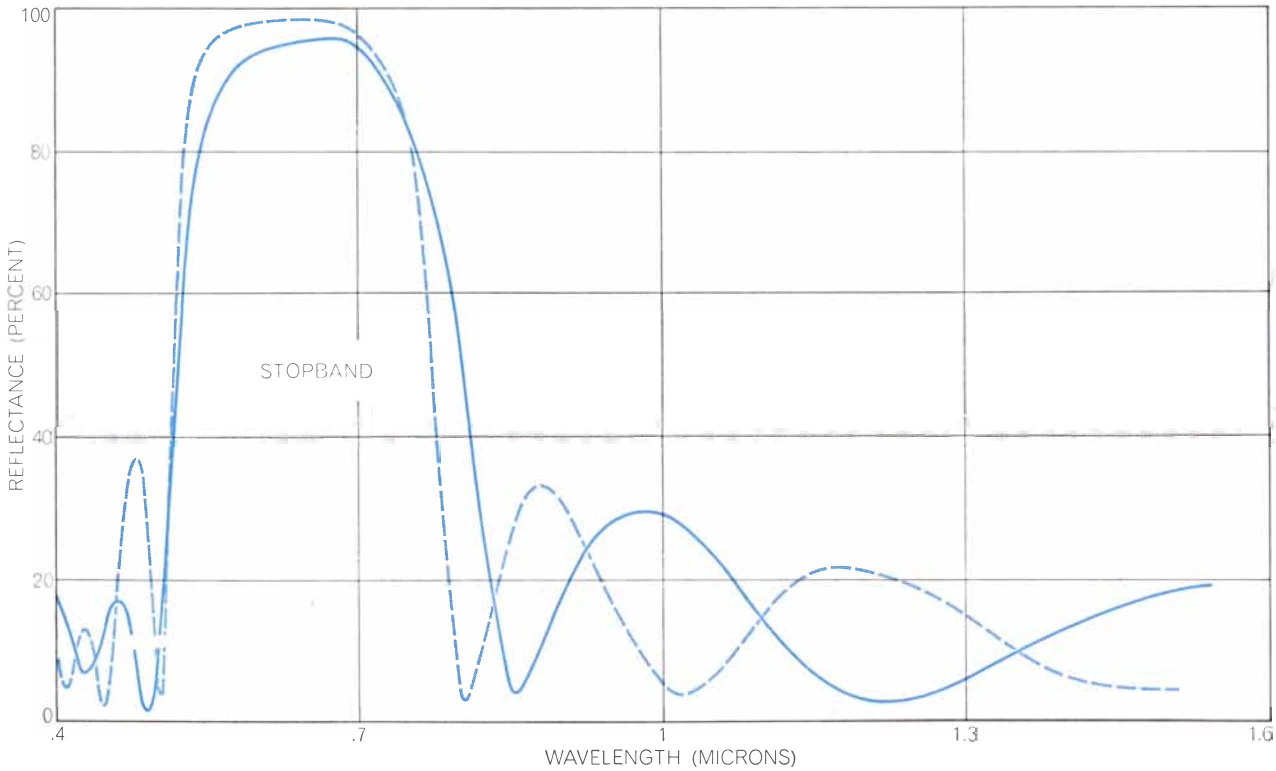
THREE-LAYER ANTIREFLECTION COATING is represented at left in terms of its physical thickness in microns and its optical thickness in wavelengths of the incident light. (The coating's optical thickness is the product of its physical thickness times its refractive index.) Reading from the glass substrate upward, the cerium fluoride layer (*bottom*) has an optical



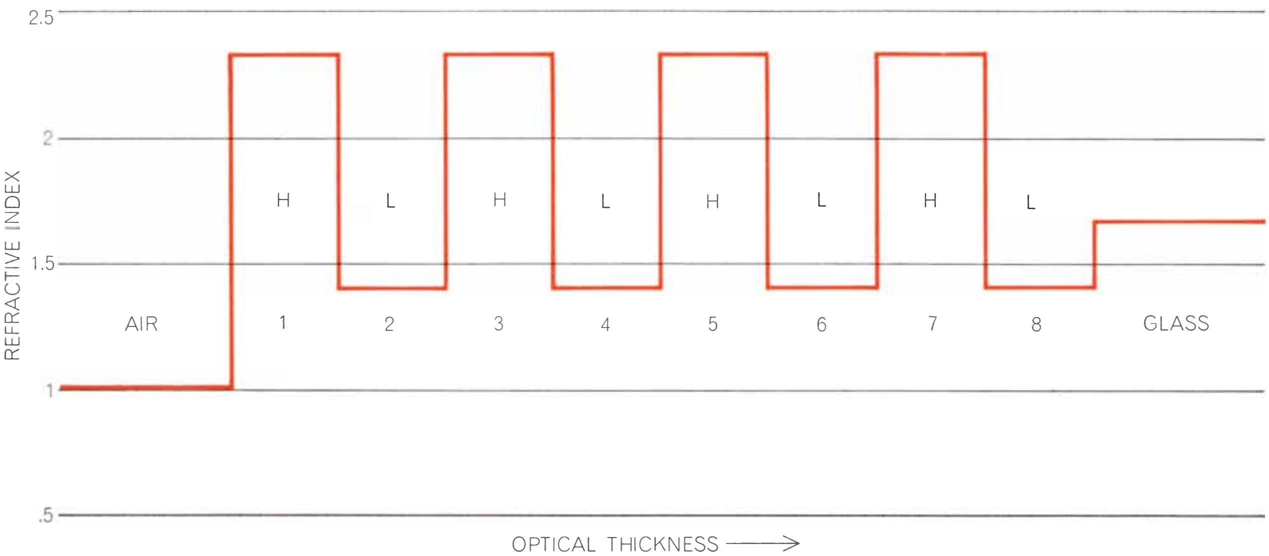
DIELECTRIC MIRROR is produced by stacking optical interference films in such a way as to enhance a surface's reflectance. (A mirror of this type is called dielectric because it is composed entirely of films that are nonconductors of electricity.) The coating at left, as in the illustration above shown in terms of both physical thickness and optical thickness, consists of eight alternating layers of magnesium fluoride (with a refractive index of 1.38)



thickness of a quarter-wave and a refractive index of 1.63, the zirconium dioxide layer (*middle*) has a half-wave optical thickness and a refractive index of 2.1, and the magnesium fluoride layer (*top*) is a quarter-wave thick and has a refractive index of 1.38. As the curves at right show, the reflectance of a glass surface covered with such a three-layer coating (*solid colored curve*) is considerably lower than the reflectance of an uncoated glass surface (*broken colored curve*) over most of the visible portion of the spectrum.



and zinc sulfide (with a refractive index of 2.32). This particular coating is called a quarter-wave stack because the films all have the same optical thickness of a quarter of a wavelength at the "tuned" wavelength of .63 micron. As the solid colored curve in the graph at right shows, the maximum reflectance of the coating at .63 micron is bracketed by a spectral region of high reflectance called a "stopband." The broken colored curve shows the effect of adding two extra layers to form a 10-layer stack of magnesium fluoride and zinc sulfide; the maximum reflectance is thereby increased from 96 to 98.5 percent, but the spectral width of the stopband is unchanged.



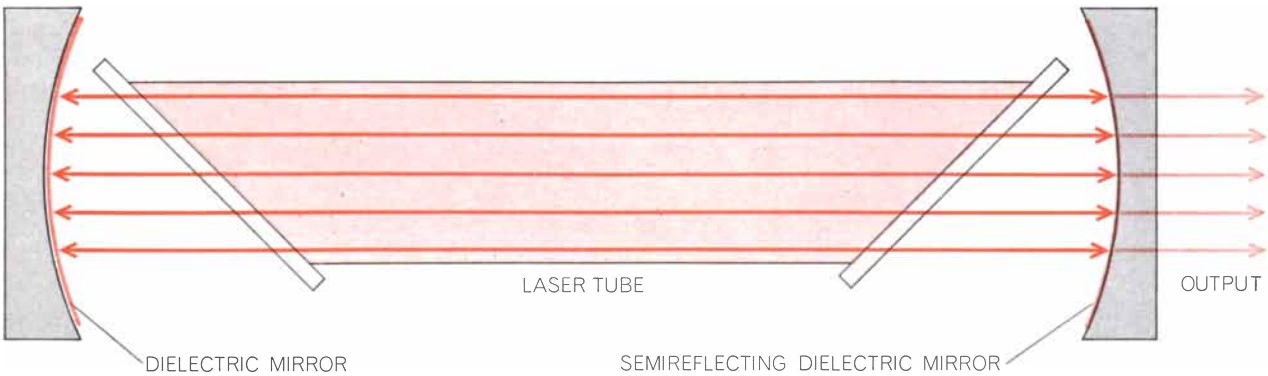
QUARTER-WAVE STACK can be viewed as a periodic medium in which a particular sequence of refractive indexes is repeated many times. In this example of the eight-layer quarter-wave stack shown in the bottom illustration on the preceding two pages the high-index layer is represented by the symbol *H* and the low-index layer by the symbol *L*. The basic period, *HL*, is repeated four times.

id). Soon a layer of solid magnesium fluoride forms on the surface and the operator is able to judge its thickness by observing its color in reflected light. The deposition continues until the film attains the proper thickness, at which time the evaporation source is turned off. Air is readmitted to the chamber and the substrates are removed. If they are to be coated on both sides, they are turned over in the rack and the process is repeated.

Such production coating units for manufacturing antireflection coatings were perfected in the early 1940's, and it was not long before the advantage of "coated optics" was fully recognized. During World War II, Britain, Germany and the U.S. coated most of their military optical equipment with such films. These coatings were considered to be so important that coating machines were installed on U.S. battleships so that the optical elements in range finders could be recoated at sea if necessary. This single-layer coating is effective and inexpensive to produce; it is still popular today.

In the early 1960's serious development was started on another type of antireflection coating: one with three layers [*see top illustration on preceding two pages*]. Although the theoretical design of such a coating was known in the 1940's, the techniques were not available for depositing films with the proper refractive index. In this coating the film adjacent to the substrate has an optical thickness of a quarter-wave and a refractive index of 1.63. The center layer has a half-wave optical thickness and a refractive index of 2.1. The layer adjacent to the air is a quarter-wave of magnesium fluoride with a refractive index of 1.38. The reflectance of this coating is lower than a single-layer one over most of the visible spectrum.

In spite of the superiority of this three-layer coating, its acceptance has been slow, for several reasons. First, it is considerably more difficult to produce than the single-layer coating. The optical thickness and refractive index of all three layers must be controlled with the utmost precision. During the deposition of these layers it is no longer possible to control their thickness by visually judging the color. Rather, the thickness is measured photometrically by a separate instrument. A three-layer antireflection coating also scatters more light than the single-layer coating does and has an absorption in the blue part of the spectrum that is as large as 1 percent. On the other hand, the three-layer coating definitely has a lower reflectance than the single-layer coating, and it is used in many optical instruments in which the advan-



HELIUM-NEON LASER makes use of optical interference in its dielectric mirror, which is the only means available to obtain the nearly 100 percent reflectance required for such a laser to operate, given its typical power amplification of approximately 1 percent.

tage of higher transmittance outweighs the higher cost and other disadvantages we have mentioned.

Various other types of antireflection coating exist, including a two-layer narrow-band antireflection coating, which is often used in laser optical systems, and several different three-layer and four-layer coatings, which are deposited on infrared optical components.

The antireflection coatings described so far reduce the reflectance of a surface. Stacks of optical interference films are also used to enhance a surface's reflectance and thus produce a mirror. In order to distinguish such coatings from conventional metal mirrors, they are called dielectric mirrors because they are composed entirely of films that are dielectrics, that is, nonconductors of electricity. These coatings are also used as band-pass filters and beam-dividers.

A typical dielectric mirror consists of eight layers that alternate between an index of 1.38 and one of 2.32 [*see bottom illustration on pages 62 and 63*]. The low-index layers are magnesium fluoride and the high-index layers are zinc sulfide. This type of coating is called a quarter-wave stack, because the films all have the same optical thickness of a quarter of a wavelength at .63 micron in the red portion of the spectrum. If the films' refractive indexes do not change appreciably with wavelength, then the maximum reflectance of the coating occurs at this "tuned" wavelength of .63 micron.

The maximum reflectance is bracketed by a region of high reflectance that extends from .52 to .75 micron. This spectral region is called a "stopband." Outside this region the reflectance oscillates between the maximum and the minimum value. If the films were nonabsorbing, the spectral transmittance would be equal to 100 percent minus the reflectance. In practice, however, there is a small amount of absorption and scattering in the layers, which degrades the performance of the mirror. This absorption and scattering must be minimized in order to produce mirrors with a reflectance that is close to 100 percent.

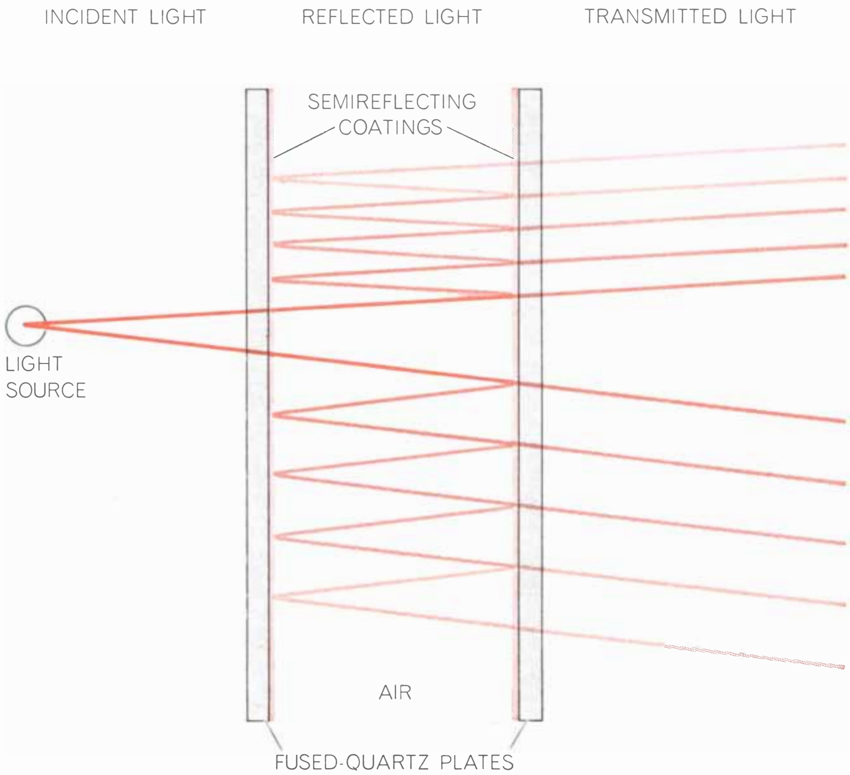
The maximum reflectance depends on the refractive indexes of the films and on the number of layers. For a given number of layers the maximum reflectance in the stopband gets larger as the ratio of the refractive indexes increases. For example, if films of titanium dioxide with a refractive index of 2.40 were substituted for the zinc sulfide layers, the maximum reflectance would increase from 96 to 97 percent. For a stack that contains given materials the reflectance in the stopband increases as more layers are added to the stack. For instance, the addition of two extra layers to form a 10-layer stack of magnesium fluoride and zinc sulfide increases the maximum reflectance from 96 to 98.5 percent. The spectral width of the stopband, however, depends only on the refractive index of the two films that are used in the stack and is independent of the number of layers.

This phenomenon of a stopband, as a spectral region in which the incident wave is strongly reflected, is best explained in terms of a wave propagating in a periodic medium. In this case the periodic medium is a particular sequence of refractive indexes that is repeated many times. For example, suppose the refractive-index profile of a quarter-wave stack is plotted against optical thickness, and the high-index layer is represented by the symbol *H* and the low-index layer by the symbol *L;* the basic period is then *HL* [*see top illustration on page 64*]. The eight-layer coating described above has four such *HL* periods and the 10-layer stack has five.

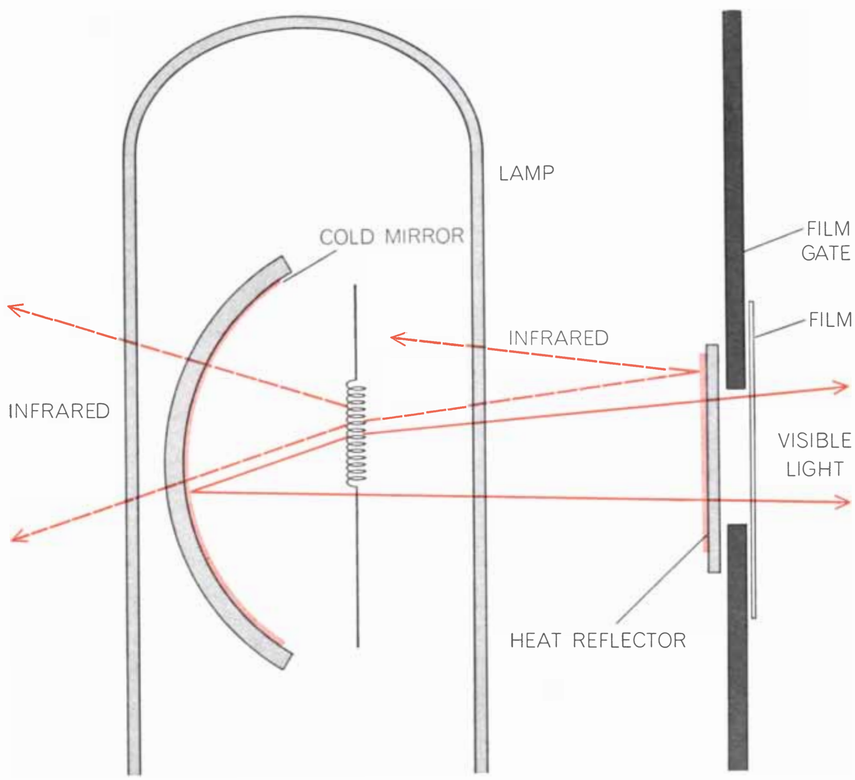
The spectral region of the stopband is determined by calculating the change in the wave's amplitude as it propagates through a basic period. If at a particular wavelength the wave is attenuated, a stopband exists at that wavelength. Since the medium is nonabsorbing, the only way for the wave to be attenuated is for it to be reflected. In the case of the quarter-wave stack this happens when the optical thickness of the basic period is a half-wave. At other wavelengths the wave's amplitude will sometimes increase and sometimes decrease as it propagates through a basic period. A "passband" is said to exist at those wavelengths.

The phenomenon of a stopband is not limited to a periodic medium in which the basic period consists of layers that are optically homogeneous, that is, with a constant refractive index. It also occurs in optically inhomogeneous layers, in which the refractive index changes in the direction of propagation. In general a stopband is found in any medium in which there is a periodic modulation of the wave's propagation velocity.

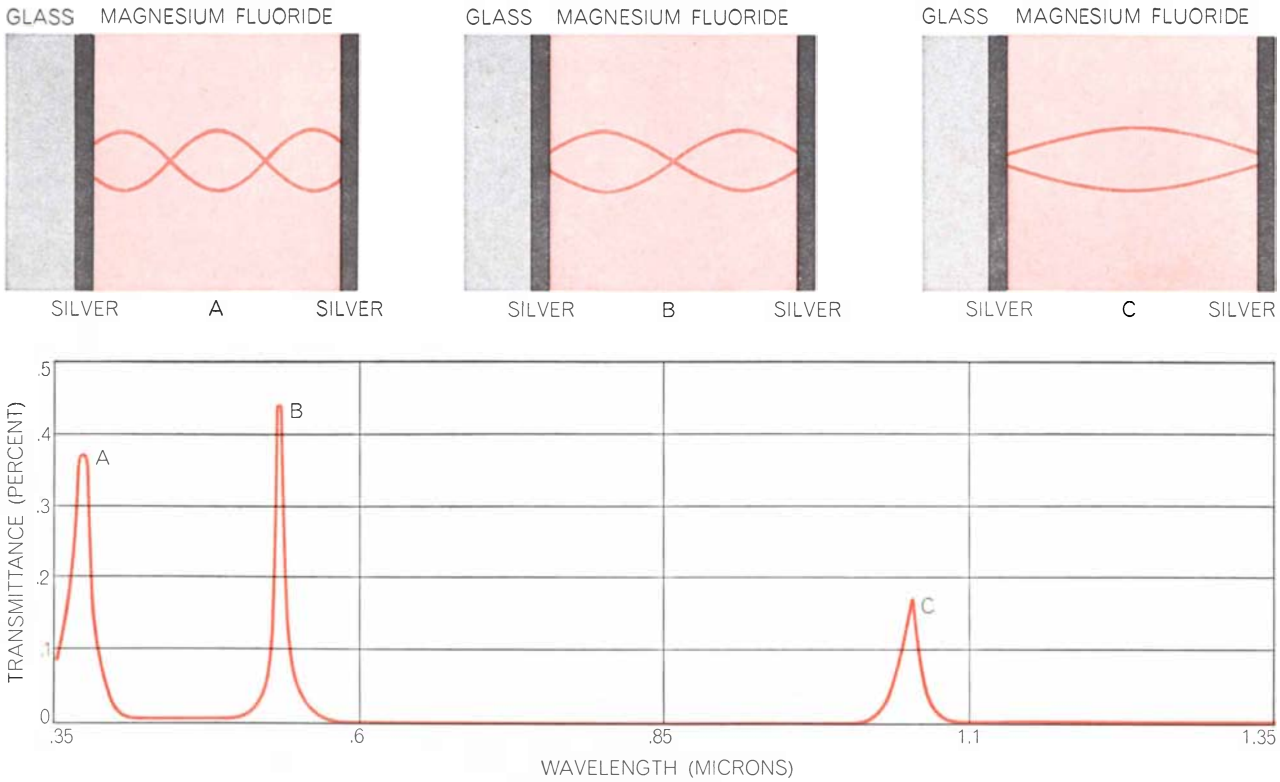
Nature has provided several striking examples of such a periodic structure, for instance in the colors of birds and in mother-of-pearl. Both exhibit iridescence, which is produced by a structure in which there is a periodic variation of the refractive index. How can the observer distinguish such colors from absorption colors such as those produced



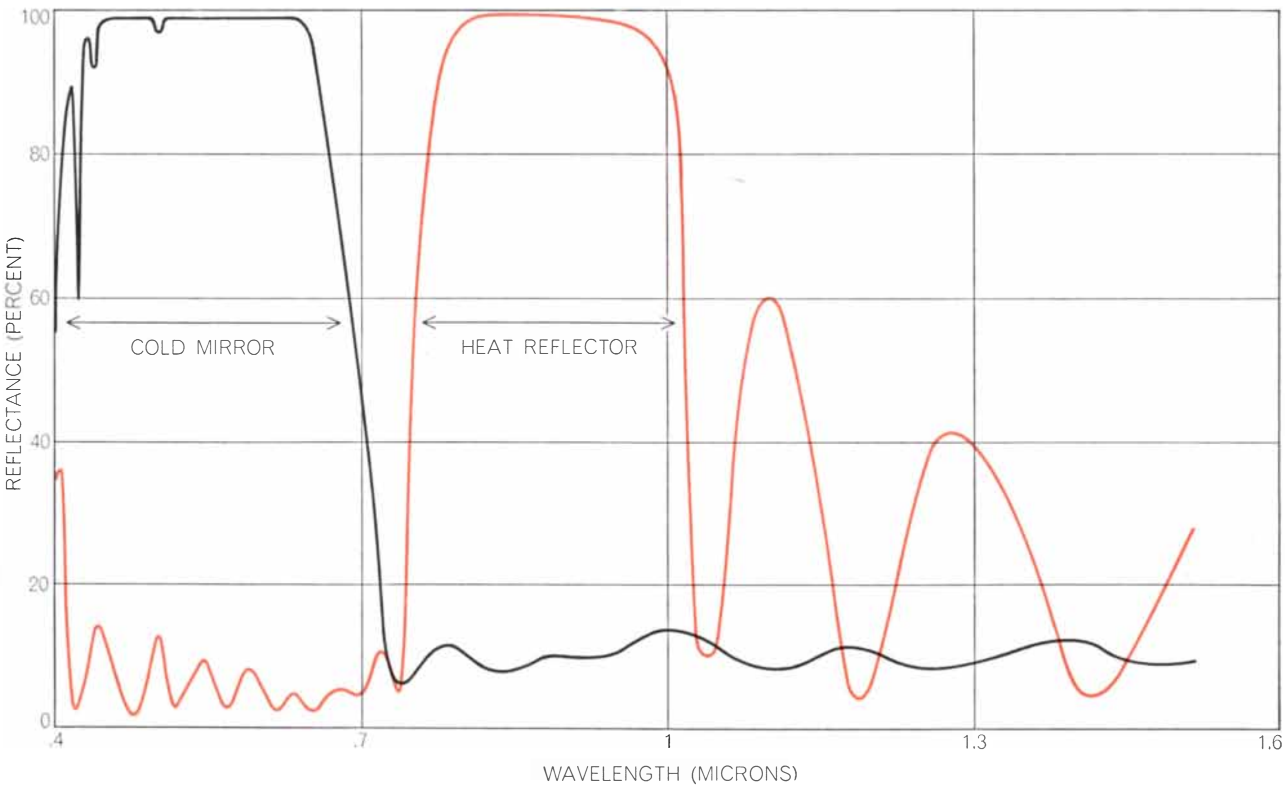
FABRY-PERÔT INTERFEROMETER, the essential parts of which are shown in this diagram, can be equipped with semireflecting dielectric mirrors in order to maintain a high reflectance while reducing the absorptance of the coated fused-quartz flats that form the interferometer's optical cavity. The object is to increase the transmittance and hence the efficiency of the device, which is used to measure the spectral profile of a light source.



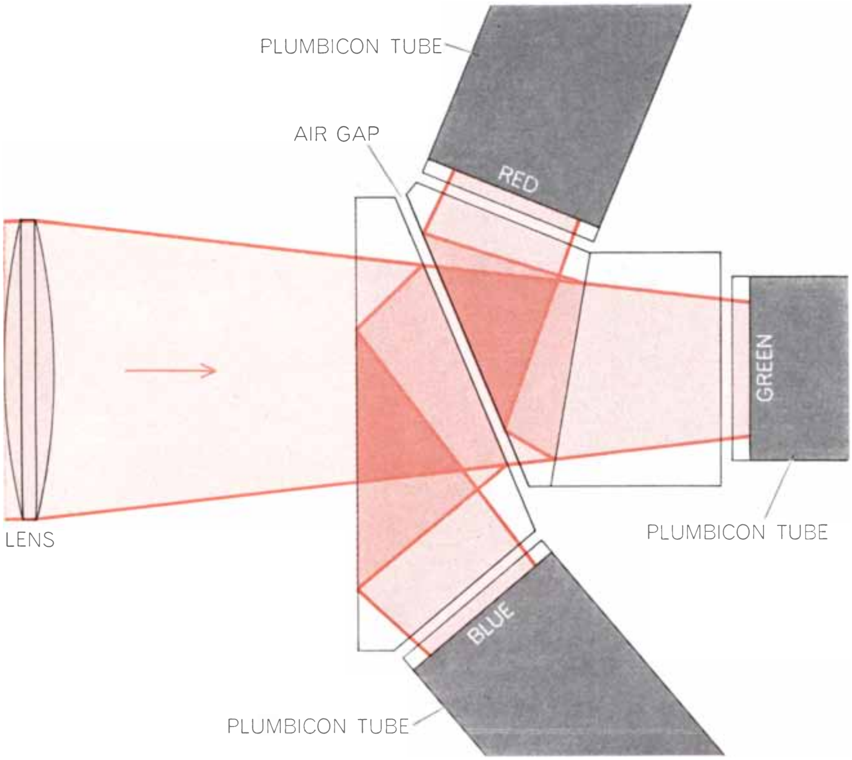
MOTION-PICTURE PROJECTOR employs coated optics for two different functions: as a heat-reflector between the projection lamp and the film gate in order to reflect heat radiation in the infrared portion of the spectrum away from the film and as a "cold mirror" be-



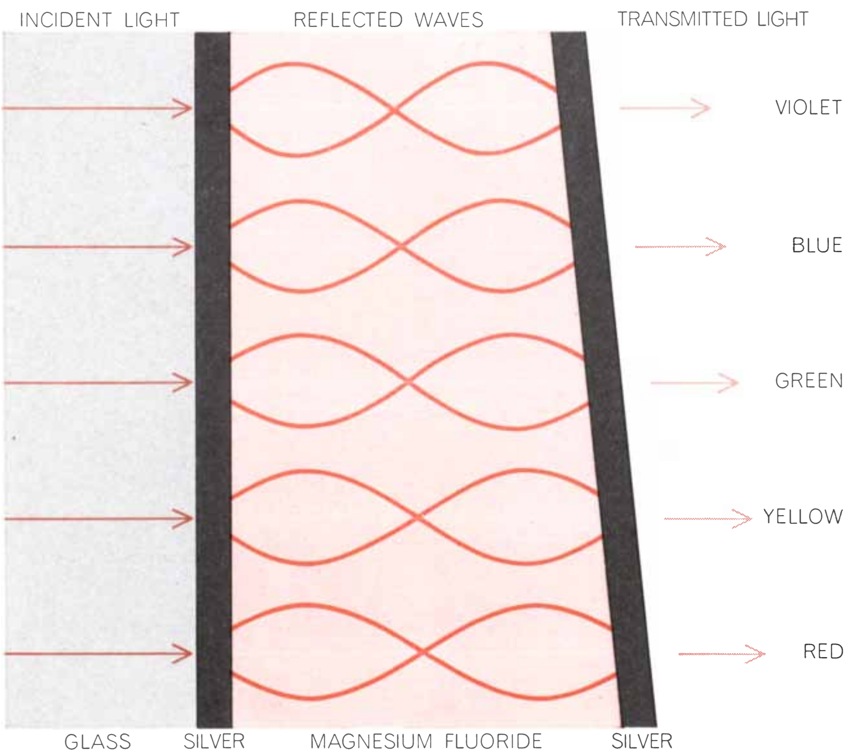
SOLID OPTICAL CAVITY composed of magnesium fluoride can be used instead of air between the semireflecting plates in a Fabry-Perôt interferometer; in this case the wavelengths of the transmittance bands depend on the thickness of the spacer layer. The first-order, second-order and third-order transmittance peaks correspond respectively to one half-wave of incident light at 1.06 microns (*C*), two half-waves at .537 micron (*B*) and three half-waves at .370 micron (*A*). When a standing wave is set up in such a cavity, the wave penetrates into the metal and hence is shown with the node about 30 degrees out of phase below the surface of the metal.



hind the filament in the lamp in order to reflect visible light toward the film while allowing the infrared to pass harmlessly into the lamp housing (*diagram at left*). The reflectance curves of the two coated surfaces are at right; the black curve represents the cold mirror; the colored curve represents the heat-reflector. The transmittance of both coatings is very nearly one minus the reflectance.



COLOR TELEVISION CAMERA consists essentially of three components: an objective lens, a beam-splitter assembly and three separate Plumbicon tubes to convert the light into an electronic signal. Light reflected from the scene being televised is split into red, green and blue channels by the dielectric band-pass filters deposited on the faces of the prisms in the beam-splitter assembly. The signals from the red, green and blue Plumbicon tubes eventually produce the corresponding colors on the picture tube in the television receiver.



WEDGED SPACER LAYER of solid magnesium fluoride is employed between two semireflecting silver films in this band-pass filter. Different wavelengths are transmitted at various positions across the filter. The thickness of the spacer layer is greatly exaggerated.

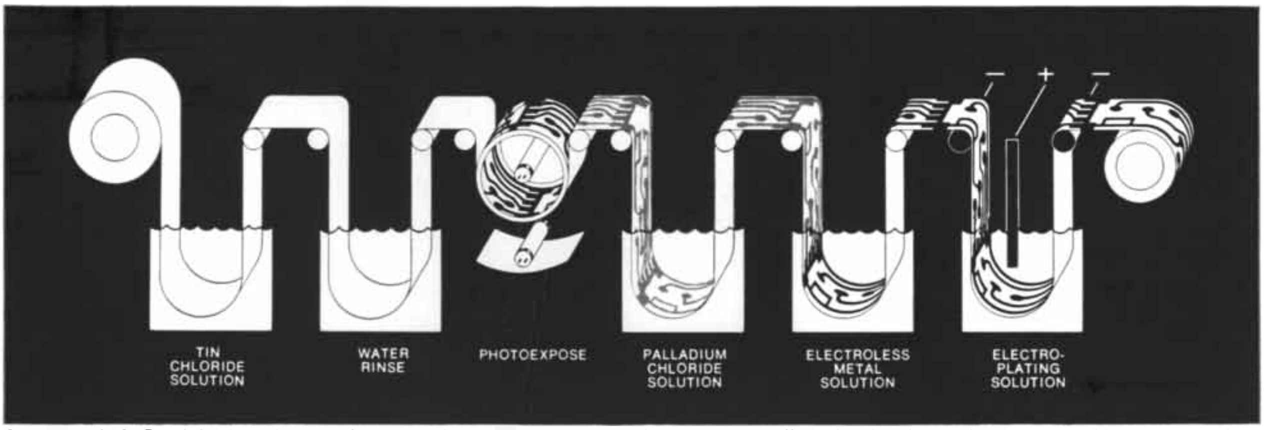
by chemical dyes or inks? One method is to notice that interference color changes as the illumination changes its angle. For example, by examining the color of a peacock feather with a single tungsten lamp as a light source, one can see how the colors change as the light's angle of incidence becomes oblique. The color shift is always to shorter wavelengths: the reds become yellows, the yellows become greens and the greens become blues. Several species of beetles and many butterflies exhibit similar interference colors in their wings. This periodic structure has also been clearly seen in electron micrographs of the platelets of hummingbird feathers.

Dielectric mirrors differ in two respects from conventional metal mirrors: they can attain a higher reflectance and their absorptance is considerably smaller. Several optical instruments take advantage of these attributes. For instance, in the Fabry-Perôt interferometer, which is an optical cavity consisting of two parallel fused-quartz flats, the inner surface of each plate is coated with a semitransparent mirror [*see top illustration on page 66*]. This instrument has been used for many years to measure with high resolution the spectral profile of emission lines. Before 1950 it was customary to coat the plates with silver, which typically has a reflectance of 90 percent, a transmittance of 6 percent and an absorptance of 4 percent. The reflectance of 90 percent is adequate for most purposes, and even when dielectric coatings are used in lieu of the silver, a reflectance in excess of 90 percent is rarely employed.

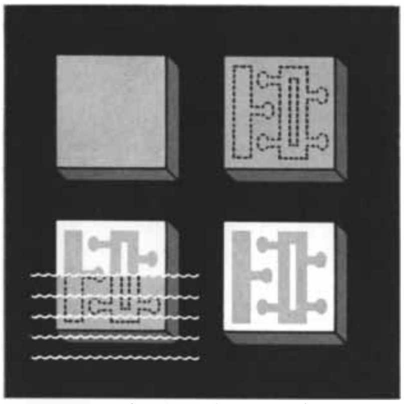
Although the silver coating suffices for many applications, the absorption loss at each plate reduces considerably the overall transmittance of the interferometer. In computing the transmittance of the interferometer, it is meaningless to consider only the coating's absorptance. Rather, the transmittance is determined by the ratio of the coating's absorption to its transmittance. As the ratio decreases, the coatings are more efficient and the transmittance of the interferometer increases. For example, the interferometer with silver coatings had an absorption/transmittance ratio of 4:6, which reduces its transmittance to 36 percent.

In the quest for greater efficiency, many spectroscopists had dielectric coatings deposited on their interferometer plates in the early 1950's. A typical dielectric mirror with a reflectance of 90 percent would have an absorptance of .5 percent and a transmittance of 9.5

Solving subtraction problems with addition



Schematic of PSMD with flexible substrate: After dipping in tin chloride solution, substrate is rinsed off, leaving tin oxide coating; exposed to UV light, dipped into palladium chloride solution, electroless metal solution, and electroplated.



Usual method of making circuits requires coating substrate with photo-resist, exposing, eliminating exposed photo-resist, and etching away uncovered copper.

Most people make printed circuits by putting a layer of copper on a substrate and etching away the unwanted part. But engineers at Western Electric's Engineering Research Center in Princeton, N.J., have devised a way to do exactly the opposite: add copper only where it's wanted. "Photo Selective Metal Deposition," now being introduced into Western Electric factories, works this way:

The substrate is coated with tin oxide, then dipped in a palladium chloride solution. Tin oxide reduces the palladium ions to palladium metal, so the surface now has a coating of palladium. If the substrate is dipped in an electroless copper bath, this palladium causes the copper to plate.

But the plating depends upon the presence of palladium, which depends upon the reducing ability of tin oxide. And *that* is destroyed by exposure to ultraviolet light.

So. We expose the coating to ultraviolet light through a mask of the circuit before dipping it into the palladium chloride. We thus get palladium—and hence copper—only on the unexposed portions. (Because chemical plating is slow, we can add electroplating if we want thick copper quickly.)

Now, our engineers have gone to considerable time and trouble to develop this new process because while the subtractive method makes perfectly fine circuits, it also makes problems. The copper salts formed by the etching-away process are quite poisonous and must be disposed of. To put down that initial layer of copper you need copper foil, which is expensive. Reclaiming the copper unused is laborious and can be expensive. *Not* reclaiming it means throwing away up to 70% of the copper you start with.

Considering the number of printed circuits Western Electric makes for the Bell System, these become major problems indeed. But by adding where we used to subtract, we not only solve those problems, we eliminate them.

We also get other benefits. The process can be used for one or both sides of rigid or flexible substrates, and with other metals beside copper. The pattern can be peeled off certain substrates, giving us an excellent way to make intricate connections. And, because the light used for exposure is UV (higher in the spectrum = shorter wavelength = better detail), resolution is good enough for us to make the kind of thing shown just above.

Grid used in Picturephone® camera, produced experimentally by PSMD: It has 8 micron lines on 1 mil centers.

Exactly the kind of development most pleasing to us at Western Electric.

Western Electric

Gifts that won't sit under the Christmas tree.

The Colorpack II. Beautiful color pictures in a minute, at a beautiful price. Electronic shutter and electric eye for automatic exposures. Sharp 3-element lens. Drop-in pack-film loading. Built-in flash for 4-shot flashcubes. Under $30.

The Model 320. The most economical in our popular line of folding cameras. Coupled rangefinder-viewfinder lets you focus as you shoot. Electronic shutter and electric eye read and set exposures automatically–even for flash. Detachable camera cover and carrying strap. Under $60.

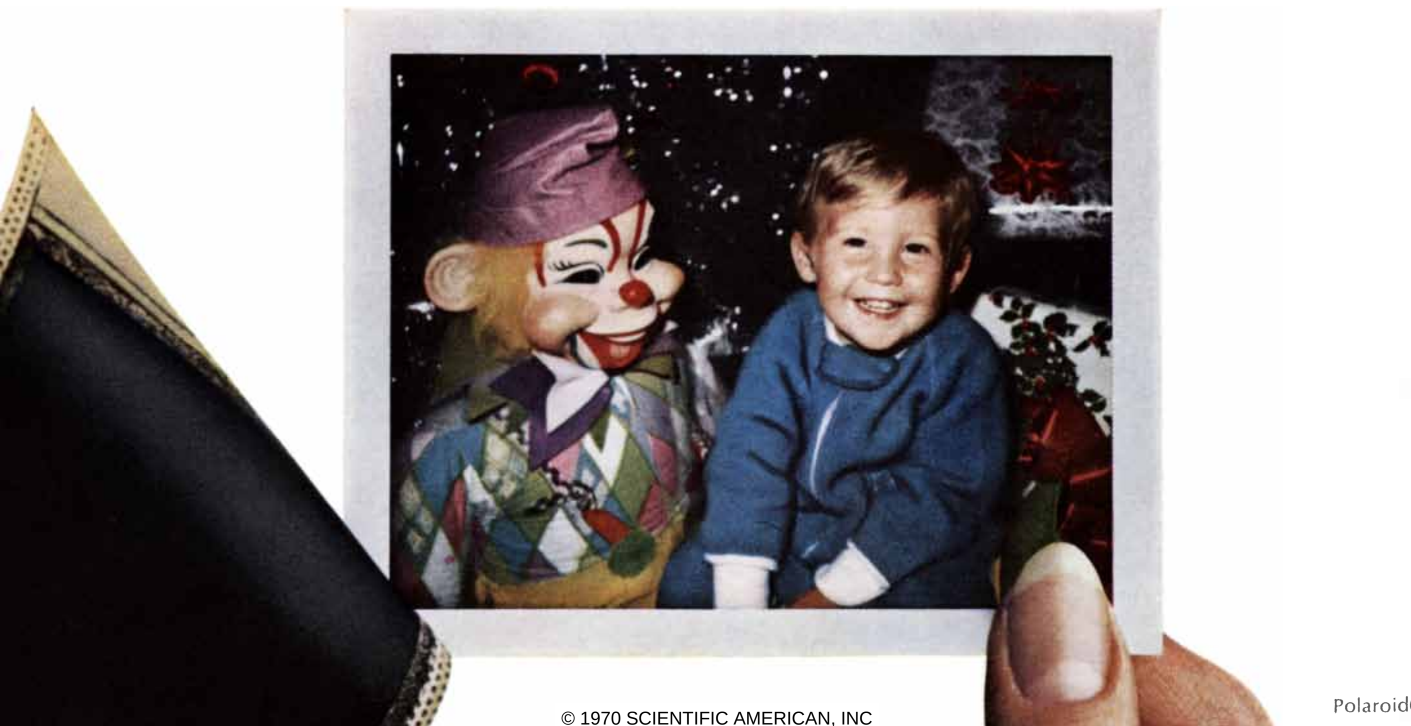
The Model 330. A lot more gift for a little more money. Built-in mechanical timer automatically tells you when your picture's ready. Transistorized electronic shutter. Precise triplet lens that can use optional filters. Double-image rangefinder-viewfinder for easy focusing. Under $80.

The Model 340. One of the most sophisticated cameras you can give for under $100. Takes indoor black-and-white shots without flash. Built-in development timer. Foldaway rangefinder-viewfinder. Four film speed settings. Handles a whole list of optional accessories such as close-up and portrait attachments. Under $100.

The Model 350. How automatic can you get? Built-in electronic timer "beeps" when your picture is perfectly developed. Takes automatic time exposures up to 10 seconds. Electronic shutter and electric eye. Single-window Zeiss Ikon rangefinder-viewfinder. Handsome all-metal body with brushed chrome finish. Under $160.

The Model 360. The most self-sufficient camera in the world. Snap-on electronic flash. (At 1/1000th of a second it can stop the action at a teenage party.) Recharges on ordinary house current. Electronic development timer. Triplet lens and Zeiss Ikon rangefinder-viewfinder. Four exposure ranges: Two color, two black-and-white. Under $200.

Polaroid Land Cameras



Polaroid®


POLAROID
ELECTRONIC FLASH
360
ELECTRONIC FLASH
AUTOMATIC
340
AUTOMATIC
350
AUTOMATIC
330
AUTOMATIC
320
POLAROID
COLORPACK II


SIEMENS
INTERNEINHEIT PROGRAMMSTEUERUNG 2
RÜCKSETZEN
BETR. KLAR
SPEICHER BEREIT
BEREIT
STOP
BEFEHLSADRESSE
IS1
IS2
B D B D
SPEICHERAUSWAHL
INTERNEINHEIT PROGRAMMSTEUERUNG 2

Siemens

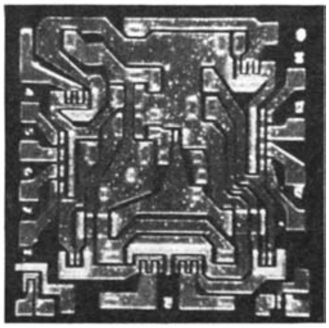
A three billion dollar name in quality products. Our new data communications exchange moves information 1000 times faster. First big test, '72 Olympics.

Athletes at the next Olympic Games will undoubtedly be the fastest in history. And the demand for fast, accurate information concerning their record-setting events will be unprecedented.

To satisfy this demand, reports, stories, statistics, and predictions, as well as other kinds of messages and data, must be routed, processed and transmitted around the world.

A major part of this job will be done by a completely new kind of data exchange that Siemens is now installing in Munich. We call it an electronic data switching system. EDS for short.

The new system is the only one of its kind now in operation offering the capacity to handle data traffic loads of this size. It handles data 1000 times faster than a conventional switching system.



Microcircuit design permits high-speed data transfer.

The need for the EDS system is critical because the increase in data traffic even during the next few years will be staggering. For example, projections indicate 50,000 computers will be linked through public networks to 1,200,000 terminals by 1974.

Like a computer controlled automatic telephone exchange, the Siemens EDS system provides interconnections between various communications channels. But there are very significant differences.

High speed digital messages from data processing systems consist of combinations of short pulses. Since these signals are completely unlike the complex waveforms of voice transmissions, noise that is common in telephone connections can often result in disastrous errors when data is transmitted on voice channels. In addition, data signals must often be translated, stored, speeded up or slowed down to match equipment at the receiving end. And this is what the new system provides.

EDS contains a unique asynchronous time-division multiplex system making it code and speed transparent. This is particularly advantageous in transmitting binary signals and handling data switching functions.

Siemens has designed comprehensive software in order to safeguard the high availability of the system.

Siemens EDS systems are designed to meet exacting requirements of data communications networks like Telex, TWX, Hotline, and various inquiry systems as well as international carriers and independents.

For more information, please contact Peter Stummvoll, Siemens Corporation, 186 Wood Avenue South, Iselin, N.J. 08830.

Siemens. A worldwide company in telecommunications, instrumentation, medical equipment, power engineering, electronic components and data systems.

percent. This much lower absorption/transmittance ratio means that the transmittance of the device is 90 percent.

In some applications the interferometer plates are still coated with either silver or aluminum films. Such films have the advantage that their reflectance is relatively constant with wavelength, in contrast to the quarter-wave stack, whose reflectance changes rapidly in certain spectral regions. It is possible to design dielectric coatings that have a broader region of high reflectance than the conventional quarter-wave stack, but they are more difficult to deposit.

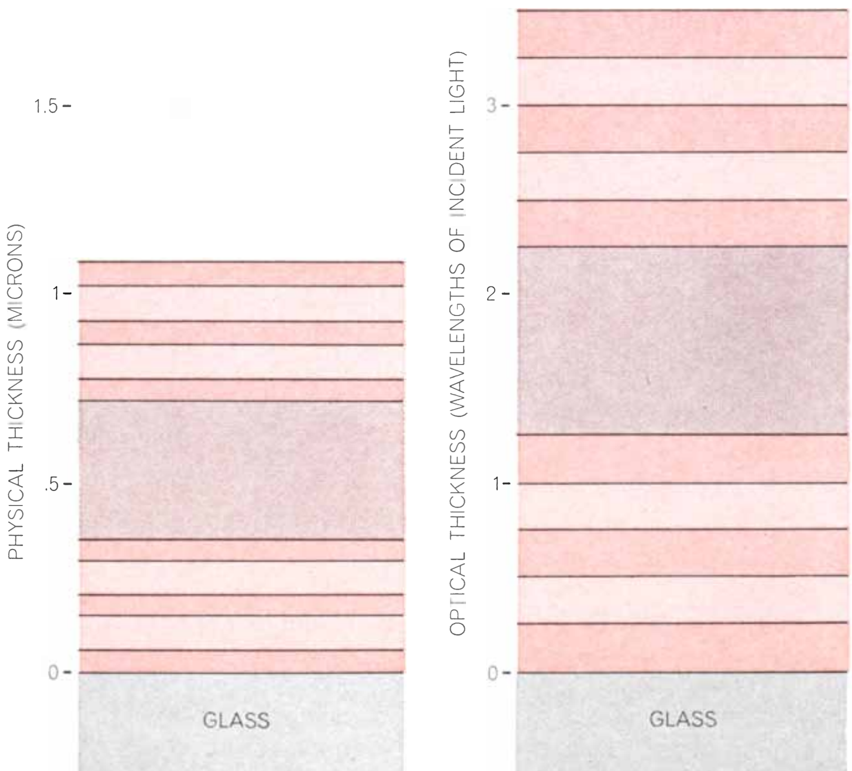
Dielectric mirrors are important components of many lasers, particularly gas lasers. A gas laser consists of two parts: an amplifier and an optical cavity [*see bottom illustration on page 64*]. The amplifier is a tube containing a plasma, a gas that is excited by an electric discharge. A typical plasma tube has a power amplification of 1 percent. This means that a wave with an initial intensity of 100 units has an intensity of 101 units after it has traversed the tube once. In a laser the tube is inserted into an optical cavity that resembles a Fabry-Perôt interferometer. When the amplified wave reflects from one of the mirrors, it suffers a power loss proportional to 100 percent minus the reflectance. If the power loss exceeds the amplification of the plasma tube, the laser will not function. In this example, if the reflectance of the mirror is not greater than 99 percent, the laser will not operate. The small amplification of 1 percent is not untypical of many gas lasers and hence they would simply not function without dielectric mirrors, which are the only means available for obtaining a reflectance close to 100 percent.

Dielectric coatings with a periodic structure are also used extensively as band-pass filters. In principle such a filter should exhibit a substantial transmittance in the spectral region of its passband and a large rejection elsewhere. The stopband of the periodic structure provides the rejection, so that the only problem in producing a band-pass filter is to alter its design slightly in order to optimize its passband transmittance. For example, consider the spectral transmittance of a filter that is designed to reflect the heat radiation in the infrared portion of the spectrum and to transmit visible light. Most of the layers have an optical thickness of a quarter-wavelength at .89 micron, where the stopband is located. A few of the layers are of a different thickness in order to improve the transmittance in the visible portion of the spectrum. Such a heat-reflector is often placed in front of the film gate in a motion-picture projector in order to reflect the heat away from the motion-picture film. It is considerably more effective than heat-absorbing glass, which is also used.

Another widely used band-pass filter has a high reflectance throughout the visible portion of the spectrum and a low reflectance in the infrared. This coating, which is called a cold mirror, is deposited on the reflector that is positioned behind the tungsten projection lamp in a motion-picture projector. A substantial portion of the lamp's radiation is in the form of heat, which is invisible to the human eye but which heats and sometimes damages the motion-picture film. The cold mirror reflects the visible light toward the film and allows the infrared to pass into the lamp housing. This arrangement is particularly effective when it is used in conjunction with a band-pass filter of the heat-reflector type [*see bottom illustration on pages 66 and 67*].

Band-pass filters are also important components of color television cameras, which consist essentially of an objective lens, a beam-splitter assembly and separate Plumbicon tubes that convert light into an electron signal [*see top illustration on page 68*]. Three channels record the primary colors of the scene being televised. The light is split into red, green and blue channels by the dielectric band-pass filters deposited on the faces of the prisms in the beam-splitter assembly. For example, the blue-channel coating is a dielectric mirror that reflects in the blue part of the spectrum and transmits at longer wavelengths in the green and red. The signals from the red, green and blue Plumbicon tubes eventually excite the red, green and blue colors on the face of the picture tube in the television receiver.

These band-pass filters and dielectric mirrors can be fabricated to operate at practically any wavelength from the ultraviolet to the far-infrared portion of the spectrum. The wavelength at which they function is controlled by making the films thicker or thinner. The chief difficulty is that in the ultraviolet and the far infrared there are not many materials that are transparent and that can be used as thin films. Many of the problems have been overcome, however, and it is now possible to buy band-pass filters at wavelengths in the range from .2 micron to 18 microns as "off the shelf" items from commercial firms. These infrared filters



ALL-DIELECTRIC BAND-PASS FILTER is constructed by replacing the silver mirrors in the conventional arrangement with dielectric mirrors. A representative filter of this type consists of a five-layer quarter-wave stack, a spacer layer and another five-layer quarter-

are important components of instruments such as the carbon dioxide laser, infrared gas analyzers, guidance systems for missiles, horizon-seekers for satellites and so on.

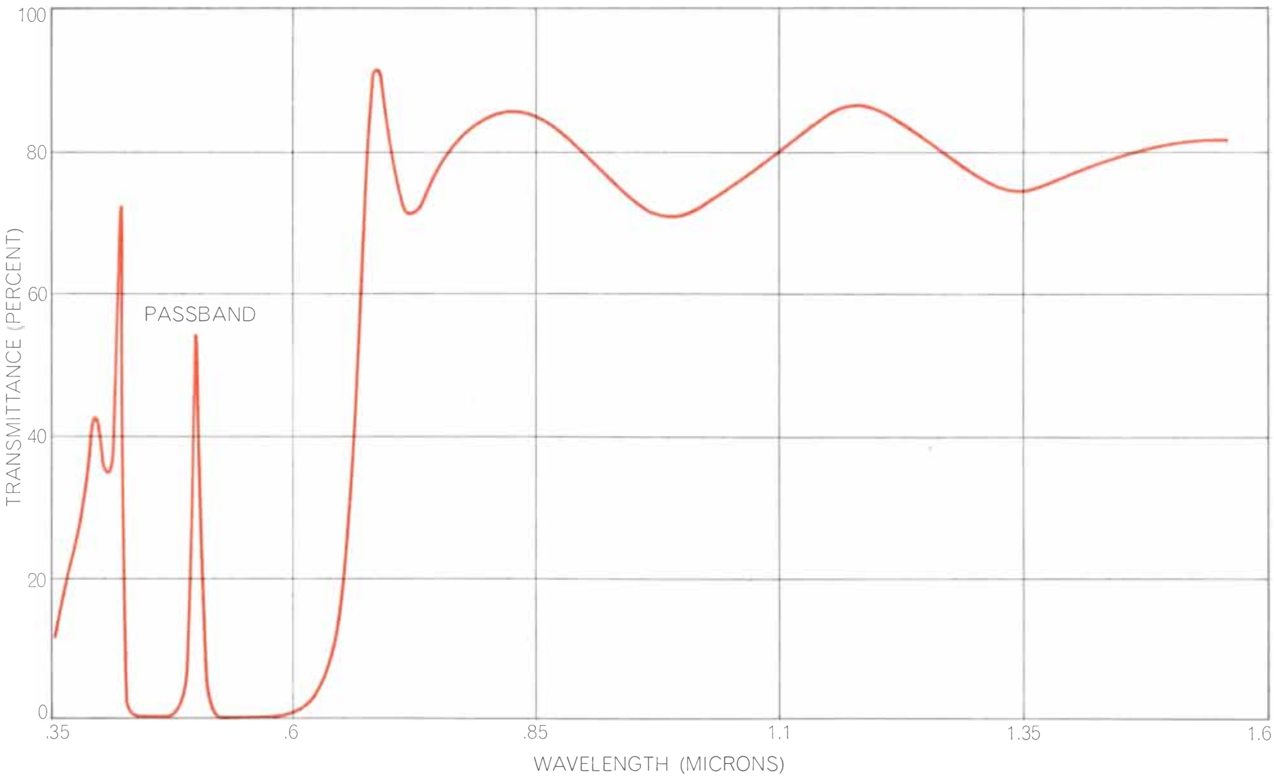
Band-pass filters that have a much narrower passband than the filters described above are also available. The simplest of these filters functions on the same principle as the Fabry-Perôt interferometer; it consists of two semitransparent silver films separated by a "spacer layer" of magnesium fluoride [*see top illustration on page 67*]. Whereas the optical cavity in the Fabry-Perôt interferometer is filled with air, however, the optical cavity in the filter consists of the solid magnesium fluoride spacer layer. The transmittance of such a filter is at a maximum when the optical thickness of the spacer layer is an integral number of half-waves. The wavelength of the passband can also be varied by changing the thickness of the spacer layer. For example, if the spacer layer in a given filter is in the form of a wedge, then different wavelengths are transmitted at various positions across the filter [*see bottom illustration on page 68*]. Thus by moving such a filter past a pair of slits, it is possible to construct a simple monochromator.

This type of filter was first produced in Germany in the late 1930's. Since it was the first type of filter to function according to the principles of optical interference, it was originally called an interference filter. Since that time, however, many other types of optical interference coatings have been produced, and hence it is no longer meaningful to describe any one particular type as an interference filter. Although the spectral width of the passband of such a filter is not particularly narrow, these filters are often used when a large attenuation outside the passband is required.

By analogy with the Fabry-Perôt interferometer, it is possible to replace the silver mirrors with dielectric mirrors and thereby construct an "all dielectric" band-pass filter. A representative filter of this type would consist of a quarter-wave stack, a spacer layer and another quarter-wave stack [*see illustration below*]. Compared with the band-pass filters that incorporate silver films, this all-dielectric filter has a greater peak transmittance in its passband and also a narrower spectral passband width, which in some filters is as narrow as a few angstroms.

These narrow-band filters are used in solar coronagraphs, spectrum-analyzers and other instruments where it is necessary to isolate a narrow region of the spectrum. For example, a laser range finder illuminates a target with laser light and determines its range from the time delay in the reflected beam. This instrument will function in broad daylight because its receiver contains a narrow-band filter that transmits the laser radiation and reflects almost all the sunlight.

This article has described some of the simpler types of optical interference coatings and a few applications. Some of the coatings that are produced today by commercial manufacturers are similar to these simple designs and many others are considerably more complex, incorporating as many as 100 layers. The design and construction of these coatings are challenging and now represent a thriving branch of optical engineering. The active research in this subject embraces such topics as new methods of designing coatings, the investigation of new coating materials and the improvement of the durability and hardness of the coatings. The technology of optical interference coatings has expanded rapidly in the past 20 years and there is every reason to expect that it will continue to do so.



wave stack (*diagram at left*). As the transmittance curve at right shows, such an all-dielectric filter has a narrower spectral bandpass width than a band-pass filter containing silver films. The passband in this case is located at approximately .5 micron. The unwanted radiation at wavelengths shorter than .4 micron and longer than .6 micron must be removed by means of auxiliary filters.