On the transmission of light through tilted interference filters

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The transmission characteristics of commercial interference filters are not quite what we expected from the specifications provided by manufacturers. The unexpectedly sharp dependences of the transmission coefficient on the incidence angle, wavelength, and on the position where the light beam falls on the filter may be important in the analysis of systematic effects in experiments incorporating interference filters.

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Despite its official appearance, this is just an informal write-up intended to summarize some observations that have surprised us (but perhaps should not have). The book [1] provides an excellent discussion of the theory and practice of interference filters; however, it does not specifically mention the effects we observe.

The setup that we used for measuring the transmission characteristics of interference filters is straightforward. The light beam from a Spectra Physics Model 117A He-Ne laser (\(\lambda = 632.8\) nm) is attenuated with a color-glass plate (transmission \(\approx 10\%\)). It then passes through the interference filter under investigation, which is mounted on a tilt stage, in turn mounted on a multi-coordinate translation stage. The transmitted light intensity is measured with a silicon photodiode.

![Figure 1](image)

**FIG. 1:** Experimental dependence of the transmitted light intensity as a function of the tilt angle of the filter with respect to the laser beam. In order to see the details of the transmission dependence on the angle at large angles where the transmission through the filter is low, data were taken with the attenuator removed from the beam path.

Figure 1 shows the transmission through a 10-nm bandpass filter with central wavelength 630nm (manufacturer unknown) as a function of the tilt angle of the filter with respect to the nominal direction of the laser beam. The colored plate was positioned 1cm away from the laser, the interference filter was placed 5cm from the plate, and the photodiode was 4.5 cm after the filter. The filter was rotated about an axis perpendicular to the laser beam and measurements were made at 0.25-degree intervals.

As expected, the transmission falls off as the tilt angle becomes large. However, instead of the expected smooth dependence, we see that there is an oscillating structure superimposed on the smooth dependence with \(\sim 10\) periods over the transmission window. The oscillating structure comprises \(\sim 15\%\) near zero tilt angles, but its relative amplitude increases as the overall transmission decreases. At large tilt angles, the oscillation becomes an essentially 100\% effect. In order to see the large-angle regions more clearly, we have also recorded the transmission with the color-glass attenuator removed (Fig. 1).

We have then looked at the spatial uniformity of the transmission through the filter with a fixed tilt angle. This was done by moving the filter with a fixed tilt angle in a direction perpendicular to the laser beam and monitoring transmission. As seen in Fig. 2, we found that, indeed, the transmission is strongly dependent on the position.

Next, we examine essentially the same effects, but in a slightly different arrangement. The images shown in Figs. 3 and 4 were produced by inserting a diverging lens \((f = -6\text{ cm})\) 1 cm after the attenuator (between the attenuator and the interference filter). The photodiode was replaced with a Coherent LaserCam II CCD camera. The negative lens converts the 1-mm diameter laser beam to a diverg-
FIG. 2: An example of the experimental dependence of the transmitted light intensity as a function of the filter displacement in the direction perpendicular to the laser beam. The normal to the filter is tilted by 8 degrees with respect to the direction of the collimated laser beam (no lens is used for this measurement).

FIG. 3: Transmission pattern through the same filter for a diverging laser beam taken with a CCD camera. Different frames correspond to the tilt angle of the filter by 0 degrees (upper left frame), 4, 8, and 12 degrees (lower right frame).

FIG. 4: Same as in Fig. 3, but for another interference filter (Corion) also centered at 630 nm. The tilt angles are from 0 to 20 degrees with increment of 4 degrees.

The effects described above seem to be rather universal. We have observed interference fringes qualitatively similar to the ones discussed above with several filters at different wavelengths with dye lasers in the yellow-red and an Ag hollow-cathode lamp emitting narrow resonance lines at 328 and 338 nm as light sources.

Obviously, it is important for anyone who is working with interference filters and narrow-band light to be aware of the transmission peculiarities such as the ones described in this note. Clearly, the oscillations such as the ones shown in Fig. 1 would also show up in a plot of transmission vs. the wavelength for monochromatic light. Yet, when a transmission plot arrives with a newly-purchased filter (or when we
take the transmission curve ourselves using a scanning spectrophotometer), oscillations are usually not there. Probably, this is because the spectral window of the spectrophotometer is broader than the characteristic period of the oscillation, so the oscillations average in the recorded spectrum.

Of course, it is not too surprising to see interference effects, albeit unwanted ones, in an interference filter. It would be interesting to apply thin-film-simulation software to model a specific filter to figure out the exact origin of the observed effects (and, perhaps, figure out ways to eliminate them). The rotation of an interference pattern with rotation of the filter suggests that this pattern is related to wedging – imperfect parallelism between layers of the filters.

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[1] H. A. Macleod, *Thin-Film Optical Filters*, Third Ed., IOP, Bristol and Philadelphia, 2001, 641 pp.