FÍSICA 1

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LASER WAVELENGTH MEASUREMENTS USING A QUARTZ PLATE AND FARADAY EFFECT

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ABSTRACT

The authors performed a polarimetric prototype for wavelength measurements. In the design both Faraday rotators acting for modulation of the incoming laser light and also as compensator, allow together with a quartz plate, a precise measurement of laser wavelength from 400 to 900 nm, with a resolution better than 0.1 nm. Equations and graphics current versus lambda for a quartz tungsten halogen lamp are presented for sensor adjustments. It is also presented a signal to noise analysis and a comparison with a conventional method.

KEYWORDS

Wavelength measurements, rotatory dispersion, Faraday rotators.

RESUMEN

En el presente trabajo se describe el diseño de un prototipo de medidor de longitud de onda polarimétrico. En el diseño los rotadores de Faraday actúan en la modulación y compensación de la luz incidente, estos unidos a una placa de cuarzo permite la medición de longitudes de onda entre 400 y 900 nm, con una resolución mejor que 0.1 nm. Las ecuaciones y los gráficos de corriente contra la longitud de onda son presentados para ajustes de los sensores. Además es presentado un análisis de la relación señal-ruido y una comparación con el método tradicional.

PALABRAS CLAVES

Mediciones de la longitud de onda, dispersión rotatoria, rotadores de Faraday.

INTRODUCTION

In research areas and in laboratory practice physics learning have been used many methods for measuring wavelength of radiation. One of the most common applications in research of these measurements is in optical metrology, for characterizing laser parameters. In this paper we shall describe a prototype and technique developed by CEADEN for laser wavelength measurements.

By other hand, Faraday rotators have been widely used as isolators in gas or diode lasers performance, before 1995 the employment of terbium doped glass and terbium gallium garnet (TGG) were commonly used in free-space isolator. Recently new crystals such as cadmium manganese telluride and mercury doped glass also have been developed. A broad range of yttrium iron garnet (YIG) epitaxially grown crystals, which includes many dopants (1) have been developed in the infrared region.

Optical spectrum analysers has been developed (2) employing a magneto-optical rotation generated by a variable magnetic film to perform spectral analysis based on detected intensity distribution of diffracted light in the thin film multilayer for known magnetic field strengths. On other hands real time spectral analysis is presently carried out in number of ways, one of which is to collimate the unknown spectral distribution, transmit it through or reflect it from a mechanical diffraction grating to separate the spectral components according to the first order angle and detect the relative spectral intensities via a charge couple device (CCD) photo-detector array (3). Another method, which is used in chemical spectroscopy analysis, replace the expensive CCD photo-detector array with a simple photo-detector and rotates the diffraction grating mechanically with the spectral component incident on the detector. The detected light is thereby related to the amount of rotation of the grating.

The cost of CCD-based systems, and the limited speed and mechanical nature of such chemical spectroscopy systems leaves a need for no mechanical electrically controllable spectral analyser, which were briefly explained in (1). All of these methods measure the wavelength according a pattern of intensities in the detector; it means an explanation of the distribution of intensities. The following method does not depend of intensity measurement of laser, it is a phase detection method, and for that reason noise sources are minimized. The idea of our method was suggested by Cummings(4) and Zander (5) in studies for rotatory dispersion of quartz and sugar samples and it is supported in the last approved equations of rotatory dispersion of quartz (6). This sensor was employed in characterization of He-Ne laser and laser diode.

THEORETICAL CONSIDERATIONS

1. Quartz sample rotation

Quartz plates are widely used as standards in polarimetric measurements. Plates with different degrees of rotations from almost 0 to 100 ° are used in visual and photoelectric polarimeters with different wavelengths.

In 1998 International Commission Unified Methods Sugar Analysis accepted the following dependence for rotation of 1 mm of quartz with wavelength (μm):

$$[\alpha] = -0.1963657 + \frac{7.262667}{\lambda^2} + \frac{0.1171867}{\lambda^4} + \frac{0.0019554}{\lambda^6} \qquad (1)$$

and analysing first derivative with wavelength,

$$d\lambda = \frac{d\alpha}{\left(-\frac{14.525334}{\lambda^3} - \frac{0.4687468}{\lambda^5} - \frac{0.117324}{\lambda^7}\right)} \qquad (2)$$

Then, angular polarimetric measurement must be better than 0.002°; it means a maximal precision of 0.07 nm or 0.02 nm. According to the rotatory dispersion equation for shorter wavelengths, precision for optical rotation must be lower than 0.07 nm (Table 1).

Table N° 1. Theoretical accuracy for wavelength measurements.

Centre of Intervals (nm)	633.8	735.0	880.0	1000.0
Accuracy (nm)	0.017	0.026	0.045	0.068

2. Model for optimizing the signal to noise ratio (S/N).

In the Faraday cell performances the optical rotation (min) is:

$$\beta(\lambda) = V(\lambda)\, HL \quad (3)$$

where V (λ) is Verdet constant in min Oe^{-1} dm^{-1}, H is the magnetic strength in the solenoid axis in Oe and L is the length of the rod in dm. Verdet constant changes with wavelength did not considerably introduce a significant noise in the modulation angles (7). The resulting signal in the detector for small angles, when it is used a lock-in amplifier arrangement is:

$$S = 1.6\,\alpha\beta\, I_0 V(\lambda) niL \qquad (4)$$

Where I_0 is the intensity of the incident radiation, α is the optical rotation of quartz, n is the number of turn per length, i is the current in the cell. Noise is obtained as follow:

$$N = \sqrt{I + A^2 I^2 + R} \qquad (5)$$

And I is the intensity in the photo-detector, consequently, signal to noise ratio is:

$$S/N = \frac{1.6\alpha\beta\, I_0 V(\lambda) niL}{\left(N = \sqrt{I + A^2 I^2 + R}\right)} \qquad (6)$$

EXPERIMENTAL SETUP

The optical-mechanical arrangement Fig. 1 is basically composed by a quartz tungsten halogen lamp of 500 W, (1) a condenser lens system (2), a double monochromator MDR 23 with a diffraction grid of 1200 lines/ mm (3), a collimating lens system (4)), a sheet polarizer (5), a magnetic shielded Faraday cell (6), a quartz plate (7), a Faraday compensating cell (8), an analysing sheet with a mechanical rotator adjustment (9) and a photo multiplier tube of flat response for whole spectrum R636. The resulting signal of the detector and modulating reference signal (10) is supplied to a lock-in amplifier (11), where they are filtered and amplified. Afterwards a dual channel oscilloscope monitors both signals, where it is obtained a corresponding Lissajous figure (frequency ratio 1:2). Modulation is driven by a wave generator at 1.8 KHz (modulating LASERPOL system) (12) and the standard signal is supplied to 5cm- 900 solenoid, which has a TF10 glass core. A 850 turn calibration cell (8) is fed by a stabilized current power supply (0-5 A, 0.25 mA ripple). The current measurement was performed by 0.1 mA scale of a digital storage multimeter Thurbly. The noise was taken as the peak-to-peak variation of the baseline before and after the rotation measurement. One point of calibration was established by using a 5 MHz digital storage oscilloscope IWATSU DS 8605. The various components of the instrument were carefully optimised during the experiments, since best extinction ratio and sensitivity of the system were very critical for the improvements in S/N ratio. Zero setting of the instrument was performed with a He-Ne laser of 0.6329914 μm. Then, without any current the zero point is set in the Faraday compensating cell (polarizer and analyzer in the crossed position). Also two more references points are established with a quartz tungsten lamp (Table 2).

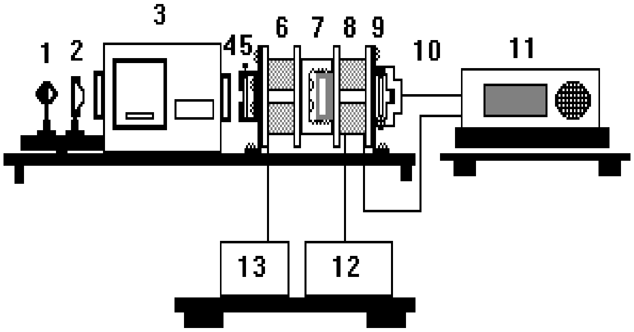


Fig.1. Block diagram of the instrument.

Table N° 2.

Wavelength measurements in MDR 23 monochromator (nm).	Wavelength fixed (nm).	Differences (nm).
454.22	454.16	-0.06
458.36	458.26	-0.10
473.30	473.30	0.00
488.23	488.23	0.00
504.93	504.88	-0.05
517.55	517.47	-0.08
533.87	533.77	-0.10
546.70	546.70	0.00
552.35	552.30	-0.05
582.60	582.60	0.00
607.45	607.45	0.00
632.95	632.96	0.01
665.70	665.70	0.00
679.85	679.85	0.00
735.05	735.03	-0.02
774.00	774.00	0.00
880.25	880.22	-0.03
999.87	999.76	-0.10

RESULTS AND DISCUSSIONS

At first glance, it seems from the resulting signal expression that simply providing a large modulation current, or more coil turns per unit length could enhance the signal. However, there are practical limits to increase the signal by these methods. One of these limits is the geometrical dimension, which has to be reasonable small. The heating of the coil is the major source of mismatching of the expression of rotary dispersion of quartz and the founded relationship in the calibration procedure. Although large current is used, the use of ramp shape pulse diminishes the power dissipated in the coil, even at 1.8 KHz.

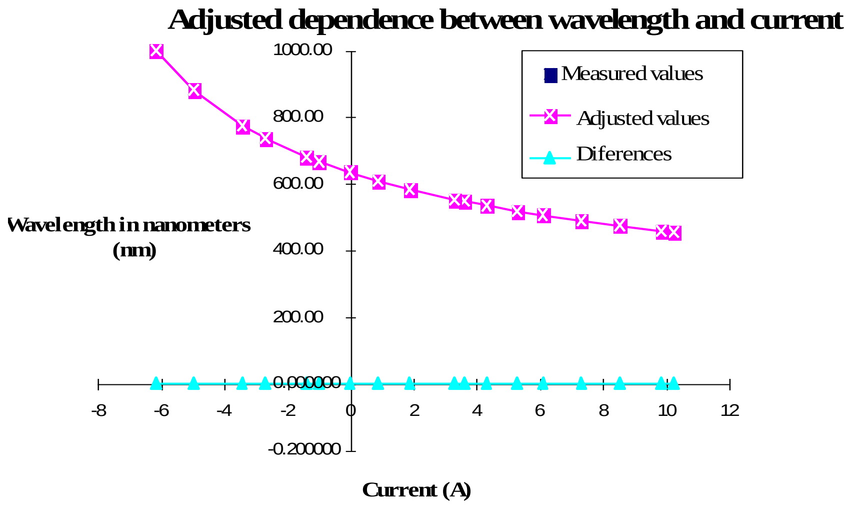
The signal to noise ratio under these conditions is 132, which allows to measure better than 0.1 nm in the whole spectrum. Further studies with higher Verdet constants cores must be considered to increase this S/N ratio.

$$\lambda = 73.60 + 1000\,(0.274185\,i + 2.830193)^{-0.55838} \qquad (4$$

where λ is in nm and i in ampere.

The results of calibration are shown in the Fig. 2. Here it was not observed a compensation between the Verdet variations of TF 10 glass and the variation of quartz with wavelength. The calibration curve was adjusted to the following expression:

The calibration was made with the best signal to noise ratio obtained and the resolution is better than 0,1 nm.



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