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Precise measurement of Faraday rotation in ZF2 and K9 magneto-optical glasses

MUHAMMAD BASHARAT*, ZAHID RAZZAQ, SHAUKAT JAVED, USAMA AFZAL
Centre of Excellence in Science and Applied Technologies (CESAT), Islamabad, Pakistan

In this paper we have presented the measurement of Faraday rotation in ZF2 and K9 magneto-optical glasses. The Verdet constant of both glasses was measured at three wavelengths: 532, 632.8 and 650 nm by a precise Faraday rotation measurement experimental setup. The wavelength dependence of Verdet constant for both glasses was investigated. It was found that Verdet constant increases with decrease in wave length of light for both glasses.

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Keywords: Faraday rotation, Magneto-optics, Verdet constant

2. Introduction

The research into materials with high magneto-optical effects has always been an interesting matter as these materials are used in many applications such as magnetic field sensor, optical isolators and optical modulators. Glass materials are of particular interest for these applications as they are transparent in visible and near infrared region. One of the magneto-optical effects, the Faraday rotation in glasses is a well known phenomenon. The Faraday rotation is wildly used in non-destructive measurement, solution concentration detection and related parameters measurement [1]. Many magneto-optical devices such as magneto-optical isolators, magneto-optical circulator and magneto-optical modulators are based on Faraday rotation [2]. The Faraday rotation has also application in the fields of scientific research, optical communication, optical information processing, optical computing, industry, astronomy and space technology [3, 4]. One of the key parameter for the application of Faraday rotation is the Verdet constant of magneto-optical materials. In this paper we have presented the Verdet constant of two magneto-optical glasses with high precision Faraday rotation measurement.

2. Principle

When linearly polarized light is transmitted through a transparent material which is placed in longitudinal magnetic field, a rotation of the plane is produced by the magnetic field in the direction of propagation of the incident light. This well known magneto-optic phenomenon is called Faraday rotation. Linearly polarized light with a given plane of polarization can be thought as a superposition of right and left circularly polarized light with a specific phase difference. The refractive indices, n^+ and n^-, for the right-hand and the left-hand circularly polarized waves, respectively, are equivalent in the absence of a magnetic field. When linearly polarized light passes through a diamagnetic material, parallel to the direction of the applied magnetic field B, n^+ and n^- diverge, causing the two polarizations to propagate with different velocities and phases. As a consequence, the plane of the polarization of the linearly polarized light rotates through the angle given by relation [5, 6]:

$$\theta = \frac{\omega}{c}(n^+ - n^-)L = VBL \tag{1}$$

Where ω is the angular frequency of light, c is speed of light, V is known as the Verdet constant, B is applied magnetic field and L is the length of the light path in the medium. The Verdet constant, which measures the strength of the effect, is different for different materials. The relationship between the Verdet constant and the wavelength dependence of the index of refraction depends critically on the nature of the medium, i.e. whether it is semiconducting, diamagnetic, paramagnetic, ferromagnetic, etc. The sign of Verdet constant and thus that angle of rotation is positive (negative) if angle of rotation is clockwise (counterclockwise) looking parallel to the vector of magnetic flux density for both direction of the propagation of the electromagnetic waves, parallel and antiparallel to magnetic flux vector B. The Verdet constant is positive for diamagnetic materials while negative for paramagnetic materials. The Faraday rotation in ferromagnets and ferrimagnets can be either positive or negative [7]. The Verdet constant of diamagnetic materials is nearly independent of the temperature and magnetic field [8]. The wavelength dispersion of Verdet constant is given by Becquerel's formula [8]:

$$V = \gamma \frac{e\lambda}{2mc}\left(\frac{dn}{d\lambda}\right) \tag{2}$$

Where λ is wave length of incident light , e and m are electronic charge and mass, c is speed of light, n is refractive index of the material and γ is a correction factor known as magneto-optic anomaly, which depends on type of material. The equation (2) indicates that Verdet constant is linearly proportional to the dispersion $dn/d\lambda$ of the material. Another simplified dispersion formula of the diamagnetic Verdet constant on the basis of single oscillator model is given by [9, 10]:

$$V = \frac{\pi}{\lambda}\left(a + \frac{b}{\lambda^2 - \lambda_0^2}\right) \tag{3}$$

Where a and b are fitting parameters to be determined by measuring the Verdet constant for given optical material at different wave lengths.

3. Experimental

Experimental setup for precise Faraday rotation measurements is shown in Fig. 1.

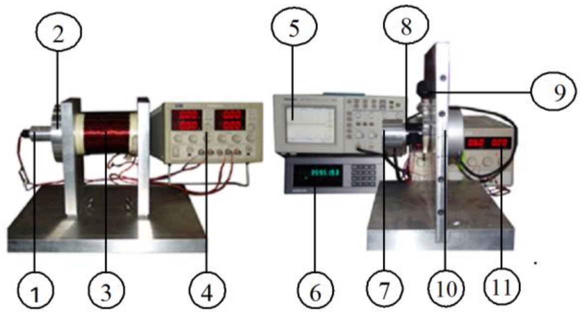

Fig. 1. Experimental setup: 1. Laser, 2.Polarizer, 3. Solenoid coil, 4. Power supply 1, 5 .Oscilloscope, 6.Optical encoder display, 7.Analyzer, 8. Detector, 9.Worm gear, 10. Optical encoder, 11. Power Supply2.

The laser diode housing was coupled with polarizer holder concentrically. The magnetic solenoid coil was made from 1.3 mm thick enameled copper wire and consists of 730 turns in 10 layers on a Teflon spool having length 100 mm and internal bore of 15 mm. The resistance of the solenoid was 2 ohms. A 28V/11A power supply was used as power source for solenoid coil and laser source. Two sheet polarizer having high extinction ratio were used. The mount of the analyzer was coupled with incremental optical encoder having accuracy of 5 arc sec through worm gear assembly. The analyzer could be rotated in steps of 1 arc sec. The laser beam leaving the analyzer was focused by a convex lens on a silicon photo detector

BPX 65 which was used to detect the transmitted light signal intensity. All components were fixed to rigid and stable plates to eliminate the alignment and stability issues during the experimentation.

The magnetic field inside the solenoid coil was measured using a Magnet-PhySIK FH 54 Gauss-/Teslameter. For the measurement of the Verdet constant the glass rods having length 100 mm and diameter of 10 mm were used. The two parallel sides of the glass rods were optically polished. The glass rods were placed inside solenoid with Teflon ends supporting sleeves. Three laser sources were used: He-Ne laser and two diode lasers of wavelengths 532 and 650 nm. Having the laser source turned on, the analyzer was set at 90° with respect to entrance polarizer to have maximum light extinction to the detector. The angle of rotation of analyzer necessary to return to maximum extinction, when solenoid magnetic field was turned on, was measured precisely with optical encoder.

4. Results and discussion

In the absence of glass rods, the distribution of the magnetic flux density along the axis of the magnetic solenoid was investigated. The flux-density was measured in steps of 3 mm. The procedure was repeated for several values of current from 0.5 to 8 A in steps of 0.5 A. It was found that the flux density increases strongly to the center of the coil and decreases to either side. The variation of magnetic flux density at coil current 3A is shown Fig. 2.

Fig. 3 and 4 shows the angle of rotation of plane polarization as a function of the magnetic flux density at wavelengths 532, 632.8 and 650 nm for ZF2 and K9 glass respectively. The linear fit of the lines gives the slope of the lines. The Verdet constant can be calculated by dividing the slope by length of the sample.

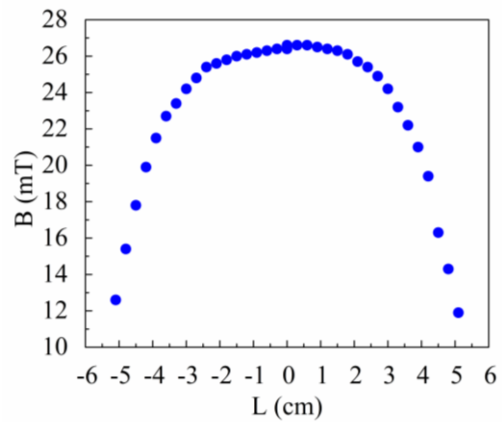

Fig. 2. Variation of magnetic field inside the coil.

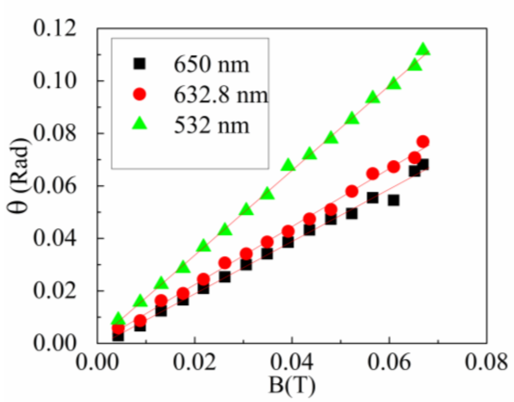

Fig. 3. Angle of rotation of plane of polarization as function magnetic flux density for ZF2.

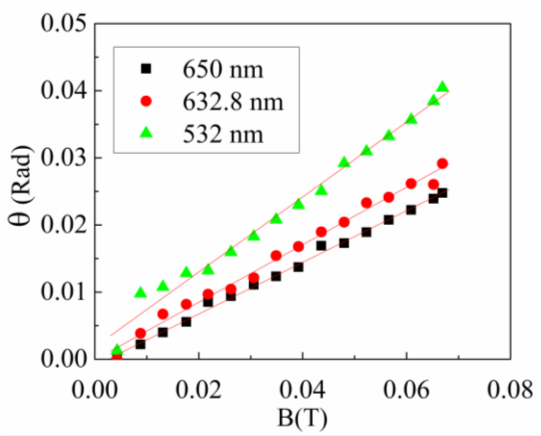

Fig. 4. Angle of rotation of plane of polarization as function magnetic flux density for K9.

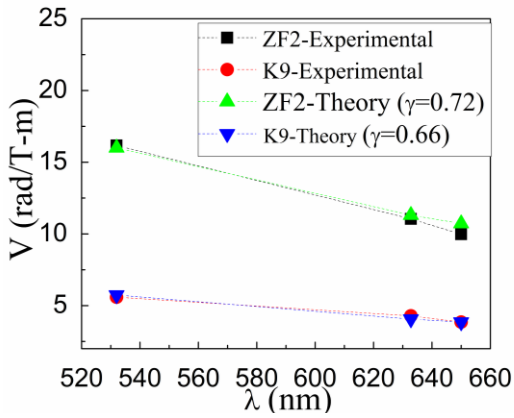

Fig. 5. The variation Verdet constant as a function of wavelength for ZF2 and K9.

The values of Verdet constant calculated at three wavelengths are given in Table 1. The accuracy of the readout of rotation angle of 5 arc sec corresponds to an absolute error of about 0.004 rad/T-m. The Verdet constant of ZF2 and K9 glass varies inversely with wavelength of incident light. To our knowledge the data for Verdet constant of ZF2 is not available to compare with. The Verdet constant of K9 glass at wavelength of 650 nm is in agreement with one reported in reference [2].

The Verdet constants of both glasses were calculated using equation 2. The correction factor γ comes out to be 0.72 and 0.66 for ZF2 and K9 respectively.

Table 1. Verdet constant of ZF2 and K9 at λ =532, 632.8 and 650 nm.

Sample	Verdet constant (rad /T-m) 532 nm	632.8 nm	650 nm
ZF2	16.17	11.05	9.98
K9	5.59	4.29	3.85

Fig. 5 shows the dispersion of measured Verdet constant along with calculated from Becquerel's equation with suitable correction factor for both glasses. The Verdet constant of both glasses decreases monotonically with increase in wave length of incident light.

5. Conclusions

Precise measurements of the Verdet constant of magneto-optical glasses ZF2 and K9 were carried out at three wavelengths 532, 632.8 and 650 nm.

The Verdet constant was found to decrease monotonically with increase in wavelength of incident light in both cases. The experimental data yield a positive Verdet constant which shows diamagnetic nature of glasses under discussion. The data presented here will be useful for the application of ZF2 and K9 in different magneto-optics devices.

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*Corresponding author: creation_mzd@yahoo.com