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THE UNIVERSITY OF ROCHESTER

THE INSTITUTE OF OPTICS

ROCHESTER, NEW YORK

PROPERTIES OF MULTILAYER FILTERS

Interim Report

Covering the Period
September 1, 1969 to February 28, 1970

Research Grant No. NGL 33 019 003
with
National Aeronautics and
Space Administration
Washington 25, D.C.

Principal Investigator: P.W. Baumeister

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ABSTRACT

The report discusses the possible uses of films of gold and silver in optical interference coatings for the spectral region from 200 nm to 300 nm. The measured transmittance of solar blind bandpass filters with a passband at 250 nm is shown.

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I. Introduction

During previous periods of this Grant, we designed interference filters for the spectral region from 1200 Å to 3000 Å. The design method is now well understood and the principles of design have been published.[1,2] Two problems remain:

(1) The manufacture of such coatings. This includes an analysis of the tolerance data -- i.e. the effect of changes in the optical constants and errors in the thicknesses of the layers.

(2) The techniques of combining such filters to attenuate in the long-wave portion of the spectrum -- i.e. the addition of blocking filters.

In this report, we focus attention upon the second problem, that of producing suitable blocking filters. In the previous report,[2] we carefully investigated the blocking of 1-M filters by adding two or more blocking filters on the long-wavelength side of the passband. These blocking filters were composed of quarterwave stacks of dielectric layers. The results were surprising. It showed clearly that the effect of the multiple reflections amongst the dielectric stacks is to increase the transmission in the blocking region. It was hoped that an attenuation of 4 optical density units could be attained. Both the theory and experiment showed that a maximum attenuation of two density units was obtained with the addition of <u>four</u> dielectric blockers in tandem with the 1-M. Furthermore, it was clearly shown the mere addition of more dielectric blockers[1] would not substantially increase the attenuation. It is patent that a radical new approach is needed.

The method now under investigation is to sandwich a film of relatively low reflectance between the highly reflecting dielectric blockers. The term "relatively low reflectance" is used to indicate that the film should have a reflectance which is low <u>relative</u> to that of the 1-M filter. Previous results show that the 1-M filter typically has a reflectance of 85% in the spectral region in which blocking is required. If this were reduced to the range of 30% to 50%, the blocking would be measurably improved. Any absorbing coating which contains aluminum has a reflectance which is not far removed from this value of 85%. Thus it is clear that the only method of achieving this reduced absorptance, is to use metals other than aluminum. This is discussed in Section II.

Finally, there is another obvious method of increasing the effectiveness of the blocking filters. This is to incline the filters at an angle, so that the multiple reflections do not occur, as shown in Fig. 1. The advantages and disadvantages of this arrangement are discussed in Section III.

II. The Properties of Metals with Low Reflectance

There are at least 30 different metals which could be considered for use in blocking filters for the spectral from 2000 Å to 3000 Å. Many of these are immediately excluded because of the absorbing oxide film which forms immediately on the surface, as for example chromium and copper. The electronic states of the transition metals and the ferromagnetic metals have many band-to-band transitions and are quite absorbing. The metals with high electrical conductivity hold the most promise. Gold has long been used for calibration of reflectance standards, etc. because of its chemical inertness and stability. In the near infrared, its reflectance is close to that of silver. The other metal is evidently silver, which would exhibit the same high reflectance as aluminum, were it not for the effect of the electronic interband transition which is manifested in the dip to low reflectance at 3200Å.

The silver films were deposited at a vacuum pressure gage reading of 10^{-5} torr. The thickness was controlled by monitoring the transmittance in the visible portion of the spectrum -- the corresponding thicknesses are approximately 150Å and 250Å for the two films, respectively.

The measured reflectance R and transmittance T of the silver films are Figs. 2 and 3 respectively. The reflectance minimum and transmittance peak at 3200Å have been the subject of many studies. The R and T tell only part of the story, if these films are to be used in optical filters. As described in more detail in previous reports and publications[1,2], it is possible to enhance the transmittance by adding nonabsorbing thin films to either side of the coating. The radiant power flow ratio $T/(1-R)$ is a measure of the potential transmittance of the coating. This is computed from the measured R and T and is depicted in Fig. 4. If the outer surface of the silver were antireflected, then the A/T ratio of the coating would remain constant, (where A is the radiant absorptance), even though both A and T would increase. For example, we see that at wavelength of 2500Å, T is 35%, R is 28%, and A is 37%. If this silver film were antireflected, then T increases by 13% to 48%, and the absorptance to 52%. This peak transmittance is barely acceptable. The problem with using silver for the blocking in the 3000Å to 3400Å part of the spectrum, is that it has a considerably higher transmittance in this region than at shorter wavelengths, notwithstanding the antireflection coatings which are applied at these shorter wavelengths. Thus we conclude that the use of silver in these filters in the 2500Å region is marginal. That is, it can possibly be used, but we should first look for other materials.

As shown in Figs. 5 and 6, the reflectance and transmittance of the gold films is considerably flatter, and does not display the troublesome transmittance leak at 3200Å, as does the silver. However, the T/(1-R) curve (shown in Fig. 7) is not very encouraging. The thinner gold film has a T/(1-R) of only 25% at 2500Å. The T/1-R is still lower for the thicker film. The transmittance of the gold blocking filter is too low to be considered for use in filters.

III. Tandem Arrays of Filters with Large Attenuation on the Long-wave Length Side of the Passband

The previous report described some tandem arrays of

1-M filters and multilayer layer blocking filters. The objective was to add attenuation to a 1-M bandpass filter with a transmittance peak in the 2500Å region so that it can be used with a solar blind CsTe photocathode.

A previous report discussed the method adding the blocking filters in series with the one-M filter, as shown in Fig. 1. The filters are all at normal incidence and the multiply reflected beams are all collected by the detector. This has the advantage that the filter package is compact, but has the disadvantage that the peak attenuation is not very large.

Another method is to arrange the filters at an angle of 30°, as shown in Fig. 1, so that the multiply reflected beam "walk off" and are reflected out of the system. In this case, it is patent that the offband attenuation increases substantially because the optical densities of the individual filters directly add. The disadvantage is that the filter assembly is now rather bulky. It also has some inclined surfaces which introduce astigmatism and other aberrations, when used in an imaging system.

In measuring the transmittance of these stacks at angle, care was taken to correct for any residual polarization produced by the spectrophotometer. That is, the flux emerging from the Cary model 14 spectrophotometer is a mixture of unpolarized and linearly polarized flux. This effect of the polarization can be taken into account by rotating the filter assembly about an azimuthal axis which is coincident with the beam. For example, Fig. 8 shows the transmittance of a one-M filter (curve a) at normal incidence. The other (curve b) is at an angle of 30° incidence. The dashed part of curve b the transmittance at 30°, with the azimuthal angle of the filter stack rotated by 90°. The transmittance actually changes slightly at all wavelengths, but is only appreciable in the passband region, as shown by the dashed curve. In all of the measurements of the other filters at non-normal incidence, the same care was taken to insure that the effect of the polarization of the spectrophotometer was taken into account. Figure 9 depicts the measured transmittance of a typical blocking filter at 30° incidence (curve b) and at normal incidence (curve a). Transmittance curves were run on the other blocking filters, but they are so similar to the curve shown in Figure 9, that there is no point in including them in this report.

Figure 10 shows the measured transmittance of the one-M filter (shown in Fig. 8) combined with two blocking filters (as shown in Fig. 9). The angle of incidence is 30° degrees and the filters are arranged so that the multiply reflected beams are deflected from the optical path. Figure 11 shows the same one-M filter, but with four blocking filters added in tandem. The angle of incidence is again 30°. An attenuation (compared to the peak transmittance) of more than <u>four</u> optical density units is obtained. In measuring the transmittance when the density is very large, care was taken to insert additional filters in the beam of the Cary model 14 spectrophotometer, in order to minimize the scattered flux.

From the results of Figs. 10 and 11, it is clear that an impressive attenuation is obtained in the long-wavelength side of the passband. However, in order to produce a truly solar blind configuration which can be used with a CsTe photocathode, the region of high attenuation should be extended to 3200Å. This means that more blocking filters should be added to the array.

IV. Personnel

Philip Baumeister:	Principal Investigator No salary charged From September 1, 1969 To February 28, 1970

Douglas Harrison: Graduate Research Assistant
No salary charged

Gary DeBell: Graduate Research Assistant
One half time
Two months, 50%

V. References to the Literature

1. *Properties of Multilayer Filters*
Interim report of NGL 33 019 003
March 1, 1969 to August 31, 1969

2. P. W. Baumeister, "Radiant Power Flow and Absorptance in Thin Films", *Appl*. *Opt*. *8*, 423, 1969

VI. Captions to the Figures

1. The arrangement of a tandem array of filters in which
   (a) the surfaces are parallel and hence the multiply reflected beams are collected by the detector, and
   (b) The surfaces are inclined and hence the reflected beams are deflected out of the system.
2. The measured spectral transmittance of silver films of thicknesses approximately 150Å (curve *a*) and 250Å (curve *b*) in thickness, deposited on a fused quartz substrate.
3. The measured spectral reflectance of the same

silver films, as described in the caption to Fig. 2. The dotted portion of the curves is extrapolated.

4. The radiant power flow ratio, $\underline{T}/(\underline{1}-\underline{R})$ of the silver films described in the caption to Fig. 2. The dotted portion of the curve uses the extrapolated reflectance values shown in Fig. 3.

5. The measured spectral transmittance of gold films of thicknesses approximately 150Å (curve a) and 250Å (curve b), deposited on a quartz substrate.

6. The measured spectral reflectance of the same gold films, as described in the caption to Fig. 4.

7. The radiant power flow ratio, $\underline{T}/(\underline{1}-\underline{R})$ of the gold films described in the caption to Fig. 5.

8. The measured spectral transmittance of one-M filter at normal incidence (curve a) and at 30° incidence (curve b). The dashed portion of curve b is with the filter rotated by an azimuthal angle of 90° about an axis parallel with the respect to beam of the spectrophotometer.

9. The measured spectral transmittance quarterwave

stack type of a blocking filter which consists of 27 layers of thorium flouride and cryolite. Curve <u>a</u> is at normal incidence and curve <u>b</u> is at 30^{o} incidence.

10. The measured spectral transmittance of a one-M bandpass filter in tandem two quarterwave stack type blocking filters. The latter are similar to the filter whose transmittance is depicted in Fig. 9. All of the filters are inclined at an angle of 30^{o} to the incidence flux and are arranged so that the reflected beams are deflected out of the system.

11. The measured transmittance of a one-M bandpass filter in tandem with four quarterwave stack type blocking filters. The description of the filters in the caption to Fig. 10 applies to these filters.

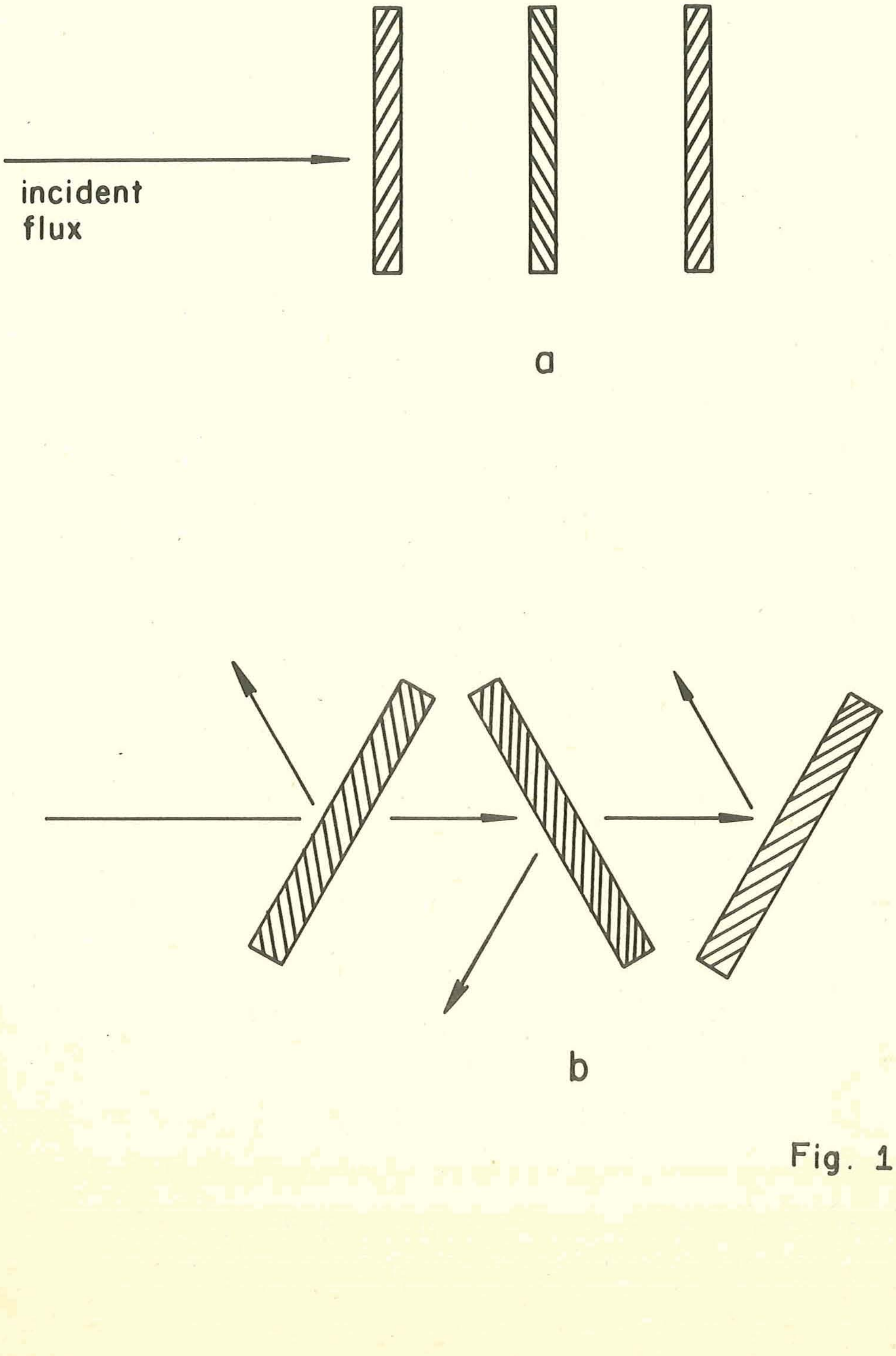

Fig. 1

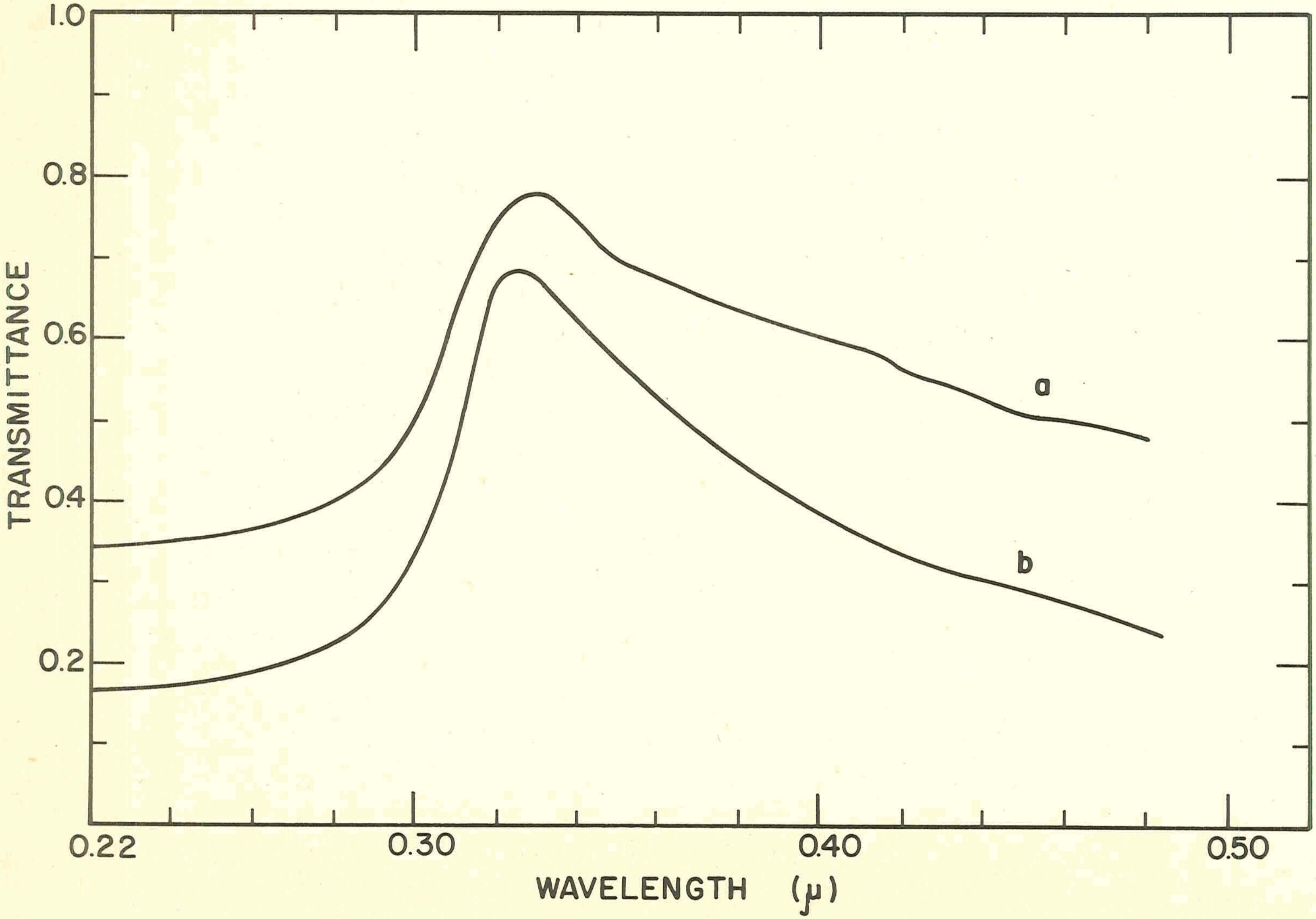

Fig. 2

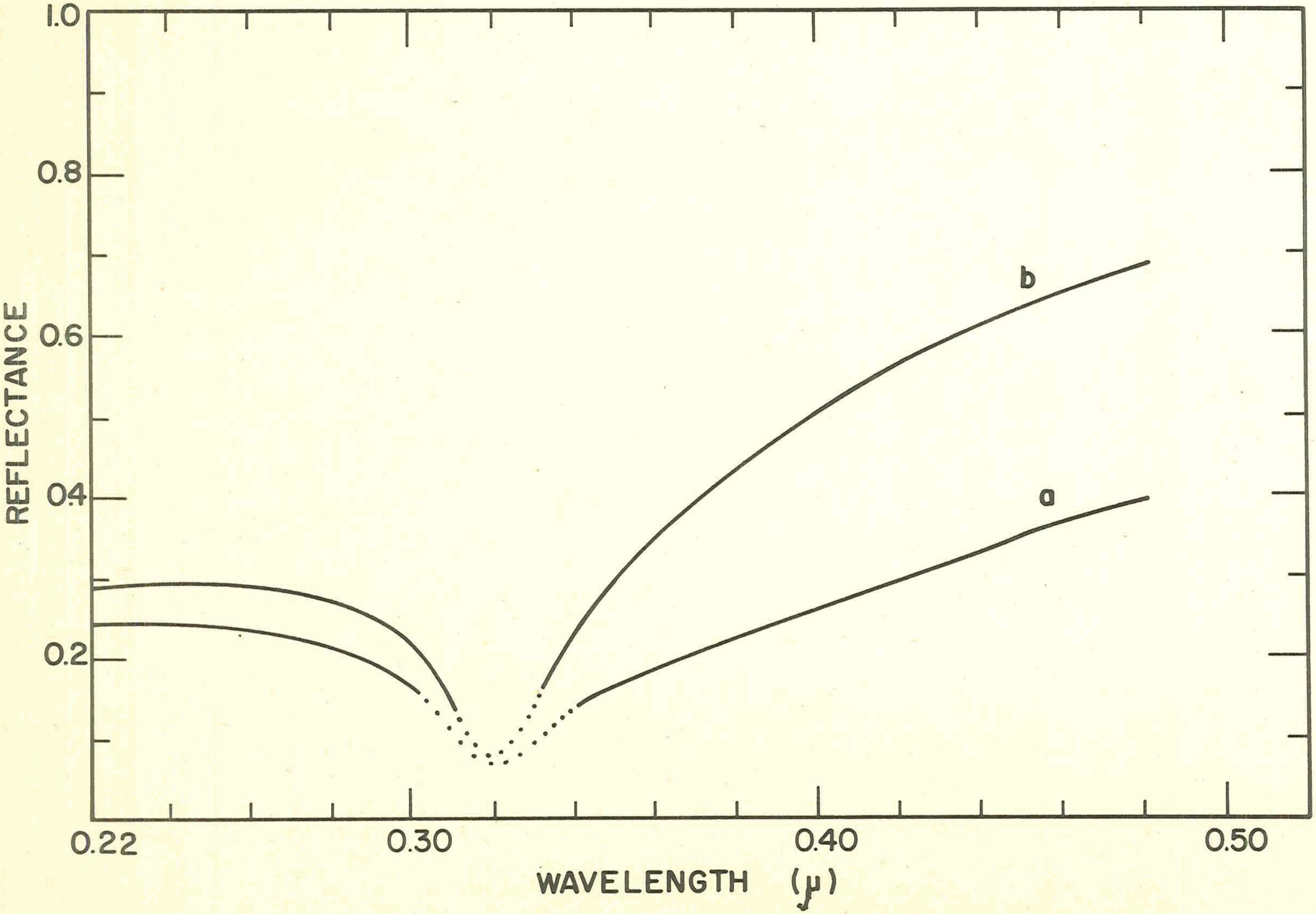

Fig. 3

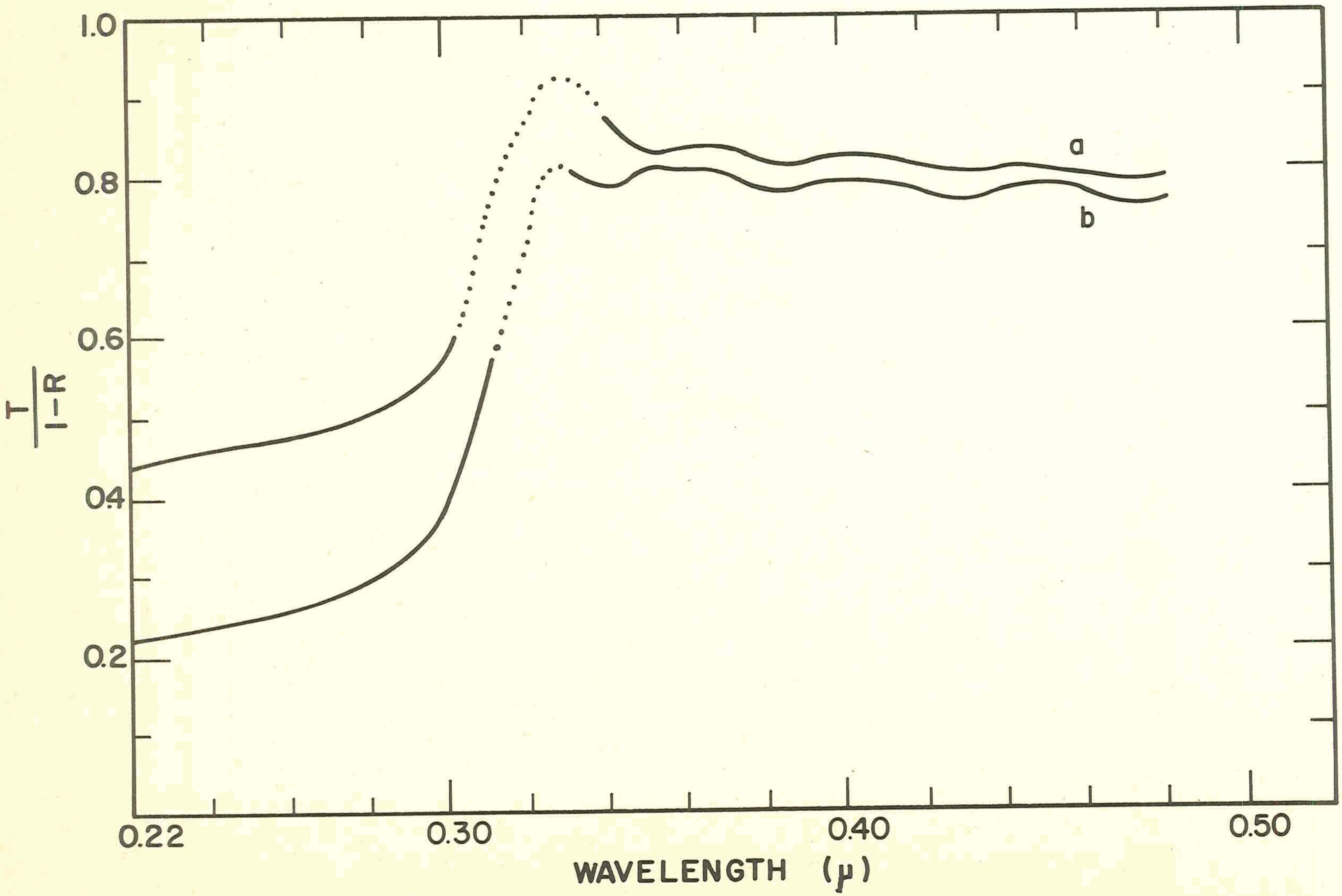

Fig. 4

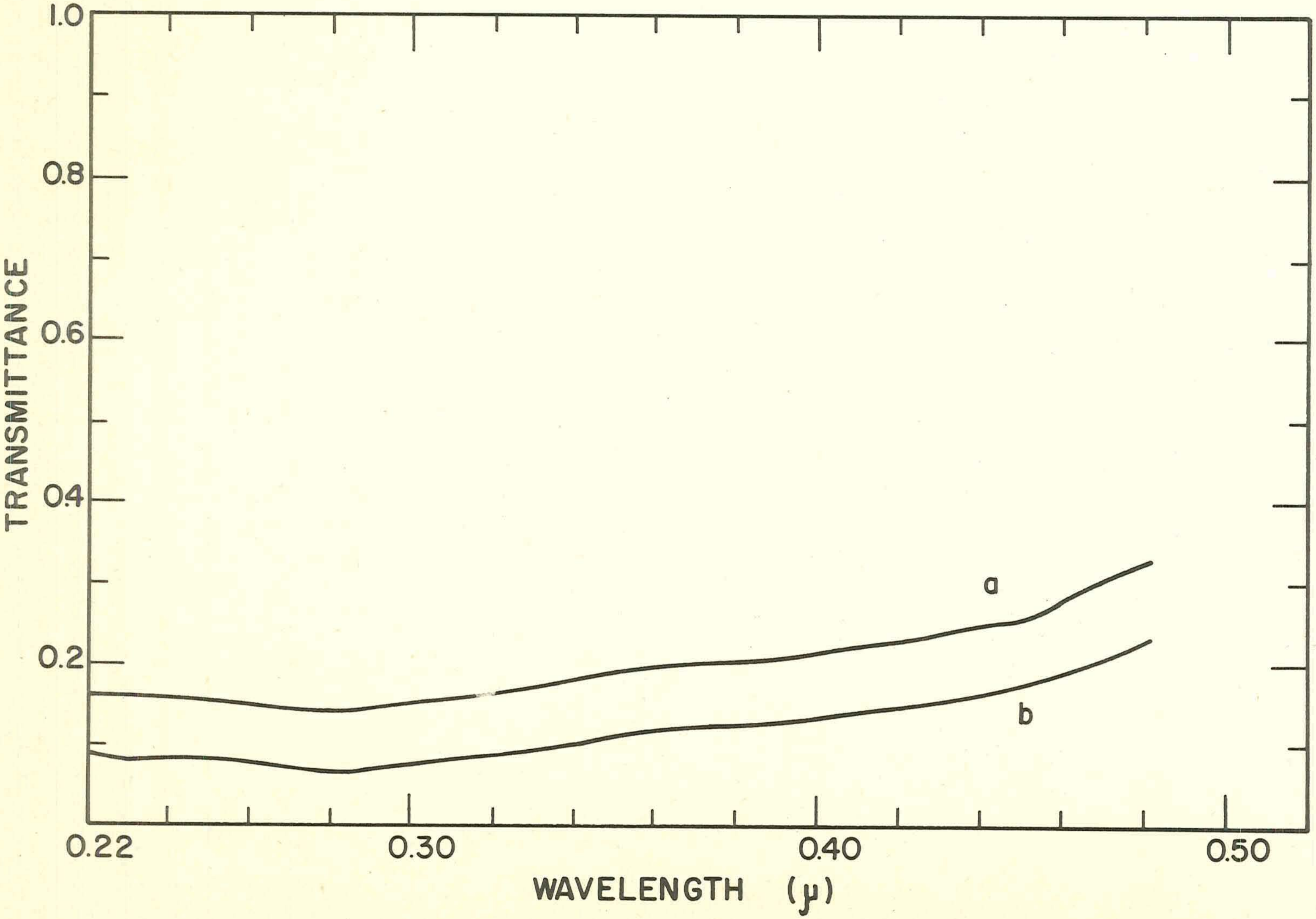

Fig. 5

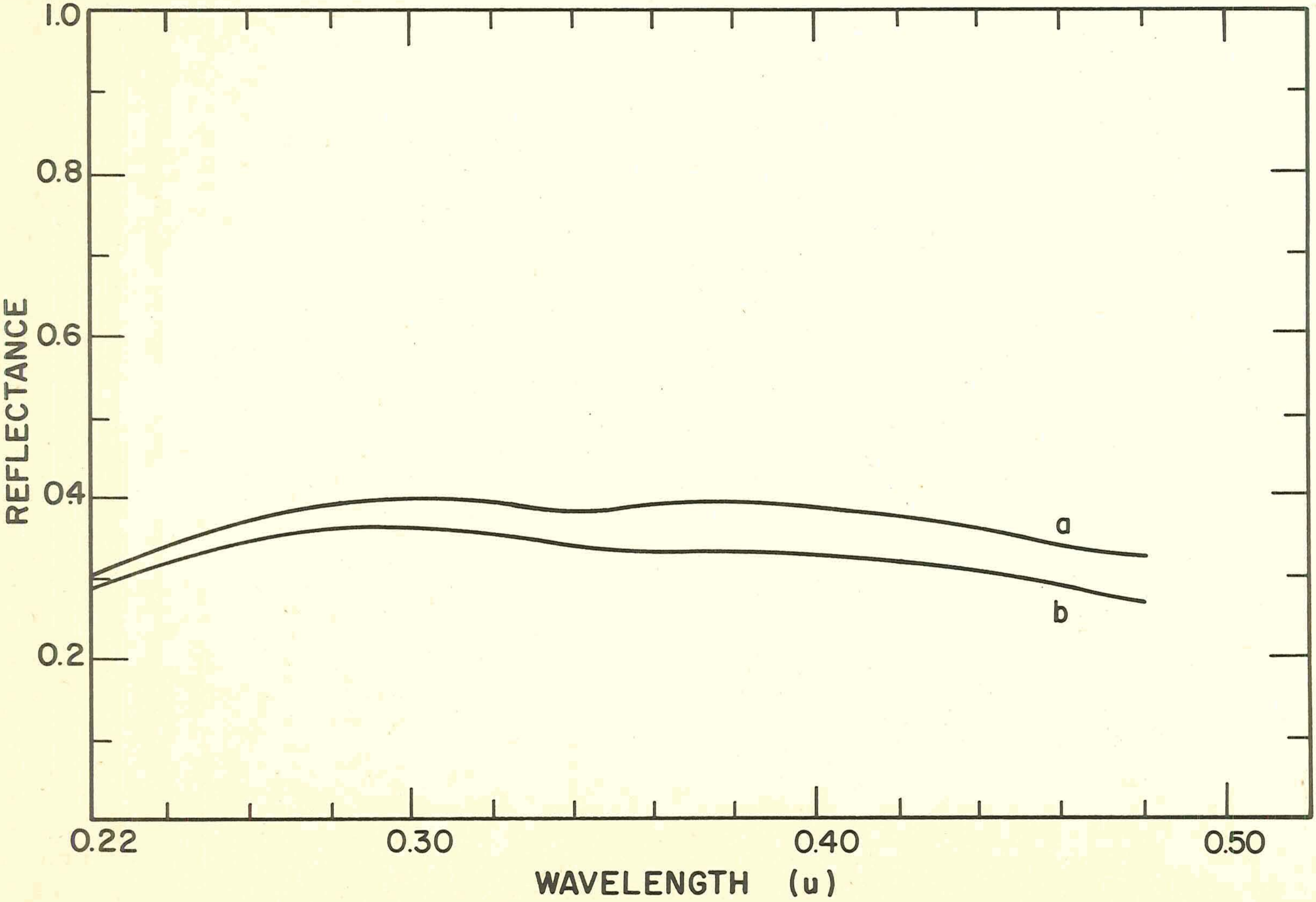

Fig. 6

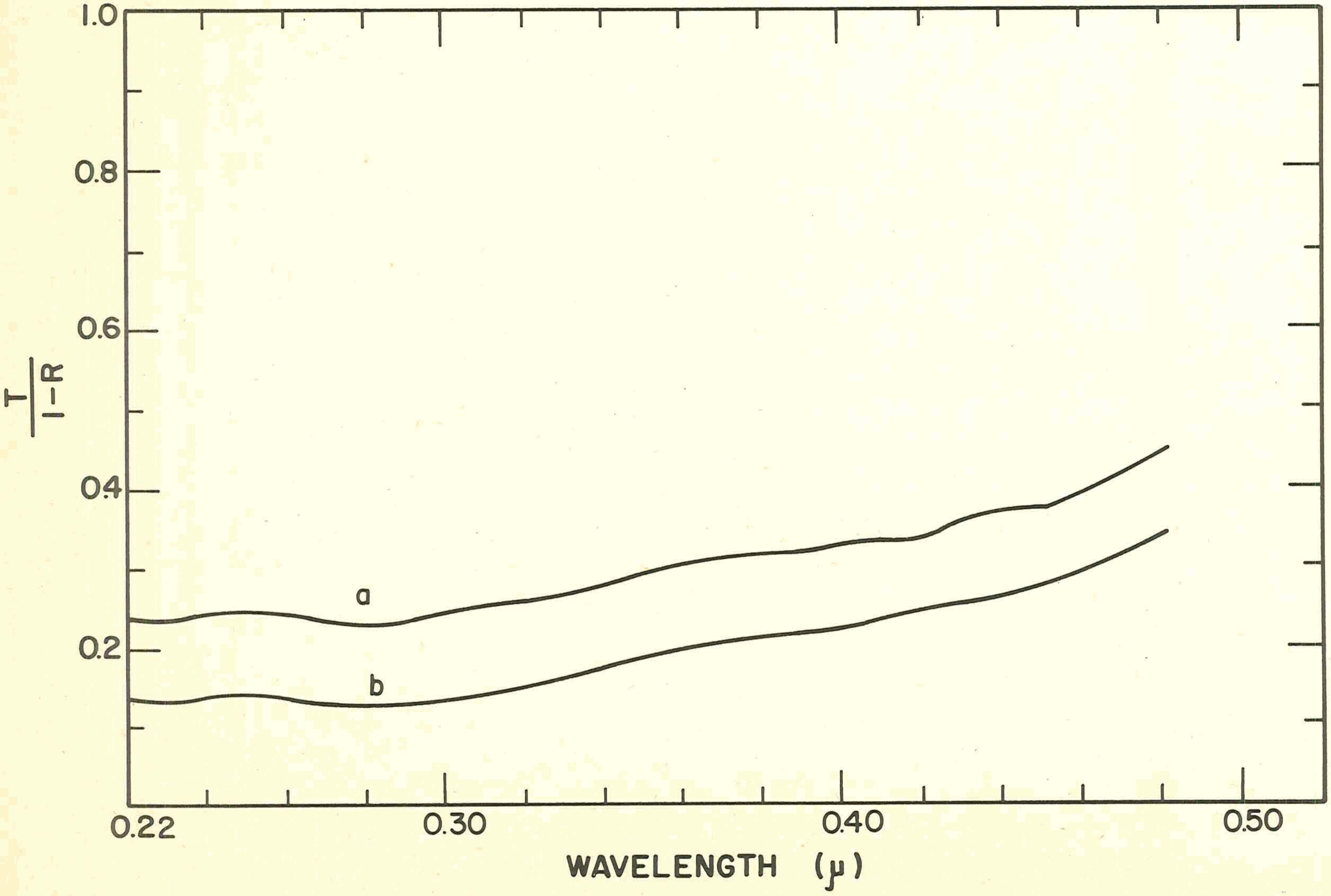

Fig. 7

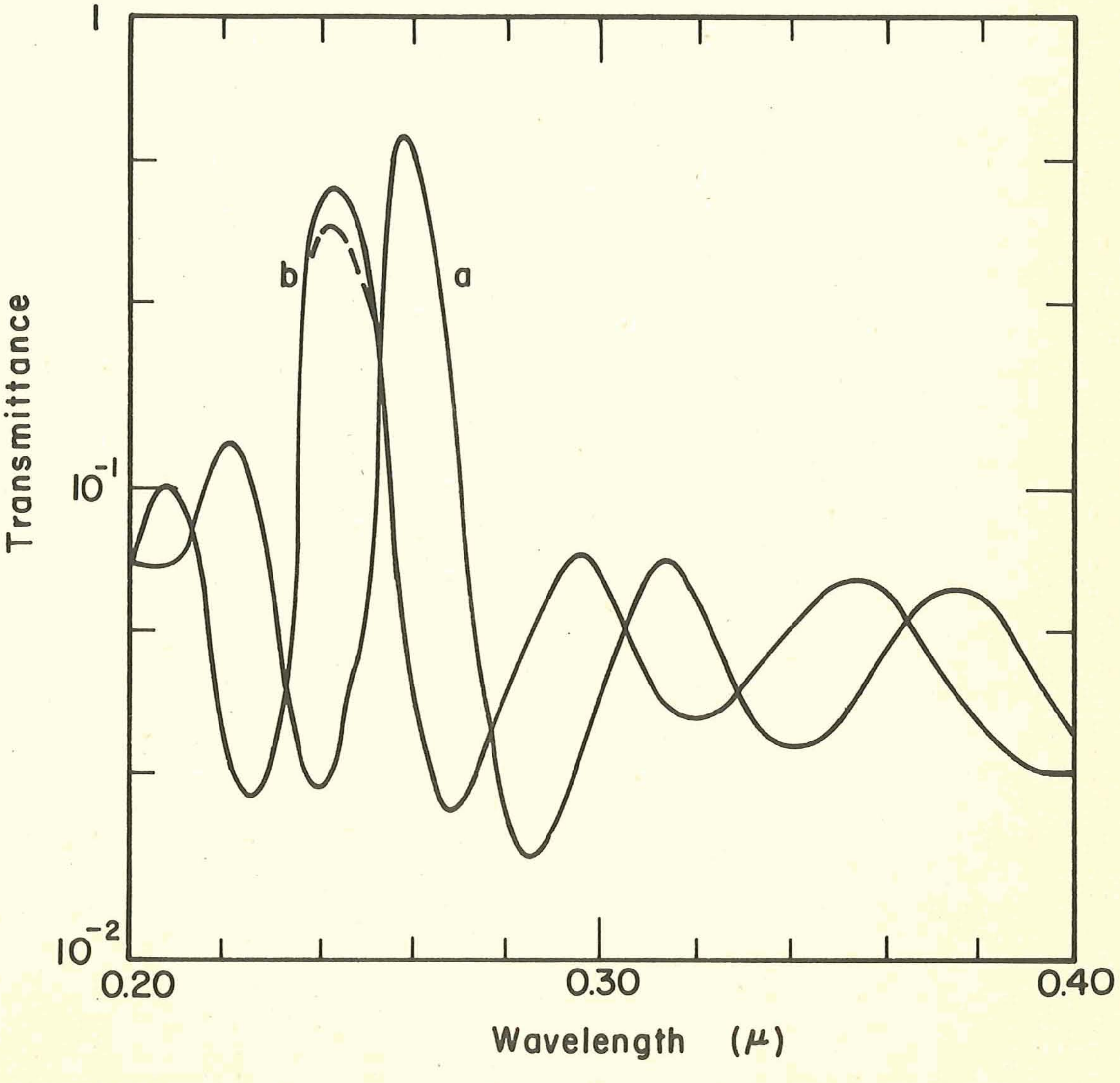

Fig. 8

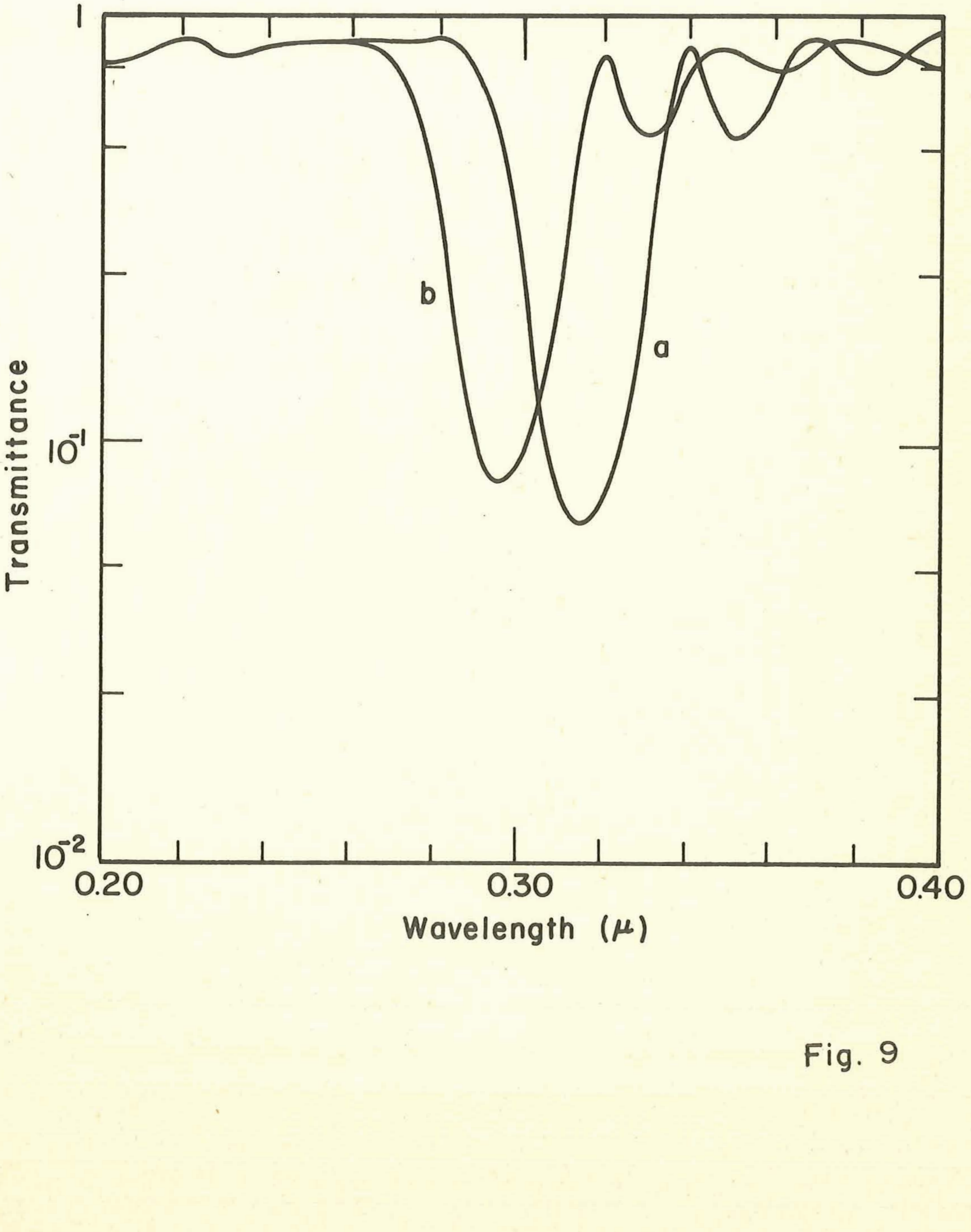

Fig. 9

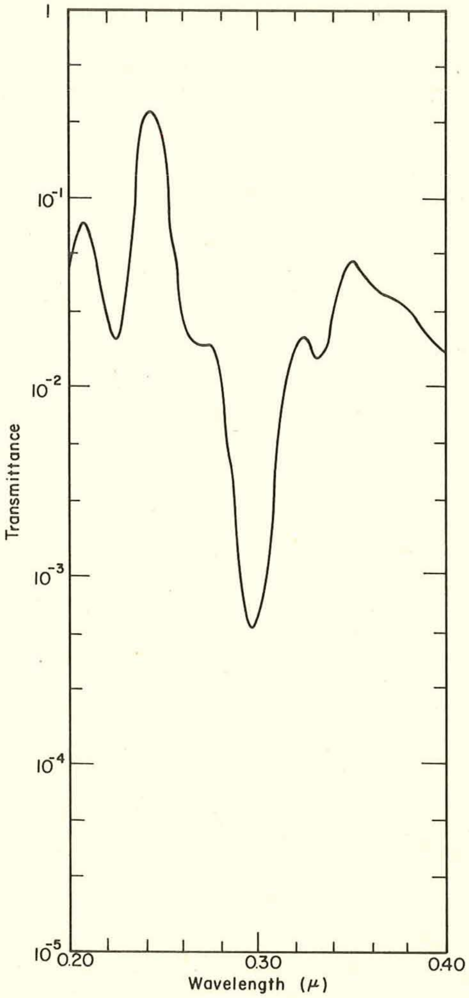

Fig. 10

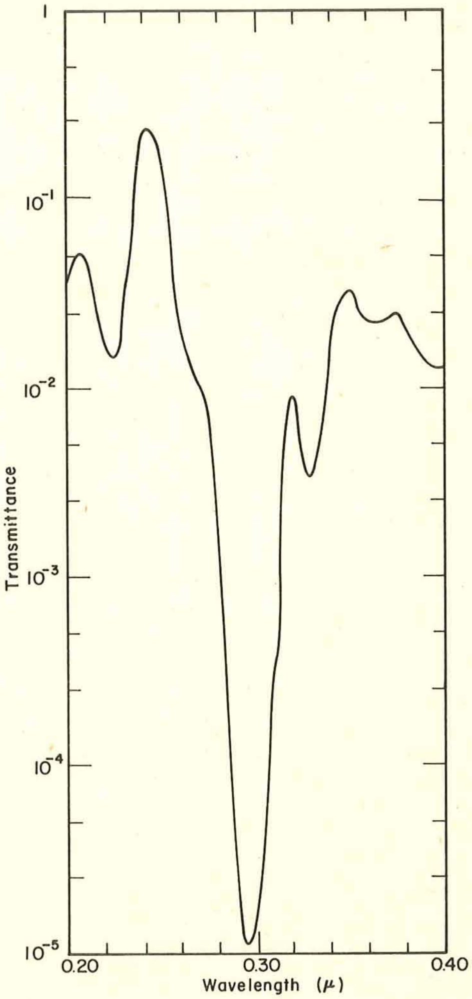

Fig. 11