Científica Vol. 11 Núm. 3 pp.149-154
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Development of a Spectrometer controlled by a PC

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Recibido el 9 de octubre de 2006; aceptado el 8 de marzo de 2007.

1. Abstract

The development of a spectrometer controlled by means of a personal computer (PC) is presented in this work. The prototype will be used to obtain the fluorescent spectra emitted by a sample under the Laser Induced Fluorescence (LIF) technique. Also, the prototype is useful to obtain spectra of diverse light sources. The spectrometer is generally formed by a monochromator associated to a stepper motor, a photo multiplier tube (PMT) and a data acquisition board (DAQ) intended to communicate with the PC. A control program has been written in the graphical programming language G of LabVIEW, which generates a wavelength (λ) sweep by moving the diffraction grating of the monochromator with the stepper motor. At each λ-value the program measures the related irradiance and processes the measurements. The program also plots this information in real time and builds the spectra detected by the PMT. We used a mercury lamp to calibrate the monochromator and it was found an error lesser then ±0.2 nm. As a result it is presented a high sensitivity automated spectrometer, with a useful range covering from 200 nm to 800 nm.

Key words: spectra, monochromator, wavelength sweep, high optics sensitivity.

2. Resumen (Desarrollo de un espectómetro controlado con PC)

En este trabajo se presenta el desarrollo de un espectrómetro con interfase a una computadora Personal (PC). El prototipo desarrollado sirve para obtener los espectros de diversas fuentes luminosas. Particularmente este será usado en la obtención de espectros de fluorescencia emitidos por una muestra bajo estudio aplicando la técnica de Fluorescencia Inducida por Láser (LIF). El espectrómetro se compone de un monocromador asociado a un motor a pasos, un tubo fotomultiplicador (PMT) y una tarjeta de adquisición de datos (DAQ) para establecer la comunicación con la PC. Se escribió un programa de control en el lenguaje gráfico G dentro del ambiente de LabVIEW, el cual genera un barrido de la longitud de onda (λ) moviendo la rejilla de difracción del monocromador por medio del motor a pasos. En cada valor de λ el programa mide la correspondiente irradiancía y procesa las mediciones. El programa también grafica la información en tiempo real y construye el espectro detectado por el PMT. Se utilizo una lámpara de mercurio para realizar la calibración del monocromador con un error inferior a ±0.2 nm. Como resultado se presenta un espectrómetro automatizado de alta sensibilidad que cubre un intervalo de 200 nm a 800 nm.

Palabras clave: espectros, monocromador, barrido en longitud de onda, alta sensibilidad óptica.

3. Introduction

Optical spectroscopy can be used to determine the identity, the structure and the environment of atoms and molecules by measuring of the radiation emitted or absorbed by them. The light emitted from a gaseous discharge, when analyzed by wavelength, is found to consist of discrete lines and bands. Each line or band is characteristic of a particular atom or molecule, and, once the characteristic line pattern of an atom is known its appearance reveals in the presence of that atom in the source. This aspect of the spectroscopy is known as espectrochemical analysis. Additionally one may deduce from the line pattern or band pattern the characteristic energy levels or stationary states of the atom or molecule. This provides the

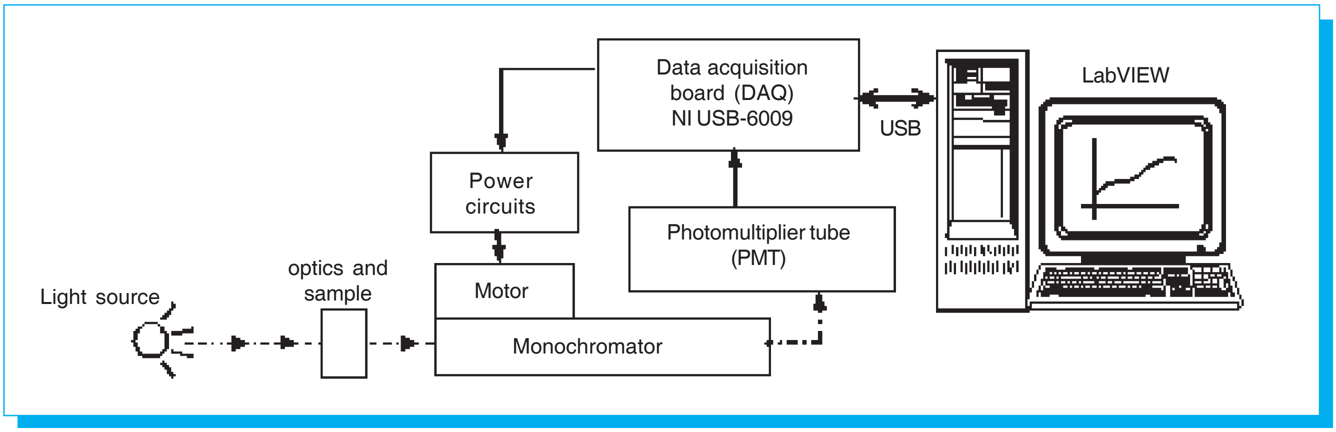

Fig. 1. Schematic diagram illustrating the developed spectrometer.

experimental basis on which the theories of the atomic and molecular structure have been developed and are still evolving. Physical properties such as temperature, pressure, etc, of the gas or plasma containing the emitting or absorbing particles, affect the intensity and wavelength distribution of the radiation in various ways. The study of these effects may be called spectrophysics [1,2].

The spectrofluorimetry is related to the measurement of the emission spectra produced by fluorescent samples. The fluorescence spectroscopy is widely used nowadays for biomedical purposes and clinical analysis, among other many applications [3].

4. Development

Figure 1 shows the schematic diagram of the developed spectrometer. The monochromator contains a diffraction grating which decomposes the input light into its different wavelengths [2,3,4]. Each one of these wavelengths can be

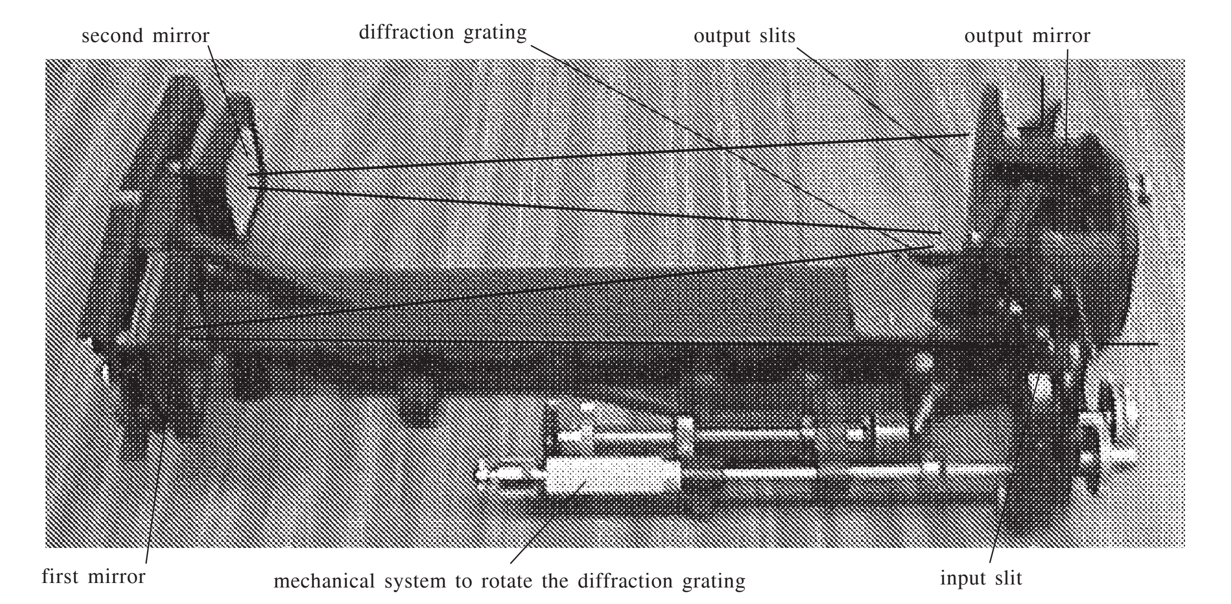

Fig. 2. Components of the monochromator used to develop the spectrometer.

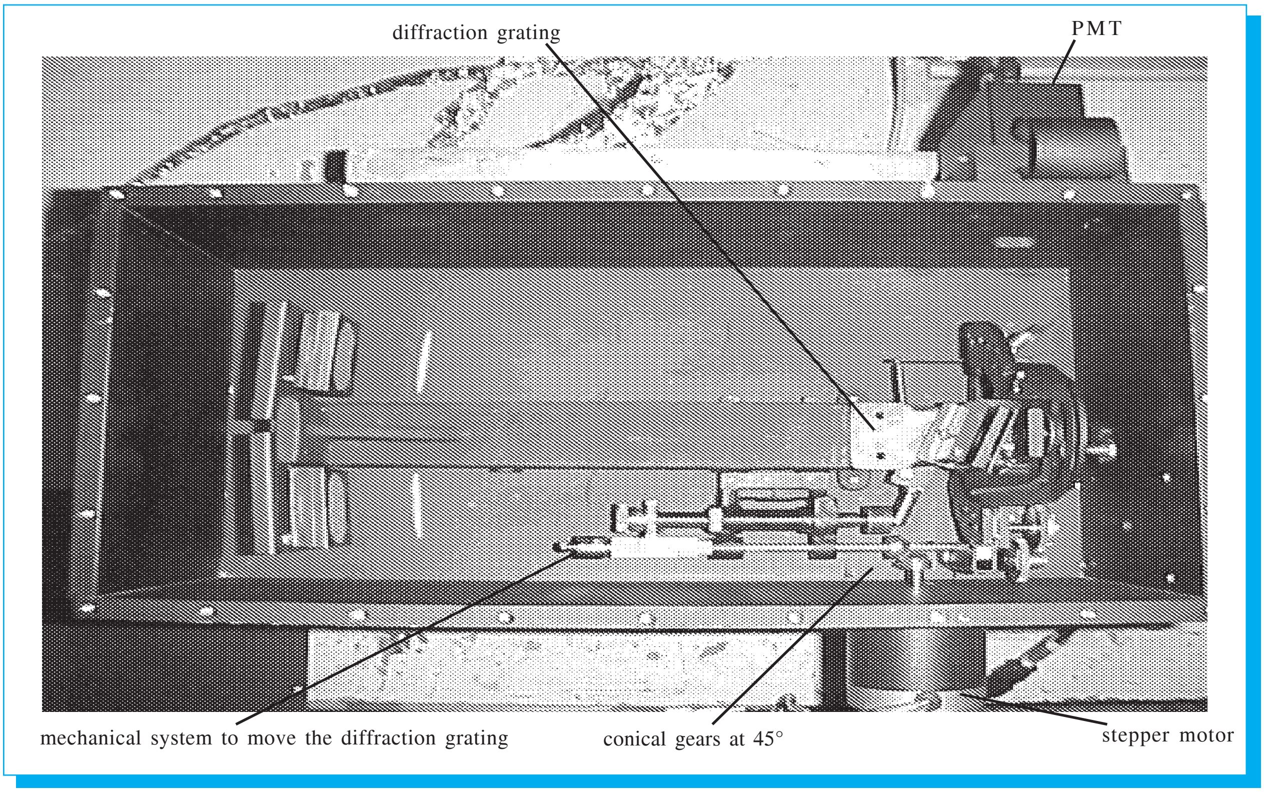

Fig. 3. Monochromator assembled in the chassis.

selected at the output of the monochromador by means of the angular positioning of the diffraction grating. This positioning is achieved with a stepper motor [5, 6] coupled to the mechanical system of the diffraction grating. Under the control of a program the DAQ board sends commands in order to move the motor and to position the diffraction grating at a specific output wavelength. Power circuits are required to supply the necessary currents to move the motor. The output light from the monochromator at a single wavelength is sent to a photomultiplier tube (PMT) [3,7]. The PMT produces a current signal proportional to the detected irradiance, which is converted to voltage. This voltage is measured with an analog input channel of the DAQ board, which converts the analog input voltage to a digital format so that the PC can recognize the measured information. The card DAQ communicates with the PC by means of a USB port [8]. The control program was developed in the graphic language G of a LabVIEW® environment [9, 10]. This program controls the angular position of the diffraction grating so to generate a wavelength sweep. At each λ-value the program measures the corresponding irradiance, processes the measures and graphs in real time the spectrum of the radiation detected by the PMT.

4.1 Monocromator and chassis

Figure 2 shows the monochromator system which is of the Czerny-Turner type with focal length of 275mm and a 32 x 27 mm 1200 grooves/mm grating. In figure 2 the main components of the monochromator and the light trajectory are indicated. A chassis of aluminum able to house the monochromator with 5/16" thick covers mounted on a rigid base of ¾".The covers and the base are slotted together in order to form light tramps. The chassis has enough rigidity to sustain firmly the monochromator and its interior is totally isolated from the external light. The chassis was thoroughly painted in black as shown in figure 3. The coupling of the stepper motor to the diffraction grating mechanical system is carried out by means of a pair of conical gears at 45º. Figure 3 shows the monochromator assembled on the chassis with its additional components that form the spectrometer.

4.2 Stepper motor and measurement system

The 57BYG084 GBM [11] stepper motor is of the unipolar type endowed with a four phase stator and a permanent

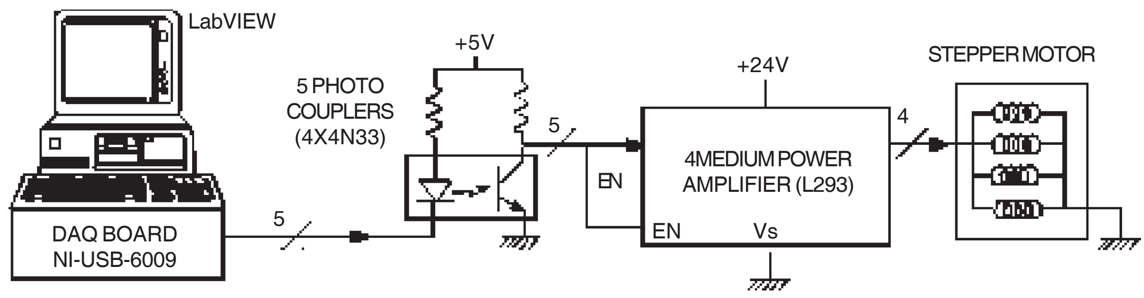

Fig. 4. Power circuits to move the stepper motor.

magnetic rotor enabling a 1.8° resolution per step. This motor can be modeled as an arrangement of 4 coils connected at single end to a common point. Each coil consumes up to 0.6 A when excited and each of them is associated to a half power amplifier of the L293 integrated circuit (figure 4). This circuit contains four independent amplifiers that can provide up to 1 A each, to a maximum voltage supply of 36 V, and includes an input (E) to disable the power outputs [12]. The state of each stepper motor coil is determined by the code written in the 4 respective output digital lines of the DAQ board. The TTL logical levels provided by the DAQ board are electrically insulated of the power stage by means of optoisolators (4N33).

In order to detect the optical signal from the monochromator the module H7732P-11 from Hamamatsu has been used. This contains a high sensitivity PMT, a dc to dc converter to provide the high supply voltage required by the PMT and a voltage input to control the gain of the PMT [13]. The module is supplied with a single +15 V signal and provides a 1.2 V reference output to control the gain of the PMT through a 10 KΩ potentiometer operated as a voltage divider. The H7732P-11 presents a 4x20 mm2 of effective area of detection and a 80 mA/W peak radiant sensitivity at 430 nm. The voltage signal from the PMT is sent to an analog input of the DAQ USB-6009 National Instruments board. Four output digital lines of USB-6009 are used to control the stepper motor and other one to enable the power outputs.

4.3 Control program

A control program was written in the graphical programming language G of LabVIEW, intended to automate the spectrometer enabling to create virtual instruments on friendly user interface [9, 10]. The main program performs one of the following four operating functions: *Move* the monocromator, *Sweep*, *Autocalibration* and *Read Files*.

Move
This function positions the optical system of the monochromator, such that its luminous output signal is of a desired wavelength. The positioning is carried out by fixing the values of the variables *Current Lamda* and *Lamda to Position*.

Sweep
The monochromator is positioned from the value of *Current Lamda* to the value of *Initial Lamda* where the sweep begins. A complete wavelength sweep is performed until the value of *Final Lamda* is reached. The step width $\Delta\lambda$ of the sweep is selected by the user. For each λ value a proportional voltage to the luminous intensity is measured. Forty samples of this voltage are measured at a rate of 4800 S/s and the average of the samples is calculated to define one point. This averaging process improves the S/N ratio. Each point of the sweep is sent to a graph on which the spectrum is being formed during the sweep. At the end of the sweep it is possible to store the spectrum obtained.

Autocalibration
With this function the monocromator performs a sweep using a mercury lamp. The program determines experimentaly the calibration equation from the calibration values stored in the program. The calbration results are stored in a file.

Read files
With this function it is possible to open a file (λ vs intensity) that was stored previously. The spectra contained in the file is presented on graph.

4.4 Calibration

Wavelength calibration was performed with a mercury lamp whose spectrum is well defined with peaks on known wavelengths. We used four of these peaks located at: 365.0146 nm, 404.6563 nm, 435.8328 nm and 546.0735 nm.

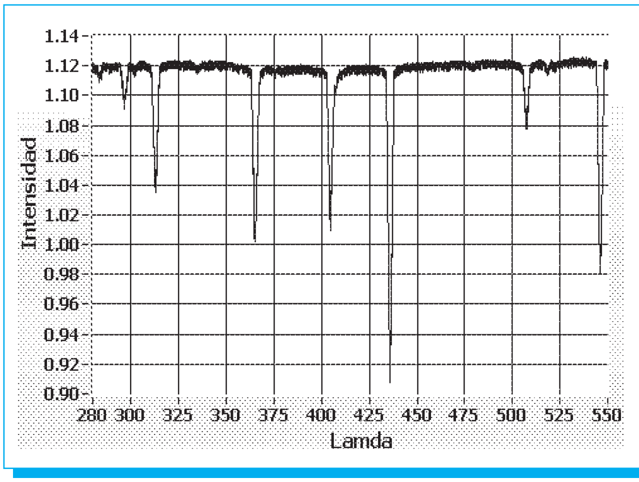

Fig. 5. Emission spectra of the mercury lamp with the spectrometer calibrated.

We carried out several sweeps on a 4000 step interval. Forty samples of luminous intensity per step were measured at a rate of 4800 samples per second and the average of the samples was calculated. With the average value of the steps to each calibration peak it was obtained a graph of steps vs λ. The experimental data were adjusted by assuming the following transfer equation:

$$\lambda = 0.050015 \text{ (nm/step)} * \text{Steps} + 54.92 \text{ nm}$$

According to the adjustment equation the resolution is 0.05 nm/step and the maximum error is ±0.2 nm or ±0.1% at 200 nm.

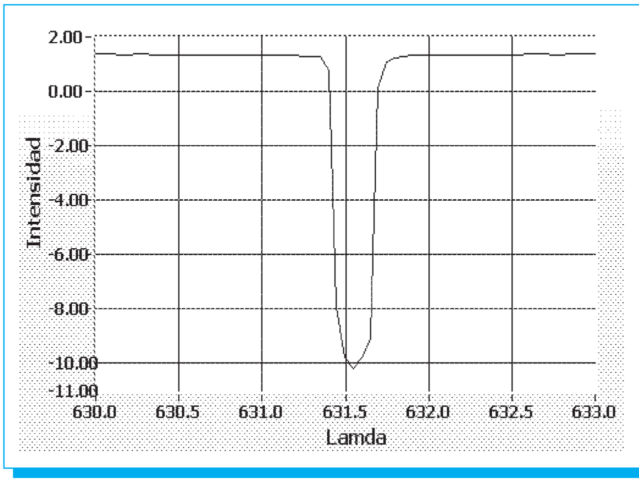

Fig. 6. Emission spectra of a helium-neon laser with high coherence and a spectral width of approximately 0.3 nm.

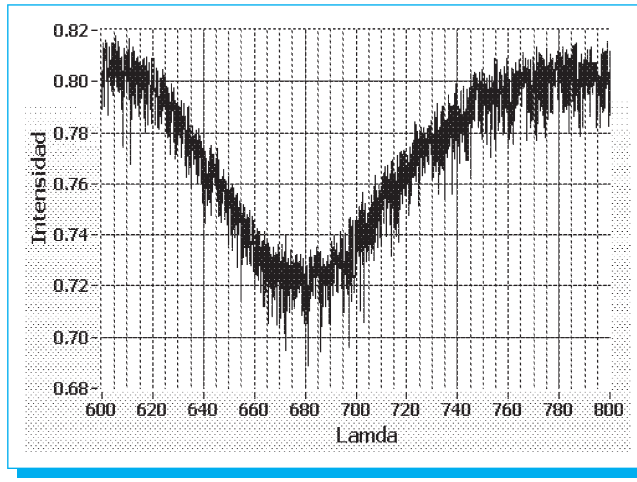

Fig. 7. Emission spectra of a standard red led without coherence and very dispersed.

Figure 5 shows the emission spectra of the mercury lamp after the spectrometer was calibrated. Figure 6 shows the emission spectra of a helium-neon laser with high coherence and a spectral width of approximately 0.3 nm. Figure 7 shows the emission spectra of a standard red light emitter diode (LED) without coherence and very dispersed. Figure 8 shows the emission spectra of an ultraviolet LED with a spectral width of almost 10 nm.

5. Conclusions

In this work we describe the mechanical assembly, the electromechanical control with their associate electronics,

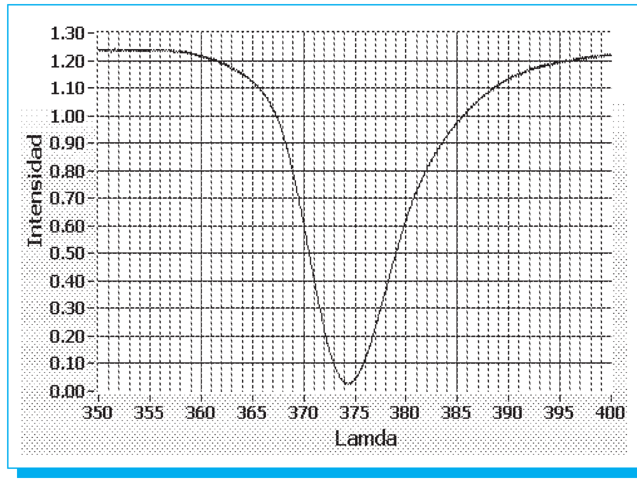

Fig. 8. Emission spectra of an ultraviolet led with a spectral width of almost 10 nm.

as well as the necessary software to operate a completely automated spectrometer endowed with an autocalibration operation. The resulting prototype of a reliable spectrometer of high sensitivity has also been presented. This prototype works satisfactorily from 200nm to 800nm (ultraviolet to visible regions) with an accuracy within ±0.2nm.

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