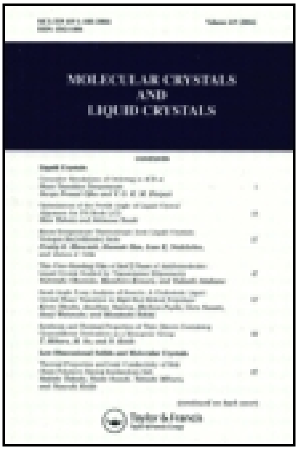

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FIBER OPTIC PRESSURE MEASUREMENT WITH CHOLESTERIC LIQUID CRYSTALS

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Abstract The paper presents the fiber-optic method for measurement of high hydrostatic pressure applied to a sensing element comprising a cholesteric liquid crystal (ChLC) being connected to multimode optical fibers for communication with a light source and a device for measurement of light intensity. The method exploiting the effect of pressure-induced changes in the wavelength of maximum light reflection observed in ChLCs, and is particularly well adapted for measuring pressure up to 100 MPa with a good linear response and sensitivity for specific ranges of pressure useful in industrial applications. The obtained data indicate that a fiber optic sensing device based on this method has pressure coefficient two orders of magnitude higher than current high-pressure sensors. The paper discusses also possible approaches towards temperature desensitization procedure of the fiber-optic method of pressure measurement.

INTRODUCTION

Over the past, cholesteric liquid crystals have been intensively investigated from both theoretical and practical points of view. They have been successfully applied as monitors of temperature fields, as single detectors of temperature, of radiation and organic-compound vapors, and as infrared-visible transducers. Other applications of ChLCs as liquid crystal displays and light beam modulators are based on two electro-optical effects: dynamic scattering with the storage mode and the cholesteric/nematic phase transition.

High pressure effect studies on liquid crystals have given new insides into the nature of molecular interactions responsible for liquid crystalline ordering and from practical point of view they have great potential for applications in high pressure metrology. Measurement under high pressure can generate additional data on basic thermodynamic quantities, specially at and in the vicinity of phase transitions between different liquid crystals phases. Pressure plays an important role in monitoring the character of the phase transitions between different liquid crystal phases. Some transitions between different liquid crystal phases are usually discontinuous, but it should be possible to make them continuous by increasing either the transition pressure or the transition temperature or both, since coexisting liquid crystal phases are thermodynamically very similar. To date, few high pressure experiments with liquid crystals have been reported, since measurement under high pressure requires a specialized apparatus for communicating with the high pressure region containing the liquid crystal sample. The influence of hydrostatic pressure on ChLCs was initially described by Pollmann [1] who determined the wavelength of Bragg reflection of light λ_R of cholesteric mesophases for pressures up to 500 MPa. His results showed that sensitivity of the wavelength λ_R to pressure can be extremely large, with a red shift of λ_R, providing a new method of pressure measurement [2].

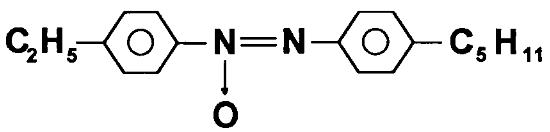
FIBER OPTIC MEASUREMENT OF HIGH PRESSURE

In last years, optical fibers have been successfully applied for the measurement of high pressure [3,4]. These newly emerging fiber optic sensing devices offer important advantages in comparison to conventional sensors: suitability for use in electrically hazardous, noisy, or explosive environments; immunity to electro-magnetic interferences, and far greater sensitivity. They are also directly compatible with fiber optic telemetry, optical data transmission systems, and optical multiplexing technology. The major drawbacks and limitations of these kinds of optical fiber pressure sensors are such as source and detector aging, attenuation changes in optical fibers and connectors, contamination of optical components, disturbing effects of temperature and mechanical vibrations, and substantial costs involved. Recently [2], we have proposed and introduced a new high hydrostatic pressure sensing method in which optical fibers were used to transport the optical signal in and out of the high-pressure region. The method utilizes cholesteric liquid crystals as a sensing element and exploits the effect of pressure-induced changes in the peak light-reflection wavelength observed in ChLCs.

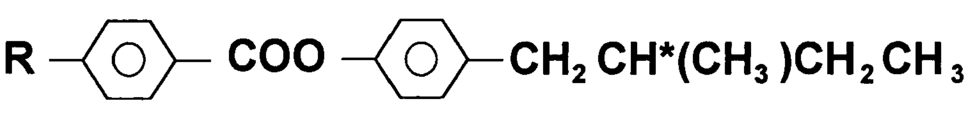
In this paper, we present further development of fiber-optic high hydrostatic pressure measurement utilizing ChLC as a sensing element. Application of optical fibers for communication with a liquid-crystal sample placed in a high-pressure region constitutes an alternative approach in studies of pressure-induced effects in liquid crystals and on the other hand, creates the possibility of liquid-crystal high-pressure measurement which can exploit all the attractiveness of fiber-optic techniques.

LIQUID CRYSTAL MATERIALS

The ChLC samples used for a sensing element were initially available from Davis LC Inc. in form of completely black, opaque and semi-rigid films with bright colors. Full color range (from blue to red) responded to about 5 degrees changes of temperature. Alternatively, cholesteric films have been obtained from dispersion of a liquid crystalline material in a polyvinyl alcohol polymer matrix. The liquid crystal material was a composition of a compound A:



and a basic mixture (B) of three chiral dopants of the form:



where R=C_6H_{13} (20.6%), $C_8H_{17}O$ (23.4%), and $C_{10}H_{21}O$ (56%).

The current effort was devoted to overcome disturbing effects of temperature accompanying high pressure measurement with ChLCs. This can be accomplished by a proper choice of liquid crystalline material used for a sensing element and/or by using one of fiber-optic reference techniques of measurement. To obtain this goal, several different compositions of liquid crystals A and B have been investigated. Finally, a liquid crystalline mixture composed of equal parts of A and B (50%:50%) and characterized by the phase sequence: smectic A (13°C) ChLC (39.5°C) isotropic phase has been selected. The ChLC mixture reflects selectively red light at room temperature (18-20°C)

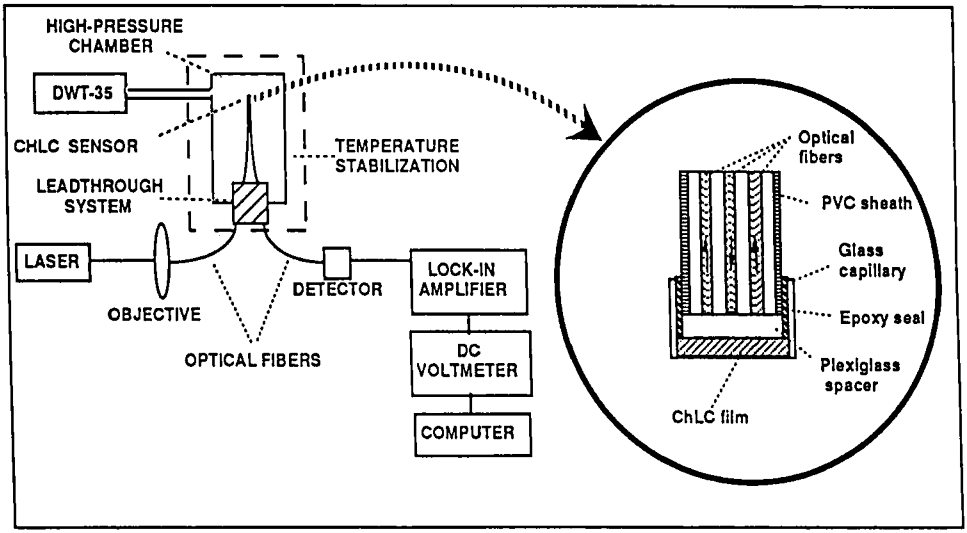


FIGURE 1 Experimental set-up of the fiber-optic high-pressure ChLC sensor

EXPERIMENTAL

Fig. 1 shows the experimental set-up with the sensor head represented in the inset. The ChLC sample was glued to a plexiglass spacer and then to input and output optical fibers. The input fiber carries optical energy which enters the ChLC sample. The output fibers deliver the light that has been reflected from the ChLC layers to the measuring electronics.

The sensor assembly was placed inside a standard thermally stabilized high-pressure chamber designed to sustain pressures up to 500 MPa. Insertion of the sensor into the chamber was accomplished using a fiber-optic leadthrough system [5]. High-pressure generation and calibration up to 105 MPa was performed using a Harwood DWT-35 deadweight tester (reading accuracy of 0.01%). The light sources were a He-Ne laser at 633 nm wavelength and a laser diode emitting at 845 nm, modulated using standard techniques. Details of the experimental procedure have been described elsewhere [6].

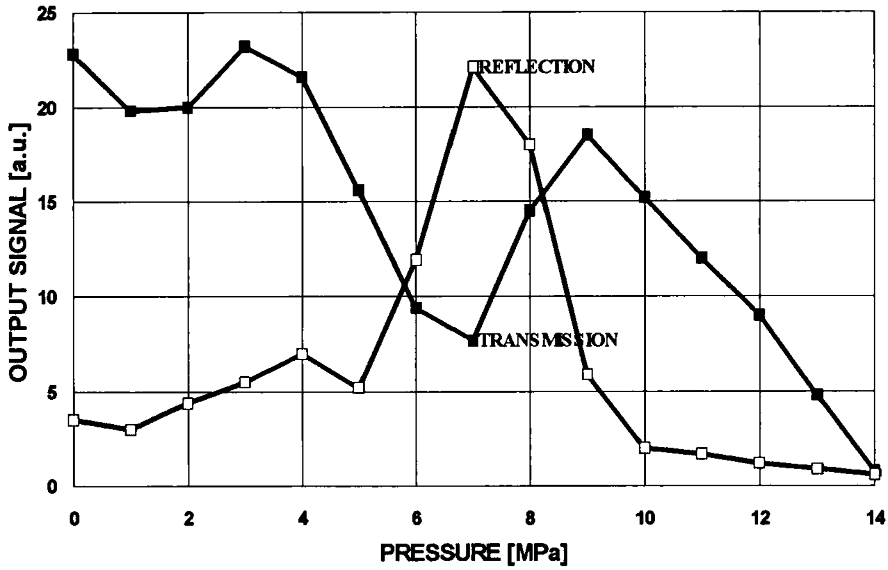


FIGURE 2 Pressure characteristics obtained for a 50%(A):50%(B) ChLC mixture at room temperature. Maximum of selective Bragg reflection (at about 7 MPa) corresponds to a visible minimum of transmitted intensity for the same ChLC material.

RESULTS AND DISCUSSION

Measurement has been performed for pressures up to 100 MPa (1000 bar) and temperatures ranging from 20^{o}C to 30^{o}C in the three configurations: a double-source sensor (633 and 845 nm), a two sensing-element sensor (head with two different ChLC samples), and a sensor with two identical ChLC sensing elements influenced by the same ambient temperature but different pressure conditions. Fig. 2 presents pressure characteristics up to 15 MPa (150 bar) obtained for a 50%(A):50%(B) ChLC mixture at room temperature. Maximum of selective Bragg reflection (at about 70 bar) corresponds to a visible minimum of transmitted intensity for the same ChLC material. Typical high pressure characteristics in double-source and two-sensing elements configurations for higher values of pressure (up to 100 MPa) are presented in Fig. 3.

Application of one of the three reference fiber-optic techniques was intended to minimize some of the essential limitations of a classical one-source fiber optic sensor, such as: source and detector aging, attenuation changes in optical fibers and connectors, contamination of optical components, degradation and aging process of liquid crystal materials but first of all was aimed to overcome disturbing effects of temperature.

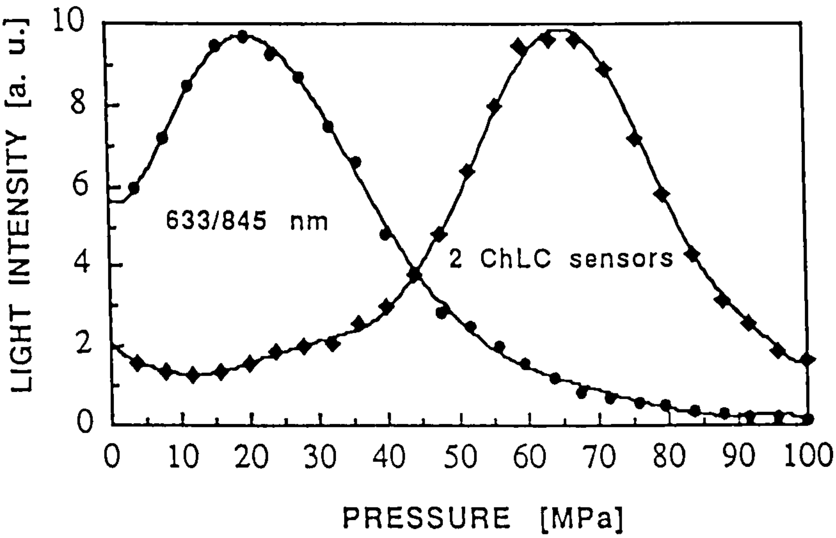


FIGURE 3 High-pressure characteristics in double-source (633/845 nm, at 28°C) and two-sensing elements configurations (2ChLC sensors, at 24°C).

Multimode optical fibers (50/150 μm) were used for guiding the light to and from the ChLC sensing element placed in the high-pressure chamber. Initial attempts have also been undertaken with single-mode (5/125 μm) and polarization-maintaining fibers (PMFs), which can preserve an input linear polarization. Application of PMFs seems to be very promising in a future construction of a polarimetric fiber-optic LC pressure sensor, since the selective reflection from ChLC layers is accompanied by a circular dichroism phenomenon.

From the data presented in Fig. 3 it follows that the output signal (I) mean pressure-sensitivity expressed as $\alpha_p=1/I(dI/dp)$ is better than 0.05 MPa^{-1} in the linear region of pressure characteristics. The pressure sensitivity was found to be nearly the same in all of the three configurations proposed. This means that the proposed optical fiber ChLC high-pressure sensor has a pressure coefficient about two orders of magnitude higher than the traditional high-pressure sensors. In comparison to a one-source sensor, the reference techniques offer an improvement in temperature desensitization of the fiber-optic pressure measurement with ChLCs. Further experiments leading to a totally temperature-independent pressure measurement utilizing a liquid crystal as a sensing element and optical fibers to communicate with high pressure region are still in progress.

We believe that application of optical fibers and liquid crystals into high-pressure sensing can complete investigations of pressure-induced effects in liquid crystals giving new insight into the nature of molecular interactions responsible for liquid crystalline ordering, and from the practical point of view it creates a great potential in high-pressure metrology.

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REFERENCES

1. P. Pollmann, J. Phys. E Sci. Instrum. 7, 490, (1974)
2. T. R. Woliński, and W. J. Bock, Mol. Cryst. Liq. Cryst., 199, 7, (1991).
3. K. Jansen and P. Dabkiewicz, Proc. SPIE, 798, 56, (1987).
4. W. J. Bock, T. R. Woliński and A. Barwicz, IEEE Trans. Instrum. Meas., 39, 233, (1990).
5. W. J. Bock and J. Chrostowski, J. Phys. E Sci. Instrum., 21, 839, (1988).
6. W. J. Bock and T. R. Woliński, US Patent No. 5,128,535, (1992).