# Lamps with Multilayer Interference-Film Reflectors

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**INCANDESCENT** lamps have always been efficient producers of infrared energy. In typical lamps of wattages used in general lighting service, about 11 per cent of input energy is converted to light and 69 per cent to infrared, while the remaining 20 per cent is dissipated in losses in the bulb. In some cases, especially in recent years, the heating capability of incandescent lamps has been utilized effectively for industrial heating and comfort heating. However, in many lighting applications the radiant heat accompanying the light from the filament has been thought of as a necessary evil. Indeed, the heat content of concentrated beams has placed some severe limitations on the illumination levels that can be used in certain types of displays.

Removing the radiant heat from incandescent light by conventional filtering has been limited in the past because most heat-absorbing glasses were almost equally low in light transmission and/or produced a significant shift in the color of the light. Newer glass filters are improved in both these respects and they are expected to find considerable use in lighting practice.

The extensive recent development of vacuum-deposited multilayer interference films has offered a new approach to the separation of light from infrared at substantially higher efficiencies than has been possible before, with good control over color characteristics of the light. After considerable study of coatings and manufacturing techniques, 300-watt PAR56 lamps have been produced, utilizing interference films in place of aluminum as a reflecting medium.

## The Coatings

Interference coatings of the type used in these lamps are sometimes referred to as "dichroic" filters, because of their capacity to separate energy into two spectral bands, one reflected and one transmitted from the filter surface. A "coating" of this type actually consists of a number of individual layers deposited on the substrate by high-vacuum evaporation and precisely designed in thickness and other characteristics to achieve the effect desired: the reinforcement or retardation of a specific spectral region.

In the filter system employed in these lamps, two materials are used in the coating. These are alternately applied and are referred to as "high-index" and "low-index" materials. The designation refers to their refractive indices relative to the index of crown glass, 1.52. In this case the low-index material is magnesium fluoride with a refractive index of 1.38 and the high-index material is zinc sulfide with an index of 2.30. The numerical spread between these indices influences the reflectivity of a single interface; in general, the greater the difference in indices, the fewer coatings are required to achieve a given reflectance.

In operation a series of layers each one-quarter wave length in thickness will result in a high reflectance band at that wave length. A succession of layers, each one-half wave length in thickness, will have no optical effect on that wave length, and the net reflectance will be only that of the substrate. Figs. 1 and 2 show the spectral reflectance characteristics of some quarter-wave and half-wave combinations. These examples illustrate the function of layer thickness in controlling the wave length at which maximum reflectance occurs.

By varying the thicknesses of various layers with respect to each other and to the wave lengths of interest, it is possible to achieve almost any spectral reflectance distribution. In many cases, as with the coatings for the PAR56 lamps, the individual layers are not of equal thickness, nor even integral multiples of each other in thickness.

Interference coatings of this type have practically no absorption in the visible and infrared, and they have the property of transmitting all wave lengths that are not reflected. This can be visually illustrated

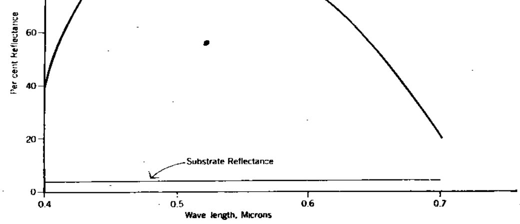


*Figure 1. Spectral reflectance of a five-layer interference film of coatings on glass in which each layer is ¼-wave thick to energy of 500-millimicron wave length in air.*

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by color-separation filters that transmit blue and reflect the complementary color, yellow. In the PAR-56 lamps discussed here, the coating is composed of seventeen layers and is designed to reflect approximately 92 per cent of the visible energy incident at the optimum angle, while reflecting only about 15 per cent of the infrared from 0.75 to 2.7 microns. The remaining 85 per cent of the infrared is transmitted through the reflector, where some is absorbed by the bulb glass, but most of it escapes through the rear portion of the lamp. Fig. 3 shows characteristic performance of "cold mirrors" of this general type.

In order to maintain the precision of color control and high reflectance required for this application, careful control of individual layer thicknesses is required. Each layer is monitored during coating with photoelectric controls to hold its thickness to an optical tolerance of plus or minus three per cent, which represents a geometric thickness tolerance on the order of one-millionth of an inch.

Another critical factor in coating manufacture for this application is maintaining coating durability and environmental stability sufficient to withstand the rigors of lamp manufacture. These capabilities are assured through selection of appropriate coating materials and the use of a complex electron-beam bombardment process in the vacuum deposition chamber.[1]

Successful development of the PAR lamp coatings owes much to experience gained in previous applications of vacuum-desposited interference filters. Among these are the following:

1. Dental spotlight reflectors with color control and infrared reduction characteristics that exceed the efficiency of earlier systems employing silver reflectors and heat-absorbing glasses.
2. "Cold mirror" coatings for bowling score projectors to produce desired screen brightness with lower temperatures on scoring tables.
3. Ellipsoidal reflectors with infrared-transmitting coatings for carbon-arc motion picture projectors. These reduce film damage and projector maintenance by reducing heat at the film aperture by 50 per cent.[2] Some internal-reflector lamps for amateur-sized projectors employ similar reflectors.
4. Color-separation filters for flying-spot scanners and camera optics in color television systems, which make available to the three-color photosensitive surfaces virtually all the energy in each color band.
5. Experimental reflectors for high-wattage Fresnel lens spotlights for studio lighting in which spherical infrared transmitters and paraboloidal infrared reflectors have been employed to achieve substantial improvements in comfort of actors and crews.[3]

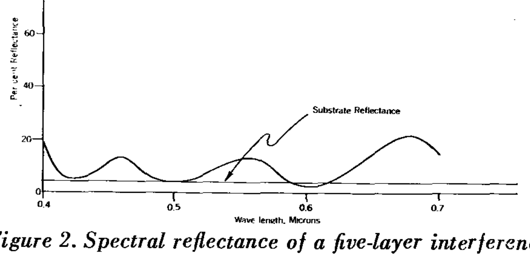


*Figure 2. Spectral reflectance of a five-layer interference film in which each layer is ½-wave thick to energy of 500-millimicron wave length in air.*

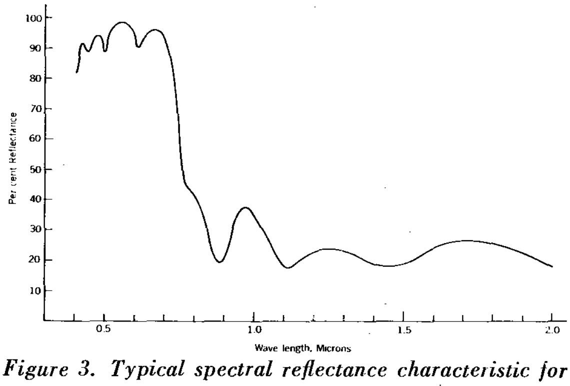


*Figure 3. Typical spectral reflectance characteristic for "cold mirrors" designed for visible reflection and near-infrared transmission. Curve shows characteristics at optimum angle of incidence of energy.*

## Lamp Design and Characteristics

The two-piece construction of glassware for PAR lamps is well suited to the application of interference coatings. With the development of better coatings, in terms of both optical characteristics and materials capable of withstanding sealing temperatures, studies were begun to incorporate the heat-control feature of the films into the optical control characteristics of PAR lamps. Studies included both reflector and cover-glass coatings.

Our studies included evaluation of spectral characteristics in the beams of lamps with various coating combinations. Fig. 4 shows spectral energy distribution in the beams of several 300-watt PAR56 narrow spot lamps to illustrate the studies that were undertaken. The area under each curve represents relative total beam energy.

Curve *A* is for a standard lamp with aluminized reflector and conventional cover glass. Curve *B* is for a lamp with a coated infrared-transmitting reflector and a coated infrared-reflecting cover glass. Curve *C* is for a lamp with a coated infrared-transmitting reflector and a plain cover glass. Curve *D* is for a lamp with an aluminum reflector and coated infrared-reflecting cover glass.

Interpreting the curves, the coated cover glass alone (Curve *D*) achieves a 50 per cent reduction in beam energy, compared to the conventional lamp,

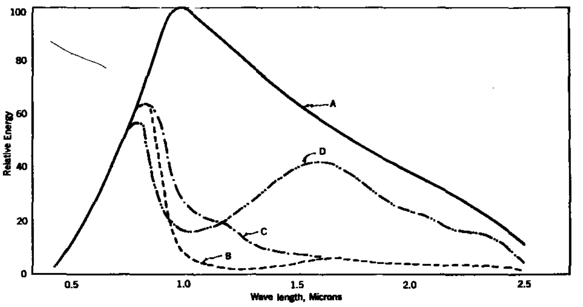


*Figure 4. Spectral distribution of energy in beams of several developmental 300-watt PAR56 lamps in this study. See text for interpretation.*

but it results in poor lamp performance because of heat trapped within the envelope. The coated reflector alone (Curve *C*) yields a beam energy reduction in excess of 70 per cent. With both reflector and lens coated (Curve *B*) beam energy is reduced slightly more than 75 per cent. Since the coated cover glass achieves only a 5 per cent greater beam energy reduction, but at substantially doubled coating costs, it was decided to use only a coated reflector in the final lamp design.

Measurements of different beam patterns and at various angles from the beam axis indicate essentially the same heat-reduction characteristics as illustrated in Fig. 4. Fig. 5 shows the spatial distribution of energy from a typical lamp of final design. The first lamps made available are 300-watt, 120-volt, PAR56 narrow spot, medium flood and wide flood types. As with their aluminized counterparts, design life is 2000 hours. Lumen maintenance is comparable to that of aluminized lamps, with no indications of noticeable deterioration of coatings during life. The inert materials used in the films do not impair lamp performance.

The interference coating on the reflector is responsible for a slight loss in candlepower because some filament radiation is incident at angles different from the optimum; additional candlepower reduction results from the transmission through uncoated center portion of the reflector. The resultant beam candlepower is about 80 per cent that from aluminized lamps; Fig. 6 shows the candlepower distribution curves for the different beam patterns.

Manufacturing techniques for the PAR56 lamps with interference coatings include several variations from conventional lamp assembly methods. These were incorporated to protect the coatings during manufacture and to preserve the desired spectral characteristics in the beams.

Other sizes of PAR bulbs have also been successfully coated and assembled into lamps, using many of the same techniques developed for the PAR56. It is therefore anticipated that other sizes of lamps employing the same principle may be introduced.

Because of infrared radiation through the coated and uncoated sections of the reflector, there was concern over the temperatures of electrical connectors and insulation, as well as possible lamp performance problems in enclosed housings commonly used with PAR56 lamps. One test of a developmental lamp in a typical enclosed housing resulted in a temperature of 277 C at the juncture of base

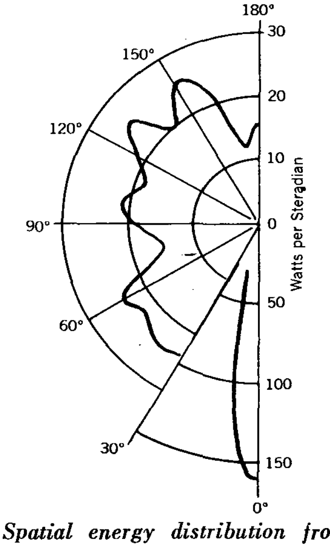


*Figure 5. Spatial energy distribution from 300-watt PAR56 wide flood lamp with interference-film reflector. Note the change in scale at the 30-degree angle. Data, taken in plane of filament, illustrate general characteristics of all three lamps.*

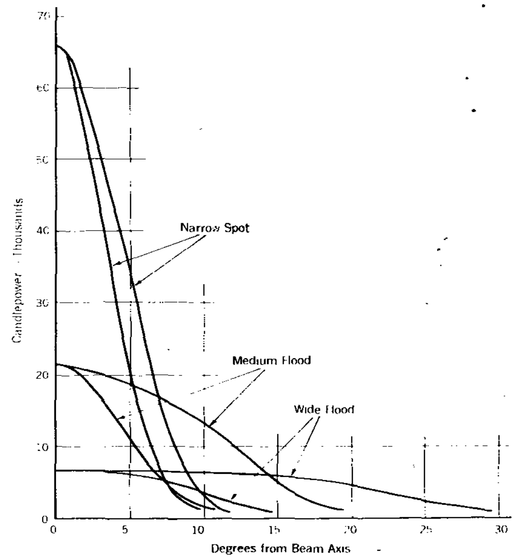


*Figure 6. Approximate initial candlepower distributions of widest and narrowest portions of beams of 300-watt PAR56 lamps with interference-film reflectors.*

prongs and connector clips. This temperature exceeds the rating of any presently approved insulation.

To preclude the use of the new lamps in tightly enclosing housings, an extended mogul-end prong base is employed. Proper attention to luminaire size and ventilation is also recommended. With a coated lamp of the final design in a ventilated luminaire, temperature tests indicated 127 C at the prong and clip juncture.

## Applications

In considering applications for the new lamps, a brief discussion of the merits and limitations of incandescent lighting begins to pinpoint the areas in which the most benefits will be derived. Lamps of relatively narrow beam spreads are frequently used for display spotlighting in store interiors and show windows, for counter downlighting in stores and, to a limited extent, for general lighting. The choice of such sources hinges on (1) their ability to produce substantial brightness increases over limited areas to attract attention to and increase the visibility of featured displays; (2) the color characteristics of incandescent lamps, which are familiar and flattering to shoppers; (3) the concentrated, high-brightness light source which achieves highlights and shadows that reveal form and texture, and which is reflected in glossy or semiglossy surfaces as "sparkle" or "sheen."

On the negative side, concentrations of incandescent lighting also lead to concentrations of heat that can cause deterioration of temperature-sensitive merchandise and display materials. A measure of the effectiveness of the new lamps in overcoming these limitations is indicated in Fig. 7, which compares the radiant-energy densities in the beams of conventional 300-watt PAR56 lamps with those in the beams of the new lamps. For purposes of simplicity in illustration, only the wide portions of the oval beams are shown. Because there is some reduction in beam candlepower with the interference-film lamps, it is also helpful to compare energy densities on an equal illumination basis. While conventional PAR lamp beams contain about 0.055 watts per square foot per footcandle, the new lamps' beams contain only about 0.02 watts per square foot per footcandle.

One of the principal application areas for the new lamps will be in lighting self-service displays of fresh meats. Our extensive contact with food-store meat merchandisers indicates that incandescent is preferred by far over other sources for lighting these displays. However, the discoloration of fresh meats is also a matter of concern. Research indicates that the chief cause of surface discoloration of fresh meat cuts is bacterial action. This, in turn, is influenced by the original bacteria count on the meat surface and the temperatures of the meat in cutting, wrapping, storage and display. One researcher has indicated that meat discolors much faster at 40 F than at 35 F, and that 30 F is probably about the optimum surface temperature for controlling discoloration rates.[4] In the self-service display case, a cooling air "blanket" passes over the meat surface; with no lighting, the ultimate temperature of the meat surface will be that of the cooling air. With light and near-infrared energy transmitted through this air and absorbed by the surface, however, the surface temperature stabilizes at some higher level depending on the temperature and velocity of air at the surface, and the incident energy density. Tests were conducted in a commercial display case, divided to separate the lighting conditions without affecting air flow. Cuts of meat were exposed, with comparisons made between surfaces that had been cut at the same time with opposite sides of the same knife blade to minimize variations in initial surface conditions. Using conventional PAR lamps and interference-film lamps to provide the same illumination, two types of observations were made. Visual appraisals of surface-color changes were made and surface temperatures were measured with thermocouples stitched to the top surface of the cuts.

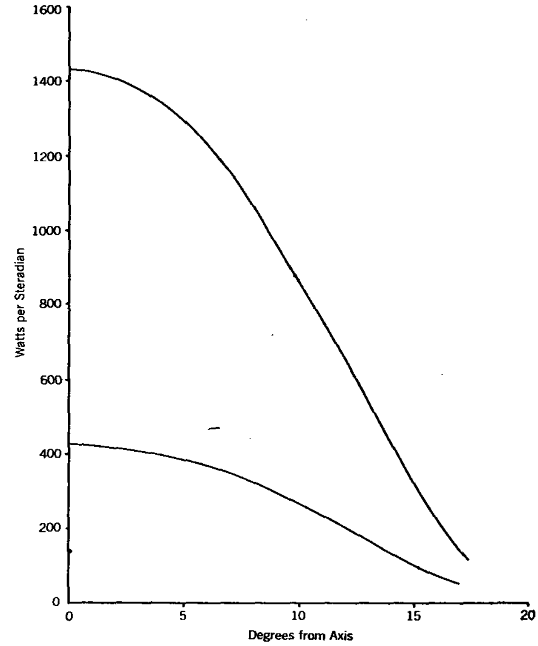

*Figure 7. Comparison of radiant energy distribution in beams of aluminized (upper curve) and interference-film (lower curve) 300-watt PAR56 medium flood lamps. Data are for wide portion of beam, and relationships are typical of those measured in other beam spreads.*

Over the range of illumination observed (from 50 to 300 footcandles), two results were apparent:

1. Surface temperatures were lower under interference-film lamps than under aluminum lamps. De-

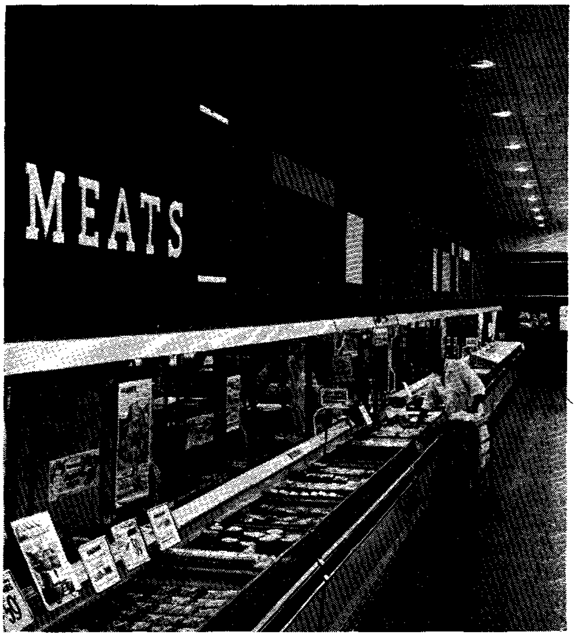


*Figure 8. Supermarket meat department in which the major component of illumination is supplied by interference-film lamps. Lamps are medium floods, spaced about eight feet on centers.*

pending on illumination and refrigeration conditions, the coated lamps produced surface temperatures 3 to 8 F below those produced by aluminized lamps. Under typical conditions, this is roughly equivalent to doubling shelf life of displays.

2. Discoloration observed during the period of exposure always occurred first and was most pronounced under the conventional lamps.

The results of these and other investigations show that the new lamps offer a practical means of providing recommended illumination levels on self-service fresh meat displays with incandescent lamps—the preferred source—without creating conditions that reduce the shelf life of displays below levels found in common practice today. Or, on the other hand, the lamps can be used at lower illumination levels, resulting in lower surface temperatures and longer shelf life.

In show windows higher-wattage PAR lamps have found wide use because of the simplicity they offer in providing well-defined beams of candlepower high enough to be effective in overcoming daytime window reflections. Illumination in highlight areas of such displays may range from 500 to 2000 footcandles or more. At these levels the radiant energy on merchandise and props creates temperatures that may damage merchandise and cause deterioration of display materials. Taylor and Pracejus[5] have indicated that fading also occurs faster at higher temperatures. The reduction in beam energy density with the new lamps is expected to alleviate these problems, since preliminary tests with mock-up displays indicate that surface temperature reductions of 20 to 40 F may be expected under high-illumination conditions. Obviously, the great variation in thermal characteristics of lighted surfaces and ambient conditions preclude any positive numerical statement on this subject, but surface temperatures of displays and the comfort of display personnel will be improved with the new lamps.

Figs. 8, 9, and 10 illustrate applications of the new lamps that have been or can be made to take advantage of their heat-reduction characteristics.

*Figure 9. Show window in which general illumination is provided by 500-watt quartz-iodine lamps in wide-beam floodlights and spotlighting is provided by two 300-watt PAR56 interference-film narrow spot lamps aimed at each mannequin.*

*Figure 10. Detail showing mounting of equipment in Fig. 9.*

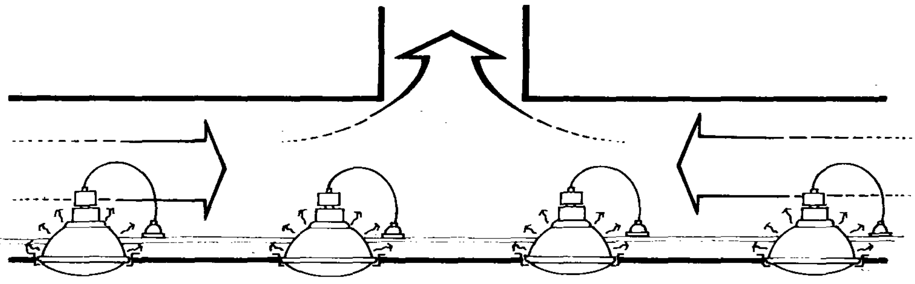

*Figure 11. Schematic sketch of duct-mounted installation of interference-film lamps used as counter downlights, with ventilation for removal of heat from system.*

Other applications that are significant and uniquely suited to the new lamps include high-level counter downlighting, lighting of candy displays, and some general downlighting. The infrared-reduction principle employed here can also be applied, of course, with these and other sizes of lamps for television studio lighting, boxing arenas, and other special applications.

The new lamps also offer interesting possibilities in connection with the concept of electrical space conditioning. Fisher and Flynn[6] have previously reported on the potential gains in environmental control that can be made by controlling lighting system heat at its source rather than after it has entered occupied air-conditioned rooms. These lamps offer possibilities for collecting and removing much of their energy with relatively simple ventilation processes. Fig. 11 schematically illustrates how a series of downlights might be ventilated to exhaust heat from the system, and Fig. 12 shows results of a test indicating that relatively little air movement may be required to exhaust a major part of the input wattage to the lamp.

It is expected that the lighting equipment employed with these lamps will fall into four basic categories, which are:

1. Simple adjustable holders with essentially open backs to permit free rearward radiation of heat.
2. Surface-mounted adjustable luminaires with enclosures having provision for natural ventilation to remove excess heat.
3. Recessed housings with spread lenses and/or aiming capabilities, either of sufficient size to achieve satisfactory surface temperatures or with provision for forced ventilation to exhaust heat.
4. "Troffer" systems, in which the enclosure serves as a wireway and ventilation duct, with the lamps mounted in individual doors for maintenance, and having provision for various modular lamp spacings.

The principal new considerations in fixture design involve dimensions for physical clearance of the extended mogul-end prong base and provision for accommodation of the considerably greater quantities of infrared energy emitted through the reflector than are present in other equipment for this wattage.

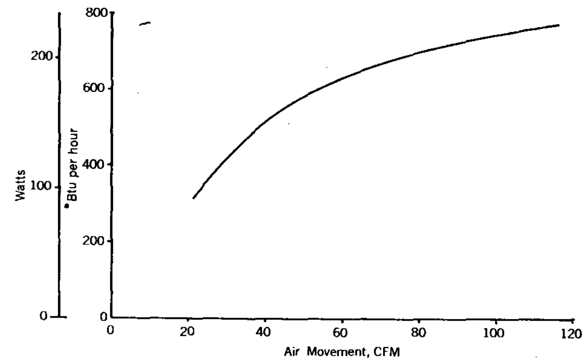


*Figure 12. Results of test to measure heat removal by ventilation of four-foot duct segment housing one 300-watt PAR56 interference-film downlight.*

## Conclusion

With the improvements that have been made in the technology of high-vacuum deposition of interference films, a new family of incandescent lamps has been established. By substantially reducing radiant-heat content in beams of reflectorized lamps, it has become possible to employ higher levels of incandescent lighting than ever before without additional concern over potential damage to lighted surfaces as a result of radiant heating effects.


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