

The Basics of the Rotation of Polarized Light

The molecules that will be studied with this device will have an overall charge of zero but will have localized polarities that can be used to orient the molecule. Suppose a charge was applied to the solution, the molecules would rotate and align with the voltage difference according to their poles. This movement would not be instantaneous, however, because of the intermolecular interactions between molecules. From this time delay it is possible to determine to what degree the molecules are interacting with each other. To measure the movement of the molecules we are expecting to use the optical properties of the molecules.

The molecules that will be studied with this device will be chiral (“of or relating to the structural characteristic of a molecule that makes it impossible to superimpose it on its mirror image” www.dictionary.com). Chiral molecules have the ability to rotate plane polarized light. A solution of chiral molecules (excluding a 50/50 solution of enantiomers) will rotate polarized light. This occurs because only the opposite enantiomer (“either one of a pair of compounds (crystals or molecules) that are mirror images of each other but are not identical” www.dictionary.com) can fully negate its mirror image. Each molecule has an optimal orientation to intersecting light, which results in the maximum rotation of light. In a single enantiomer solution, the molecules are randomly oriented to the intersecting light. Therefore, the light will not always hit the molecules at the optimal angle, instead it may rotate light at a fraction of the maximum or in the opposite direction of the optimal rotation. However, only the mirror image (enantiomer) can completely negate the optimal rotation. Therefore, in a single enantiomer solution, the net rotation of light will not be zero. Likewise, in a 50/50 mix of

enantiomers the net rotation will be zero. It is expected the solutions this device will be measuring will not have a 50/50 mix of enantiomers.

In our setup the molecules will have instances when they will not be randomly oriented. Each individual molecule will rotate the light at the same magnitude and direction. This cumulative rotation from the oriented solution will be measurably different from the net rotation of the randomly oriented solution. It is possible to measure the time it takes a randomly oriented solution to become aligned and vice versa.

Design Setup

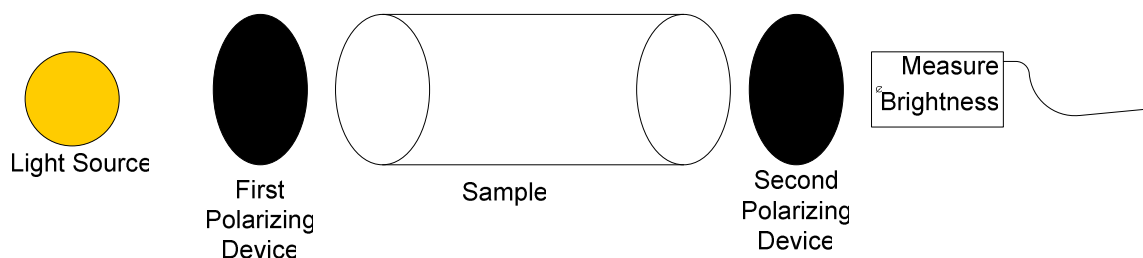


Figure 1 – Polarized Light Design Setup

Figure 1 illustrates the general setup for this design approach. Light is emitted by the light source and then is polarized into a known plane by the first polarizing device. The light then enters the sample and is rotated. The second polarizing device is oriented so that it maximizes light passage when the sample is oriented (while the maximum charge is applied). If the sample is not at maximum orientation (i.e. randomly oriented), the light passing through the second lens will be a fraction of the light that would pass through at maximum orientation. The brightness of the light that passes through the second polarizing device will be measured. The maximum and minimum brightness for the sample will be recorded in the analysis software for calibration. Both the applied voltage and the change in brightness will be stored and plotted for analysis.

The design can be broken up into these major components: 1) Light source, 2) Polarizing devices, 3) Sample container 4) Photodiode and accompanying circuit 5) Calibration setup 6) Computational analysis.

Light Source

In most cases where polarized light is used to measure molecular properties, a monochromatic light source ranging between 600-700 nm in wavelength is used. In theory, any light source within in the visible light spectrum would be adequate for these kinds of measurements. In order to accommodate samples with different properties (i.e. some samples may absorb a specific light wave), multiple monochromatic light sources will be available in this design. Power Technology, Inc. (Alexander, AR) offers laser diodes that meet our requirements for our design (high power: 10mW, low dispersal: 8X8, and desired wavelengths: 635, 650,670,690). The light emitted by these diodes is polarized, eliminating the need for a pre-sample polarizing device. This will be beneficial to our setup because for each polarizer that the light passes through, over 50% of the light is lost. This will allow for a more accurate final measurement.

Polarizing Devices

Since the light source emits polarized light, the design will need only one polarizer (located before the brightness sensor). Plastic dichroic polarizing sheets (often found in science classrooms or sunglasses) will be the best type of polarizer for this design. Melles Griot (Carlsbad, CA) sells sheets that are fixated in-between two glass pieces, which is then mounted on an aluminum ring. The polarizing device fits within our wavelength range (600-700 nm) and has desirable physical dimensions for our design

(12.5 mm). Using a mounted polarizer will be more durable and easier to implement than the polarizing sheets that are typically available.

Sample Container

The design setup requires a container for the sample liquid that is optically transparent, holds less than 20 μL , and has electrodes. Hellma (Mullheim, Germany) sells ultra-micro cuvettes that are optically transparent and hold small volumes (10 or 20 μL). To be able to apply a voltage to the liquid, gold tipped electrodes can be placed inside the chamber (care must be taken in this extremely small volume so that the electrodes do not come into contact with one another). The cuvette has a light path of 10mm, which is standard in most light/liquid experiments. Light path length is an important property that cannot be sacrificed in these types of measurements because, in order to obtain an accurate and significant reading from the device, the light must be able to travel through an adequate length of sample. Hellma's cuvettes are designed for small volumes, without compromising light path distance.

Photodiode

To analyze the difference in the brightness, as voltage, between the initial LED light and the impeded light due to alternating molecules in the sample fluid, a photodiode will be utilized. Photodiode devices are capable of converting light energy into electrical energy as electric charge or a voltage. The effectiveness of the photodiode to translate light energy into electrical is given by the quantum efficiency equation:

$$\text{Q.E. [\% based on 100]} = 1.24 \times 10^5 \text{ R [A/W]} / \lambda \text{ [nm]} \text{ Eq. (1)}$$

Where λ is the wavelength of the light and R is the responsivity of the diode. If the photodiode were to be connected to a resistor, in this case, the sample fluid, it would

functions as a current source; thus, the change in voltage of due to the sample would be proportional to the power of the radiated light.

Photodiodes are usually assembled from highly purified silicon wafers. There is a direct relationship between the silicon and the electrical resistivity, that is, the greater the purity of the silicon, the greater the resistivity of the device. A typical resistivity range for a photodiode is between 10 Ohm-cm and 10,000 Ohm-cm, indicating a wide range of current opposition. The basic construction of a photodiode is indicated in the following sketch:

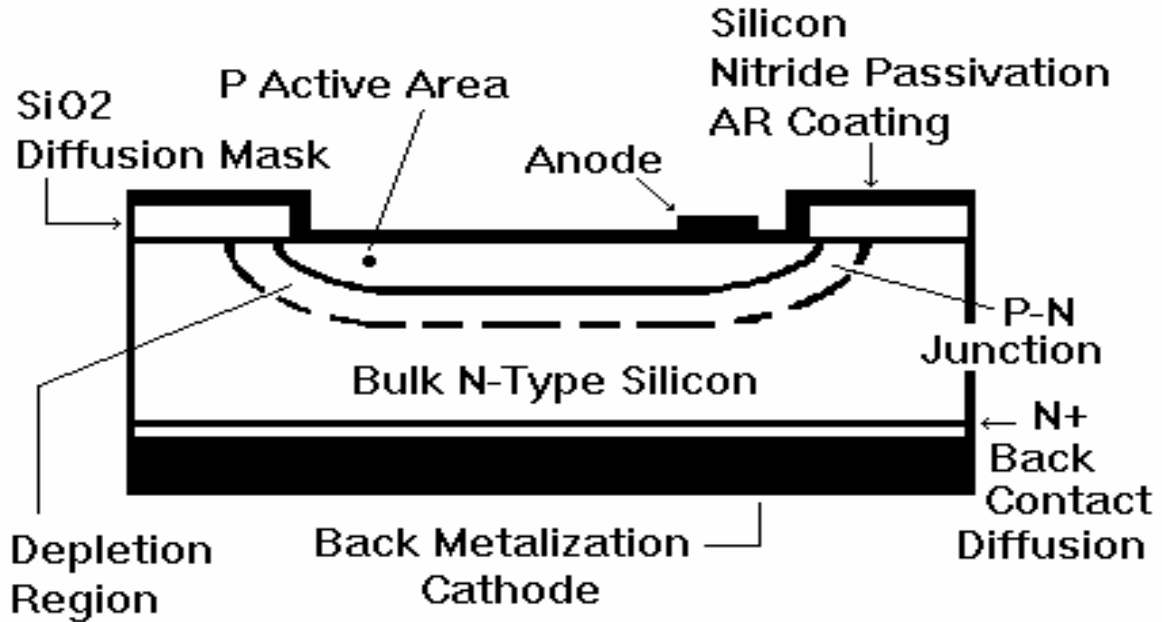


Figure 2 – Basic Construction of Silicon Photodiode

Whereby the N-type silicon is the material used to construct the photodiode, and forms a junctions with the “P” material, usually made of boron. The back contact represents the device cathode, and the front contact represents the anode. The silicon nitride used for passivation coating functions as an anti-reflection coating and protects the active area of

the diode. This coating regulates which wavelengths can be detected and thus is varied to accommodate various irradiation waves.

The depletion region represents an area where the silicon is exhausted of electrical charge. This region is the most sensitive to radiation, hence it is an integral component of the device, and can be directly regulated by increasing and decreasing the bias voltage across the region, thus increasing and decreasing the depth, respectively. The stored energy of the device, the capacitance, is also dependent on the thickness of the depletion region, as demonstrated in a graph of capacitance versus voltage and area:

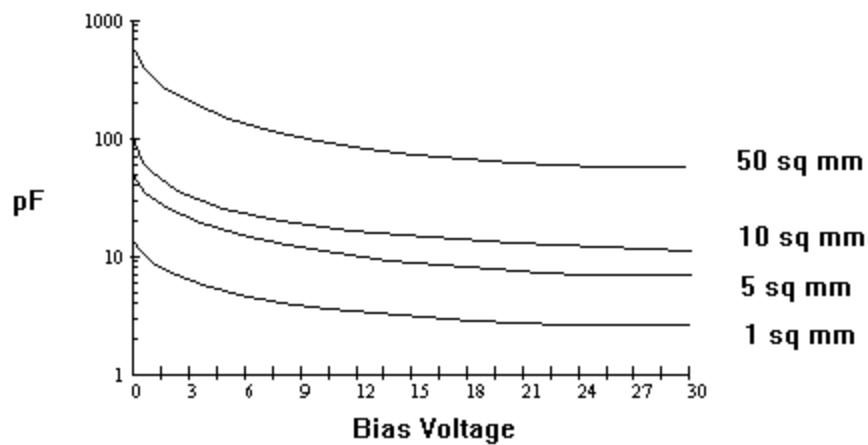


Figure 3 – Junction Capacitance, Voltage, Area Graph

When the photodiode is used in practice, light is absorbed in the active area, protected by the silicon nitride, and an “electron – hole” pair forms. These electrons and holes are separated in the PN junction as the electrons move into the N region and the ‘holes’ move into the P region. The result is a phenomenon known as the “photovoltaic effect”, whereby a current is generated which is facilitated by the light absorbed.

For the device in question, a concentrated light source will be utilized which will be subsequently reduced in intensity by polarizing discs and the actual sample fluid. Thus, a low level light sensor, such as the OSD35-LR presented by centrovision, will be the optimal device to use. The low level sensor is equipped with a large area silicon diode, which is designed for setups that require a current extender, as with the device in question. The sensitivity of the sensor is measured by the current of the diode, given as amps/cm², over the radiant energy absorbed, given in watts/cm², which equates to the responsivity of the device given in amps/watts. The responsivity of the OSD35-LR is presented below:

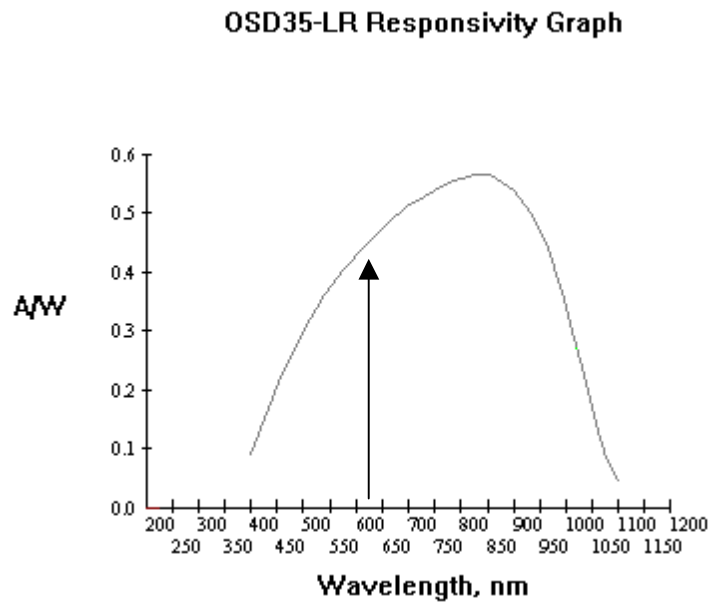


Figure 4 – Responsivity Curve of Low Level Light Sensor

The LED that will be utilized for this device functions at a wavelength of 635nm. This wavelength is appropriate for absorption by this sensor, as indicated by the arrow on the graph, and thus will provide the user with suitable results.

Sending the Signal to the Computer

Our client wants the final fluid properties as well as the raw data to be displayed on a personal computer. This will allow our client the ability to have more thorough documentation of the measurements and more freedom in evaluating the sample's properties. After the impedance is analyzed the data will be converted from analog to digital with a PIC16F874 (a 14-Bit 333 kSPS Serial A/D Converter from Analog Devices) microprocessor. The data will then be prepared for serial port communication with the computer with a MAX232ACPE (MAXIM Dallas Semiconductor) microprocessor. The device will be connected to the personal computer through an RS-232 serial cable. Overall circuit performance will be tested by selecting test points with predictable outputs throughout the circuit that can be measured with an oscilloscope.

The client also prefers a wall outlet power source. A commercially available power supply will be used to power the device. Functionality of the power supply will be tested using a digital multi-meter.

Calibration setup

Initial calibration is essential in proper results for this device. Before any sample is measured, the device must be calibrated for that specific sample. The second polarizer will be aligned so that when the molecules are fully aligned in solution, the maximum amount of light is received at the sensor. Therefore, when the alternating current is turned on, the graph of brightness vs. time will correspond to the alternating current being applied. This will make the calculations simpler.

Constants for the equations for finding viscosity and viscoelasticity will be found through recording the net rotation of light when there are no solute molecules in the sample.

Computational Analysis

In the study of solution rheometry there are many new ways to determine the viscosity of a sample under study. In the analysis of this design the setup uses a polarizing technique to determine the viscosity of the sample. The light being sent by the photo diode is received at the other end of the setup after it has been polarized and passed through the solution. The molecules of the sample rotate according to the voltage source applied across, within the time frame where this positioning occurs is what determines the viscosity of the sample. Some of the light penetrating the sample becomes diffracted due to these rotating molecules. The amount of light being received by the photodiode depends on the factors that affect it by the molecules internal forces. For instance a more viscous sample would have higher molecule-molecule adhesion forces than a sample with less viscosity. The size of the molecule and polarity all determine the amount of light that will penetrate through the sample and received by the photodiode. The photodiode receives the light intensity and from that conducts a sequence of electrical wave pulses that is sent to a processing control where the viscosity will be calculated. The light intensity received will decrease with each oscillating period of the molecules due to the A/C voltage source. This decreasing intensity will be viewed as an exponential graph in which viscosity calculation can be conducted. The equation used for determining the viscosity includes some constants which simplifies most of the in depth calculations needed for the calculations.

Optical Set-up for Viscometer

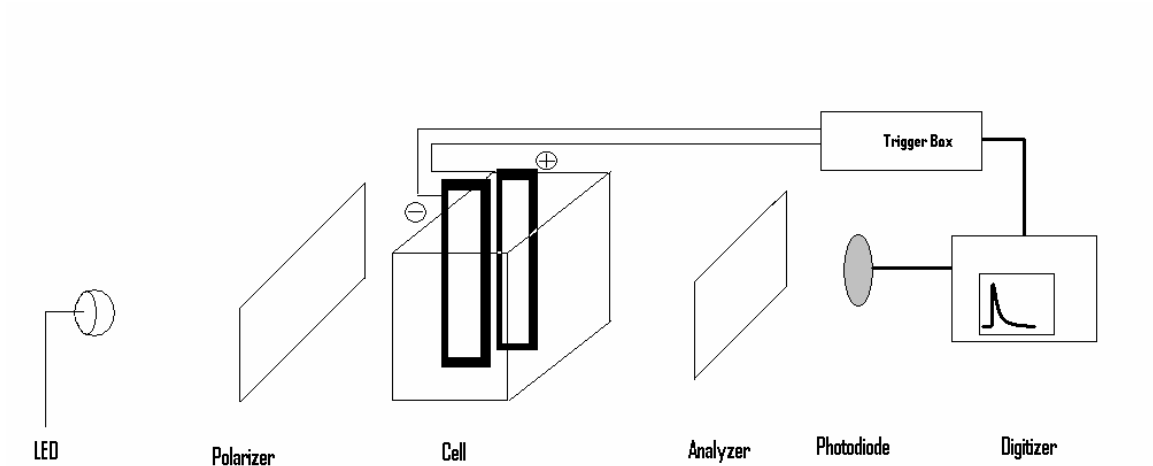


Figure 1

For mono-disperse rigid macromolecules of major dimension L , the decay of the signal in exponential form is given by:

$$\Delta n = \Delta n_0 \exp(-6 Dt) \text{ where } D = \frac{\Phi k T}{\pi \eta L^3} \text{ \& } k = \text{Boltzman's Constant}$$

For spheres of diameter L , Φ is unity and for rods with axial ratio of ρ and length L , it is given by $3(\ln 2 \rho - 0.8)$. η is the viscosity of the solvent and T the absolute temperature.

Δn : is the field induced orientation of the molecules

Δ : is the phase difference between the vertical and horizontal components of the probing light.

$$\Delta n = \frac{\lambda \delta}{2 \pi l}$$

l is given as the path length and λ the wave length

At the end of each voltage pulse the molecules begin to relax into their original conformation, this results in the decrease of light intensity which is received by the photodiode. The decay results in an exponential graph form which is then analyzed by the processor to calculate the sample viscosity.

Reference:

*Equations and figures are presented from a paper written by Doctor Kalonia which is not available on the "World Wide Web".

Dept. of Pharmaceutical Sciences

University of Connecticut

School of Pharmacy

372 Fairfield Road, Unit 2092

Storrs, Connecticut 06269-2092

Phone: (860) 486-3655

Fax: (860) 486-4998

E-Mail: kalonia@uconn.edu