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On application of the chiral liquid crystal materials to the design of optical isolators

J. Kuśnierz, M. Kuźma

Institute of Physics, College of Pedagogy, ul. Rejtana 16a, 35–310 Rzeszów, Poland.

A. Dubik, J. Owsik

Kaliski Institute of Plasma Physics and Laser Microfusion, P.O. Box 49, 00–908 Warszawa, Poland.

A. Szymański

Institute of Physics, Technical University of Rzeszów, ul. Wincentego Pola 2, 35–959 Rzeszów, Poland.

Optical Bragg reflection phenomenon in cholesteric liquid crystals has been explored for construction of laser beam isolator for big power laser systems with $\lambda = 1.06$ μm. The isolator with this material was experimentally tested.

1. Introduction

The exploitation of the high power neodymium glass laser systems in examinations of plasma compression is possible only when the elements protecting the system against the radiation reflected from the plasma are available. Due to incomplete saturation of the active medium in the course of laser action there exists such a level of population inversion in the amplifying heads that the radiation reflected from the plasma and travelling back into the laser system is there strongly amplified. As a consequence, some components of the system may be damaged. In order to minimize the harmful phenomena, it is necessary to use the isolators attenuate the radiation reflected from the plasma to the safe level.

2. Optical isolators

2.1. Principle of operation

The principle of operation of an optical isolator may be defined as one-way optical valve, which transmits the radiation travelling along the laser system in the direction of plasma and scatters the reflected radiation travelling back in the opposite direction. Nowadays, the devices used most frequently in the laser systems are isolators based on Faraday effect. However, due to the relatively high costs of such devices, the conventional methods start to be replaced by the new ones, particularly, by those based on optical properties of chiral liquid crystals [1]. Chiral liquid crystals are optically active materials of periodic structure arranged in layers. In the oriented layers of these materials, there occur the following optical phenomena: optical activity, circular dichroism and selective light scattering (SLS) [2]. Due to these optical properties it is possible to achieve the effect of optical isolation.

The action of an isolator filled with the chiral material, giving both the effect of circular dichroism and selective light scattering, is shown schematically in Fig. 1. Within the range of the wavelengths, for which the said phenomena occur, the polarized either circularly or elliptically light beams are transmitted through the layer practically without any losses or scattered selectively (practically 100% of incident energy is scattered for the layer thickness greater than critical) depending on the sense of the electric vector rotation. In a laser system, in which sense of electric vector rotation for the reflected beam is opposite to that of the incident one, the thin layer of suitably selected chiral material eliminates the first one from the system, as it is shown in Fig. 1.

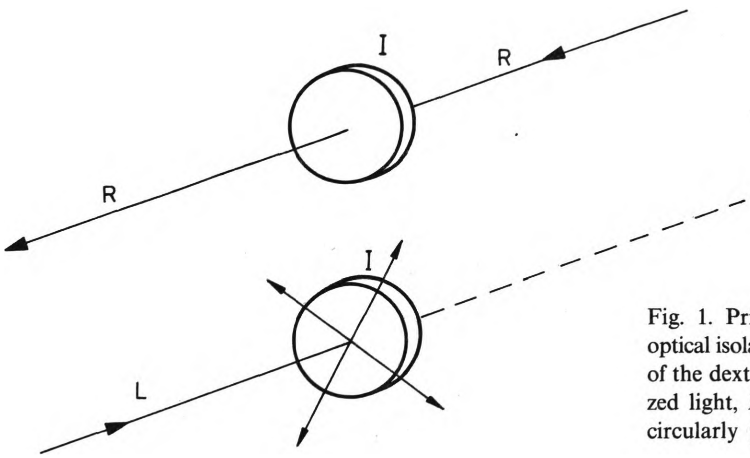

Fig. 1. Principle of operation of the optical isolator: *I* – isolator, *R* – beam of the dextrorotatory circularly polarized light, *L* – beam of leavorotatory circularly polarized light

Cholesteryl liquid crystals, their mixtures, chiral nematics and chiral smectics C shown chiral properties [2], [3]. It is characteristic of all the above mentioned materials that their optical properties depend strongly on: temperature, vestigial dopings of other, both mesomorphic and nonmesomorphic materials, pressure electric and magnetic fields. Low chemical stability of these materials (being attacked by oxygen and tending to decompose when irradiated by UV radiation) and very diversified structural stability of their mixtures are obvious shortcomings as far as their technical applications are concerned. Therefore, the practical application of the said materials is difficult.

2.2. Technical requirements

Due to the specific conditions under which the optical isolators work in the systems of interest, they should only slightly attenuate the incident light beam and do not disturb the incident wavefront. Then should, moreover, be resistive to the high power laser radiation. Apart from the above, minimization of the weight, size and energy consumption of the isolators is very desirable.

3. Elaboration of the chiral mixtures of cholesteryl materials suitable for the design of the optical isolators

An ideal active material for an optical isolator should be characterized by the following features:

i) matching of the spectrum line for SLS to the wavefront λ_0 of the beam generated by the laser system.

ii) high resistance to the radiation of high power density,

iii) low costs, easy production and application to arbitrary apertures,

iv) low temperature sensitivity of the SLS maximum,

v) low distortion of the wavefront travelling in the direction of the target.

The most important point is the matching of the SLS line to the working wavelength of the laser system. The shape and the temperature dependence of this line define the basic properties of the optical isolator. There exist several models of the theoretical description of the SLS spectral lines obtained for an ideal planar structure [3].

In practice, for this description the knowledge of the molecular parameters as well as the planar structure is required. For the mixtures this approach is of low usefulness. Hence, it appears that the values of interest should be determined experimentally.

3.1. Determination of the SLS lines

There exists a rigorous dependence between the selective transmission (STL) and selective light scattering which causes that the shape of the line corresponds to the shape of the other one (for the given chiral material under the same conditions).

The determination of the shape of the SLS line is difficult due to the angular distribution of the scattered radiation. Hence, the determined shapes of the SLS lines suffer from high errors, whereas the shape of the STS lines may be measured by using a standard optical apparatus (such as Backman spectrophotometer or Specord UV–VIS 80 M).

In our work, the wavelenght of the SLS maximum and the shape of the STS lines were determined by employing different setups. In order to determine the wavelength corresponding to SLS maximum, we have used the setup including GDM–1000 monochromator, described in the Appendix, while the STS lines were determined by using the setup with a SPM–2 monochromator. Its description is given in the Appendix as well. The results obtained in this way have been compared with those received from the spectrophotometers of Backman and Specord UV–VIS 800 M types, respectively, and a satisfactory agreement was stated. The temperature dependence of the STS lines was measured on the setup with the SPM–2 monochromator and on the UV–VIS 80 M Specord spectrophotometer.

3.2. Elaboration of the mixtures

The wavelength of the SLS maximum depends on the period p of the chiral structure. For the cholesteryl materials this dependence follows from the Fergason formula [4]

$$\lambda_{max} = 2n_{av}\, p \cos\frac{1}{2}[\arcsin(1/n_{av} \sin \Phi_p) + \arcsin(1/n_{av} \sin \Phi_o)]$$

where: p — period of the chiral structure, n_{av} — average refractive index of the liquid crystal, Φ_p, Φ_o — angle of incidence and angle of observation, respectively.

Since, the single-component ester of cholesteryl showed no desired properties, the production of mixtures of the required parameters became necessary.

For the two-component cholesteryl or nematic-cholesteryl mixtures, the resultant period p of the mixture may be predicted due to the formula proposed by BAK and LABES [5]

$$1/p = w_1/p_1 + w_2/p_2$$

where: p_1, p_2 — periods of the cholesteryl structures for the components 1 and 2, respectively, w_1, w_2 — percentages by weight of the components 1 and 2, respectively. In general, this dependence is of limited applicability because the desired properties of the SLS lines can be hardly achieved in the two component mixtures. It has been shown that it is also very difficult to achieve the desired parameters in the case of three-component mixtures. On the other hand, the multi (more than three) component mixtures may be produced only in an experimental way. Our mixture of given parameters has been prepared from the cholesteryl materials presented in the Table.

The components of the mixtures

Cholesteryl materials	Mesophase range [°C]
Cholesteryl nonanoate	78–91
Cholesteryl propioniate	85–112
Cholesteryl oleate	46–52
Cholesteryl p-nitrobenzoate	189–263
Cholesteryl chloride	97

The components of the mixtures (Table) were received from the Physics Department of the Rzeszów Technical University (Poland). These materials were preliminary cleaned by using the method of column chromatography, the solvent vapours being removed very carefully later on. The desired optical properties were achieved for the mixtures of the following composition: CO — 36.6%, CN — 12.53%, CP — 8.0%, CNb — 0.87%, CCl — 42%.

For the mixture denoted by symbol V the shape of the STS line at different temperatures, is shown in Fig. 2. Figure 3 presents the wavelength corresponding to

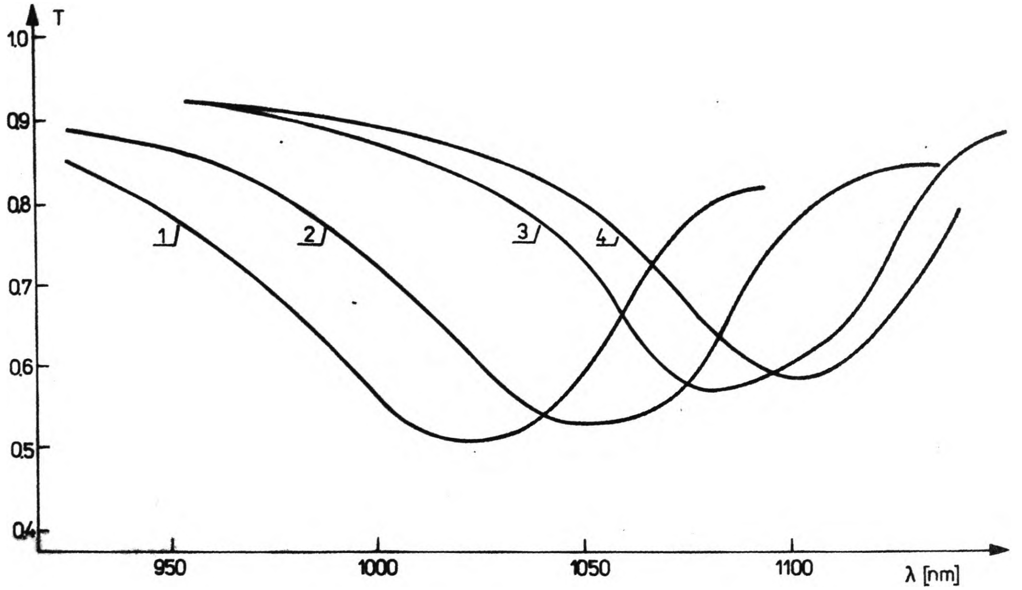

Fig. 2. Spectral lines of selective transmission of the mixture V for temperatures: 1 — 19.7, 2 — 22.5, 3 — 25.1, 4 — 26.6°C (*T* — relative transmission)

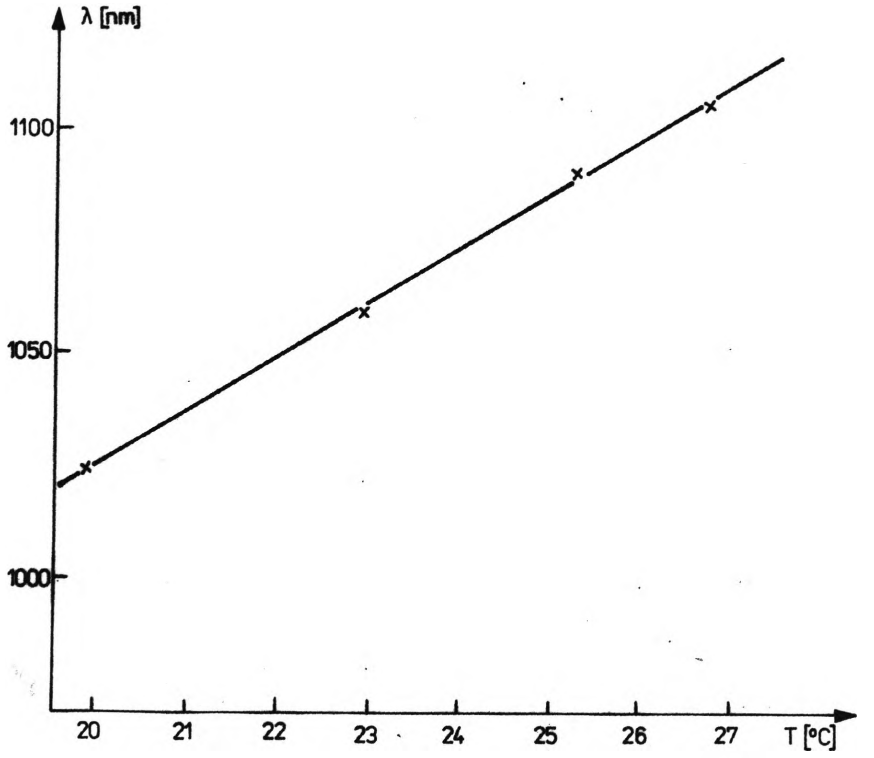

Fig. 3. Dependence of the wavelength of the selective light scattering maxima on the temperature of the mixture V

the maximum of SLS as a function of temperature. The measurements have been made with the help of the setup with SPM–2 monochromator described in the Appendix.

3.3. Verification of the isolation and resistance effects in the chiral material with respect to the neodymium glass laser radiation

Two aspects of the influence of irradiation on the change of properties of the obtained chiral material have been examined:

i) influence of irradiation on the texture of the liquid crystal stated by microscopic observations of the layer, before and after irradiation,

ii) optical properties of the above mentioned mixtures after a series of sample irradiations.

The sample has been irradiated consecutively by a beam of the maximum energy density equal to 2×10^7 J/m^2. No changes in the texture have been observed even for the focused beam (of highest energy density). After having irradiated the sample with a laser beam, the shape of STS line has been examined at the trial temperatures. No deviations from the previous shape were found. The effect of optical isolation may be seen in the photography (Fig. 4), where, however, only the effect caused by the incident beam is visible.

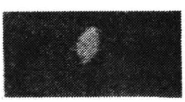

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Fig. 4. Illustration of the optical isolation effect (Nd-laser): 1 — trace of the circularly polarized light, 2 — trace of the circularly polarized beam after having passed through a 40 μm thick layer of material V, invisible in the photo due to low intensity.

4. Description of the construction of the optical isolator model

In the model of optical isolator, plane parallel glass plates made of BK–7 glass (of 10 mm thickness and surface roughness within the 14 class) have been used as the boundaring surfaces. The spacers were made of aluminium foil 40 μm thick. The whole isolator was closed in a special holder shown in Fig. 5. Thus constructed optical isolators were examined in the Kaliski Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland [6]. They proved to preserve the useful properties for the period longer than half a year.

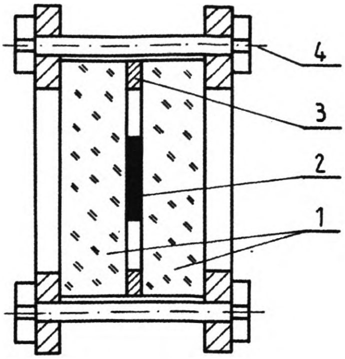

Fig. 5. Schematic design of the isolator model: 1 – glass plates, 2 – chiral material layer, 3 – spacers, 4 – holder

5. Final remarks

In the paper, it has been shown that the expensive optical isolators based, for instance, on the Faraday effect may be replaced by those made of liquid crystals. However, there are two problems which should be solved in the future. The first one is the reduction of the temperature dependence of the wavelength of the SLS maximum. The second problem is the prolongation of the lifetime of liquid crystal elements.

Appendix

System with the GDM–1000 monochromator (Carl Zeiss, Jena) has been shown in Fig. A. The setup enabled us to record the wavelength corresponding to the maximum of the selective light reflection.

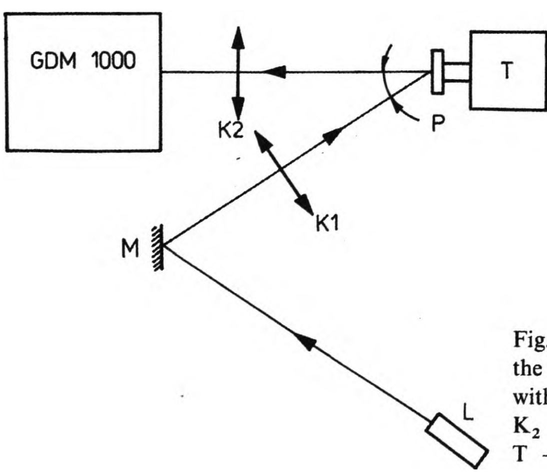

Fig. A. Scheme of the setup to determine the wavelength corresponding to SLS maximum with the help of GDM–1000 monochromator: K_1, K_2 – condensers, M – mirror, L – light source, T – thermostate, P – sample fastening

For the measurement of STS line width, the SPM–2 monochromator equipped with a specially constructed thermostatic chamber was used. The detector of radiation was a photodiode of BPYP–30 type. The measurement was made by using a comparative method (the ratio of the signal from the liquid crystal to that from the empty measurement chamber).

References

[1] Jacobs S. D., J. Fusion Energy **5** (1986), 65.
[2] De Gennes P. G., *The Physics of Liquid Crystals*, Clarendon Press, 1974.
[3] Beliyakov B. A., Sonin A. C., *Kholestericheskie zhidkie kristally*, [Ed.] Nauka, Moskva 1982 (in Russian).
[4] Fergason J., Mol. Cryst. **1** (1966), 293.
[5] Bak C. S., Labes M. M., J. Chem. Phys. **62** (1975), 805.
[6] Cesarz T., Dubik A., Kuśnierz J., Owsik J., Szymański A., [In]: *2nd Symposium of Laser Techniques*, Szczecin 1987, p. 278 (in Polish).

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Применение хиральных жидкокристаллических материалов к конструкции оптических изоляторов

Селективное отражение света на холестерических жидких кристаллах использовано в стороении оптических изоляторов лазерночо луча. Запроектирован и сделан жидкий кристалл применимый в работе лазеров большой мощности с $\lambda = 1{,}06$ µм. Сделанный на основе этого материала изолятор был подвержен практическим испытаниям.