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A New Type of Analog Voltmeter Using Electrooptic Effect in Nematic Liquid Crystals

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An analog voltmeter, in which a nematic liquid crystal is used both for a sensor part and a display part is proposed. Its several characteristics are investigated by employing the DAP effect as an example. The linearity in the relation between the indicated lengths and the voltages to be measured is fairly good, though the rise and decay time are rather long.

1 INTRODUCTION

Electrooptic phenomena in nematic liquid crystals such as deformation of vertical aligned phases (DAP),[1-3] twisted nematic modes,[4] guest-host effects and dynamic scattering modes (DSM),[6] have been applied to digital display devices. It seems, however, that these effects have been seldom employed in analog display devices. In addition to this, attempts to apply these effects to a detector of voltages have not been reported.[7] In this paper, an analog voltmeter, in which a nematic liquid crystal is used both for a sensor part and a display part of a voltmeter, is described.

2 PRINCIPLES

A schematic set-up of an analog voltmeter is shown in Figure 1. DAP effect is employed in this case. As transparent electrodes, two strips of glass plates

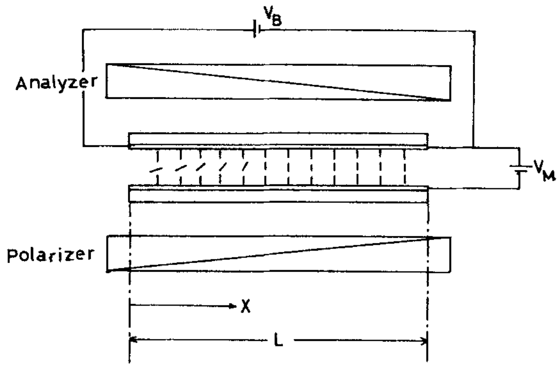

FIGURE 1 Schematic set-up of an analog voltmeter.

coated with In_2O_3 or SnO_2 film are used. A nematic liquid crystal with negative dielectric anisotropy is sandwiched between two electrodes. Homeotropic molecular alignments are required for operation in a DAP effect.

The voltage V_M to be measured is applied between two electrodes. Further, the bias voltage V_B is applied between both ends of one strip. It is desirable that this strip has as high resistivity as possible in order to avoid heating effects by the current going through this strip. If x coordinate is taken as shown in Figure 1, the voltage between two electrodes at x is given by

$$V(x) = \left(1 - \frac{x}{L}\right)V_B + V_M \tag{1}$$

Now, V_B is taken as the threshold voltage V_{th} for DAP effect. When $V(x_0) = V_{th}$,

$$V(x) > V_{th} \quad \text{for } 0 \leq x < x_0$$

and

$$V(x) \leq V_{th} \quad \text{for } x_0 \leq x \leq L.$$

Then, for the region $0 \leq x < x_0$, the light is transmitted. For the region $x_0 \leq x \leq L$, the light is shut out. Substituting $V_B = V(x_0) = V_{th}$ into Eq. (1), we obtain

$$x_0 = \frac{V_M L}{V_{th}}. \tag{2}$$

From Eq. (2), it is seen that the length of bright region (indicated length) x_0 is proportional to V_M. Thus, an analog voltmeter which can measure the voltage between 0 and V_{th} in linear scale is possible.

Here, one point must be commented. In the case of a.c. voltages, liquid crystals respond to the root mean square voltages. Therefore, in order to satisfy Eq. (1) also with the root mean square quantity, V_B and V_M must have same frequency and must be in phase. Otherwise, Eq. (2) does not hold and the relation between x_0 and L becomes more complicated.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

We fabricated this type of analog voltmeter and examined its several characteristics. Two strips of glass plates coated with SnO_2 film was used as transparent electrodes. The surface resistivity of this film with 10 mm × 10 mm size was 1 KΩ. The size of a strip was 25 mm × 100 mm and the display area was 5 mm × 90 mm. The cell thickness was 16 μm. In this experiment, MBBA, a typical nematic liquid crystal with negative dielectric anisotropy was used. Surface coupling agents were doped in it to obtain a homeotropically aligned cell.

When V_M alone is applied, usual characteristics of DAP effects can be observed. Figure 2 shows the relation between light transmission and applied voltages. The frequency of applied a.c. voltages was 1 KHz. A 633 nm He–Ne laser was used as a light source. The experiment was done at 20°C. It is seen from Figure 2 that the threshold voltage is about 4.0 V and the on-off characteristic is very sharp.

When the set-up was used as a voltmeter, the cell was illuminated from the back by a tungsten lump. Because the voltage dependence of light transmission of DAP cell depends on wavelength,[3] the color of the transmitted

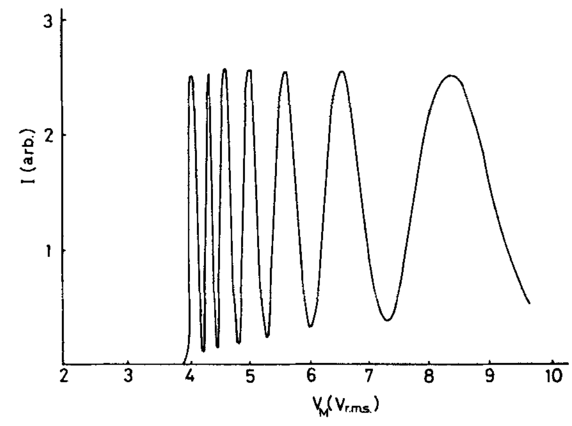

FIGURE 2 The relation between light transmission and V_M when V_B is not applied (DAP effect).

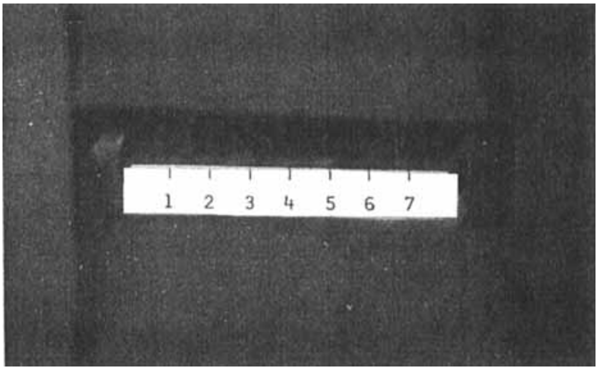

FIGURE 3 Fabricated analog voltmeter. $V_B = 3.66$ V and $V_M = 2.1$ V.

light is different at different x coordinates. As the threshold voltage, however, does not depend on wavelength, there is no inconvenience in using white light as a light source. Due to the tungsten lump, the temperature of the liquid crystal rose and V_{th} became a little lower and was reduced to 3.66 V in this case. Therefore, V_B was set at 3.66 V. Then, V_M was applied in phase with V_B. Figure 3 shows the photograph of the cell when V_M was 2.1 V. The relation between the indicated length x and V_M is shown in Figure 4. The linearity was fairly good. Hysteresis was not observed.

Figure 5 shows the relation between x and the frequency of the applied voltages when $V_B = 3.66$ V and $V_M = 2.01$ V. Because V_{th} is almost constant

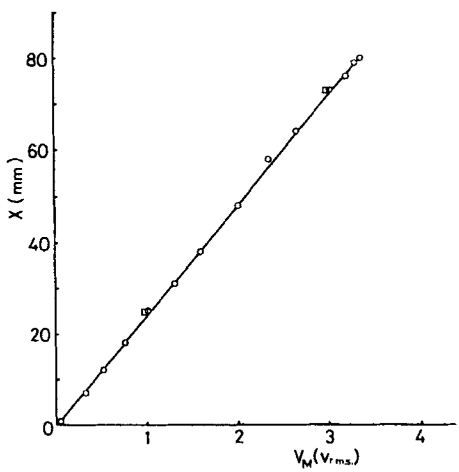

FIGURE 4 The relation between the indicated length x and V_M. Circles are data when V_M was raised and squares are data when V_M was lowered.

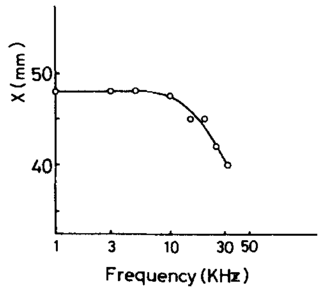

FIGURE 5 The relation between the indicated length x and the frequency of the applied voltages.

up to 10KHz, x is constant. When the frequency increases exceeding 10KHz, x decreases because V_{th} increases.[3] Therefore, V_B and the scale of the indicator must be readjusted for the voltages with higher frequency than 10KHz.

The threshold voltage depends also on the temperature of the liquid crystal. For the sample used here, V_{th} is almost constant from 15°C to 25°C. For the higher temperature, however, V_{th} decreases as the temperature rises.

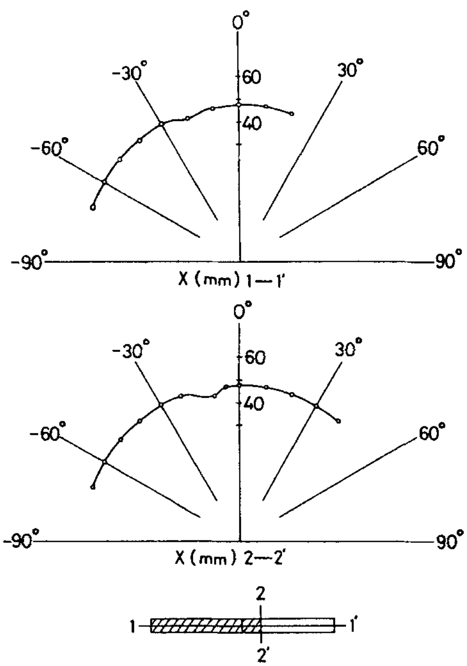

FIGURE 6 The viewing angle dependence of the indicated length. The radial length denotes the indicated length x and the azimuthal angle indicates the viewing angle measured from the normal to the cell.

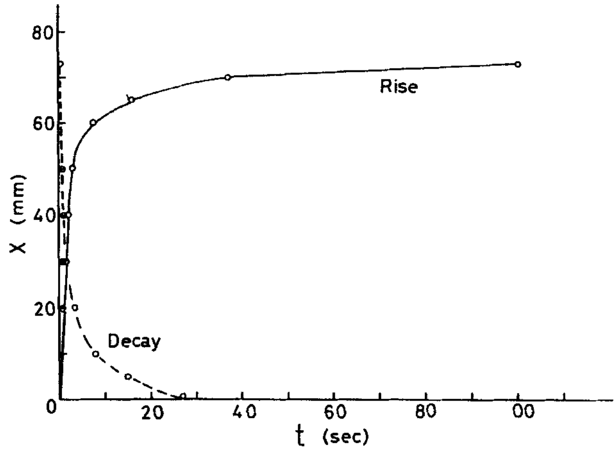

FIGURE 7 The rise and decay characteristics.

Then, V_B and the scale of the indicator must be readjusted again. For practical use, however, it is desirable that the temperature control need not be done. Therefore, this device must be used in the temperature range where V_{th} is constant.

The viewing angle dependence of x is shown in Figure 6. The upper figure shows the one in the plane which is perpendicular to the cell and contains the 1-1′ line. On the other hand, the lower figure shows the one in the plane which is perpendicular to the cell and contains the 2-2′ line. In both curves, a dip appeared. This is due to the fact that the molecules were inclined in that direction. When the viewing angle increased at a certain degree, the boundary between the bright region (light transmitted) and the dark region (light shut out) became not sharp. This phenomenon is common in the field effect type of display devices.

An example of the time dependence of x after V_M is applied, is shown in Figure 7. In this case, $V_B = 3.66$ V and $V_M = 3.0$ V. Both the rise time and the decay time were rather long. This rise and decay characteristic may be improved a little by the selection of a liquid crystal which has the lower viscosity, and the improvement of the cell, but, essentially, these facts are inevitable for this type of display devices because the working voltages are near V_{th}.

4 CONCLUDING REMARKS

An analog voltmeter, in which a nematic liquid crystal is used both for a sensor part and a display part was proposed. Its several characteristics were examined by employing the DAP effect as an example. Other types of electrooptic phenomena in nematic liquid crystals may work. But, it is essential for this application that the on-off characteristic is very sharp. From this point of view, the DAP effect seems to be best. In addition to this, V_{th} does not depend on the cell thickness in the case of DAP effect. This fact is favorable because the lack of uniformity in the cell thickness does not affect it severely.

The voltmeter considered here is suited to measure a.c. voltages because the DAP effect has fairly sharp on-off characteristics for a.c. voltages.[3] In this case, root mean square values of the voltages are measured.

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7. After submitting this paper, we found that Soref proposed the similar type of analog voltmeter in his paper named Electronically Scanned Analog Liquid Crystal Displays (R. A. Soref, *Applied Optics*, **9**, 1323 (1970)). He employed, however, the dynamic scattering modes, so the resolving power of the voltmeter was rather low because the on-off characteristic was not so sharp as the DAP effect. Besides, he did not refer to its performance in detail.