Photonics Laboratory
Physics 472
Spring 2024

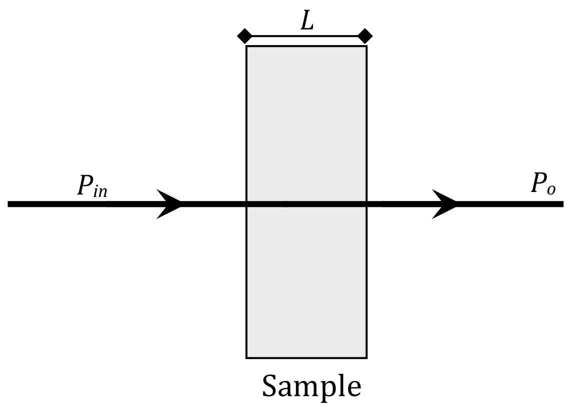
Experiment#5 Absorption, Reflection, and Index of Refraction

BACKGROUND

Optical absorption, in part, occurs when the energy of the radiation matches the energy difference between electronic levels. After absorption the energy is reradiated in the form of photons and heat or both. This is due to radiative (gives photons) and nonradiative (gives heat or energy will be transferred to another constituent in the material) decay of the excited atom.

In this experiment you will learn how to, experimentally, determine the absorption coefficient α of a material at a given wavelength. Normally, the unit of α is cm^{-1}. The procedure is simple. You need to measure the input power (intensity) incident on the front surface of the sample and the output power of the laser beam after it exits the sample. Keep in mind that the main loses of light are mainly due to absorption within the sample and the reflections at the sample surfaces. Therefore, you need to know the reflection coefficient at normal incidence for your sample.

Now let us derive the relation that can be used to find the absorption coefficient. Consider the laser beam of power P_{in} incident on the sample surface from the left and exits from the right with power P_{out}, see the figure. Without including the losses due to reflection, we can write the power at a distance z within the sample to be



$$P(z) = P_{in} e^{-\alpha z}$$

This is called "Beer-Lambert's law". If the reflection coefficient from each surface is R, then the actual amount of light entering the sample is (1-R) P_{in} and the power inside the sample is

$$P(z) = P_{in}(1 - R)e^{-\alpha z}$$

Note also that the exit surface of the sample allows only (1-R) of the power incident on it to exit. Therefore, the actual output power is

$$P(L) = P_{out} = P_{in}(1-R)^2 e^{-\alpha L}$$

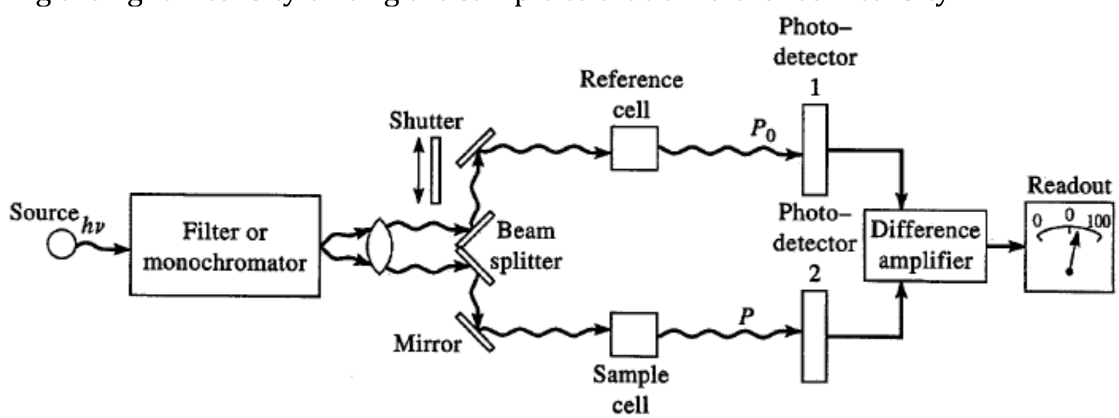
Here we are not interested in the actual power; rather we are interested in measuring the relative change of the power. Therefore, we can use a power meter or a photodiode and an oscilloscope to measure the input and output power. To determine α you need to measure the input and output power and the reflection coefficient (R) at normal incidence.

To determine R at normal incidence (θ=0°) you need to know the index of refraction of your sample at the wavelength of interest or measure R directly. If you measure the reflectance at about 5 degrees is a good approximation for reflectance at normal incidence. Or you need to measure R at different angles of incidence then plot your data and fit it with the *Fresnel formula* given below.

$$R_s = R_\perp = \left[\frac{n_1 \cos(\theta_1) - n_2 \cos(\theta_2)}{n_1 \cos(\theta_1) + n_2 \cos(\theta_2)}\right]^2$$

In this case n is the fitting parameter. In both cases you need to know n.

Optical absorption measurements are mostly done using double-beam grating monochromator, see the diagram below. In this case the absorption is determined by comparing the light intensity exiting the sample to that of reference intensity.



Spectrometers may record absorption as percent transmission $(P_{out} / P_{in}) \times 100$ or as optical density (OD) defined as

$$OD = \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

This means that 10% transmission corresponds to 1 OD absorbance and 1% transmission to 2 OD.

Absorption spectrometers give OD as a function of λ. You should recognize that the OD and α are related by $e^{-\alpha L} = 10^{-OD}$. This will enable you to find the absorption coefficient as a function of λ.

It is well known in optics that the refractive index of materials can be measured by the Brewster's angle experiment. It is usually performed to get a quick estimate of the refractive index to about one or two decimal places. The technique requires one polished surface and can be done on both transparent and opaque materials. At the Brewster's angle, the intensity of the reflected light is a minimum since only s-polarized light is reflected. This intensity change, as one rotates through the Brewster's angle, can be monitored by eye. By introducing a CCD camera with a laser beam profiler to monitor the intensity change, we can isolate the angle close to the resolution of the sample rotation stage. By using the relation $n = \tan\theta_B$ the refractive index is easily found. The uncertainty in the refractive index measurement is typically in the third decimal place.

To find the index or refraction at any wavelength you do not have to measure it directly at all wavelengths of interest. You need to find the index of refraction at two wavelengths then use Cauchy dispersion formula.

$$n = A + \frac{B}{\lambda^2}$$

And once you know the index of refraction you can find the reflection coefficient at any angle of incidence for any wavelength.

Cauchy dispersion formula does not work for large wavelengths (above 800nm). In this case Sellmeier's equation is used.

$$n^2 = A + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2}$$

EXPERMENTS

Task#1: Measuring the reflectance and absorption coefficient using a single beam from a light source.

(a) You will be given two glass samples doped with rare-earth ions (Eu^{+3}, Pr^{+3}) and other liquid samples. You are required to find the absorption coefficients for these samples at λ=405 nm, 450nm, 520nm, 635 nm, 650nm, and 670nm. Again, you need to measure the input and output powers in each case for at least 5 different input powers. The input power can be obtained by using an attenuator in from of the laser before it impinges on the sample. Be sure to make the incident beam normal to the sample surface. You may need to place the sample on a tip-tilt stage to be able to do that. When you plot the output power vs. the input power you can determine α from the slope once you know R.

(b) Measure the reflection coefficient at 5 degrees for the wavelengths used in part (a). be sure to use at least 5 different input powers. Then find R from the plot of reflected power vs. incident power.

(c) Try to directly measure the reflectance at normal incidence using a beam splitter. In this case you need to find the transmission and reflection factor for the beam splitter to be able to find the absolute reflectance.

Task#2: Determine R by measuring n using Michelson interferometer.

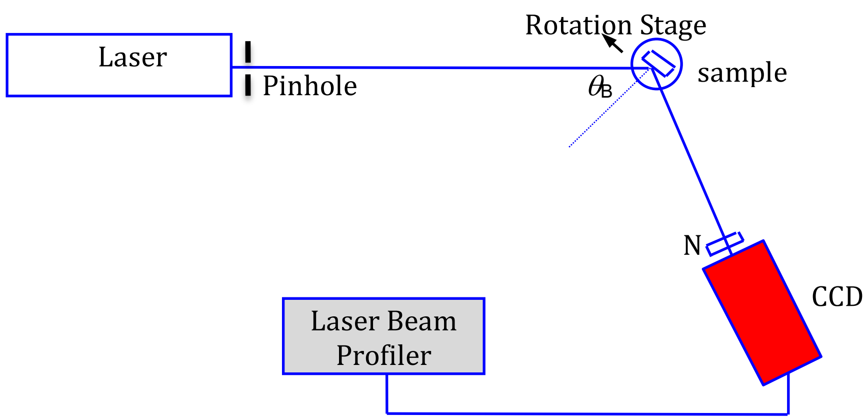
Remember, you need to know the reflection coefficient, *R*, at normal incidence for each sample at each wavelength. As I mentioned before, this can be done by measuring the index of refraction at the wavelengths of interest. Measure the index of refraction using the Michelson interferometer technique that you used before. To get accurate result count at least 100 fringes as you rotate the sample. In addition, this will allow you to find the reflection coefficient at any angle using Fresnel reflection formulas.

Task#3: Determine *R* by measuring *n* using Fresnel reflection.

In case you don't have a Michelson interferometer, *R* can be found using *Fresnel formula* at different angles of incidence (θ =5°, 10 °, 15 °, 20 °, 25 °, 30 °, 35 °). Remember that R is the ratio of the reflected power and the incident power ($R=P_{ref}/P_{in}$). Remember that you need to measure the input power. Place the sample on a rotational stage and measure the reflected powers at different angles. Plot *R* vs. θ, then use the *Fresnel formula* to fit the data by adjusting *n*. Once you find *n* you need to substitute in the *Fresnel formula* for θ=0 to find *R* at normal incidence. Do this for both “s” and “p” polarizations.

Task#4: Determine *R* by measuring *n* using the Brewster angle technique

Measuring the index of refraction by using the Brewster's angle technique. The experimental setup is very simple and can be quickly assembled and is shown in figure. Apart from the sample and laser source, the experiment requires the following: sample holder, rotation stage, CCD camera connected to a laser beam profiler, and neutral density filters to attenuate the beam going into the camera. It is very important to make sure the incident laser beam is perpendicular to the sample surface since the Brewster's angle is measured with respect to this normal. This can be easily accomplished by aligning the back-reflected beam with the incident one. However, to be more accurate, we place a pinhole concentric with the incident laser beam and close to the laser source.



Now, align the back-reflected diffraction rings so that they are properly centered on the pinhole. The greater the distance between the sample and the pinhole the greater the assurance the beam is normal to the sample. This can therefore eliminate (or minimize) the uncertainty in our Brewster's angle measurements that comes from initially non-normal beams. The pinhole can subsequently be removed or a variable aperture can be used in its place. Now carefully rotate the sample and place a card about 10 to 20 cm from it and monitor the change in the reflected intensity by eye. Once you approximately find this angle from the surface normal, you move the CCD camera in place. By making small rotational increments, you can see the intensity dip through a minimum on the monitor of the laser beam profiler as we rotate through the Brewster's angle. This reflected intensity change can be observed on the monitor of the beam profiler as a change in the color of the cross-section of the beam and also the peak intensity of the beam profile. You can adjust the gain and background level on the camera and accurately find the angle close to the resolution of our rotation stage which is 0.01°.

The introduction of the CCD camera along with the laser beam profiler makes the detection of the Brewster's angle simple to do. The fact that the CCD camera has a larger effective detection area than most photodiodes and PMT's and the fact that the reflected beam does not have to be centered on this area makes the CCD camera a better choice for this experiment. you can easily scan through the Brewster's angle without having to adjust the camera position. This is particularly advantageous since the reflectivity near the vicinity of the Brewster's angle is a very shallow function. In addition, we can adjust the gain and background level on the camera to better isolate the angle.