A Hydrocolloid-based Photoelastic Modulator

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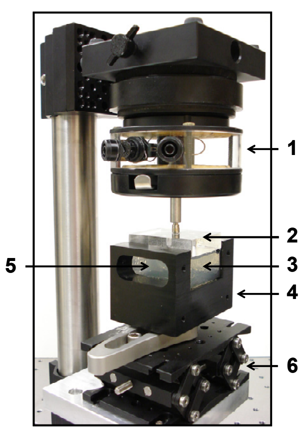
Introduction

Driven harmonically by a speaker coil, a block of birefringent gelatin acts as a variable retarder and can thus be used to sinusoidally vary the polarization of a laser beam. We model this effect with Mueller matrices and show that the system behaves much like a commercial photoelastic modulator. As such, it is well-suited for a variety of polarimetry experiments in an advanced undergraduate optics course.

A Gelatin PEM

Since commercial PEMs cost thousands of dollars, we have sought ways to build a number of inexpensive ones from off-the-shelf materials. After testing stiff birefringent plastics like polycarbonate, which require inconvenient magnitudes of stress, we decided to try a material with a much lower elastic modulus and more easily manipulated birefringence. We discovered that gelatin works quite well as the optical element of an inexpensive PEM. Gelatins and related hydrocolloids have a long history of polarimetric applications, so their birefringent properties are well known.

Our gelatin PEM uses a PASCO Mechanical Wave Driver instead of a PZT to apply sinusoidal stresses to the optical element. The device's resonant frequency is about 30 Hz. The gelatin sits in a plastic mold with a microscope slide on each end to serve as an optical window. A lab jack allows us to coarsely adjust the average level of stress birefringence (offset retardance), and an adjustable dc voltage offset from the function generator that controls the Wave Driver allows for fine tuning of this parameter.



1. PASCO Mechanical Wave Driver
2. Plastic compressor
3. Gelatin block
4. Plastic mold
5. Microscope slide as an optical window
6. Lab jack

Performance

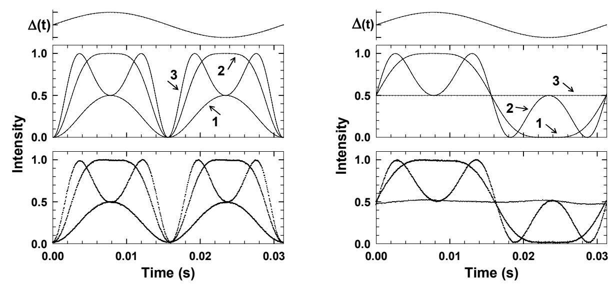
When placed between crossed polarizers, the gelatin PEM causes the intensity of a laser beam to modulate according to the equation

$$I(t) = \frac{1}{2}\left(1 - \cos\Delta(t)\right)$$

where

$$\Delta(t) = \Delta_0 \sin(\omega t) + \Delta_{offset}$$

is the time-dependent retardance of the device. The following graphs reveal that the device operates as expected. The top graphs show generic plots of retardance at the driving frequency, the middle graphs are theoretical predictions, and the bottom graphs display experimental data captured by a digital oscilloscope.

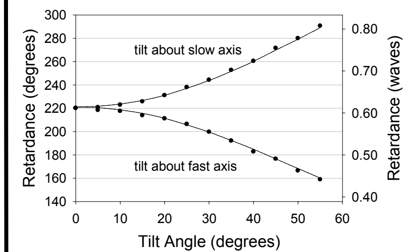


Curves 1, 2, and 3 of the left graphs are for quarter-wave, half wave, and three-quarter wave retardance amplitudes, respectively, when the offset retardance is zero. Curves 1 and 2 of the right graphs are for quarter-wave and half-wave retardance amplitudes when the offset retardance is a quarter-wave. Curve 3 of the right graphs is for input linear polarization that is aligned with the PEM's fast axis.

Since the gelatin PEM produces such nice experimental results, it can be used in many of the applications that a commercial device is used for (if high-precision is not required). We have successfully employed it to measure retardances of wave plates, optical activity in chiral molecules, and the quality of linear and circular polarizers.

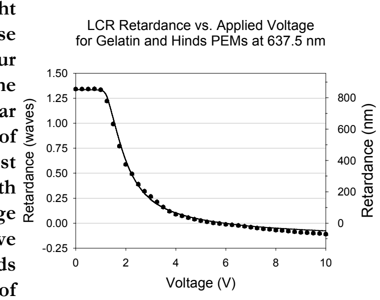
We are now investigating other hydrocolloids such as agarose gel and urethane rubber to see if they can also be employed in inexpensive PEMs.

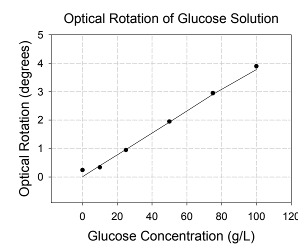
Example Measurements



780nm half-wave plate tilted about the fast and slow axis. 637.5nm laser used. Solid curves show results of Hinds PEM. Dots show result of our gelatin PEM.

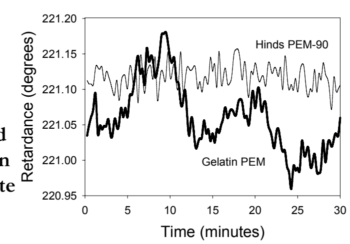
The graph on the right demonstrates the close similarity in results of our gelatin PEM compared to the Hinds PEM for linear retardance measurements of an LCR. LCR retardance (fast axis at horizontal) varies with voltage supplied over a range from 0 V to 10 V. Solid curve shows the results of the Hinds PEM. Dots show results of our gelatin PEM.





We used the gelatin PEM to measure the optical activity of a glucose solution, with concentrations varying between 0 and 100 g/L. The line is from the Hinds PEM and the black dots show the gelatin PEM results, indicating a close match between the two devices. A 637.5 nm laser was used for all measurements.

We compared the stability of the gelatin PEM with the Hinds PEM by measuring the retardance of a 780nm half-wave plate for 30 minutes. The Gelatin varies 0.23º p-p compared to 0.08º for the Hinds. The gelatin PEM is suitable for undergraduate Laboratory experiments, but not high precision polarimetry.



See our article "A Simple, Inexpensive Photoelastic Modulator," *American Journal of Physics*, Vol. 76, No. 11, November 2008.

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