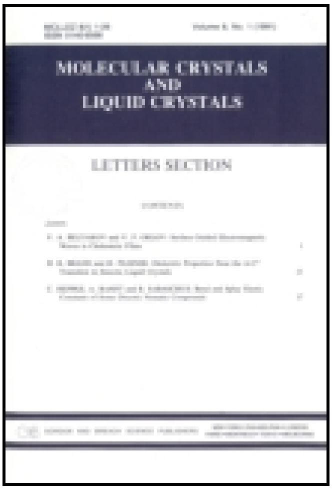

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Technique for Spectropolarimetry Based on Liquid Crystal Polarization Diffraction Grating

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Technique for real-time spectropolarimetry is developed. An embedded system for circular dichroism registration is designed based on National Instruments single board reconfigurable I/O platform for ultraviolet and visible spectroscopic needs. The basic functional unit of the proposed device is liquid crystal polarization diffraction grating. In order to expand the dynamic range the control of data accumulation time is provided. Two NMOS sensor linear arrays provide an excellent linearity of response.

Keywords Circular dichroism; polarization diffraction grating; spectroscopy; liquid crystal

Introduction

In spectrophotometry, while registering small signals, it is important to realize the record of light with low signal/noise ratio in linear photodetection mode. For example, in the circular dichroism (CD) spectroscopy the requirement for the light intensity measurements' precision is one hundredth of a percent.

The currently existing devices for circular dichroism measuring are based on the use of photo-elastic modulators. The main drawback of these devices is huge light losses, caused by the process of beam separation onto the left- and right-polarized components. This leads to the registration system complication due to the small value of signal/noise ratio, causing the complexity in operation, the high cost and large size of such devices.

In recent years, due to the synthesis of new polymers, to make polarization diffraction gratings (PDG) [1] that allow spatial separation of light beams with left and right circular polarizations become possible practically without any losses. The use of such elements allows determination of circular dichroism by measuring the difference between the intensities of left- and right-polarized light beams.

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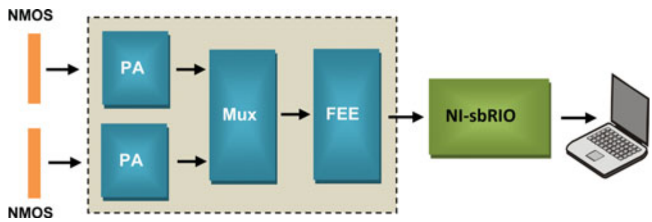

Figure 1. Scheme of registration system.

In this paper the developed technique for recording the difference of intensities of left- and right-circularly polarized light beams in the fixed spectral range in real-time is described.

Design of spectropolarimeter

A system for bio-objects CD registration is designed (Fig. 1). The key component of designed spectropolarimeter is a liquid crystal (LC) PDG. The unique properties of polarization gratings are polarization selectivity of the diffraction efficiency and the capability of these gratings to convert the polarization states of diffraction beams [2–7].

LC PDG spatially separates the left- and right-circularly polarized components of incident light. In proposed spectropolarimeter the PDGs recorded on the glass substrate using LPP ROP-103/2CP [8] as a photo-alignment layer and LCP ROF 5102 [8] as a liquid crystal polymer. The efficiency of this grating at 325 nm wavelength is ~100%. More detailed information about used LC PDG is presented in [9].

The light, passing through the sample, spatially separated by PDG to left- ($N_L h\nu$) and right- ($N_R h\nu$) circularly polarized beams, which are detected with linear sensors arrays. Difference between the numbers of photons for left- and right-circularly polarized beams (N_L and N_R) is proportional to CD.

Due to the small difference between intensities (less than 10^{-4}), the requirements for the registration system sensitivity, linearity and signal/noise ratio are rigid enough. Considering these requirements a technique for CD small values registration is developed. Linear NMOS matrixes are used as photoreceivers. The photocurrent of detectors is amplified by transimpendance preamplifier (PA) and applied to multiplexer (Mux). Multiplexer reads the signals from PA in accordance with the generated by Front-End Electronics (FEE) [10] control pulses, and transmits them to the NI DAQ-card, where the registered from the preamplifier voltages are converted to CD according to the designed algorithm.

At the photon absorption by a reverse-biased photodiode, the linearly proportional to the number of photons photocurrent is generated in the external circuit due to the internal photoeffect. An 1024 pixels array of photodetectors has been used, where each pixel registers a certain wavelength radiation. Hamamatsu S3903-1024Q NMOS photodiode arrays designed specifically as a linear light sensors for multichannel spectroscopy was used. Due to the provision of excellent output linearity and a wide dynamic range, the current output type was used, since it's ideally suited for use in applications, where high accuracy is needed and gives a high-speed readout in current-to-voltage conversion mode in spectral range 200–1000 nm (Fig. 2).

This driver circuit basically consists of a control signal generator and a video signal processor. The block diagram of used driver circuit is shown in Fig. 3.

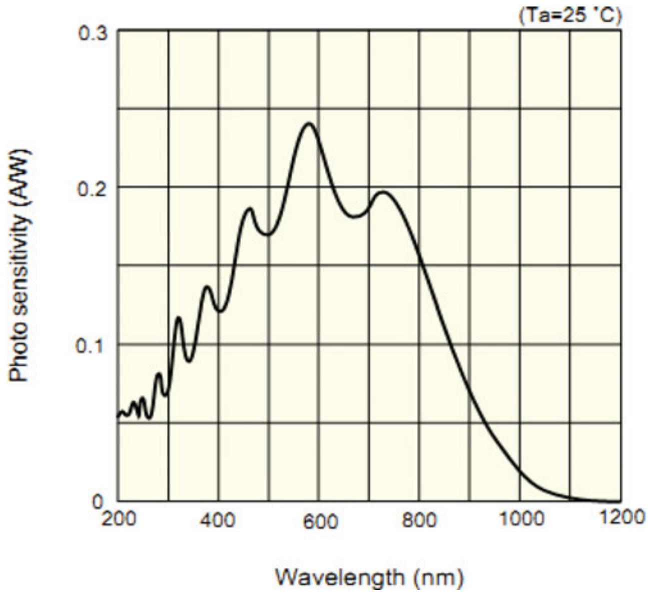

Figure 2. Spectral sensitivity of S3903-1024Q linear sensor.

The control signal generator produces various control pulses required for the image sensor and external signal processor. The video signal processor performs current-to-voltage conversion, differential amplification and then outputs the processed signal. By applying external voltages for digital/analog circuitry, and also master clock and master start pulses, this driver circuit provides a data video output, trigger pulse and end-of-scan (EOS) pulse (Fig. 4).

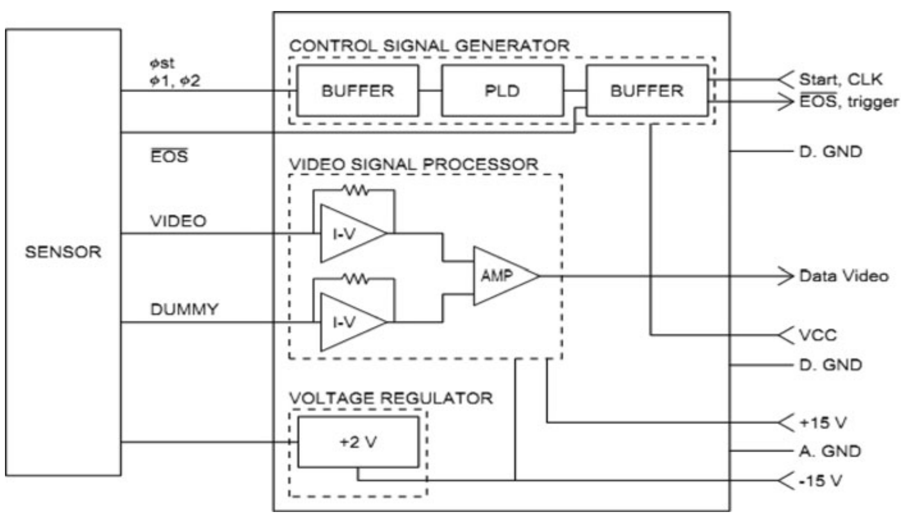

Figure 3. Block-diagram of driver circuit.

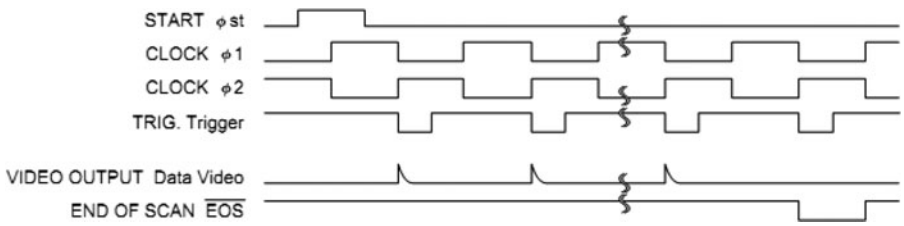

Figure 4. Control signals generated by programmable logic device.

The control signal generator consists of a PLD (programmable logic device), and generates a start pulse and two-phase clock pulses to operate the shift register. The control signal generator also provides a trigger signal for external sample-and-hold and outputs it via a buffer. These signals are synchronized with an external master clock pulse, and are initialized by an external master start pulse. The master clock and master start pulses are input to the PLD via a buffer. The video signal processor is made up of three sections. The active video output current from the image sensor is first fed to the inverting input terminal of the first-stage amplifier and converted into a voltage. The non-inverting input terminal is applied at a video bias voltage of 2V. Similarly another first stage amplifier performs current-to-voltage conversion of the dummy video output from the image sensor. The output of this first stage is a positive going signal with respect to the 2V video bias voltages with a differential waveform. The active video output includes the signal and switching noise components, while the dummy video output only consists of a switching noise component. In the differential amplifier of the next stage, the switching noise component, which is fixed pattern noise, can be eliminated by differential amplification of these two outputs. Thus a signal output without switching noise is derived from the data video terminal as the final output. This final output has a differential waveform of positive polarity with respect to ground level. The end-of-scan signal appears synchronized with the ϕ_2 timing immediately after the last pixel is scanned, and is available to an external device from the EOS terminal via a buffer.

In the Frontend Electronics FEE-HS based configurations, the electronic multiplexers may be used to connect up to eight spectral sensors or photodiode arrays with their preamplifiers to single readout electronics. This allows performing multisensor measurements

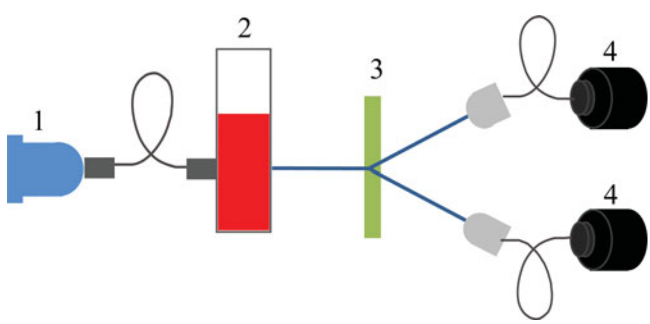

Figure 5. Experiment scheme of circular dichroism measurement of vitamin B12: 1 – LED (425 nm); 2- cuvette with sample; 3-Circular diffraction waveplate; 4- light intensity controllers SN P2001297 (ThorLabs).

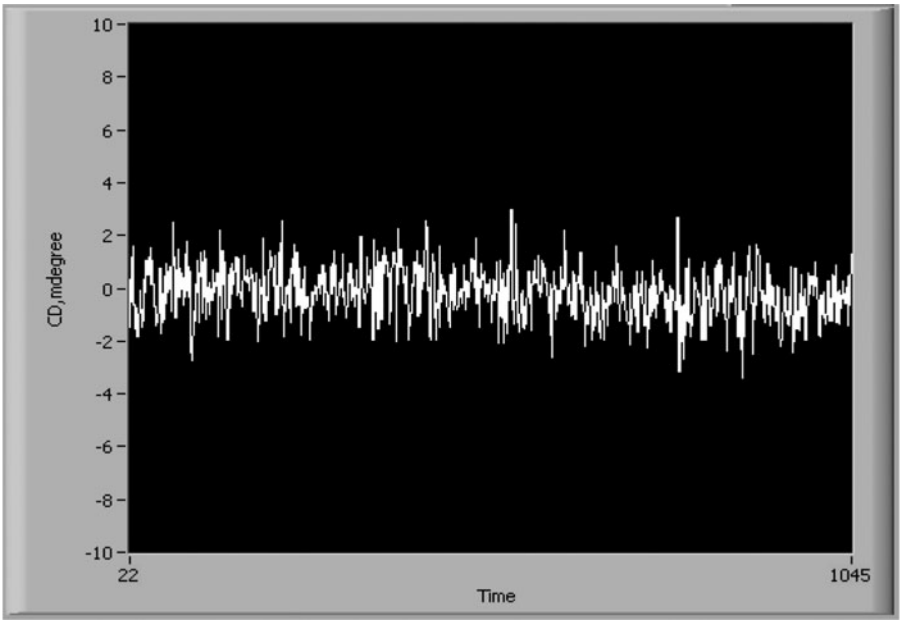

Figure 6. Behavior of baseline, registered at the developed device.

in sequential or simultaneous modes. These configurations are particularly useful for all types of high-precision process analysis, in which a reference channel has to be observed simultaneously. To achieve negligible time delay between two channels, the reference (e.g. monitoring the light source) and sample channel measurements are interwoven: variations of the light source or other temperature effects can be effectively compensated.

In the signal chain following the multiplexer, signals from all sensors pass identical circuitry for video data processing and analog-to-digital conversion, so that all measurement channels are influenced in an identical manner by potential inaccuracies of electronics.

The size of a spectral data array is equal to the number of pixels of the active sensor. The scans are overlapping with a time shift of only one pixel readout clock. The multiplexer operating mode (the active sensor or the combination) is selected by software and transferred to the MUX via the Front End Electronics of the Operating Electronics.

The scan time covers the actual readout process, given by the number of pixels to be read out, and the inverse Clock frequency respectively the time to read out one pixel.

The NI sbRIO-9633 embedded control and acquisition device integrates a real-time processor, a user-reconfigurable FPGA, and I/O on a single printed circuit board (PCB). It features a 400 MHz industrial processor; a Xilinx Spartan-6 LX25 FPGA; 16 single-ended, 12-bit analog input channels at 500 kS/s; four 12-bit analog output channels; and 28 digital I/O (DIO) lines. The sbRIO-9633 offers a −40 to 85°C local ambient operating temperature range along with a 9 to 30 VDC power supply input range. It provides 128 MB of DRAM for embedded operation and 256 MB of nonvolatile memory for storing programs and data logging. Five LEDs with different wavelengths has been used as a light source. To install the investigated sample, a special holder was designed providing a rigid fastening of cuvette. Light from a source was supplied to the holder via an optical fiber. The light passing through the sample fell to a rigidly fastened polarization diffraction grating.

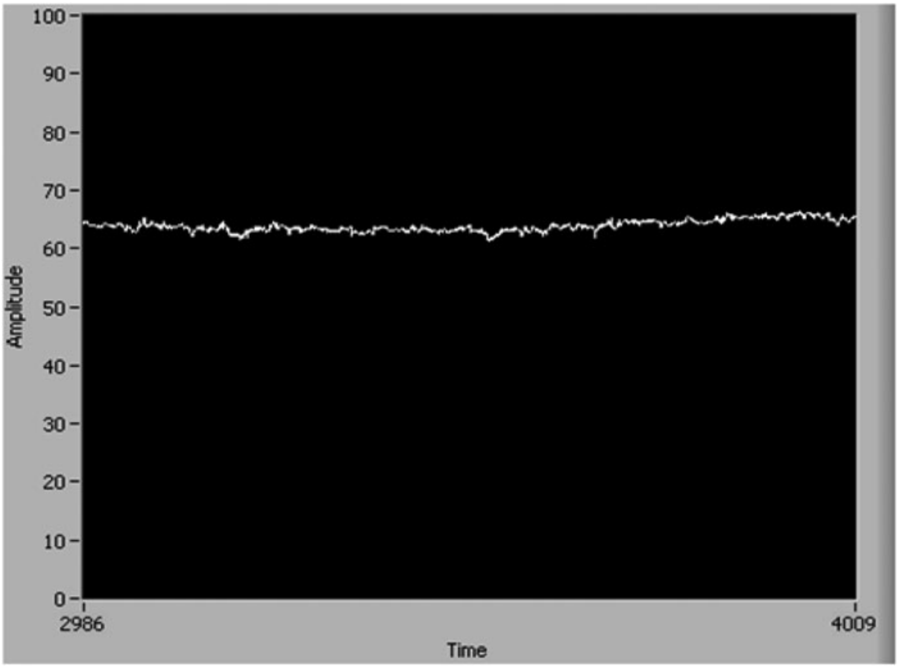

Figure 7. CD of vitamin B12 at 425 nm.

Diffracted +/−1 orders were recorded by linear sensors arrays. The signals from the arrays come through a computer for further processing.

The circular dichroism of vitamin B12 was measured at 425nm using the developed device and the results were compared with the reference data [11]. The scheme of the experimental setup is shown in Fig 5.

In Fig. 6 and Fig. 7 the base-line behavior for deionized water and the circular dichroism spectrum of vitamin B12 are shown correspondingly.

The results of CD measurement of vitamin B12 in the spectral range 420–500 nm are in good agreement with the reference data.

Conclusions

Thus, the developed system for registration of intensities difference of right- and left-circularly polarized light beams allows determining the circular dichroism with accuracy better than 1mdegree.

Funding

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