Broad-Spectrum Measurement of Retardance

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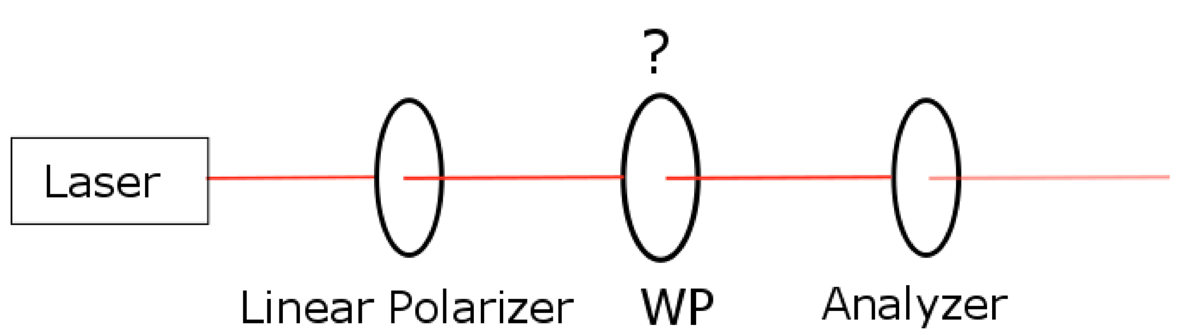
BACKGROUND

We have developed a method to characterize an optical retardation plate to enable sorting the collection of unlabeled devices that often accumulates in labs. In as few measurements as possible, we would like to measure the retardation and design wavelength of any unknown plate easily and quickly. After exploring several methods, we settled on a procedure to determine the thickness, order, and retardation over a broad spectral range.

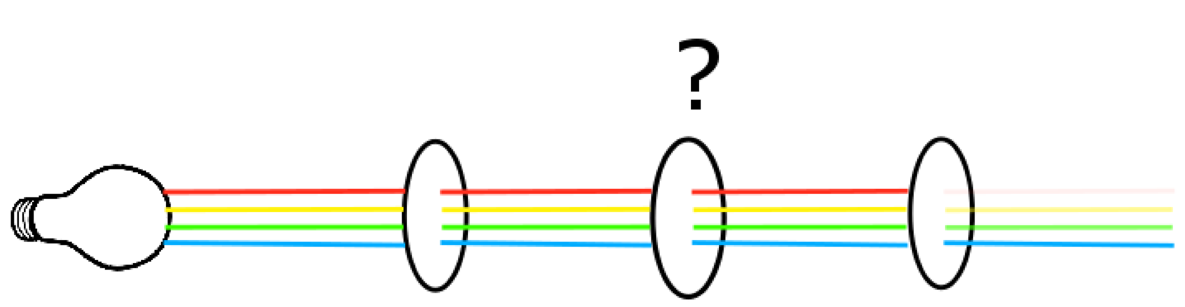
DEVELOPMENT OF A METHOD

A conventional method to determine if a wave plate is λ/4 or λ/2 is to adapt the following setup:



Using the analyzer (another polarizer) one can determine the optical axis of the WP. Once this is established the plate is set to 45° from its axis. Turning the analyzer, if the intensity does not change, the WP retardation is λ/4. If extinction occurs at two points 180° apart, the WP retardation is λ/2. The issue with this method is that if the incorrect wavelength is chosen for the WP neither of the conditions will be met.

However, if a white light source was used we can find retardance across a spectrum, in our case we used multiple sources together to get a range over 350nm-1050nm



This was done with a spectrum analyzer and to simplify the process, $\varepsilon \equiv \frac{I_c}{I_p}$ is introduced, where I_c is the intensity when the polarizers are set to extinction, I_p is intensity when polarizers are set to full pass.

Retardance, $\delta = 2\,tan^{-1}(^{1}/_{\varepsilon})$, can then be found as a function of λ and wavelengths can be found where the plate is λ/2 and λ/4. This method is very quick but it erroneously labels 3λ/4 plates as λ/4. This is fine in many applications but to get more correct retardance information, as we have set out to do, a different method was adopted.

SPECTRAL TRANSMISSION METHOD

A powerful but more involved method described in Ref 1 provides a means to measure thickness, order and phase shift simultaneously, knowing only the birefringence dispersion relation of the wave plate by measuring the transmission through the previous setup:

$$d = \frac{\lambda_i \lambda_{i+2}}{\Delta n(\lambda_i)\lambda_{i+2} - \Delta n(\lambda_{i+2})\lambda_i}$$

$$\delta(\lambda_0) = \frac{2\pi}{\lambda_0}\frac{\Delta n(\lambda_0)\lambda_i \lambda_{i+2}}{\Delta n(\lambda_i)\lambda_{i+2} - \Delta n(\lambda_{i+2})\lambda_i}$$

$$N = INT(\frac{\delta(\lambda_0)}{2\pi})$$

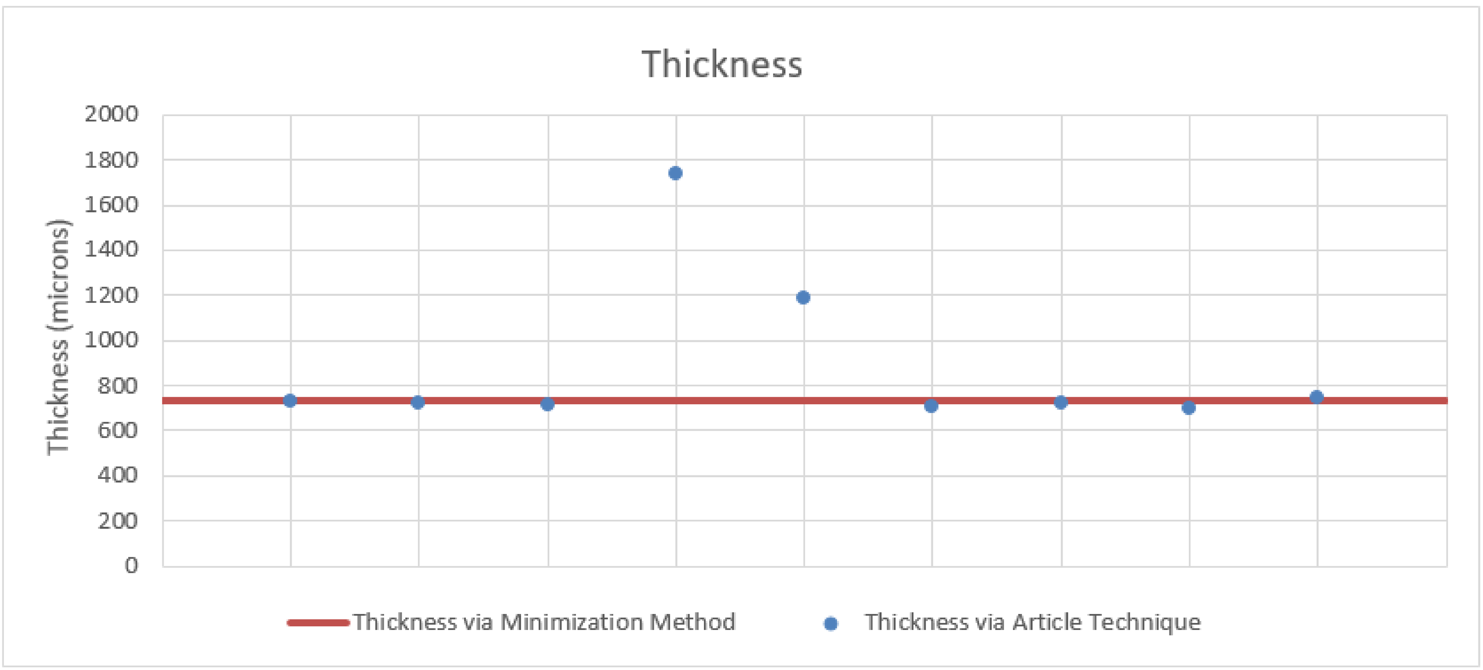
Where d is thickness, $\delta(\lambda_0)$ is absolute retardance at λ_0, N is order, Δn(λ) is the birefringence dispersion relation to wavelength, and λ_i and λ_{i+2} are intersection points on the transmission plot as shown to the right.

This method requires knowledge of Δn(λ) and for a totally unknown WP the method fails. When this is the case we can instead couple d and Δn(λ) giving the following relationship:

$$\Delta n * d = \frac{\lambda_i \lambda_{i+2}}{\lambda_{i+2} - \lambda_i}$$

$$\delta(\lambda_0) = \frac{2\pi}{\lambda_0}\Delta n * d$$

The find the order, N, we use a minimization technique that minimizes the difference between $M \equiv \frac{\Delta n(\lambda) * d}{\lambda}$ and its integer part. This technique requires guessing at the order to minimize the difference of the two values over all observed λ. Using this technique we get a single value of thickness that does not depend on intersection points.



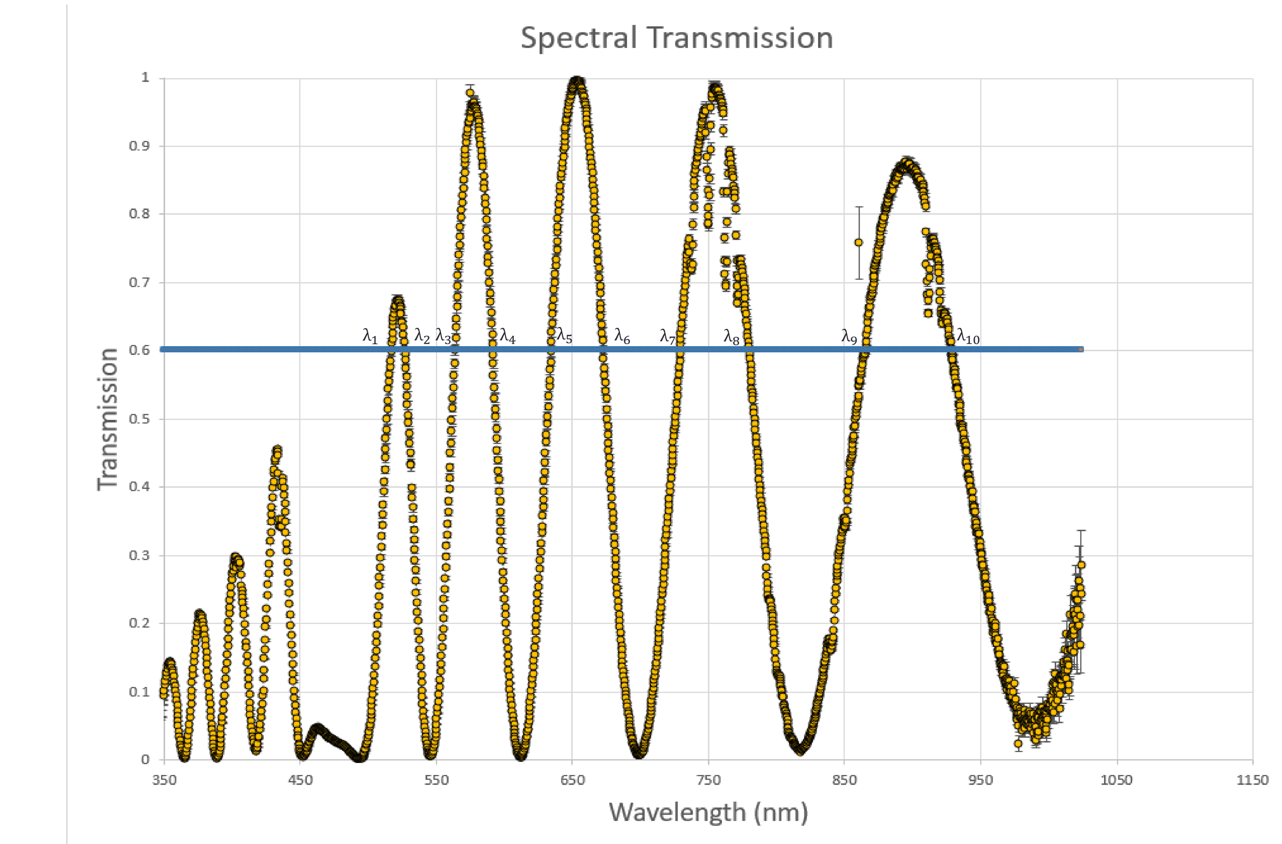
The minimization technique has the added benefit of giving a more consistent thickness compared to the method in Ref 1 because it is less susceptible to errors in transmission intersection points.

This method also makes use of the entire spectrum that was measured, since we have used a broad spectrum with an analyzer this allows for much more data to be considered in the measurement of d, and order.

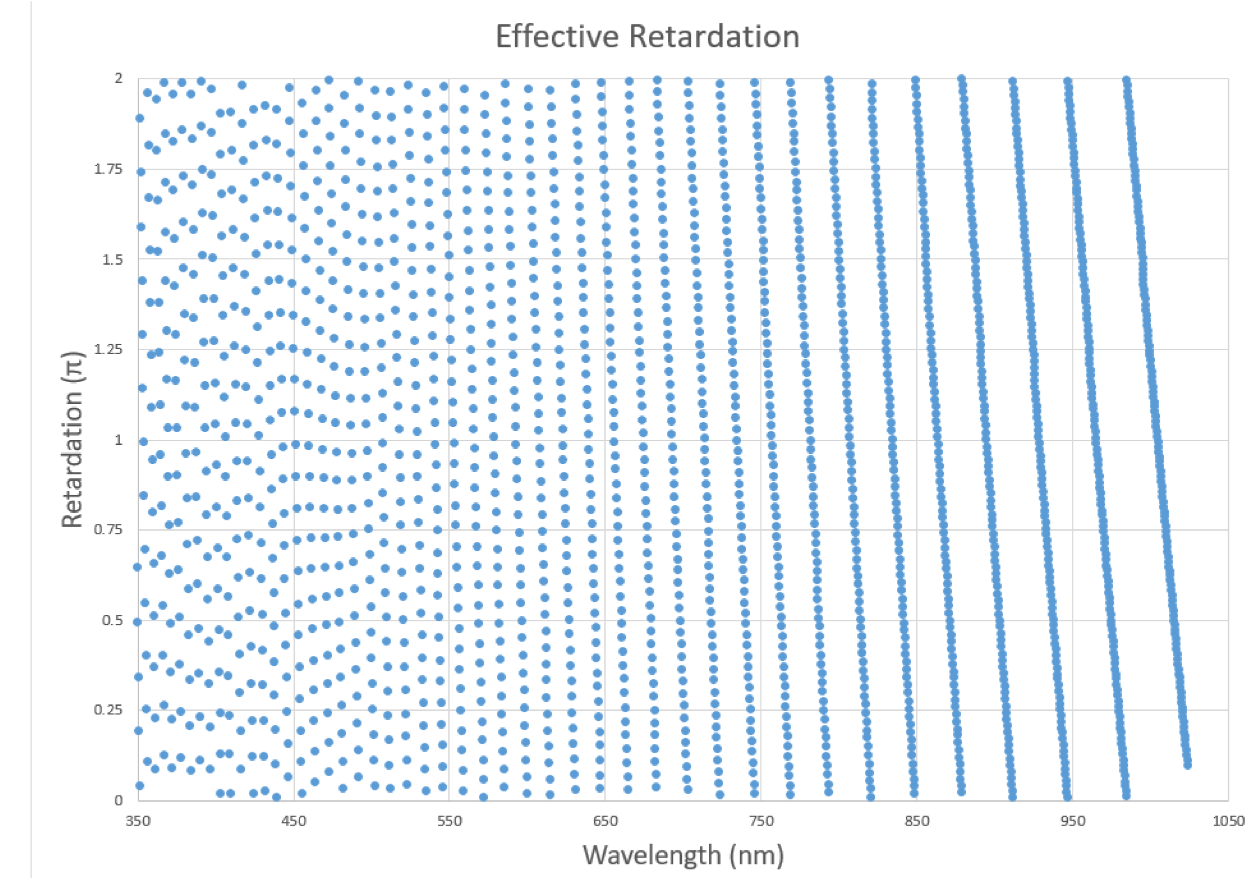
RESULTS

Spectral transmission method method applied to an unknown WP:

Transmission measured by the first method to be a QWP for 633nm:



The retardation as a function of wavelength:



Order was measured to be 38 at 633 nm

$\Delta n * d$ = 2.463 μm ± .0014 μm

Assuming the plate was quartz crystal: d = 2.06 ± .017 mm

REFERENCES & ACKNOWLEDGEMENTS

1) W. Wang, J. Chen, Z. Liu, Chin. Opt. Lett. 13, 012601 (2015)
2) P. Hariharan Optical Engineering, Vol. 35 No. 11 (1996)

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