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Compensation for the temperature drift of the wavelength adjustment in an acoustooptic spectrophotometer

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***Abstract*. It is shown that the temperature drift of the wavelength adjustment in acoustooptic spectrophotometers can be compensated by using the reference channel of the spectrophotometer in which the absorption lines of neodymium-doped yttrium – aluminium garnet are employed as reference lines.**

Keywords: *acoustooptics, spectrophotometry, temperature drift.*

Acoustooptic spectrophotometers [1], which offer a number of advantages over conventional spectrophotometers, have, however, their own drawbacks. As was shown in Ref. [2], the wavelength of such a spectrophotometer shifts when the temperature of the sound duct of an acoustooptic filter (AOF) changes. In particular, for a collinear AOF made of a $CaMoO_4$ crystal, the relative temperature shift for a wavelength of 633 nm near room temperature is

$$\xi_{CaMoO_4} = \frac{1}{\lambda}\frac{d\lambda}{dT} \approx 7 \times 10^{-5}\ K^{-1}.$$

The wavelength adjustment of collinear AOFs is determined by the expression

$$\lambda = V\Delta n/f, \tag{1}$$

where V is the velocity of a sound wave propagating in the AOF sound duct; $\Delta n = n_e - n_o$ is the difference of the refractive indices of the AOF material for the extraordinary and ordinary light beams (hereafter, we will call it birefringence); and f is the acoustic-wave frequency. The frequency f is determined by the frequency of a high-frequency voltage applied to the AOF piezoelectric transducer and can be set and stabilised with high accuracy. However, the quantities V and Δn, being parameters of the sound-duct material, depend on its temperature, which results in the temperature shift of the adjusted wavelength.

A standard method for decreasing the temperature dependence of the adjusted wavelength is thermal stabilisation of a temperature-sensitive element. In this paper, we propose a more simple, in our opinion, method of compensating for the temperature dependence of the spectrophotometer wavelength.

The method is based on the use of a reference channel in the spectrophotometer in which a reference medium is placed. The reference medium has a narrow absorption line whose position only weakly depends on temperature. We used a plane-parallel 3 mm thick plate made of a Nd^{3+} : YAG crystal as such medium.

We have chosen the Nd^{3+} : YAG crystal because it has many narrow absorption lines (the transmission spectrum of the Nd^{3+} : YAG crystal at room temperature is presented in Fig. 1). In addition, this crystal is easily available because it is widely used as a laser crystal and, finally, as is shown below, the relative temperature shift of the 795.5-nm absorption line of this crystal near room temperature satisfies the condition

$$\xi_{YAG} \ll \xi_{CaMoO_4}.$$

The scheme of the spectrophotometer used for compensation for the temperature drift is shown in Fig. 2. Light from source (*1*) propagated through acoustooptic monochromator (*2*) is incident on sample (*4*) and detected with photodetector (*5*). Beamsplitter (*3*) placed in front of the sample deflects a fraction of light to photodetector (*7*) in the reference channel. A plane – parallel Nd^{3+} : YAG crystal plate (*6*) is placed in front of photodetector (*7*).

The spectrophotometer is controlled with a control and detection unit (CDU), which is connected via a serial port with a PC. According to computer commands, the CDU produces a high-frequency voltage with the required frequency f, which is applied to the AOF of the monochromator. The output photoelectric signals from pho-todetectors (*5*) and (*7*) are fed to the CDU, where they are digitised and are fed to the computer for further processing.

Before each cycle of measurement of the spectral characteristic of sample (*4*), the 795.5-nm absorption line of the Nd^{3+} : YAG crystal is measured with photodetector (*7*) at seven equidistant wavelengths in the range from 794.5 to 796.5 nm.

Then, the parabolic approximation of the shape of the absorption line is performed by these seven points by the method of least squares and the wavelength λ_{01} of the maximum of the absorption band is thus determined. It is assumed that the difference

$$\delta\lambda = \lambda_0 - \lambda_{01} \tag{2}$$

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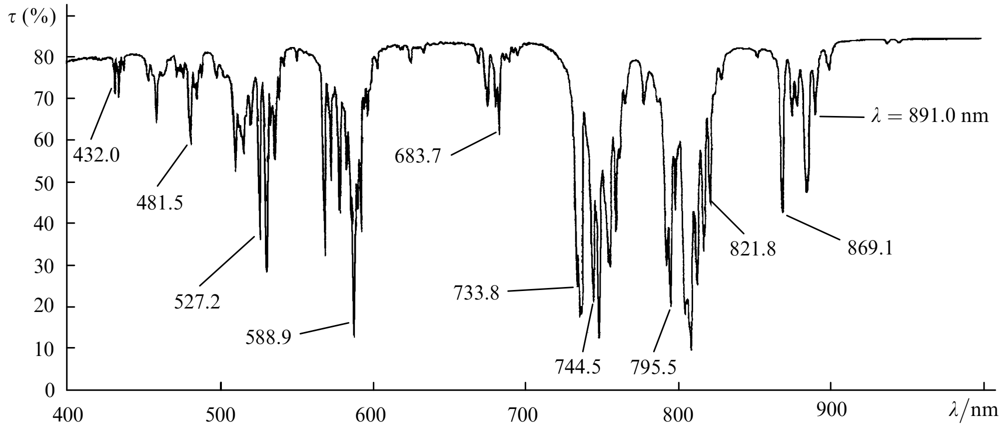

Figure 1. Transmission spectrum of neodymium-doped yttrium – aluminium garnet.

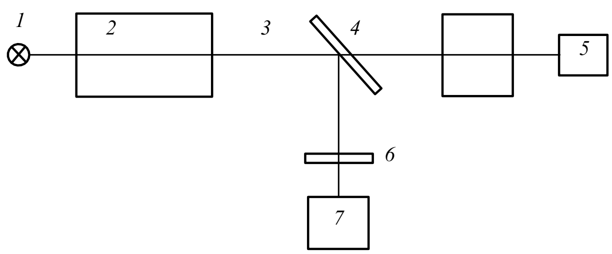

Figure 2. Scheme of a spectrophotometer with optical compensation for the temperature drift of the dependence $\lambda(f)$: (*1*) lamp; (*2*) acoustooptic monochromator; (*3*) beamsplitter; (*4*) mount with a sample; (*5*) photodetector in the operating channel; (*6*) Nd^{3+} : YAG plate; (*7*) photodetector in the reference channel.

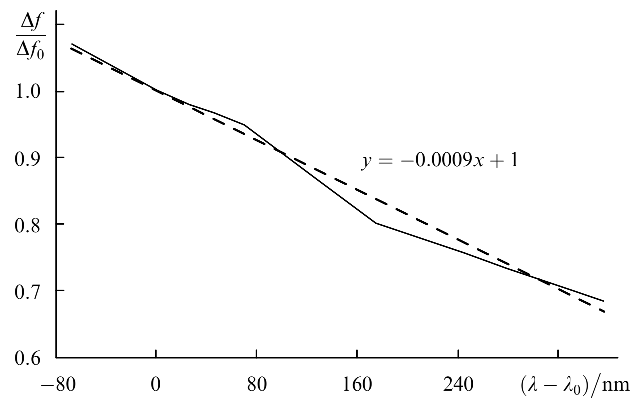

Figure 3. Experimental dependence of the relative sift of the control frequency on the wavelength of light and its linear approximation (dashed line).

is nonzero when the temperature of the AOF sound duct differs from the nominal temperature (i.e., the temperature at which the dependence $\lambda(f)$ was obtained).

Therefore, the reference channel in Fig. 2 serves in fact for measuring the deviation of the AOF sound-duct temperature from its nominal value. The mismatch signal $\delta\lambda$ could be fed as a feedback signal to the thermostat of the AOF, however, this is not required (as well as the thermostatic control of the AOF in general). It is sufficient to introduce a dynamic correction into the dependence $\lambda(f)$ upon recording the spectrum of the sample (which we did in this study).

In the general case the correction depends on the wavelength. To find this dependence, we performed the following experiment. By using an AOS-3S acoustooptic spectrophotometer, we recorded emission lines of neon at 728.1, 865.5, 966.5, and 1152.3 nm emitted by a neon – helium discharge tube of an OKG-13 He – Ne laser. The measurements were performed at two fixed temperatures of the AOF, $T_1 = 291.5$ K and $T_2 = 303.5$ K. The error of measurements was ± 0.5 K. The experimental data are presented in Table 1, where f_1 and f_2 are the frequencies of the control signal, which is fed to the AOF for separating light at the wavelength λ at temperatures T_1 and T_2, respectively, and $\Delta f = f_1 - f_2$.

Table 1.

λ/nm	f_1/kHz	f_2/kHz	Δf/kHz (for $T_2 - T_1 = 12$ K)
728.1	34222	34178	44
865.5	26270	26231	39
966.5	22494	22461	33
1152.3	17870	17842	28

The experimental dependence $\Delta f(\lambda)$ shown in Fig. 3 can be approximated by the empirical expression

$$\Delta f = \Delta f_0[1 + k(\lambda - \lambda_0)], \quad (3)$$

where $k = -9 \times 10^{-4}$ nm^{-1} and Δf_0 is the difference of control frequencies, which corresponds to the temperature shift $\delta\lambda$ (2). The approximation error does not exceed 4.5 %, which gives the error in the wavelength adjustment no more than 0.004 nm.

Therefore, to calculate the dynamic correction in the wavelength range from 720 to 1175 nm, it is sufficient to measure the frequency deviation corresponding to the minimum transmission of the Nd^{3+} : YAG plate at 795.5 nm from the calculated value and to use expression (3).

To verify this method of compensation for the temperature drift, we assembled an acoustooptic spectrophotometer according to the scheme in Fig. 2. As a sample, we used a 5.5-mm thick Nd^{3+} : YAG crystal mounted in the operating channel of the spectrophotometer. We studied the behaviour of the 869.1-nm absorption line of this crystal.

Fig. 4a shows the transmission spectra of this crystal detected directly after the switching on of the spectrophotometer (curve *1*) and after an hour of its continuous operation (curve *2*) without compensation for the temperature drift. The wavelength shift of curve (*2*) relative to

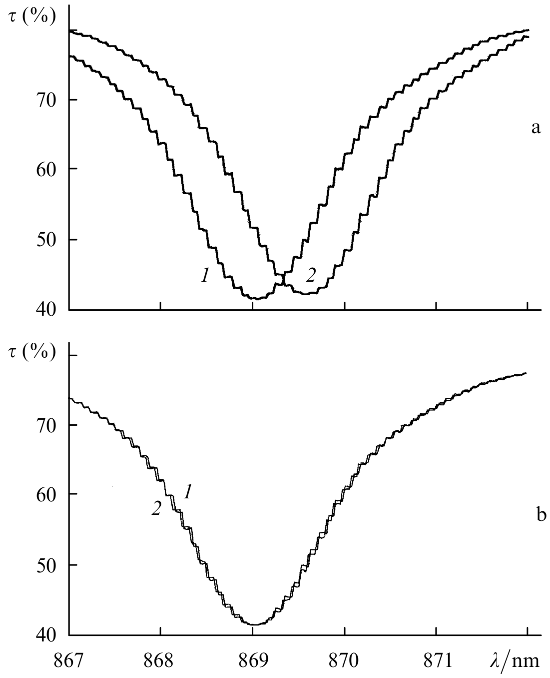

Figure 4. Stability of measuring the spectral-line position with an acoustooptic spectrophotometer using the temperature-drift correction (b) and without it (a) immediately after the switching on of the spectrophotometer (*1*) and after operation for an hour (*2*).

curve (*1*) is caused by the heating of the AOF sound duct during the spectrophotometer operation. The same spectral curves recorded using the temperature-drift compensation (Fig. 4b) demonstrate the efficiency of our method.

The temperature shift of the 795.5-nm absorption line of the Nd^{3+} : YAG crystal near room temperature was measured using a setup shown in Fig. 5. Light from halogen lamp (*1*) was focused with lens (*2*) and directed to the entrance objective of monochromator (*4*) of the AOS-3S spectrophotometer. Thermostat (*5*) with a Nd^{3+} : YAG crystal plate (*6*) mounted inside it was placed in a cell compartment. The temperature was controlled with temperature controller (*7*). Temperature sensor (*8*) of this meter based on the AD590 microcircuit was pressed via a thermally

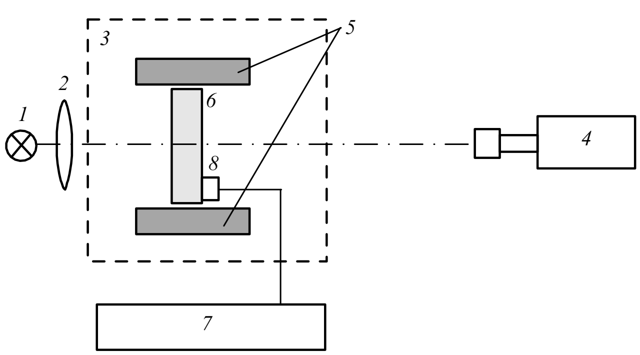

Figure 5. Scheme of the experimental setup for measuring the temperature dependence of the position of absorption lines of a Nd^{3+} : YAG crystal: (*1*) lamp; (*2*) lens; (*3*) cell compartment; (*4*) monochromator; (*5*) thermostat; (*6*) Nd^{3+} : YAG crystal plate; (*7*) temperature controller; (*8*) temperature sensor.

conducting paste directly to the crystal surface outside the illuminated region.

The thermostat temperature was changed from 298 to 345 K and was measured with an accuracy of ~ 0.5 K. The absorption line was measured in the spectral range from 792.25 to 798.75 nm with a step of 3.25×10^{-2} nm. The line profile was measured no less than five times at each temperature. Then, the position of the minimum of the transmission coefficient was calculated for each spectrum by the method of least squares using the parabolic approximation over 31 points. The error of measurements of the wavelength of the transmission minimum did not exceed $\pm 3 \times 10^{-3}$ nm. The variation in the ambient temperature during experiments did not exceed 1 K. To control the possible drift of the adjusted wavelength of the spectrophotometer, we placed another (not heated) Nd^{3+} : YAG crystal in the cell compartment immediately after the measurement and recorded its spectrum.

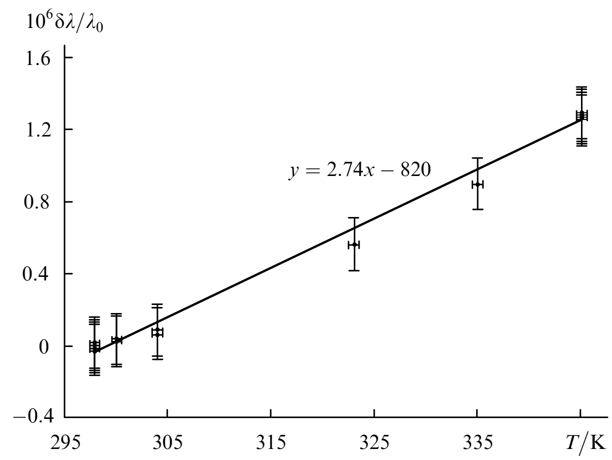

Figure 6. Relative change of the 795.5-nm absorption line wavelength of Nd^{3+} : YAG crystal with increasing the crystal temperature.

Our experiments showed that the absorption line of the Nd^{3+} : YAG crystal shifted to the red by 0.101 ± 0.003 nm when the temperature of the crystal was increased by 47 ± 0.5 K. The result of this experiment is shown in Fig. 6.

The processing of the experimental results obtained for the 795.5-nm line assuming a linear temperature dependence of the line shift gives $\xi_{YAG} \approx (2.7 \pm 0.1) \times 10^{-6}$ K^{-1}, which is far less than ξ_{CaMoO_4}.

Therefore, the 795.5-nm absorption line of the Nd^{3+} : YAG crystal can be used as the reference wavelength for acoustooptic spectrophotometers based on $CaMoO_4$ AOF.

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