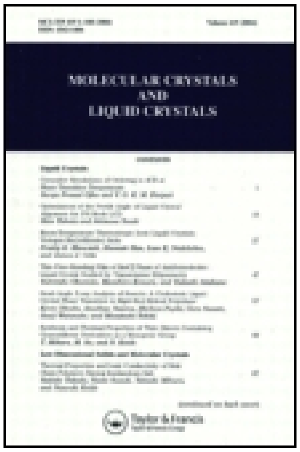

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Liquid-Crystal Electric and Magnetic Field Sensors†

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Liquid-Crystal Electric and Magnetic Field Sensors†

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Molecular-orientations in liquid-crystal cells can be changed by the external electric field even if voltages are not directly applied across the electrodes. Then the strength of the electric field can be measured by the change of the molecular orientations, that is, of the optical properties of the liquid-crystal cells in the electric field, as well as in the magnetic field. Both reflection and transmission type field sensors are prepared by using TN cells and optical fiber systems. When the substrate surface of the cell is perpendicular to the field, the transmittance increases above the threshold of the field strength. On the other hand, when the surface is parallel to the field, the transmittance continuously increases according to the increase of the field covering the wide range.

Keywords: liquid-crystal sensor, electric field sensor, magnetic field sensor, optical fiber, TN cell

INTRODUCTION

It is well known that the molecular orientations in liquid-crystal cells can easily be controlled by applying relatively low voltages across the electrodes, and that many trials of their practical application to display devices have been made so far. Usually the liquid-crystal layers are sandwiched by two glass (or plastic) plates with transparent conductive electrodes and, then, driving voltages are directly applied across them from a voltage source. As a result, the electric field is produced between the two electrodes. Since the liquid-crystal molecules have either positive or negative dielectric anisotropy, their orientations can be changed by the electric field above a threshold field strength.

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The molecular orientations can also be changed by the external electric field even if voltages are not directly applied across the electrodes of the cells. Therefore, the strength of the electric field can be measured by the change of the molecular orientations, that is, of the optical properties of the liquid-crystal cells in the field. Then it can be said that the magnetic field is to be measured in the same way.

So the aim of this paper is to present the concepts of the liquid-crystal electric and magnetic field sensors. The liquid-crystal sensors described in this paper have some advantages. That is, they hardly disturb the measured field and the distribution of it, since they consist of insulting materials and have no metallic parts, and the field strength can be measured with low power dissipation. In comparison with the sensors using electrooptic crystals,[1,2] the liquid-crystal sensor is lightweight and materials used are not expensive. In addition, the higher sensitivity and the wider dynamic range can be anticipated.

EXPERIMENTAL PROCEDURE

Twisted nematic type liquid-crystal cells are prepared by using pentylcyanobiphenyl (BDH K15), spacers with suitable thickness, and glass substrates with or without transparent conductive electrodes. The schematic structures of a transmission type and a reflection type sensor are shown in Figure 1 (a) and (b), respectively. The relationship between the optical transmittance and the field strength is measured by using a light-emitting diode (Stanley, FH511 GaAs: $\lambda = 660$ nm), a photodiode (Hamamatsu Photonics, S-1336), and optical fibers. The dimension of the liquid-crystal cell in the transmission type is typically 7 mm $\times$ 7 mm. The side length of the prism used in this work is 7 mm. The diameter of plastic fibers used is about 1 mm. Two rod lenses (Selfoc: graded index type) are used to increase an optical coupling efficiency. In the reflection type cell, several slender plastic fibers for output light are located around the central fiber for input light, and a dielectric reflecting mirror (8 mm $\times$ 8 mm) is used as shown in Figure 1 (b). The plastic fibers used in both types have a length of 1 m.

As the electric field sensor, the sensor head is placed between two copper disks connected to ac (50 Hz) high voltage source (up to about 15 kV). A diameter is about 30 cm and a distance is 3.5 cm. The magnetic field sensor head is placed between two pole pieces of a magnet. All experiments are carried out at room temperatures.

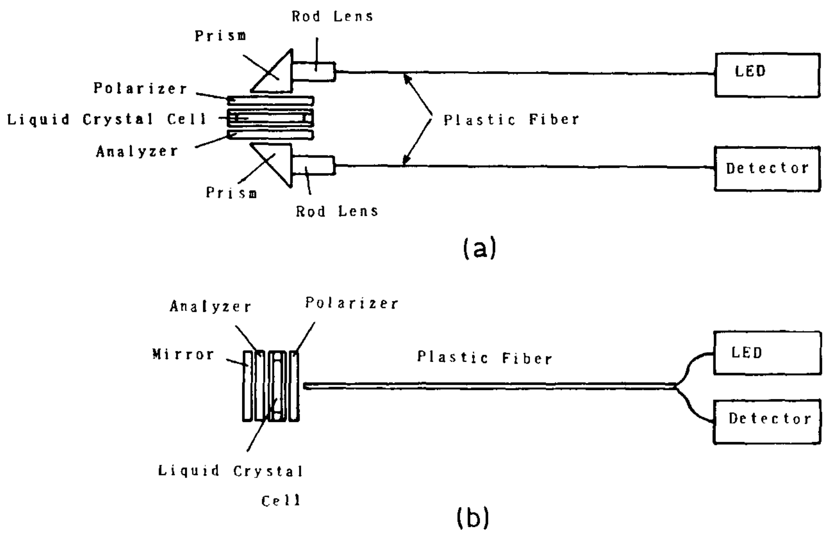

FIGURE 1 Structure of field sensors. (a) transmission type, (b) reflection type.

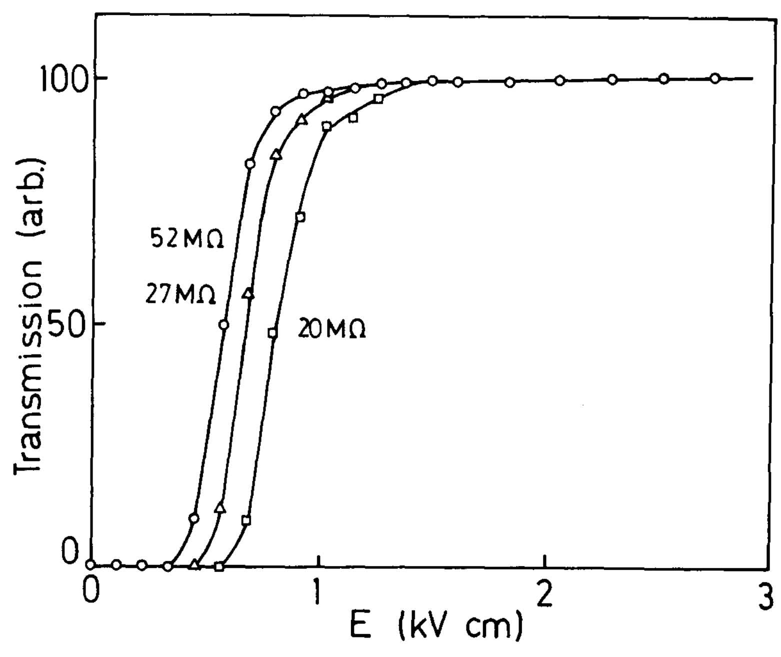

FIGURE 2 Transmission vs. electric field strength.

RESULTS AND DISCUSSION

Figure 2 shows transmission properties (in the transmission type) as a function of electric field strength when the substrate surface of the liquid crystal cell (corresponding to the director of the liquid-crystal molecules) is perpendicular to the field. The thickness of the spacer used is 100 μm. The transmission light intensity steeply increases above the threshold of the field strength, and soon will be saturated as increasing the electric field, as shown in Figure 2. These properties are very similar to those observed in the ordinary TN type cells. The threshold field strength increases as the electric resistance of the cell decreases, while it decreases as the thickness of the liquid-crystal layer increases. The transparent electrodes are required in this configuration. When the liquid crystal cell has no electrodes, no sensitivity for the electric field is observed.

Figure 3 shows the relationship between the threshold of the electric field strength and the electric resistance of the cell. The cell resistance is controlled by doping an organic compound (tetrabutylammonium-bromide) into the liquid crystals and the thickness of the spacer is also 100 μm. The threshold field strength seems to vary inversely to the cell resistance. Since a polarization against the electric field is created by a drift of residual ions, the electric field inside the liquid-crystal cell becomes small by doping, then the threshold of the field strength increases.

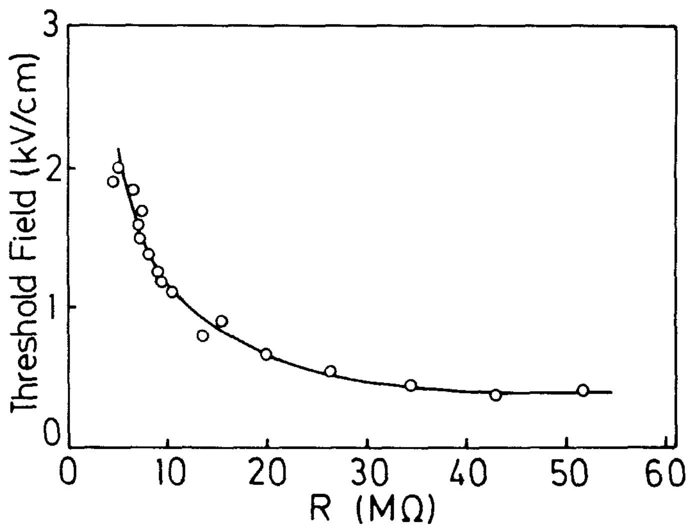

FIGURE 3 Threshold field vs. cell resistance.

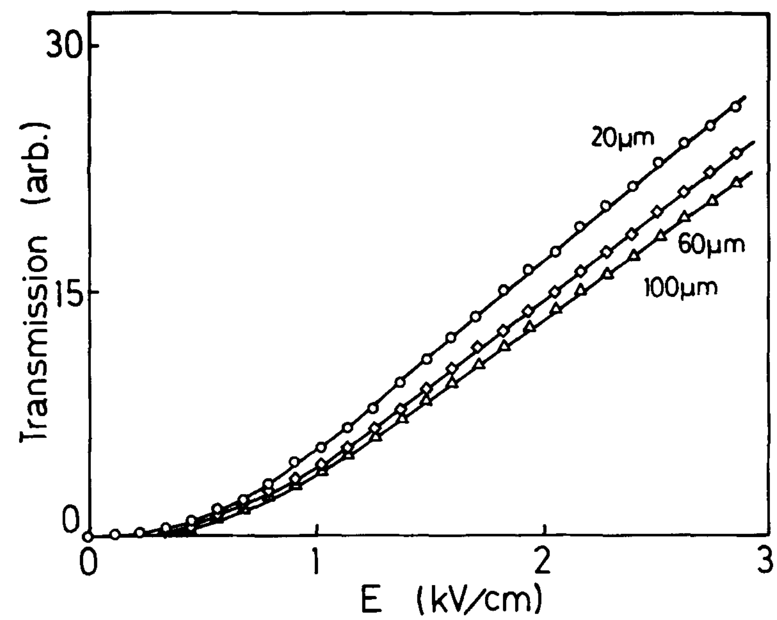

FIGURE 4 Transmission vs. electric field strength.

When the substrate surface of the liquid-crystal cell is parallel to the field, the relationship between transmission light intensities and the electric field strength is shown in Figure 4. In this measurement, the liquid crystal cells are prepared by using the glass substrates without the transparent electrodes. The transmission light intensity

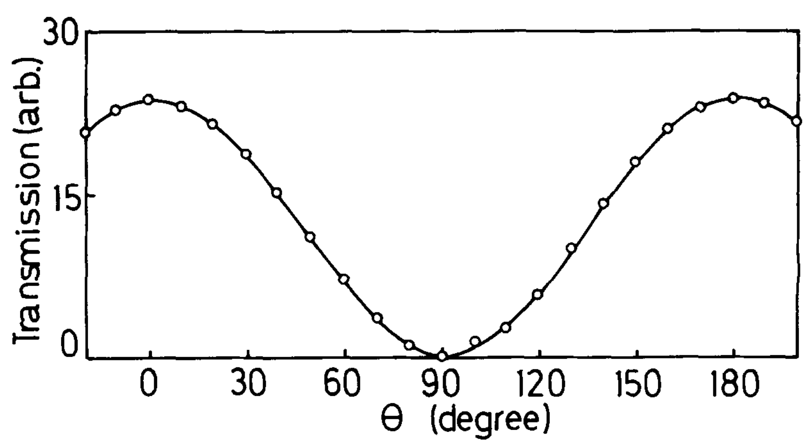

FIGURE 5 Angular dependence of transmission properties.

continuously increases according to the increase of the electric field strength covering the wide range. No threshold properties are observed. As the thickness of the cell decreases, the transmission level increases. Similar results are obtained in the magnetic field. The transmission properties shown in Figure 4 depend on the angle between the direction of the field and the director of the liquid crystal molecules, as shown in Figure 5. The maximum sensitivity is obtained at the angle of 0° and 180°, that is, where the substrate surface of the cell is parallel to the field. Any changes in the transmission properties are not observed at the angle of 90° and 270°, where the substrate surface is perpendicular to the field and the situation corresponds to the results in Figure 2 without electrodes.

The experimental results obtained in the reflection type head is quite similar to those obtained in the transmission type head except that the input light passes twice through the liquid crystal layer in the former type. Optical transmission properties as a function of the electric field as well as the magnetic field strength are shown in Figure 6. The thickness of the spacer is 25 μm. The scales of both fields are calibrated so as to fit each point in the experimental results. It is seen that the electric field of 1 kV/cm corresponds to the magnetic field of about 4 kG for the same changes of transmission properties. However, corrections of effective field strength for the glass prisms, the glass substrates, and the polarizers have to be carried out so as to compare them more exactly.

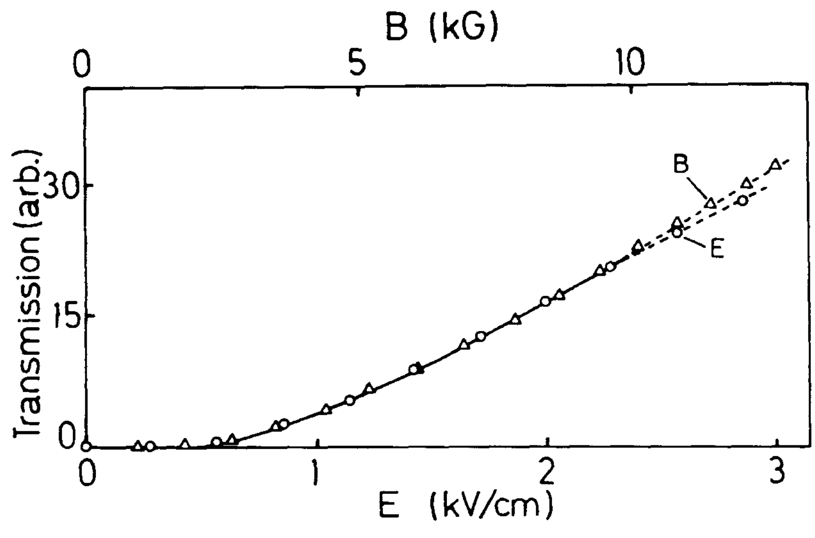

FIGURE 6 Transmission vs. electric field and magnetic field strength.

CONCLUSIONS

Both electric and magnetic field strength can be measured with the transmission type and the reflection type sensor head constructed by using the TN type liquid-crystal cells and optical fiber systems. When the substrate surface of the liquid-crystal cell is perpendicular to the field, the transmittance steeply increases above the threshold, which increases as the cell resistance decreases, while it decreases as the cell thickness increases. When the substrate surface of the cell is parallel to the field, the transmittance continuously increases as the field strength increases. In this configuration, high sensitivity (about 10 V/cm) and wide range (up to several tens kV/cm) measurements may be attainable.

The liquid-crystal sensor hardly disturbs the field distribution, besides it is inexpensive and light-weight. Since the electric resistance of the liquid crystal cell cannot be maintained at a very high value, the measurement of dc electric field is difficult, but it becomes possible by rotating the sensor head.

Further improvement of the sensitivity of the liquid-crystal sensors, development of switching devices or memory devices for the maximum field strength can be attained by using the suitable liquid-crystal cells, since there are various modes of molecular orientations in the liquid crystal cells and many kinds of liquid-crystal materials with various values of material constants such as dielectric anisotropy, magnetic anisotropy, elastic constants, etc.

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