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To cite this version:


HAL Id: jpa-00213234
https://hal.archives-ouvertes.fr/jpa-00213234

Submitted on 1 Jan 1967

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THE VARIATION OF THE TRANSMISSION WAVELENGTH
OF INTERFERENCE FILTERS BY THE
INFLUENCE OF WATER VAPOR

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Abstract. — The shift of the wavelength of maximum transmission of all dielectric interference filters of the Fabry-Perot type consisting of ZnS and MgF₂ layers under the influence of a partial vapor pressure of water was investigated. It was found that under certain conditions the wavelength of maximum transmission can be reproducibly shifted back and forth over a range of about 50 Å without any measurable change of the other optical data such as maximum transmission or half-width of the band pass.

Résumé. — On a étudié le déplacement de la longueur d’onde du maximum de transmission de filtres interférentiels du type Fabry-Perot à couches dielectriques de ZnS et MgF₂ sous l’influence d’une tension de vapeur d’eau partielle. On a trouvé que dans certaines conditions on pouvait déplacer d’une façon reproductible la longueur d’onde du maximum de transmission d’environ 50 Å dans les deux sens sans provoquer de variation mesurable des autres données optiques telles que la transmission maximale ou la largeur de bande.

I. Introduction. — During the production of all dielectric interference filters of Fabry-Perot type consisting of ZnS and cryolite or of ZnS and MgF₂ it was observed that the wavelength of maximum transmission measured after the evaporation is always larger than that, which follows from the thickness control during the evaporation. For filters made of ZnS and cryolite the mean value of the shift is about 1.5 % and for those made of ZnS and MgF₂ about 3.5 %. In order to get more reproducible results for different evaporations the reason for this effect was investigated.

It could be shown that the wavelength of maximum transmission is identical within a few Å to the wavelength for which the layers have been deposited if the filters are measured after the evaporation still in the vacuum and that the shift is produced during the admittance of the air to the apparatus. If the admitted air is completely dry no shift is observed. But different partial vapor pressures of water, which were achieved by changing the temperature of a water reservoir connected to the evaporation receptacle cause a different change of the wavelength of maximum transmission proving that the humidity of the atmospheric air admitted to the receptacle causes the shift.

It is known from a paper of Koppelmann, Krebs and Leyendecker [1], who investigated single cryolite layers under similar conditions that the refractive index of cryolite may change when the partial vapor pressure of the water is changed in the surroundings. Therefore it seems that a change of the optical path in the spacer layer is responsible for the shift of the filters. There are no measurements corresponding to those of Koppelmann et al. for the refractive index of MgF₂ but it seems plausible that this substance exhibits a similar behavior. There is no significant change in the high reflecting layers by the water vapor because the coefficient of maximum transmission and the half-width of the pass band are not changed within the accuracy of the measurements during the shifting of the filters.

For many purposes of optical and especially of optical high frequency spectroscopy interference filters are used. It is therefore interesting to get quantitative values for the variation of the wavelength of maximum transmission caused by the humidity of the surroundings because the stability of a filter depends on this. The aim of the investigations at present was not to clarify the phenomenon but to see how large the shift can be and also whether it could be used for a tuning of the wavelength of maximum transmission of an interference filter desirable for many experiments. Moreover the investigations have been limited to interference filters consisting of multilayer filters of ZnS and MgF₂ since the shift of the wavelength of maximum transmission
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for such filters is larger than those made of ZnS and cryolite. Moreover MgF₂ seems to be more resistant against damage by humidity than cryolite.

II. The Optical Set-up. — The vacuum evaporation apparatus for the deposition of dielectric layers is described by Hefft, Kern, Nöline and Steudel [2]. The optical set-up used for the measurement of the transmission spectrum of the different interference filters is shown in Fig. 1. The white light source was a projector lamp of 100 W and 12 V. The bandwidth of the spectrum transmitted by the monochromator was always smaller than 6 Å. The cross-section of this light beam at the place of the filter was about $2 \times 3 \text{ cm}^2$. So the results obtained in the measurements are mean values over this area. The diameter of the filters was 6 cm. To measure the light intensity a EMI 6256 photomultiplier was used. The glass vessel with the mount for the interference filter is shown in detail in figure 2.

![Diagram of the optical set-up](image1.png)

It is connected to a water reservoir the temperature of which is determined by a surrounding bath. For the measurements described below the temperature was varied between $-20^\circ$ and $+20^\circ$ C. The gas pressure in the glass vessel and the water reservoir was 0.1 $- 1 \text{ mm Hg}$. This pressure was chosen to enable a fast diffusion of the water vapor.

![Diagram of the glass vessel](image2.png)

It can be moved into or out of the path of light beam by pushing or pulling the button to the left. The arrow indicates the connection to the vacuum apparatus and to the water reservoir.
III. Results of the Measurements. — Some typical results are presented which show the general behavior of the interference filters under the influence of the water vapor. The change of the wavelength of maximum transmission observed at different vapor pressures for a filter measured in the evaporation chamber after evaporation without admitting air is shown in Fig. 3 (curve 1). The different values are reached in about ten to twenty minutes after a new set point of the temperature bath of the water reservoir had been attained. Within the experimental accuracy there is a linear connection between the shift of the wavelength of maximum transmission and the logarithm of the vapor pressure of the water. The straight line was determined by a least square fit of the different points. The same connection is also found for the other measurements discussed below. The results for another filter are shown in Fig. 4. This was removed from the evaporation chamber and kept in a closed container with atmospheric pressure and a relative humidity of 25 % for 30 days. \( \lambda_0 = 5181 \text{ Å} \). The bars indicating the errors of the measurements are representative for all the points of one curve.

When the filters are old nearly no change of \( \lambda_0 \) and also of the possible variation by the vapor pressure is observed. This is shown in Fig. 5, curve 1. Only when they are kept under high vapor pressure of water they will continue to change (Fig. 5 curve 2). For all the measurements described the other optical data is kept constant. This was done by covering the filter layers with a glass plate and cementing it with a synthetic resin (e.g., Araldit) at the edge.

**Fig. 3.** Shift \( \Delta \lambda \) of the wavelength of maximum transmission with respect to the corresponding wavelength \( \lambda_0 \) for 1 mm Hg for different partial pressures of the water. Type of filter: second order filter, \( 2 \times 7 \) reflecting layers of ZnS and MgF\(_2\), spacer layer MgF\(_2\). Maximum transmission \( T_{\text{MAX}} = 81 \% \), half width of pass band \( \delta \lambda_{50} = 45 \text{ Å} \), wavelength of maximum transmission measured in the vacuum after the evaporation \( \lambda' = 4995 \text{ Å} \).

Curve 1. — Measurement of the filter in the evaporation apparatus after evaporation without admitting air. \( \lambda_0 = 5106 \text{ Å} \).

Curve 2. — Measurement of the filter in the glass vessel (Fig. 2) after keeping it in a closed container after evaporation at atmospheric pressure and a relative humidity of 30 % for 10 days. \( \lambda_0 = 5181 \text{ Å} \). The bars indicating the errors of the measurements are representative for all the points of one curve.

**Fig. 4.** Shift of the wavelength of maximum transmission with respect to the corresponding wavelength \( \lambda_0 \) for 1 mm Hg, for different partial pressures of the water. Type of filter: second order filter, \( 2 \times 7 \) reflecting layers of ZnS and MgF\(_2\), spacer layer MgF\(_2\). \( T_{\text{MAX}} = 58,2 \% \), \( \delta \lambda_{50} = 38 \text{ Å} \), \( \lambda' = 4204 \text{ Å} \) (for notation see the caption of figure 3).

Curve 1. — Measurements of the filter in the glass vessel (Fig. 2) after keeping it in a closed container after evaporation at atmospheric pressure and a relative humidity of 25 % for 6 days. \( \lambda_0 = 4353 \text{ Å} \).

Curve 2. — Measurement of the filter 95 days after evaporation keeping it under the same conditions as above. \( \lambda_0 = 4373 \text{ Å} \).
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FIG. 5. - Shift of the wavelength of maximum transmission with respect to the corresponding wavelength \( \lambda_0 \) for 1 mm Hg, for different partial pressures of the water. Type of filter: second order filter, 2 \( \times \) 7 reflecting layers of ZnS and MgF\(_2\), spacer layer MgF\(_2\), \( T_{\text{max}} = 87.0 \% \), \( \Delta \lambda_{\text{sh}} = 32 \AA \), \( \lambda' = 4.438 \AA \) (for notation see the caption of figure 3).

Curve 1. — Measurement of the filter in the glass vessel (Fig. 2) after keeping it in a closed container at atmospheric pressure and a relative humidity of 25 \% for 240 days after evaporation. \( \lambda_0 = 4.651 \AA \). The measurements have been repeated after another 145 days keeping the filter under the same conditions. The results obtained were the same, as before, even \( \lambda_0 \) had not changed.

Curve 2. — Measurement of the filter after keeping it in the glass vessel at a vapor pressure of the water of 18 mm Hg for 3 days. \( \lambda_0 = 4.655 \AA \).

parameters of the filters such as half-width of the band pass and maximum transmission do not change within experimental accuracy.

The support of the Deutsche Forschungsgemeinschaft and the niedersächsische Minister für Wirtschaft und Verkehr is gratefully acknowledged.

Bibliographie


INTERVENTIONS

B. Billings. — At Baird Atomic we had humidity problems about 15 years ago. Not only did the filters drift but they changed wavelength in spots rather than uniformly over the surface. Do your filters change wavelength uniformly?

Réponse: The results described (Fig. 3, 4 and 5) are mean values of the optical data over an area of 2 \( \times \) 3 cm\(^2\). In order to investigate the variation of the wavelength of maximum transmission for smaller areas some filters have been probed also by a light beam of 1 mm diameter. It was found that for different points of the surface the shift differed from the medium shift by at most 2 \%.

R. S. Sternberg. — Has it been found possible to «freeze» a filter at a desired wavelength, by exposing it to an atmosphere of suitable water vapour pressure, and then sealing it with a cemented cover glass.

Réponse: Yes, that we have done many times. After the filter had reached the desired wavelength it was covered by a glass plate and sealed by synthetic resin. After that no further variation of the transmission wavelength was observed.

J. Katzenstein. — What is the change if any in the form of the transmission curve of the filter after a number of humidification cycles?

Réponse: For variation of humidity in the range used for the measurements described no change of the optical parameters of the filters as half width of the band pass and maximum transmission was observed even after many humidification cycles.

J. Ring. — Another way of tuning filters in a small range of wavelength is to use the temperature effect. Typically this about 5 \( ^\circ \text{C}/\text{Å} \) so that 10-20 \( \text{Å} \) shift is easily obtained.

G. Henderson. — I would like to say that this phenomenon is most interesting in that it may well explain anomalous results some workers have obtained in the study of airglow. It was thought that possible temperature effects on the forefilter might be the cause but until now I don’t think that humidity effects have been considered.