INFRARED FILTERS OF CONTROLLABLE TRANSMISSION

By A. H. Pfund
Rowland Hall, Johns Hopkins University

(Received May 26, 1930)

Abstract

When using an echelette grating for work in the infrared it is necessary to eliminate overlapping, higher orders. Since no adequate series of true filters covering the entire infrared is known, a new type of filter has been developed. Essentially, this type of filter consists of a powder spread uniformly over a surface of polished speculum. Short wave-length radiations are reflected diffusely while long wave-length radiations are largely transmitted since the Rayleigh scattering for long waves is feeble. The region of transition from opacity to transparency is controlled by choosing powders of proper particle-size and by depositing these in layers of appropriate thickness.

Specific examples, involving the use of particles whose mean diameter covers the range: 0.22μ to 2.5μ, are presented to show how filters for almost any portion of the spectral range: 2μ to 7.5μ may be largely freed from the effects of superposed, higher orders. Filters for greater wave-lengths may be produced by much the same methods.

FOR the attainment of large dispersion and high resolving-power in the infrared, the diffraction grating, in particular, the echelette grating is coming into wide use. It suffers, however, from one drawback, i.e. superposed orders. If for example, an echelette grating be adjusted for work in the first order near 3μ, there is superposed on this a large amount of second order 1.5μ energy, third order 1μ energy, etc. Due to the fact that the usual Nernst lamp has its energy maximum near 1.6μ, the energy of the contaminating radiations exceeds greatly the energy at 3μ. It is proposed to discuss in the following a new type of filter which, though by no means perfect, does minimize the effect of contaminating radiations.

The term filter is here employed in the broad sense of being a device which either isolates narrow spectral regions or which experiences a change from opacity to transparency within a relatively small wave-length interval. To be specific, a satisfactory filter for an echelette grating, operating between the limits 3μ to 3.5μ, would be one which is quite opaque for all radiations shorter than 1.75μ and quite transparent for radiations greater than 3μ. To realize so great a change in transparency within so narrow a spectral range is difficult.

Methods now in use for filtering out the undesirable radiations are here enumerated: I. Infrared monochromator.[1] II. Residual rays.[2] III. Reflection from rough surfaces.[3] IV. True absorption filters.[4] Without going

[1] Sleator, Astro. Phys. J. **48**, 127 (1918).

[2] Rubens and Aschkinass, Ver. deutsch phys. Ges. **17**, 42 (1898).

[3] Gorton, Phys. Rev. **7**, 66 (1916).

[4] Coblentz, Supplementary Investigations of Infrared Spectra 5–7, Carnegie Inst. of Washington (1908).

A very comprehensive list of references, dealing with the infrared, is to be found in "Le Spectre Infrarouge" by Jean Lecomte, Les Presses Universitaires de France (1928).

into a detailed discussion of the various devices it may be stated that most of them are limited in the range of spectrum which can be covered; again, some lack flexibility, i.e. if true filters or crystals (employed for residual rays) fail to show high transmission or reflection, respectively, in the region to be studied, there is nothing to be done about it. As for reflection from rough surfaces it may be said that the wave-length interval separating regions of low and high reflection is entirely too great to be considered seriously for the present purpose.

The new filters about to be described are a by-product of some work that is being carried out on the measurement of particle-size of finely divided powders by studying their transmission in the infrared. Rayleigh's inverse fourth power law of scattering is strictly applicable only if the particle-size be small in comparison with the wave-lengths employed. If, however, the particle-size be large in comparison with the wave-length, the particles assume the role of small mirrors which reflect vigorously. Consequently, if transparent particles of a uniform and suitable size be produced it will be found that they reflect the regions of short wave-lengths strongly and scatter those of great wave-length feebly. Used in transmitted light a film of such small particles will be virtually opaque to the short wave-lengths and highly transparent to the longer. Body-color, involving true absorption, plays no necessary part in the functioning of these filters.

The pulverized materials used in the construction of such filters must fulfill certain necessary conditions: 1. The material must be highly transparent in the spectral region to be studied. 2. A large range of particle-sizes must be available, and the particles in any individual class must be essentially constant in size. 3. The substratum on which the pulverized film is deposited must be transparent. 4. The films must be of uniform thickness.

Concerning condition (1) it may be said that short of 20μ, oxides, sulphides and halides have been found most transparent. Thusfar the most satisfactory films have been formed by the process of "fuming" as, for example, by allowing the oxide fumes from burning magnesium ribbon to collect on a plate. Condition (2) is not as yet realized. It is to be pointed out, however, that methods for accomplishing this purpose are known. The well-known process of "air-flotation" and subsequent settling has been used. Again, the method of successive centrifugings has been employed for bringing about uniformity of particle-size. The nature of the substratum (condition 3) depends largely upon the spectral region to be studied. Microscope cover glass 0.2 mm thick will serve up to 4μ while a thin plate of rock-salt will be useful at least up to 18μ. In order to eliminate completely the element of transparency of the substratum the procedure of coating a polished speculum plate with the pulverized film has been adopted—particularly for the region of long waves. Such a mirror will reflect all wave-lengths while the film will reflect the short waves diffusely but will transmit the long ones regularly. Attention is to be drawn to the fact that, while the widest possible spectral range may be covered by using a speculum or some other reflecting surface, the performance of such a "reflection" filter is less satisfactory than that of a transmission filter. The reason is that the diffusely reflected light of shorter λ is in part added to the regularly reflected light in the case of the reflection filter, but not so in the transmission filter.

A few examples of the performance of these filters are here presented. Measurements were carried out by means of a rock-salt spectrometer and thermopile. Since it is difficult to control the film thickness accurately, it is necessary to resort to the use of a spectrometer in order to decide when a film of the proper characteristics has been deposited. In Fig. 1 are presented "transmission" curves (*A* and *B*) for zinc-oxide which was fumed on microscope cover glass. The fumes were supplied by an arc burning between zinc

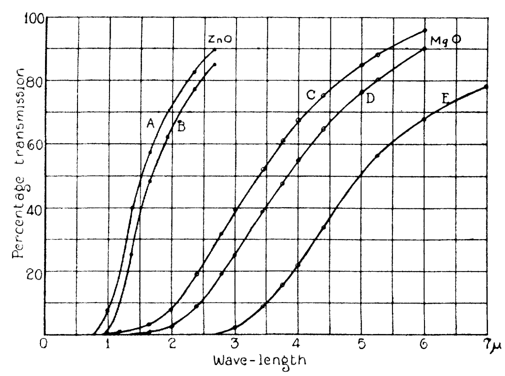

Fig. 1. Transmission curves for films of ZnO and MgO.

terminals. For the thicker film a deep, ruby-red image of an incandescant lamp filament was visible in transmitted light. A similar series for MgO, fumed on speculum is shown in curves *C*, *D* and *E* which apply to films of increasing thickness. In order to obtain the "incident energy" the oxide film was wiped off the speculum mirror.

It is known that zinc oxide particles are smaller than those of magnesium oxide. This is borne out by the curves which show that the transition region for ZnO lies at the shorter wave-lengths. While it is possible to shift this transition region somewhat in the direction of increasing wave-lengths by increasing the film-thickness, a limit is set to this mode of procedure as is evident from the decreasing slope of curve *E*, Fig. 1, in the region of high transparency. It is thus shown that, to produce filters for increasing wave-lengths, particles of increasing size must be used.

Even though a filter, as judged by its transmission curve, may appear to be entirely satisfactory, it is not necessarily so. The total energy associated with any wave-length is given by the product of the following quantities: 1. energy emitted by source. 2. transmission of total air-path. 3. reflection factor for the echelette grating, and 4. transmission factor for filter. This is illustrated in the following curves for films of increasing thickness. In Fig. 2 are plotted the true transmission coefficients of MgO plus cover glass while in Fig. 3 the actual energies are plotted for the same filters. The Nernst lamp was operated at such a temperature as to place the wave-length of maximum emission at 1.9μ, no correction for irrationality of dispersion having been applied. It is this powerful maximum which must be rendered innocuous if regions of greater wave-length are to be studied. It is usually possible to realize any desired freedom from contamination from shorter wave-lengths; but this is accomplished at the expense of transmission. For the time being two arbitrary criteria for acceptable filters have been laid down, i.e. (1) the transmission, in the region under consideration, λ, must be at least 50%, (2) the energy at $\lambda/2$ ought not to exceed 5–10% of the energy at λ. Applying these criteria to specific filters it is evident that filter III, (Figs. 2 and 3) is

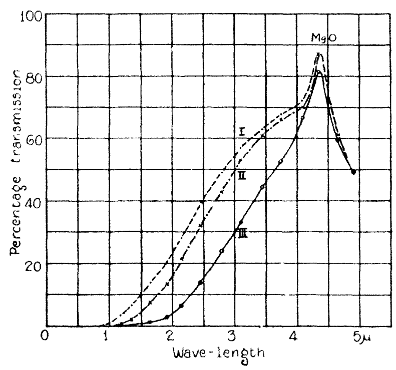

Fig. 2. Transmission curves for various thicknesses of MgO on glass of 0.2 mm thickness. Transmission of glass included in curves.

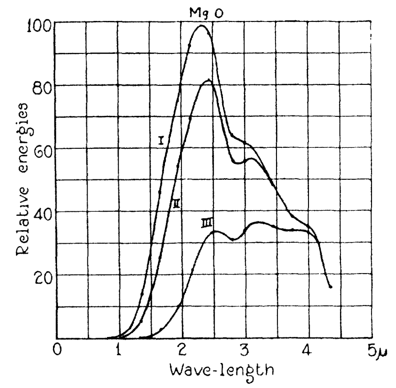

Fig. 3. Relative energies from Nernst lamp transmitted by same films shown in Fig. 2.

most satisfactory in the 3.75μ region. If a wedge-shaped film of oxide be deposited on an over-size speculum mirror, it is easy to pick out the position of the film having the best thickness. If, on the other hand, the film be deposited on microscope cover-glass the latter may be rotated about a vertical axis, thus changing the effective thickness of film, or again, a wedge-shaped film may be deposited.

While the deposition of fumed films is comparatively simple, it becomes difficult to make the thickness uniform whenever the pulverized material is furnished as a dry powder. It is proposed to form films of these materials by the well-known method of "air-flotation." For the time being, films were prepared by dispersing these pigments in water. A small amount of pigment and water were placed on a flat plate of glass and the mixture was ground to a paste of uniform consistency by means of a glass "muller." The latter was then used for applying the paste to the speculum surface. Unfortunately, films produced in this manner are non-uniform in thickness and, as a result the transition range is broadened out. While a graded series of NaCl powders would have been desirable it was found necessary to use such coarser particles as were available, despite the fact that they were known to have bands of absorption in the region of longer waves. The series of filters shown in Fig. 4 were obtained through the use of the following powders whose respective average diameter of particle[5] is given in Table I.

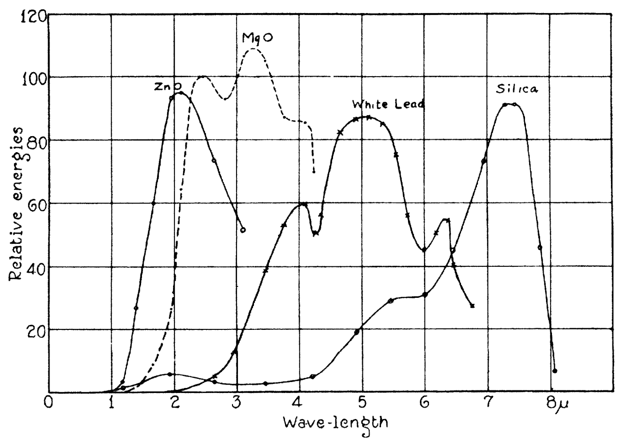

Fig. 4. Relative energies from Nernst lamp transmitted by various filters.

TABLE I.

Powder	Average particle diameter	Mode of application
I. Zinc oxide	0.22μ	Fumed
II. Magnesium Oxide	0.35	"
III. Basic carbonate of white lead	0.50	Water Paste
IV. Silica	2.5	"

These curves for relative energies are so plotted that the maxima have approximately the same heights. Inspection shows that a very fair degree of separation between short and long waves has been effected and that, each filter may be used to advantage in the region of maximum energy. In fact it is evident that, following this general mode of procedure, a filter for almost any desired spectral region may be produced.

The sharp drop of the curve for Silica (SiO_2) near 8μ is due to the true absorption of this material; the same may be said for the sharp drop at 7μ for basic carbonate white lead. In this connection it may be stated that the writer has on record a large number of "transmission" curves for films of powdered sulphates and carbonates spread on polished speculum. These curves reveal a great deal more complexity than do the curves obtained by reflection from polished crystals. The results will be published at a later date.

In carrying out precise measurements with an echelette grating, together with these new filters, it is essential that the slight effect of superposed orders, higher than the first, be taken into account. To accomplish this, it is neces-

[5] The measurements of particle-size were kindly carried out by Mr. G. S. Haslam of the Research Laboratory of the New Jersey Zinc Co.

sary to procure a series of filters whose characteristics are exactly the reverse of those already described. To be specific, if the 4μ region be studied, it is necessary to procure a filter which is entirely opaque at 4μ and highly transparent at 2μ and at all shorter wave-lengths. Fortunately, this problem is relatively simple. As is well known, layers of water, glass, quartz, fluorite, etc., when given the proper thickness, can be made to fulfill the conditions imposed on this type of filter. In this connection it is to be stated that, if nonaqueous filters be desired in the region of the near infrared, corex glass and a urea-formaldehyde condensation product known as Pollapos, are very effective. Corex glass of 3.2 mm thickness is opaque at 3μ while Pollapos of 4.5 mm thickness transmits virtually nothing at 1.6μ. It is harldy necessary to add that the effectiveness of a powder-filter can be increased by choosing a light source such that the emission of shorter wave-lengths is suppressed while that of the longer ones is enhanced as, for example, in case of the Welsbach mantle.

This report is incomplete since specific direction for powder filters covering the entire range of the infrared are not available. It is felt, however, that having described the general mode of procedure, the individual investigator will be guided in the production of filters required for his special needs.