Development of Brewster angle measurement instrument using microcontroller unit

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Abstract – Brewster’s angle method is one that commonly used for measuring high index material. This method enables one to measure unlimited range of refractive index. Due to complicated setup of measurement, measurement is commonly carried manually. This paper presents an automatic instrument for measuring Brewster’s angle designed using microcontroller unit (MCU) Arduino. Calibration was made by comparing what was measured by this method with that measured using ABBE Refractometer. It was found that both method showed resembling results. The designed instrument is used to measure the value of the refractive index of the Soda-lime planar waveguide, PMMA glass, and Silica glass. From the measurement, it is known that the refractive index value of the three materials are 1.522, 1.463, and 2.055 respectively.

Keyword: Optical instrumentation, Refractive index measurement, Brewster’s angle

1. Introduction
One of the optical properties possessed by a material is the refractive index. The Refractive index is the ratio of the speed of light to the vacuum and materials [1]. The value of refractive index plays an important role of various materials. For a waveguide, the refractive index determines the number of modes that enter into the waveguide. In addition, the refractive index also controls the width of the reception angle of the waveguide. The refractive index of a material in influenced by several factors, i.e. electron density, material density, and thermal expansion [2].

The refraction index of the materials can be identified by many methods, such as by using ABBE Refractometer[3], Parallel plate refraction methods [4], and conventional Brewster’s angle methods [5]. One method that has the highest measurement limit is the Brewster’s Angle Method. Brewster’s angel method is conducted by firing a TM polarization light to the material, from the light that concern the material will form into two lights, the reflected light and the transmission light. Then made a graph of the relationship between the intensity of reflected light with the incident angle. From the graph, it will be known the incident angle that has the lowest intensity. The Brewster’s Angle is the angle where all the lights passing through the boundary between two materials are all refracted (no reflection) [6].

The refractive index of a material can be determined by using the Snell’s law, which is simplified in the Brewster’s angle equation that can be described as bellow
\[ n = \tan \theta_b \]  

(1)

Where \( n \) is the refractive index of the sample, and \( \theta_b \) is the angle of the incident light.

Measurement of material refractive index by using Brewster angle method has a weakness, that is data retrieval takes a long time because it is done manually [2]. This research aims to design the Brewster angle reader instrument from various materials. The instrument was designed based on microcontroller unit (MCU) Arduino Uno R3. Arduino is used as a main data processor of the sensor. The mechanical system of the instrument uses two servo motors that control the laser arm and the sensor arm, so that the angle of the laser can be varied, and the reading of the light profile can be performed automatically.

After the instrument has been designed, the instrument is used to read reflected light profiles of planar waveguide Soda-lime, PMMA glass, and silica glass. The light profile obtained was analyzed to find the Brewster angle value of the three materials. After meeting Brewster’s angular values and the refractive index of the three materials, the results were compared with the reading of the refractive index using the ABBE refractometer.

2. Materials and Method

This study is divided by two steps, the first step is manufacture of the Instrument which will use to read the image of the profile of light. The next step is measurement the Brewster angle of Soda-lime planar waveguide, PMMA glass, and silica glass by using Instrument. The Instrument was built with Microcontroller Unit (MCU) Arduino Uno R3 as a main controller and processing data, Light Depending Resistor (LDR) to convert the electromagnetic waves into electrical signal, Motor Servo used for moves the arm which LDR attached to. The Instrument is shown in Figure 1.
After the manufacture of the Instrument, we add the algorithm using Arduino IDE software. After the algorithm is added, we can control the Instrument and use it to read the image of profile of light. To obtain the data of the Brewster’s angle, in this study we are transmitting a TM polarization of light into the material and we read the profile of the light from the reflection of the materials. From the light profile formed, the peaks are taken. After reading the peak intensity of the reflectance, the TM polarization light varied from 0 degrees to 90 degrees with increment of 1.05 degree and performed the same thing.

After we find the intensity of the reflectance light at 0 degree until 90 degree of laser beam, we make a graph with intensity of the reflectance light in the function of angle of incident laser beam. From the graph, we know where the lowest intensity of the reflectance light will be. The lowest intensity of the reflectance light shows where Brewster’s angle was performed.

3. Result and Discussion
This research used three samples, there are planar waveguide, PMMA glass, and Silica glass. Planar waveguide samples were prepared by Na⁺-Ag⁺/K⁺ salt diffusion with ion exchange method, there were six planar waveguide samples with variation of time. Samples of PMMA glass are available on the market. Silica glass samples were obtained on previous studies. From the previous research and literature, the values of the refractive index for each samples were 1.522 [3], 1.491, and 1.911-2.005 [5].
Figure 2. The reflectance graph of TE and TM polarization of a planar waveguide with a time diffusion variation of 25 min

Figure 2 shows the reflectance graph of TE and TM polarization light of the planar waveguide with a time variation of 25 min. The Brewster’s Angle appears when a TM polarization of light is fired into the sample. After the reflectance reading of TE and TM polarization of the planar waveguide with a time variation 25 min. We measured the TM polarization reflectance of the six planar waveguide samples and produced the graph as in Figure 3. From Figure 3 graph analysis, it was found that Brewster’s Angle for the all six planar waveguides fell at an angle 56.7 degree.

From the research was conducted by Yu and Kwok [6], it is found that the reflectance pattern with function of incident angle comes by the TE and TM polarization has trend as in Figure 2. The Brewster’s Angle will be visible on the TM polarization light, so we use this mode to find the Brewster’s Angle of the three materials.

Figure 3. The reflectance of six samples planar waveguide

The planar waveguide samples that we have is Soda-lime glass diffused with AgNo salt with variation of diffusion time of 25, 100, 225, 400, 625, and 900 minutes. From the six samples, we measured the reflectance of the TM polarization light and got the graph as shown in Figure 3. From the graph above, it is known that the planar waveguide sample with variation of diffusion time 25 minutes has the smallest reflectance value. However, it has the same Brewster’s angle with five other samples. This indicates that the sample has a smallest electron density. From the graph analysis above, we found the Brewster’s angle for the six samples is 56.7 degree.
Figure 4. Graphs of reflectance as a function of incident angle by (a) PMMA glass and (b) Tellurite glass

Figure 4 shows the reflectance graph of a TM polarized light with a function of incident angle by PMMA glass and Tellurite sample. The graph trend shows the same thing as the previous graph. From the graph analysis, it is known that the Brewster’s angle of both material is 55.65 and 64.05. After we know the Brewster angle’s values of each material under test, then using the Snell’s equation is calculated its refractive index value and yields the data as in Table 1.

Table 1. Comparative measurements by using the instrument and the references.

| Material        | Refractive Index |
|-----------------|------------------|
|                 | Previous Measurement | Instrument     |
| Planar Waveguide 1 | 1.522 | 1.522 |
| Planar Waveguide 2 | 1.522 | 1.522 |
| Planar Waveguide 3 | 1.522 | 1.524 |
| Planar Waveguide 4 | 1.523 | 1.520 |
| Planar Waveguide 5 | 1.523 | 1.523 |
| Planar Waveguide 6 | 1.524 | 1.522 |
| PMMA Glass       | 1.491 | 1.463 |
| Tellurite Glass  | 1.911-2.005 | 2.055 |

4. Conclusion

Instruments for reading the refractive index values of various materials have been successfully designed, refractive index was read by the Brewster’s Angle Method. Instrument using Microcontroller Unit (MCU) Arduino Uno R3 as main data processor and used two servo that serves to move two arms, that’s sensor arm and a laser arm. Therefore, the measurement can be done automatically and has a high accuracy. From the measurements which used the designed instrument, the refractive index values for planar waveguide, PMMA glass, and Tellurite glass are 1.522, 1.463, and 2.05. Planar waveguide measurements were performed on six different samples of diffusion time variation. In addition to measure the refractive index of samples by the Brewster angle method, the instrument can also be used to predict the dopant ion content of the material by analyzing the reflectance trend of the formed graph.
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