## Using cellophane tape to experience interference birefringent filters

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### Abstract

In this work we propose and demonstrate a very simple method to fabricate interference multilayer birefringent filters. We employ the birefringence properties of common cellophane. Cellophane tape layers can be very easily superimposed with different orientations in order to generate different spectral responses. We experimentally demonstrate this behaviour with the aid of a portable spectrophotometer. This technique represents a simple and inexpensive way of experimentally investigating the optical properties of birefringent filters.

### Keywords

Polarization, Birefringent filters, Cellophane tape

### 1. Introduction

The birefringent properties of some cellophane tapes are well known and can be used in demonstrations and easy experiments such as kaleidoscopes [1,2]. The birefringence of the cellophane can be easily verified by placing a piece of tape between two crossed polarizers and observing whether it looks transparent [3]. Because cellophane tape layers can be superimposed with specific orientations, they are an easy way to build a uniaxial optical multilayer. The transmission spectra of this kind of filters can be described using usual Jones matrix formalism [4]. Therefore, a cellophane tape filter is a very useful tool to teach polarization effects, birefringence and birefringent filters.

### 2. Cellophane birefringence

The first step in the proposed experimental demonstration is to calibrate the cellophane tape birefringence as a function of the input light wavelength. For this purpose we place the cellophane tape between parallel and crossed polarizers. The cellophane tape is placed in between with the principal axis oriented at 45° with respect to the polarizers. The normalized transmission is given by [5] :

$$i_{parallel}=\cos^2(\phi/2), \quad i_{crossed}=\sin^2(\phi/2), \qquad (1)$$

where $\phi$ is the phase shift introduced by the cellophane, which is given by $\phi=(2\pi/\lambda)\Delta n\,d$, being $\Delta n$ is the difference between the ordinary and extraordinary refractive indices, $d$ the physical thickness of the layer and $\lambda$ the wavelength. Equation (1) indicates that the measured spectrum will be an oscillating curve as a function of the wavelength. From these relations, the phase shift can be calculated as:

$$\phi = 2\arctan\left(\sqrt{\frac{i_{crossed}}{i_{parallel}}}\right). \qquad (2)$$

Figure 1 shows a picture of the experimental setup. We employ a portable UV-visible Stellar-Net spectrophotometer, model EPP2000, operating in the range 195 nm to 850 nm, a nonpolarized light from a tungsten lamp (Stellar Net SL) and two photographic linear polarizers from Hana.
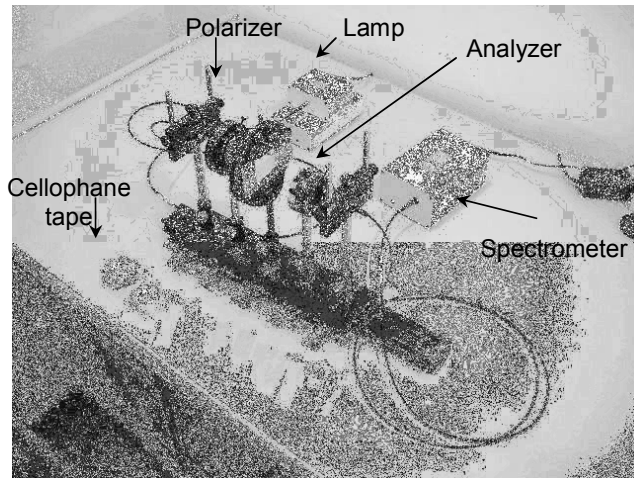
Fig. 1. Experimental setup

Figure 2 shows the measured experimental intensity transmission for parallel and crossed polarizers for one and eight cellophane layers aligned parallel. The results show the expected oscillating behaviour. The number of oscillations increases with the number of cellophane tape layers. From these experimental data, we have made a Cauchy-type fit of the phase shift as a function of the wavelength [5].

## 3. Cellophane birefringent filters

Once the birefringence has been calibrated, the cellophane tape can be used to build birefrinfent filters. The first example we show here is a classical *folded Solc* filter. It consists of a set of identical wave plates whose azimuthal angle maintains its absolute value, but changes sign from one layer to the next, placed in between crossed polarizers [4]. The transmission is maximum at the wavelengths for which the birefringence is an odd multiple of , while it decreases rapidly for other wavelengths. We built a Solc filter consisting on 6 wave plates, each one composed of three parallel aligned cellophane layers, being the azimuthal angle for each consecutive wave plate =±7.5°. Figure 3(a) shows the simulated normalized transmission, and the experimental measured spectrum. The filter provides a maximum transmission centred at =659 nm, with a spectral width =80 nm.
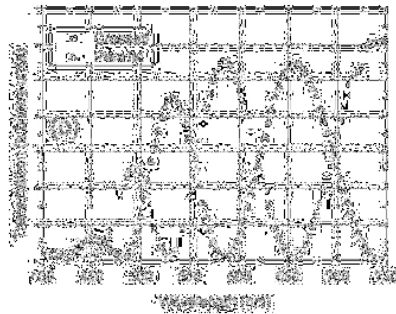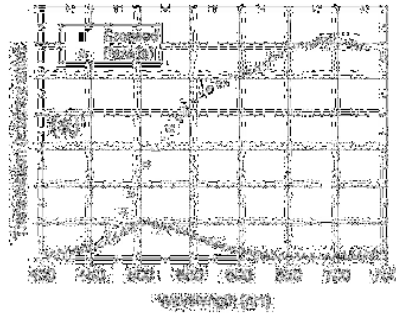




Fig. 2. Transmission through parallel aligned cellophane tape layers inserted between crossed and parallel polarizers oriented at 45° with respect to the principal axis. (a) 1 layer, (b) 8 layers.

The second design is a birefringent filter which provides a transmission that approximates a square wave, with flat regions near zero and 100% transmission [6]. Again, the filter is placed between two crossed polarizers. It consists on four cellophane tape layers oriented at +45° with respect to the polarizers, followed by other eight layers oriented at -15°, and finally other eight tape layers oriented at +10°. Figure 3(b) shows the simulated transmission together with the experimental data obtained by the spectrophotometer. Again, an excellent agreement is obtained.

## 4. Conclusion

Summarizing, we have demonstrated a very simple way of building birefringent filters based on the use of cellophane tape layers. We first calibrated the birefringence of the tape, and used this information to design the filters. This technique represents an inexpensive way of experience the properties and applications of the polarization of light.
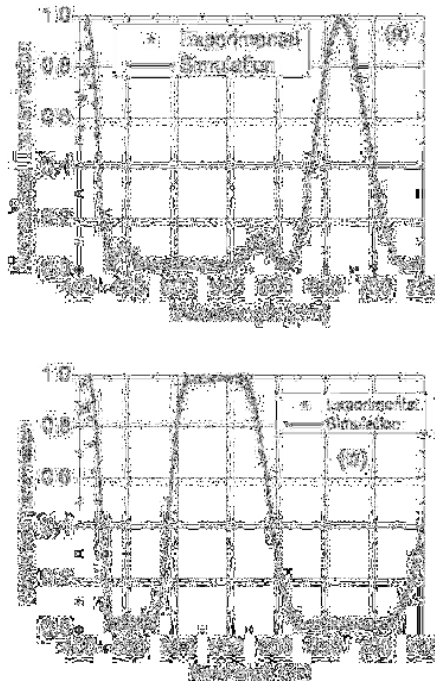


Fig. 3. Normalized spectral response of (a) folded Solc filter and (b) birefringent filter designed to give a square wave response. Simulation is shown as a continuous line, while

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