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INFLUENCE OF ELECTRODE MATERIAL AND SPACING BETWEEN ELECTRODES ON MEASUREMENT OF KERR CONSTANT IN CASTOR OIL

The influence of the electrode material and of the spacing between electrodes on Kerr constant in castor oil is investigated. It is shown that the spacing of the electrodes influences the measurement of Kerr constant whereas the electrode material has no influence on the results of the measurement.

Keywords: castor oil, electrode material, electro-optic effect, Kerr constant.

1. INTRODUCTION

Kerr effect is a change of refractive index of a medium induced by electric field. The effect is directly proportional to the square of the applied electric field. The change in indices of refraction differs for polarizations of light parallel and perpendicular with respect to the applied field. Such optically anisotropic medium is called birefringent. The birefringence defined as the difference Δn between refractive indices is given by the formula:

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

where λ is the wavelength of light, K is Kerr constant and E is the electric field strength.

Castor oil is a nearly transparent yellow liquid obtained from seeds of *Ricinus communis* plant and its main component is ricinoleic acid [1]. Applications for castor oil range from personal care products through industrial materials up to component of biodiesel [2], and biodegradable foam plastics [3]. Research shows [4] that the electro-optic Kerr effect can be used to estimate the ageing processes in castor oil and probably in other oils of natural origin. Our previous work [5] shows that birefringence and dichroism arise between parallel plate electrodes made of stainless steel without electric field applied. Both effects might significantly influence the measurement of Kerr constant [6]. However no investigations were conducted concerning influence of electrode material and their separation on measurement of Kerr constant in castor oil.

The aim of this work is to investigate whether the electrode material, namely stainless steel, aluminum and copper, influences the measurement of Kerr constant in castor oil and also to study the dependence of Kerr constant on the electrodes spacing.

2. EXPERIMENTAL

Dynamic polarimetric method [7] was used to measure the Kerr constant. The method is based on harmonic analysis of the intensity of light passing through the Kerr cell placed between crossed polarizer and analyzer. The intensity of emerging light beam from such a system is given by following equation [8]:

$$I = I_0\left\{\cos^2(\alpha) - \sin(2\rho)\sin[2(\rho-\alpha)]\sin^2\left(\frac{\Gamma}{2}\right)\right\} . \tag{2}$$

The incident light intensity is denoted by I_0, α is the angle between the planes of polarization in the polarizer and analyzer, ρ stands for the angle between the plane of polarization in the polarizer and direction of the applied electric field. The phase difference Γ between ordinary and extraordinary beams is given by the formula:

$$\Gamma = \Gamma_0 + kL\Delta n, \tag{3}$$

where Γ_0 is phase difference independent of the electric field, $k = 2\pi/\lambda$, L is electrode length and Δn stands for birefringence induced by electric field. When crossed polarizers are oriented so that $\rho = \pi/4$ and the phase difference introduced by quarter wave plate $\Gamma_0 = (2m + 1)\pi/2$ where m is a natural number, then Eq. (2) simplifies to the following form:

$$I = \frac{I_0}{2}\left[1 + \sin\left(kL\Delta n\right)\right]. \tag{4}$$

For sinusoidal modulating voltage, the Kerr constant may be expressed as:

$$K = \frac{ad^2}{\sqrt{2}\pi L}, \tag{5}$$

where d is the spacing between electrodes, a is slope in the simple linear regression of modulation index $m_{2\omega}$:

$$m_{2\omega} = \frac{U_{2\omega}}{U_{dc}} \tag{6}$$

expressed as a function of square of the modulating voltage U_m:

$$m_{2\omega} = aU_m^2 + b. \tag{7}$$

$U_{2\omega}$ is the RMS value of the voltage measured at second harmonic of the light transmitted through the system of which constant component is proportional to U_{dc} voltage measured. The error ΔK was calculated using exact differential method which gives the formula:

$$\Delta K = \frac{d^2}{\sqrt{2}\pi L}\Delta a + \frac{2ad}{\sqrt{2}\pi L}\Delta d + \frac{ad^2}{\sqrt{2}\pi L^2}\Delta L. \tag{8}$$

The analysis of error indicates that over 90% of ΔK corresponds to the second term of Eq. (8). For the purpose of this experiment, three sets of plane-parallel electrodes were polished to minimize surface contamination and sharp edges. The electrodes were placed in the glass cuvette and filled with analytical grade castor oil produced by Sigma-Aldrich designated by catalog number 259853 and batch number MKBL5196. Each pair of the electrodes of length equal to 99 mm was separated by five separators providing 3 mm gap between the electrodes. The theoretical analysis of measurement of quadratic electro-optic effect in castor oil [6] predicts that for two positions of quarter-wave plate, P_1 and P_2, differing by the angle $\pi/2$, the systematic error increases the result for one position of quarter wave plate and decreases it, by the same percent, for the other position. The systematic error was eliminated by measurement of K in both positions and averaging the results.

The experiment was performed in three phases. First, each electrode material was used to measure Kerr constant using sinusoidal modulating voltage of 417 Hz frequency. The second part of the experiment was the measurement of Kerr constant using modulating voltage frequencies ranging from 117 Hz up to 5017 Hz. Third part of the experiment was performed using copper electrodes with spacing ranging from 2.1 mm to 8.3 mm. For the purpose of this experiment, the ranges of applied modulating voltage corresponded to the same range of applied electric field. Whole experiment was performed employing He-Ne laser of wavelength λ = 633 nm. The RMS value of modulating voltage U_m was within range from 200 V to 3000 V. The measurements were performed using lock-in technique and computer controlled data acquisition system.

3. RESULTS

The first part of measurements was performed at temperature 295 K using modulating voltage frequency 417 Hz. Figure 1 presents results of the measurements for stainless steel, copper and aluminum electrodes. The average results for each material are gathered in Table 1.

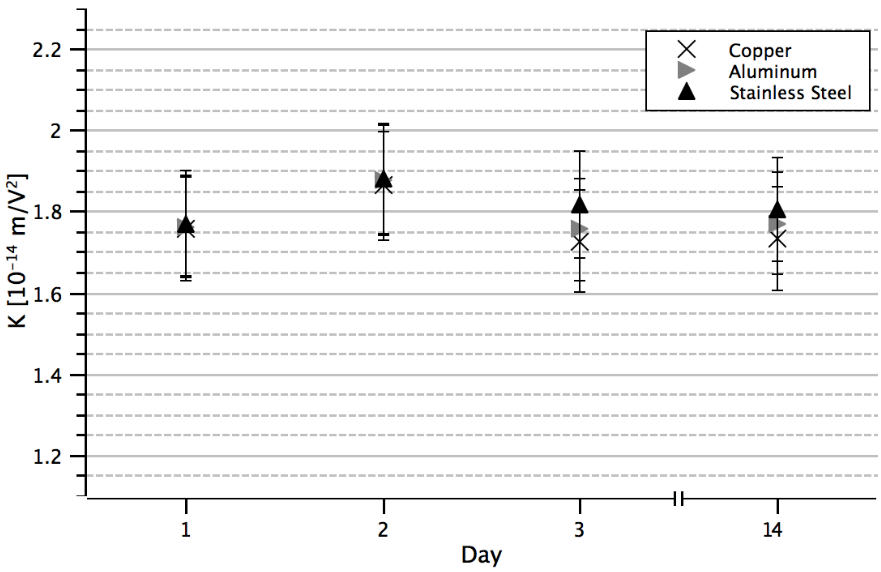

Fig. 1. The average values of Kerr constant for two equivalent positions of the quarter wave plate differing by $\pi/2$ with corresponding error $\Delta K = 0.13 \cdot 10^{-14} \mathrm{m/V^2}$

Table 1
The average results for each material; first part of measurements, $\Delta K = 0.13 \cdot 10^{-14} \text{m/V}^2$

Day	Copper $K\,[10^{-14}\,\text{m/V}^2]$	Aluminum $K\,[10^{-14}\,\text{m/V}^2]$	Stainless Steel $K\,[10^{-14}\,\text{m/V}^2]$
1	1.76	1.76	1.77
2	1.86	1.88	1.88
3	1.73	1.76	1.82
4	1.73	1.77	1.80
average	1.77	1.79	1.82

The results of the second part of the measurements, performed with use of various modulating voltage frequencies, are presented in Figure. 2 and in Table 2 with measurement error $\Delta K = 0.13 \cdot 10^{-14} \text{m/V}^2$.

Table 2
The average results for each material; second part of measurements $\Delta K = 0.13 \cdot 10^{-14} \text{m/V}^2$

ω[Hz]	Copper $K\,[10^{-14}\,\text{m/V}^2]$	Aluminum $K\,[10^{-14}\,\text{m/V}^2]$	Stainless Steel $K\,[10^{-14}\,\text{m/V}^2]$
117	1.72	1.75	1.81
217	1.74	1.76	1.82
317	1.73	1.76	1.82
417	1.72	1.76	1.80
517	1.72	1.74	1.78
617	1.72	1.73	1.77
817	1.71	1.73	1.75
1017	1.71	1.73	1.77
1517	1.72	1.75	1.78
2017	1.73	1.76	1.79
2517	1.74	1.77	1.78
3017	1.78	1.81	1.83
3517	1.74	1.77	1.79
4017	1.71	1.74	1.75
5017	1.70	1.76	1.77

The results of the third part of the experiment presented in Fig. 3 and Table 3 are related to the dependence of Kerr constant on electrode spacing for positions P_1 and P_2 of quarter wave plate differing by $\pi/2$. Copper electrodes with spacing 2.1 mm, 3.0 mm, 4.0 mm, 6.2 mm and 8.3 mm were used. The ranges of modulating voltage U_m corresponds to the same range of applied electric field, namely from 90 kV/m to 350 kV/m.

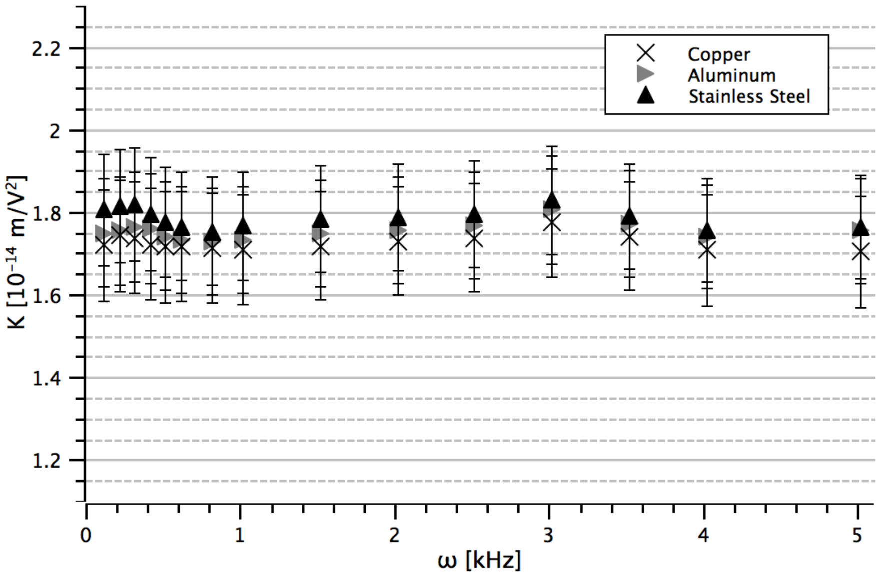

Fig. 2. The dependence of Kerr constant on frequency for different electrode materials

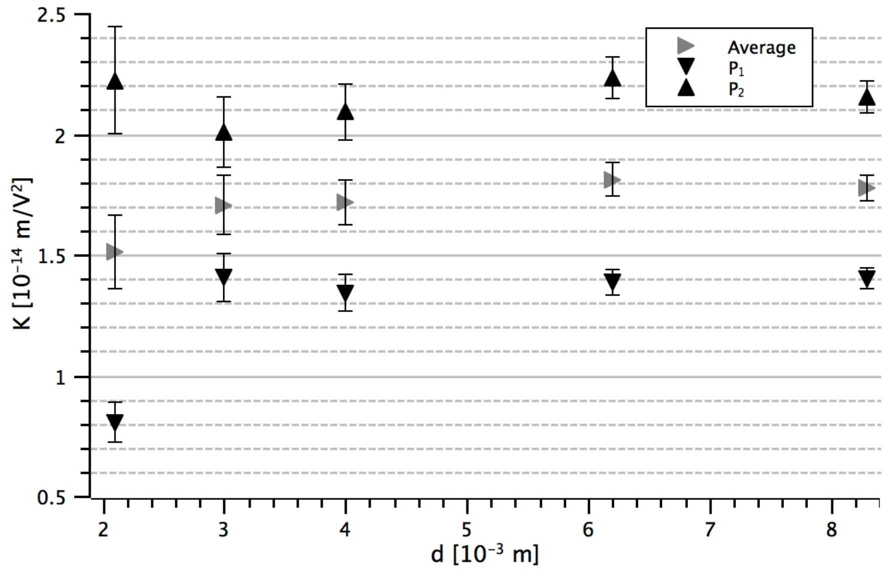

Fig. 3. The dependence of Kerr constant on electrode spacing for positions P_1 and P_2 and their average

Table 3

The Kerr constant dependence on spacing between electrodes

Distance d [mm]	Position 1 $K\,[10^{-14}\,\mathrm{m/V^2}]$	Position 2 $K\,[10^{-14}\,\mathrm{m/V^2}]$	Average $K\,[10^{-14}\,\mathrm{m/V^2}]$
2.1	0.81 ± 0.08	2.22 ± 0.22	1.52 ± 0.15
3	1.41 ± 0.10	2.01 ± 0.15	1.71 ± 0.12
4	1.34 ± 0.07	2.10 ± 0.12	1.71 ± 0.10
6.2	1.39 ± 0.05	2.24 ± 0.09	1.81 ± 0.07
8.3	1.40 ± 0.04	2.15 ± 0.07	1.78 ± 0.06

4. CONCLUSIONS

The results obtained during the first part of experiment indicate that examined electrode materials, namely copper, aluminum and stainless steel, had no influence on Kerr constant during 14 days of measurements or their influence is smaller than the measurement error. The second part of the experiment indicates that stainless steel might increase Kerr constant over broad spectrum of frequencies, however the temperature log shows that copper and aluminum were measured at temperature 295 K along with every other measurement except stainless steel which was measured at 292 K during this part. According to [4], the decrease in temperature by 3 K would increase Kerr constant by $0.07 \cdot 10^{-14}\,\mathrm{m/V^2}$. In fact, similar differences are observed in Table 2. Such susceptibility of Kerr constant to changes of temperature suggests a need for temperature control. The third part of experiment demonstrates the influence of distance of electrodes on Kerr constant. The castor oil in a sufficiently high volumes is an non-dichroic isotropic liquid of $\infty\infty$ symmetry. However, previous research [5] shows that the same oil placed between plane-parallel electrodes becomes dichroic and anisotropic with the optical axis perpendicular to the plane of electrodes, even when the spacing between electrodes is in the order of millimeters. The linear birefringence and dichroism arise between electrodes even without electric field applied. This indicates that the electrodes cause the transition of the oil symmetry from $\infty\infty$ to $\infty 2$ Curie group, which is associated with a change in the form of the tensor of the quadratic electro-optic effect (the tensor is given, e.g., in Ref. [6]). Additionally recent research [9] and [10] also demonstrate linear birefringence $n_{01} - n_{03}$ arising between plane-parallel electrodes. Therefore the dependence presented in third part of the experiment might be caused by orientational ordering of ricinoleic acid molecules induced by narrow gap between electrodes. Knowledge about induced orientation of oil molecules might be crucial when the molecules are oriented by electric field, such induced orientation might influence Curie group describing internal symmetry of the oil [5].

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WPŁYW MATERIAŁU ELEKTROD I ODLEGŁOŚCI POMIĘDZY ELEKTRODAMI NA POMIAR STAŁEJ KERRA W OLEJU RYCYNOWYM

Streszczenie

Przedstawiono wyniki badań wpływu materiału elektrody oraz odległości pomiędzy elektrodami na pomiary stałej Kerra w oleju rycynowym. Pokazano, że odległość pomiędzy elektrodami wpływa na wyniki pomiaru stałej Kerra oraz że materiał elektrod nie ma na nie wpływu.