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Dynamic characteristics of a nanocomposite on the basis of porous Al_2O_3 doped by liquid crystal with magnetite under carbon monoxide influence

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Abstract—The present paper concerns the dynamic characteristics of a nanocomposite on the basis of a cholesteric liquid crystal (CLC) with a magnetite dopant introduced into porous structures. We studied the behavior of spectral characteristics of transmittance of CLC2103L with Fe_3O_4 introduced in porous structures of Al_2O_3 under carbon monoxide influence. The pores diameter of Al_2O_3 is 20 nm, 35 nm and 50 nm, and the CO concentration is in a range of 0÷100 mg/m^3. The interaction of an investigated nanocomposite is the most intensive in the first minutes of CO influence. A further increase in interaction time does not lead to structural changes of the CLC.

Carbon monoxide is a toxic gas causing severe poisoning of the human organism. Today numerous sensors are developed for detection of carbon monoxide using semiconductor [1-2] and organic materials [3]. Modern optical sensors widely use optical methods of generating a data signal. In such a type of optical sensors the signal is generated by selective reflection of light from the sensor's sensitive element which interacts with gas. We propose using a CLC doped with Fe_3O_4 nanoparticles and introduced in porous Al_2O_3 as a sensitive element of the gas sensor.

Nanocomposites on the basis of a CLC with a magnetite dopant introduced in the porous structure are used as sensitive materials for primary transducers of carbon monoxide sensors [4-5]. Such structures change their optical properties, as a result of gas molecules adsorption through their surface. The change of optical properties of such nanocomposites is proposed to be used as sensing elements of an optical gas sensor.

The CLCs are characterized by the effect of selective reflection of light. The spectral location of a selective reflection band is defined by the values of equilibrium helical pitch and refractive indices of a particular CLC. The introduction of Fe_3O_4 nanoscale dopants into the CLC matrix causes a slight wavelength shift of the selective reflection peak.

In paper [6] the comparison dependencies of pure CLC and CLC doped by Fe_3O_4 nanoparticles are presented under the CO molecules influence. There are no significant changes in the optical transmission spectra of undoped CLC-2103L at the action of carbon monoxide.

The interaction of such nanocomposites with carbon monoxide produces a shift of the minimum of the transmittance peak, the magnitude of the shift depending on a concentration of CO [6].

The nanocomposite on the basis of porous Al_2O_3, with cholesteric liquid crystal mixture CLC2103L doped with 0.67 wt. % of Fe_3O_4 nanoparticles is obtained by the method described in paper [7]. The experimental setup to study the influence of carbon monoxide on nanocomposites is described in paper [4].

We have investigated spectral characteristics of nanocomposites on the basis of CLC with Fe_3O_4 nanodopants introduced into Al_2O_3 porous structures with a 20, 35 and 50nm pore diameter in the 200÷1200nm spectral range, and depending on their concentration and interaction time with carbon monoxide. The concentrations of carbon monoxide are in a range of 0÷150mg/m^3, and interaction times are 1÷10 minutes at room temperature (18^{o}C) and pressure (98kPa). The average diameter of F_3O_4 is 7.55±7.30nm.

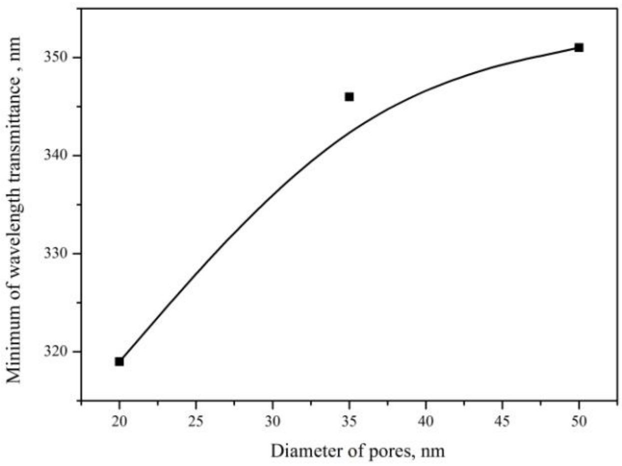

Fig. 1. The dependence of minimum of wavelength transmittance of nanocomposites on the basis of CLC2103L CLC with 0.67 wt. % of Fe_3O_4 introduced into Al_2O_3 versus diameter of pores.

Figure 1 shows the dependence of a wavelength transmittance minimum of nanocomposites on the basis of CLC2103L CLC with 0.67 wt. % of Fe_3O_4 introduced into Al_2O_3 versus the diameter of pores. As we can see

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from the dependence, the transmission minimum shifts toward the long-wavelength region with an increase of pores diameter.

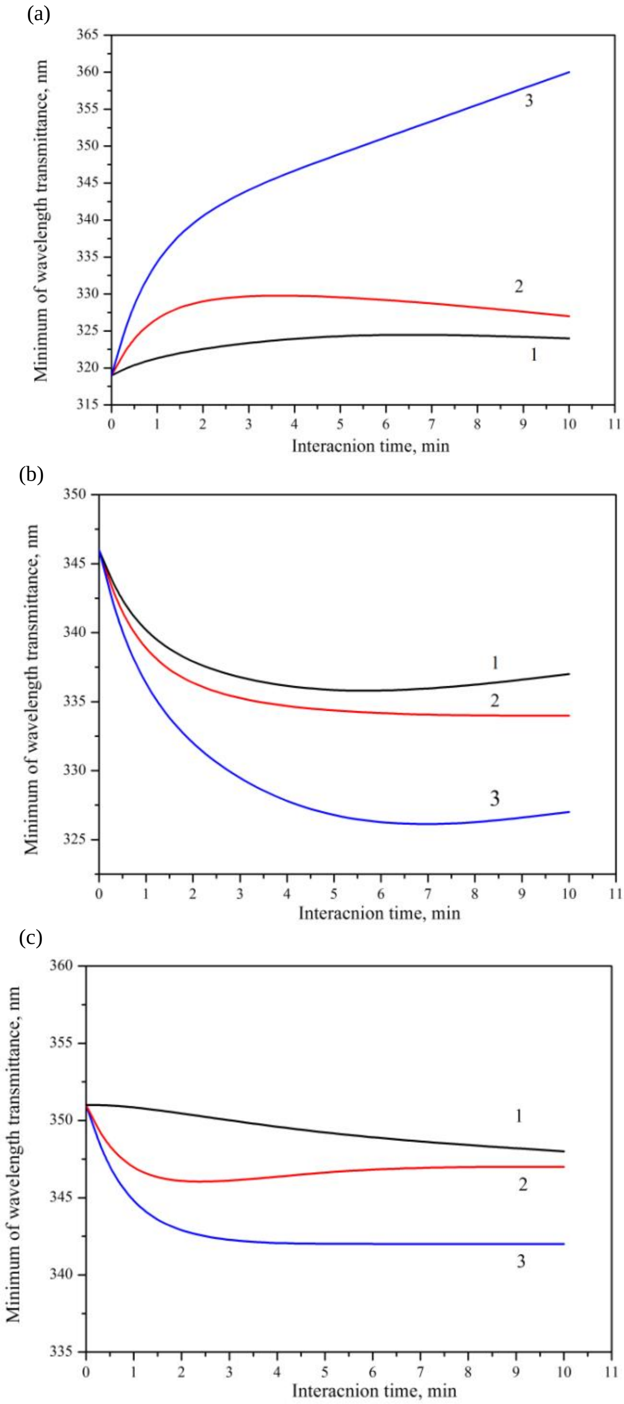

Fig. 2. The dependencies of a wavelength transmittance minimum of the nanocomposite structure versus the interaction time with CO gas with concentrations of: (1) 20mg/m^3, (2) 50mg/m^3 and (3) 100mg/m^3; pores diameter: (a) 20nm, (b) 35nm, and (c) 50nm.

This means that larger pores have a weaker influence on the CLC helical pitch due to effectively decreased strength of interaction of the CLC with the surface of pore walls. Figures 2a÷c show the dependencies of the position of a transmission minimum on the interaction time of structures with carbon monoxide. Let us analyze these dependences.

The main feature of these dependencies is a shift of the minimum of wavelength transmittance towards the long-wavelength range of spectrum with a 20nm diameter of pores in Al_2O_3, and a shift of the minimum of wavelength transmittance towards the short-wavelength range of spectrum with a 35 and 50nm pores diameter. In all investigated nanocomposites significant changes of the helical pitch are observed only during the first minutes of interaction with CO.

The rate of a helical pitch change is 15nm/min, 9nm/min and 6nm/min for a pores diameter of 20, 35 and 50nm, respectively (Fig. 3).

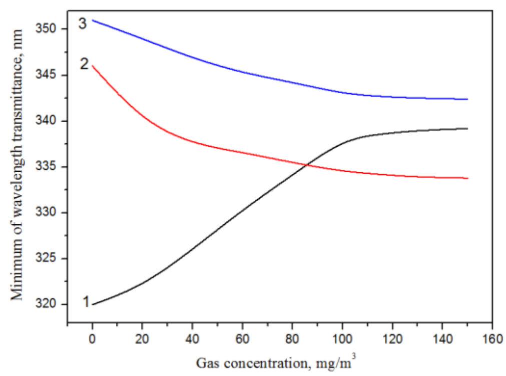

Fig. 3. The dependencies of a wavelength transmittance minimum of the nanocomposite structure versus CO gas concentrations, of pores diameter: (1) 20nm, (2) 35nm, and (3) 50nm.

As can be seen from the dependence shown in Fig. 3, the maximum sensitivity to CO concentration changes is observed for nanocomposite with a 20nm pore diameter. As you know, the sensitivity is determined by the tangent of the curve slope. With an increase in pore diameters the nanocomposite sensitivity decreases under the CO influence. The saturation process may be observed at CO concentrations of more than 100mg/m^3, which does not depend on pore diameters (Fig. 3). After the introduction of a CLC mixture doped with magnetite into the pores of Al_2O_3 the deformation of a helical pitch is observed and as a result, the transmission minimum of nanocomposite shifts, as shown in Fig. 1. In the case of "confined geometry" (the size of pores is comparable with that of LC molecules) due to the interaction with the inner surface of pores the cholesteric helical pitch is unwound.

The influence of the confining surface on a CLC helical pitch is the strongest in the smallest pores of the 20nm diameter, and weaker in larger pores of 35nm and 50nm diameter. In the case of the 20nm pores diameter the cholesteric helical pitch increases, and in 35nm and 50nm pore diameters the cholesteric helical pitches decrease.

The most significant changes occur during the first minutes of interaction of investigated nanostructures with CO Moreover, the described changes are characteristic of pores of a different diameter. A further increase of the CO concentration does not lead to changes in the structure of cholesteric liquid crystal, and the saturation of all curves is observed, as shown in Fig. 2. If the concentration of CO is increased, this interaction is more intensive and does not depend on the size of pores.

In conclusions, the interaction of a nanocomposite on the basis of CLC2103L cholesteric liquid crystal with Fe_3O_4 introduced into the Al_2O_3 pores is the most intensive during the first minutes of interaction. A further increase of interaction time does not lead to a change in the CLC structure.

With constant interaction time, the intensity of interaction process is proportional to the concentration of CO. For pores with a diameter of 20 nm the rate of a wavelength change is 15nm/min at a 100mg/m^3 CO concentration.

The most significant influence of the confining surface of Al_2O_3 nanocomposite pores on the CLC doped with Fe_3O_4 nanoparticles is observed when the diameter of pores is 20nm, and is weaker when the diameter of pores is larger.

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