ECE 182

POLARIZATION

I. OBJECTIVE

To study how a linear polarizer and a quarter-wave retardation plate modify the polarization state of optical radiation.

II. GENERAL BACKGROUND

Linear Polarizer

A polarizer is an optical component which when placed in an incident unpolarized beam produces a beam of light whose electric vector is vibrating primarily in one plane, with only a small component vibrating in the plane perpendicular to it. If a polarizer is placed in a linearly polarized beam and is rotated about an axis parallel to the beam direction, the transmittance $T$ will vary between a maximum value $T_1$ and a minimum value $T_2$. (The quantities $T_1$ and $T_2$ are called the principal transmittances, in general $T_1 >> T_2$).

If the polarizer is placed in a beam of linearly polarized light, its transmittance is

$$T = T_1 \cos^2 \theta$$

where $\theta$ is the angle between the plane of the transmission axis and the plane of vibration (of the electric vector) of the incident beam.

If the polarizer is placed in a beam of unpolarized light, its transmittance $T = 1/2 \ T_1$, so that a perfect polarizer would transmit only 50 percent of an incident unpolarized beam.

Brewster-angle Polarizer

The reflection of light from the boundary between two dielectric materials is polarization dependent (recall Fresnel Equations for TE and TM polarizations). A linearly polarized light beam does not get reflected if it is polarized in the plane of incidence (TM polarization) and the incidence angle is equal to the Brewster angle

$$\theta_B = \tan^{-1} \frac{n_2}{n_1}$$

At this angle only the TE component of the incident light is reflected, so that reflector can serve as a polarizer.

Quarter-Wave Plate

A retardation plate is a piece of birefringent, uniaxial (or uniaxial-appearing) material in
which the ordinary and extraordinary rays travel at different velocities. Thus, one ray is retarded relative to the other, and the path $n\lambda$ between the two rays is given by

$$n\lambda = d(n_e - n_o)$$

(3)

where $n_o$ - refractive index of ordinary ray, $n_e$ - refractive index of extraordinary ray, $d$ - thickness of plate, and $\lambda$ – wavelength.

Since $n\lambda$ is the path difference between the two rays, $n$ can be considered as the retardation expressed in fractions of a wavelength. For example, $n = 1/4$ for a quarter-wave (or $\lambda/4$) plate, $1/2$ for a half-wave (or $\lambda/2$) plate.

The phase difference between two rays traveling through a birefringent material is $2\pi/\lambda$ times the path difference, so that the phase retardation $\delta$ is

$$\delta = 2\pi n = 2\pi d(n_e - n_o) / \lambda$$

(4)

Thus, phase differences of $\pi/2$, and $\pi$, are introduced between the two beams in quarter-wave and half-wave plates, respectively.

A retardation plate can be made from a crystal which is cut so that the optic axis lies in a plane parallel to the face of the plate. Consider a beam of unpolarized or linearly polarized light normally incident on the crystal. It can be resolved into two components traveling along the same path through the crystal but vibrating at right angles to each other. The ordinary ray vibrates in a direction perpendicular to the optic axis, while the extraordinary ray vibrates in a direction parallel to the optic axis.

In a positive uniaxial crystal $n_e > n_o$, so the extraordinary ray travels more slowly than the ordinary ray. The fast axis is defined as the direction in which the faster-moving ray vibrates; thus in a positive uniaxial crystal, the fast axis (ordinary ray) is perpendicular to the optic axis, while the slow axis (extraordinary ray) coincides with the optic axis. For a negative uniaxial crystal, the fast axis coincides with the optic axis.

The most common type of retardation plate is the quarter-wave plate. The quarter-wave plate will generate circularly polarized light, if linear input polarization is used, and oriented at $\pm 45^\circ$ with respect to the fast-axis of the wave plate. Note that $+45^\circ$ and $-45^\circ$, the senses of the circularly polarized light are opposite. If circularly polarized light is incident on a quarter-wave plate, a linear output polarization will be generated and is oriented at $+45^\circ$ or $-45^\circ$, depending on the sense of the circular polarization.
III. EXPERIMENTS

In this Lab you will be using the interferometer setup you are familiar with from the Michelson Interferometer experiment. Refer to that Lab handout for a setup description. There is however one difference: the CCD camera is replaced by an observation screen, and instead of oscilloscope an optical power meter is used.

A. Linear polarizer characteristics

1. Position the first polarizer in the path of the output laser beam. Using the power meter to detect the intensity, rotate the polarizer within its mount such that the transmitted power is maximized.
2. Position the second polarizer after the first one. Rotate the second polarizer to minimize the transmitted intensity. At this point you know that the polarizers are crossed (the angle between the transmission axes of the two polarizers is $\theta = 90^\circ$).
3. Vary $\theta$ from $90^\circ$ to $0^\circ$ by rotating the second polarizer, and measure the transmitted intensity.
4. Plot the intensity output versus the angle $\theta$. Describe the shape of the plot.

B. Brewster angle

1. Rotate the polarizer so that the beam is horizontally polarized.
2. Position a right-angle prism (or plain parallel plate) that is mounted on a rotating stage and calibrate the incidence angle to zero by noting the reflection. The stage has 360 1-degree markings on it.
3. Increase the incidence angle as you monitor the reflected spot. Note the Brewster angle and deduce the index of refraction for the prism from this value.
4. Change the polarization of incident beam to vertical. (If the output laser beam is horizontally polarized, what an extra optical element you can use for it? Give two simple ways how to change horizontally polarized beam to vertically polarized.)
5. Rotate the prism and monitor the reflected spot again. Could you find the Brewster angle? Explain the difference in case of horizontally and vertically polarized incident beams.

C. Quarter-wave plate characteristics

1. Set up the Michelson interferometer and observe the interference pattern on the observation screen.
2. Make sure the quarter-wave plate rotation angle is set to $45^\circ$ on its scale.
3. Place the quarter-wave plate in one of the interferometer beam paths, between the beam-splitter and mirror.
3. What happens to the interference pattern? Why? (Hint: block the mirrors one at a time and use the polarizer to check the polarization state of each beam incident on the screen.) What conclusions can be made about the propagation direction of incident polarization through a quarter-wave plate?