SCIENTIFIC BULLETIN OF THE TECHNICAL UNIVERSITY OF LODZ
No. 1057 Physics, Vol. 30 2009

PIOTR GÓRSKI, RAFAŁ LEDZION, MARCIN SADOWSKI, WŁODZIMIERZ KUCHARCZYK

Institute of Physics, Technical University of Łódź, Wólczańska 219
90-924 Łódź, Poland. e-mail: ptgorski@p.lodz.pl

EFFECT OF TEMPERATURE ON THE REFRACTIVE INDEX AND KERR EFFECT OF THE TRANSFORMER OIL NYNAS NYTRO TAURUS

The temperature dependence of refractive index of the mineral transformer oil Nynas Nytro Taurus within the range 278-385K is determined. Changes with temperature in the quadratic electrooptic response of the oil are investigated. The results obtained indicate the usefulness of the oil as immersion liquid in measurements of the quadratic electrooptic effect and electrostriction in crystals.

Keywords: transformer oil, Kerr effect, quadratic electrooptic effect, refractive index.

1. INTRODUCTION

In isotropic media, including liquids, phenomena described by odd-rank polar tensors, like the linear electrooptic effect, are forbidden by symmetry rules and the lowest-order electrooptic effect is the quadratic one [1]. The changes in the refractive index ***n*** proportional to the square of low-frequency electric field ***E*** are often called as the Kerr effect [2]

$$\Delta n = B\lambda E^2, \tag{1}$$

where ***B*** is the Kerr constant and λ is light wavelength.

Previously, we considered the usefulness of different synthetic and mineral transformer oils as immersion liquids in measurements of quadratic electrooptic effect and electrostriction in crystals [3-6]. Such measurements are of special interest because the quadratic electrooptic effect in crystals attracts attention as related to numerous nonlinear phenomena (see, e.g. [4]). To increase the accuracy of measurements, particularly in hygroscopic crystals, and to reduce the risk of electric breakdown, the sample is often placed in a bath containing a liquid which does not solve the crystal. In measurements of electrooptic properties based on interferometric methods the use of two immersion media with different refractive indices makes also possible to evaluate changes in the optical path due to the electrostriction [5]. However, any immersion liquid is a source of an additional contribution to the modulation of the light beam related to the fringing electric field and the Kerr constant of the liquid [3]. Thus to estimate this contribution, the Kerr constant (or quadratic electrooptic coefficient) has to be determined.

This work presents subsequent results related to our attempts to find an extensive set of immersion liquids with different refractive indices and viscosities useful to increase the sensitivity of measurements. The investigations are often performed at different temperatures, therefore the Kerr constant of the oil is also determined as a function of temperature.

Previously we have investigated both experimentally and theoretically conditions allowing for precise determination electrooptic effects in crystals (see, e.g. [3-5,7,8]). In our measurements we have also found that the properties of transformer oils used as immersion liquids have been changing with time. Therefore, the further aim of this work is to test if the refractive index the oil change after aging.

2. MEASURMENTS OF THE REFRACTIVE INDEX OF FRESH AND AGED NYNAS NYTRO TAURUS OIL

The temperature dependence of the refractive index of the fresh and aged oil was determined employing the Abbe refractometer (RL1 PZO) for λ=589 nm The measurements were performed within the temperature range 278K - 363K. The oil was aged by 6 cycles of heating up to 385 K and next cooling to room temperature. The results obtained are shown in Fig.1. The plots presented in Fig.1 indicate that the changes in the refractive index with temperature may be approximated by the linear relationship

$$n(T) = aT + b . \qquad (2)$$

The parameters of fitting for the fresh and aged oil are compared in Table 1.

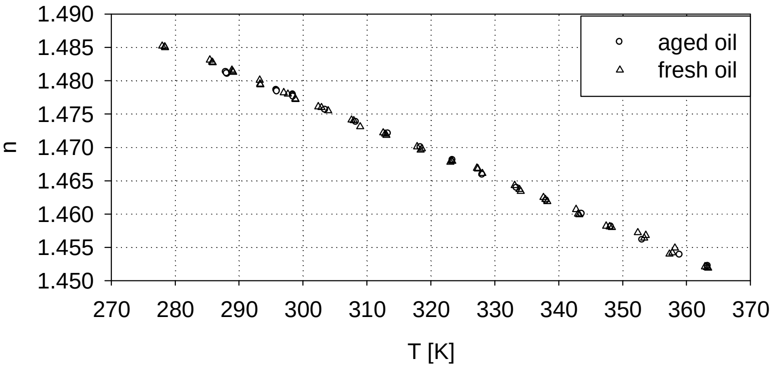

Fig. 1. Changes of the refractive index with temperature in the fresh and aged oil Nynas Nytro Taurus, respectively Δn = 0.0005

Table 1

Comparison of parameters used to fit the temperature dependence of the refractive index of the fresh and aged Nynas Nytro Taurus oil.

Oil	$a \pm \Delta a \left(10^{-4}\ \frac{1}{K}\right)$	$b \pm \Delta b$
Fresh	$-3{,}91 \pm 0{,}01$	$1{,}5941 \pm 0{,}0006$
Aged	$-3{,}89 \pm 0{,}01$	$1{,}5935 \pm 0{,}0005$

The results obtained indicate that either the differences between the refractive indices of the fresh and aged oil and their temperature dependencies are practically negligible.

3. MEASURMENTS OF THE KERR EFFECT AND QUADRATIC ELECTROOPTIC EFFECT OF THE OIL

We have used the dynamic method the basis of which is the harmonic analysis of light passed through a cell containing an investigated medium placed between the polarizer and analyzer and modulated by an electric field $E(t) = E_0 \sin(\omega t)$ (see, e.g. [6,9]). The optical bias allowing for measurements on the linear, most sensitive part of the transmission characteristic of the system was provided by a quarter-wave plate. The lock-in technique and computer controlled data acquisition and processing system were employed to measure the modulation index $m(2\omega) = I(2\omega)/I_0$, where I_0 is the constant component of the light intensity transmitted by the system and $I(2\omega)$ is the second harmonic of the emerging light intensity. In the measurements the He-Ne laser (λ = 0.633 μm) was employed and the electric field of frequency 417 Hz was applied to the cell. As usually in the dynamic technique [6,9], the Kerr constant was determined using the following expression

$$B = \frac{m(2\omega)d^2}{\sqrt{2}\pi U^2 l}, \tag{3}$$

where d is the distance between electrodes, l is the length of electrodes and U is the amplitude of the modulating voltage. The Kerr constant may be related to the effective quadratic electrooptic coefficient g_{ef} of the oil by the following formula [10]

$$g_{ef} = \frac{2\lambda B}{n^3} . \tag{4}$$

Here, the coefficient g_{ef} is defined as

$$g_{ef} = \frac{2}{n^3}(g_{1122} - g_{1111}), \tag{5}$$

where g_{1122} and g_{1111} are the quadratic electrooptic coefficients related to the main axes of the optical indicatrix describing the birefringence of the oil subjected to the electric field. The effective quadratic electrooptic coefficient of the liquid has to be known to estimate the contribution due to the fringing field and the quadratic electrooptic response of the liquid.

The changes in g_{ef} with temperature, are shown in Fig. 2. To obtain these values the temperature dependence of the refractive index of the oil was taken into account.

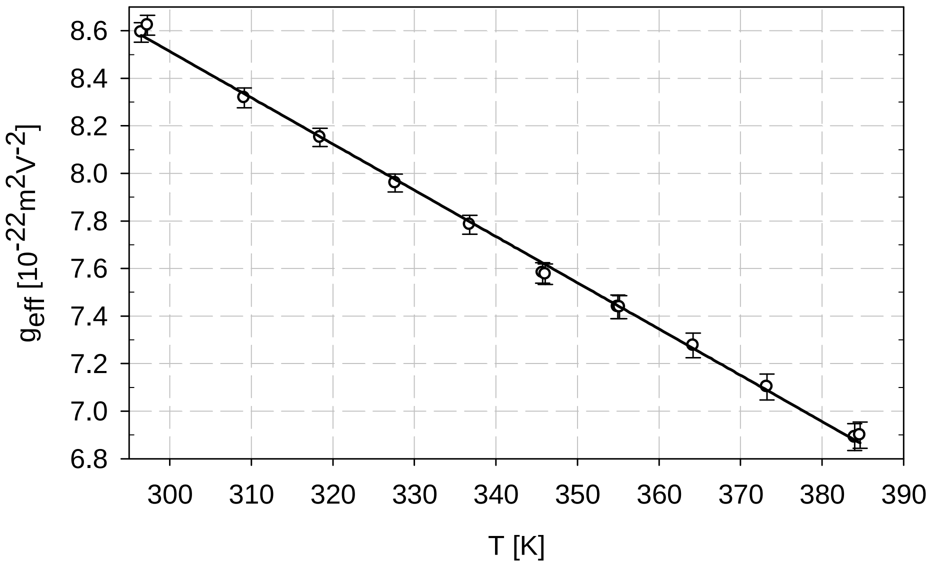

Fig. 2. Temperature dependence of the effective quadratic electrooptic coefficient of the Nynas Nytro Taurus oil. The line represents the relation:

$$g_{ef}(T) = (-1{,}96 \pm 0{,}01) \cdot 10^{-24} \left[\frac{m^2}{V^2 K}\right] \cdot \mathrm{T} + (14{,}40 \pm 0{,}04) \cdot 10^{-22} \left[\frac{m^2}{V^2}\right].$$

4. DISCUSSION

The results obtained show that in the Nynas Nytro Taurus oil the Kerr constant and coefficient g_{ef} possess comparable values with those observed in mineral transformer oils investigated previously [3,11,12], i.e. K is of the order of magnitude 10^{-15} m/V^2 and g_{ef} is about 10^{-22} m^2/V^2. The Kerr constant of the oil used as the immersion liquid is small enough not to disturb significantly measurements of electrooptic properties of crystals. Immersion liquids of appropriate viscosity can reduce mechanical noises improving considerably the sensitivity of measurements, particularly, those based on interferometric methods. The more extensive set of immersion liquids of different refractive indices and viscosities is available, the more precise measurement may be performed.

REFERENCES

[1] **Nay J.F.,** Physical Properties of Crystals. Their Representation by Tensors and Matrices, Clarendon Press, Oxford, 1957.

[2] **Kerr J.** ,Phil. Mag. Ser. 4, 50, 337 (1875).

[3] **Ledzion R., Bondarczuk K., Górski P., Kucharczyk W.,** Quant. Electronics **34** (1999) 745.

[4] **Gunning M.J., Raab R.E., Kucharczyk W.,** J. Opt. Soc. Am. B **18** (2001) 1092.

[5] **Gunning M.J., Raab R.E., Kucharczyk W.,** Ferroelectric Lett. **24** (2001) 93.

[6] **Ledzion R., Górski P., Kucharczyk W.,** J. Phys. Chem. Solids **68** (2007) 1965.

[7] **Izdebski M., Kucharczyk W., Raab R.E.,** J. Opt. Soc. Am. A **19** (2002) 1417.

[8] **Izdebski M., Kucharczyk W.,** J. Opt. Soc. Am. B **25** (2008) 149.

[9] **Ledzion R., Bondarczuk K., Górski P., Kucharczyk W.,** Cryst. Res. Technol. **34** (1999) 745.

[10] **Yariv A., Yeh P.,** Optical Waves In Crystals, Wiley, New York, 1984.

[11] **Okubo H., Wakamatsu M., Inoue N., Kato K.,** IEEE Trans. Electr. Insul., **10** (2003) 956.

[12] **Kucharska A.,** MSc Thesis, Technical Univ. Fac. FTIMS, Łódź, 2007.

WPŁYW TEMPERATURY NA WSPÓŁCZYNNIK ZAŁAMANIA ŚWIATŁA I EFEKT KERRA OLEJU TRANSFORMATOROWEGO NYNANS NYTRO TAURUS

Streszczenie

Wyznaczono temperaturową zależność współczynnika załamania światła w oleju mineralnym Nynas Nytro Taurus w zakresie temperatur od 278 do 385 K. Zbadano właściwości elektrooptyczne tego oleju w funkcji zmian temperatury. Uzyskane wyniki wskazują, że badany olej może być stosowany jako ciecz immersyjna w pomiarach efektów elektrooptycznych i elektrostrykcji w kryształach.