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Temperature dependence of the $Bi_{12}GeO_{20}$ optical activity

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Abstract

This paper presents measurement of the $Bi_{12}GeO_{20}$ optical activity temperature dependence. The measurement was performed by orthogonal polarization detection and the temperature was measured using a thermographic camera. Since $Bi_{12}GeO_{20}$ crystals exhibit both the Faraday rotation and the optical activity, the analysis of electromagnetic wave propagation through such crystals is presented. Compensation of the temperature dependence for current and magnetic field sensors based on Faraday rotation is proposed.

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Keywords: Optical activity temperature dependence; Faraday effect; Orthogonal polarization detection

1. Introduction

Although discovered in 1845, the Faraday or magneto-optical effect is nowadays extensively investigated, mainly for the research and development of fiber optic current sensor (FOCS). Fiber optic sensing technology finds its applications where conventional sensors work inadequately [1], and FOCS has a few advantages compared to current transformer [2]. An important problem in the development of FOCS is temperature stability. Our intention is to use an optical activity temperature dependence to compensate the effect of temperature variations on FOCS output. The first step in this task is the measurement of optical activity temperature dependence. Since the polarization state has to be determined precisely, orthogonal polarization detection and lock-in technique were used. In the third chapter electromagnetic wave propagation through crystals that posses Faraday rotation as well as optical activity was analyzed. After determining the connection between Faraday rotation and optical activity, compensation of Verdet constant temperature dependence was proposed.

2. Experimental

For the light beam source we choose the GLMC1-1 green laser diode module (LD), a class II, 1 mW, 532 nm and CW laser. Polarizing prism (PP) follows the laser and linearly polarized light impinged the $Bi_{12}GeO_{20}$ (BGO) crystal. In order to measure slight changes in the polarization state, due to temperature variations, orthogonal polarization detection polarimetric scheme, with appropriate optical, optoelectronic and electronic components, was used in order to maintain a gain balance of two channels necessary for accuracy of the measurement. The birefringent crystal ($CaCO_3$) placed behind the BGO crystal will spatially divide laser beam into two components with mutually orthogonal polarizations. Irradiations of both beams depend on the source intensity in the same way. Using this fact we can calculate the angle θ that is independent on irradiation of the light source by a difference-over-sum method [1]. This concept is illustrated in Fig. 1.

Beam irradiations were measured using two segments of a quadrant photodiode (4QPD), followed by a dual transimpedance (DUAL TIA) stage. Stages were identical, based on dual operational amplifier, having the same transimpedance gains. After setting the polarization state at 45° to the fast axis of walk-off crystal, by rotating polarizing

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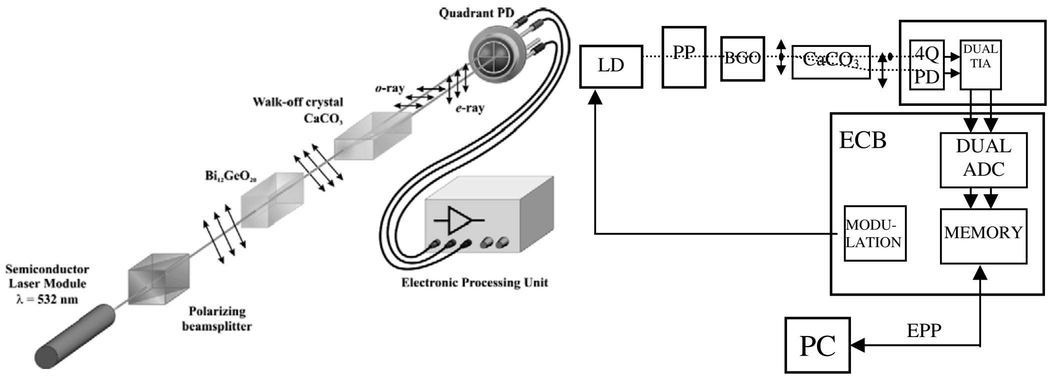

Fig. 1. Twin beam current sensing concept with measurement setup block diagram.

beamsplitter, output signal voltages U_1 and U_2 after transimpedance stages are

$$U_1 = \frac{k_1 \Gamma_0}{2}(1 + \sin(2\theta)), \quad U_2 = \frac{k_2 \Gamma_0}{2}(1 - \sin(2\theta)), \tag{1}$$

where Γ_0 is the beam irradiation and k_1 and k_2 are constants that include optical losses and optoelectronic conversion efficiency. In order for this sensing system to achieve a desired accuracy, it is required that the detection gains of two beams be identical. Therefore, we first set $k_1 = k_2$, with all crystals removed from the beam path, by adjusting parameters of the transimpedance stages.

Desired result θ is then:

$$\theta = \frac{1}{2} \arcsin\left[\frac{U_1 - U_2}{U_1 + U_2}\right]. \tag{2}$$

Angle θ determined in this manner does not depend on the light source intensity and optical losses of the light beam incident on birefringent crystal. Thus, the only part of the optical path that can cause incorrect results, due to disparity in light beams irradiation losses, is between beam splitter and photodiode. By using the birefringent crystal instead of polarizing prism and making the separate optical paths parallel this imbalance was minimized. This configuration also enabled us to use a quadrant photodiode and to match optoelectronic conversion gains as much as possible.

In order to accurately sense beam intensities, we have chosen a lock-in measurement technique. Instead of chopping the light, the laser diode source was modulated in an on/off way, and instead of analog demodulation, we have decided to calculate the modulating signals by means of a DFT. The laser diode module was digitally modulated at the frequency of 375 Hz from the electronic control block (ECB) producing on/off light beam modulation. Transimpedance stages were driving dual 20 bits sigma delta AD converters (DUAL ADC), CS 4222 from crystal semiconductor, with excellent linearity and noise performance, synchronously converting both channels with the sample rate of 48 kSPS. Modulation clock was obtained by dividing the sampling clock. Since the carrier and sampling timings are synchronized and in phase, DFT of the time series does not suffer from leakage and picket-fencing effects. AD converters provided high pass filtering of the TIA signals in order to eliminate DC components and optimize dynamic range. Time series were collected and transferred to a PC for signal processing. PC computed the DFT of the signal and extracted magnitudes of the fundamental signal harmonic for both channels. Magnitudes obtained in this way were used to calculate rotation of the plane of polarization inside the crystal as described in Eq. (2).

BGO crystal was cooled to 280 K and heated spontaneously to room temperature. All other optical and electronic components were at the room temperature all the time. Temperature of the BGO crystal was measured using Wöhler IK-21 infrared camera. This camera, operating in 8–12 μm spectral range, features a linear array of 120 uncooled thermoelectric detectors, thermal resolution of 0.1 K, and provides 120×120 pixels thermograms. Camera was connected to a PC via RS 232 interface, and remotely controlled using SnapView Pro software. Thermograms were recorded by the camera, operating in an automatic acquisition regime, and transferred to a PC at the rate of three per minute. Prior to the thermogram recording, crystal emissivity and background temperature were determined and manually set and the camera was positioned and focused. After the cooled crystal was put in its place the recording of thermograms was initiated. When the crystal re-warming process ended, both data and thermogram acquisition was stopped. The sequence of recorded thermograms was analyzed using SnapView Pro and MathCad 12 software packages. As the each recorded thermogram contains information on the exact time when it was captured, it was possible to reconstruct the whole re-warming process.

3. Faraday effect and optical activity

Bismuth germanium oxide – $Bi_{12}GeO_{20}$ – BGO crystal has cubic symmetry, space group $I23$ and it is without birefringence, but posses optical activity. The BGO crystal is cut parallel to (1 1 0) plane. We assume that z axis is orthogonal to this plane, that magnetic induction is along $\pm z$ axis and that there is no absorption of electromagnetic energy. Considering these circumstances we assume the dielectric tensor $\boldsymbol{\varepsilon}$ in a form: