TECHNICAL NOTE

CONSTRUCT A MONOCHROMATOR FROM A SINGLE INTERFERENCE FILTER

Researchers in the behavioral and visual sciences frequently need a source of monochromatic light whose wavelength can be varied. The purpose of this note is to describe principles and construction of a reliable and inexpensive monochromator.

This monochromator produces monochromatic light by filtering collimated light with an interference filter; wavelength is varied by changing the angle of incidence of the filter relative to the collimated light beam. Interference filters of this type are constructed of many closely spaced metal films (termed metal-dielectric-metal interference filters). Interference between light rays reflected and transmitted by the metal films functions to isolate a narrow band of monochromatic light. Wavelength of the monochromatic light depends upon spacing between the metal films. If the filter is rotated from a position perpendicular to the light beam (normal incidence), the effective spacing as traversed by the light ray is increased and the wavelength changes toward shorter values.

The upper panel of Figure 1 shows the output of a Bausch and Lomb 641-nm interference filter at five different angles of incidence. The peak wavelength of the distribution moves toward shorter wavelengths by increasing the incident angle, and the band pass broadens. For the shortest peak wavelengths, the band pass is shown to be bimodal. One mode results from the interference of light polarized in the plane of incidence and the other from light polarized perpendicular to the plane of incidence (Heavens, 1965). When plane polarized light is used with the same filter (lower panel of Figure 1) there is no band-pass distortion, even at the largest angle of incidence (50 degrees).

Imperfect collimation and polarization will produce a slight broadening of the band pass, which may occur to only one side of the peak wavelength. Within limits, however, a slight broadening will be inconsequential for researchers in the behavioral sciences.

Wavelength calibrations were made with an Edgerton, Germeshausen, and Grier (EG&G) 580-585 spectroradiometer. The interference filter was positioned perpendicular to the collimated light beam. At normal incidence, peak wavelength of the interference filter is longer than at any other incident angle; this was verified. Slit widths of the EG&G spectroradiometer were set for a 5-nm band pass and the light energy passed by the interference filter was calibrated every 5 nm, 25 nm on either side of the peak wavelength. Without moving the interference filter or the spectroradiometer, the polarizer (Pola Coat Inc.) was removed from the light beam and the calibrations repeated. The angle of incidence was changed, and the procedure repeated. Following these calibrations, the interference filter was removed from the collimated light beam and the light energy calibrated every 5 nm, both with and without the polarizer in the light beam. The per cent transmittance was calculated, and these values were plotted in Figure 1.

Bandwidths at half peak transmittance for the functions in the lower panel of Figure 1 are shown to be about 12 nm. The actual bandwidth is 8 nm as specified by Bausch and Lomb. Bandwidths of the functions in Figure 1 are inflated because the EG&G spectroradiometer itself had a band pass of 5 nm; any energy within this 5-nm band pass was recorded as being located at its center.

Figure 2 shows the change in peak wavelength for changes in the angle of incidence. The peak wavelength changes as a linear function of the cosine of

Fig. 1. Transmission characteristics of a Bausch and Lomb interference filter at five different angles of incidence (upper panel) and at six different angles of incidence (lower panel).

the incident angle. Wave-number is the reciprocal of wavelength, and is directly related to the frequency of light by a multiplicative constant, the speed of light. Functions for three different filters are shown in Figure 2; they have peak wavelengths of 652.6, 602.2, and 565.0 nm at normal incidence. The linear functions are parallel with slopes of 706. A wave-number scale expands the shorter end of the wavelength scale, and when plotted on a linear scale of wavelengths the functions in Figure 2 would be concave upwards. The filters were rotated in a collimated light beam with the axis of polarization parallel to the plane of incidence (that plane containing the incident and the reflected light rays). If the polarizer (Pola Coat Inc.) had been oriented so that its axis was perpendicular to the plane of incidence, then the linear functions in Figure 2 would have been somewhat steeper.

A monochromator constructed according to these principles has been used by the author for over 9000 trouble-free experimental hours (Wright, *in press*). The interference filter was held securely in an aluminum mounting. A shaft from the mounting was coupled to a Superior Electric (Model # HS50E) stepping motor, so that the wavelength could be automatically varied. The interference filter was simply flooded with collimated and polarized light from a 150-w xenon arc source. Calibrations every 100 experimental hours showed that the system reproduced wavelengths within the resolvable limits (± 0.1 nm) of the calibration equipment (EG&G spectroradiometer).

Whenever possible, it is best to calibrate the output from the monochromator system directly as was done for the system here reported. If a spectroradiometer is unavailable, the functions in Figure 2 provide a way to calibrate the monochromator. The functions in Fig-

ure 2 are linear and of the same slope, so that if the wavelength at one angle of incidence is known, then wavelengths at other angles of incidence can be calculated from the function. Bausch and Lomb will, upon request, supply filters with their precise peak wavelength (at normal incidence). This wavelength can be plotted at zero angle of incidence on a set of coordinates identical to those of Figure 2 and a straight line of slope 706 drawn through the point. Wavelengths at other angular orientations can be calculated from the function. A scale, *e.g.*, compass rose, and a pointer on the interference filter mount can be used to monitor the angle. It would seem that the angle of the filter to the light beam could be calibrated (and the scale adjusted) by substituting a spectral source for the white light source. A spectral source has its energy concentrated at several known wavelengths. The filter can be rotated until the observed transmission of the spectral source is maximal. This position of the filter will be the angle as calculated from the function for maximum transmission; the scale can be adjusted to agree with this value. Light intensity from the monochromator can be calibrated somewhat more easily than its wavelength; photocells are available with spectral response curves traceable to the National Bureau of Standards. For a thorough discussion of photocells see Wyszecki and Stiles (1967, p. 197).

Distributions of light energy passed by the interference filters asymptote at zero per cent transmittance and extinction is not as complete as it is with grating monochromators. Incomplete extinction is a problem when investigations are conducted in the extreme reds and violets because energies are generally greater (to equate photometrically the wavelengths) and the energy in one of the "tails" is located in a sensitive spectral

Fig. 2. Peak wave-number as a function of the cosine of the angle of incidence for three different interference filters.

region. This energy in the "tail" may be sufficient to alter the dominant wavelength to the extent that it will no longer correspond to the peak wavelength, thus complicating stimulus specificity. When interference filters are used to produce monochromatic light, researchers should probably avoid the extreme spectral regions.

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