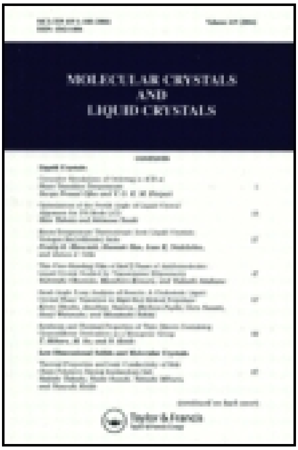

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Colorimetric Characterization of TN and GH mode LCDs†

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Twisted nematic liquid crystal displays (LCDs) using two kinds of practical polarizers (neutral gray and bluish gray) as well as a guest host mode display device were examined colorimetrically using CIE 1976 (L^* u^* v^*) space. Psychophysical colorimetric data of these LCDs were obtained and were compared with the conventional performance parameter, contrast ratio which is determined by physical photometry.

The lightness of the twisted nematic display devices for both polarizers are cube root function of the transmittance with the white light.

We also made a comparison of the colorimetric data of the guest host LCD with those of the TN LCDs.

INTRODUCTION

A number of various types of color display devices using nematic liquid crystal have been studied by many authors. Among them, the tunable birefringence (TB) mode,[1] the twisted nematic (TN) mode with dichroic polarizers,[2] and the guest host (GH) mode,[3] are the typical three types of the liquid crystal color display modes.

The performance parameter for achromatic display devices of the liquid crystal is defined by the transmittance (brightness) of the sample with the white light.[4] In the liquid crystal color display (LCCD), however, we must consider not only the brightness but also the chroma and the hue. Since the colorimetric treatment of the three attributes for color is complicated, the

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performance parameter for LCCD is hardly defined yet. However, recently several authors reported the colorimetric treatment for LCCD.[5,6]

In this paper, we propose a colorimetric method for estimating the performance of the LCDs taking into account the hue, the chroma, and the lightness. The lightness and the color difference of the TN mode LCDs with neutral polarizers are computed in the uniform color space, the CIE 1976 (L^* u^* v^*) space.[7]

Moreover we report on the relationship between the conventionally defined transmittance and the colorimetric quantities of the lightness with respect to the applied voltages.

TRICHROMATIC SPECIFICATION

The CIE 1976 (L^* u^* v^*) space recommended by the committee was used in order to estimate the color difference uniformly including the lightness scale of color. This trichromatic specification is defined as follows:

$$L^* = 116(Y/Y_0)^{1/3} - 16, \qquad Y/Y_0 > 0.01 \tag{1}$$

$$u^* = 13L^*(u' - u'_0), \tag{2}$$

$$v^* = 13L^*(v' - v'_0), \tag{3}$$

where Y_0 is the luminance factor of the perfect reflecting diffuser and u'_0 and v'_0 stand for the (u' v') chromaticity coordinate for the white point at a given color temperature. Chromaticity coordinate (u' v') are expressed by the following equations:

$$u' = \frac{4X}{X + 15Y + 3Z}, \tag{4}$$

$$v' = \frac{9Y}{X + 15Y + 3Z}, \tag{5}$$

where X, Y, and Z are the tristimulus values in the CIE 1931 standard colorimetric system. The tristimulus values X, Y, and Z are formulated as follows:

$$X = \frac{\int_{vis} \bar{x}_\lambda P_\lambda T_\lambda \mathrm{d}\lambda}{\int_{vis} \bar{y}_\lambda P_\lambda \mathrm{d}\lambda} \tag{6}$$

$$Y = \frac{\int_{vis} \bar{y}_\lambda P_\lambda T_\lambda \mathrm{d}\lambda}{\int_{vis} \bar{y}_\lambda P_\lambda \mathrm{d}\lambda} \tag{7}$$

$$Z = \frac{\int_{vis} \bar{z}_\lambda P_\lambda T_\lambda \mathrm{d}\lambda}{\int_{vis} \bar{y}_\lambda P_\lambda \mathrm{d}\lambda} \quad (8)$$

where P_λ and T_λ are the spectral power distribution of the illuminant at a given temperature and the spectral transmittance of a sample devices, respectively. The quantities $\bar{x}_\lambda, \bar{y}_\lambda$, and $\bar{z}_\lambda$ are the color matching functions of the CIE 1931 standard colorimetric observer. The three integrations were done in a visible region (vis) from 380nm to 700nm in this experiment.

The color difference ΔE (1976 CIE) is formulated as follows:

$$\Delta E = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2} \quad (9)$$

where ΔL^*, Δu^*, and Δv^* are the difference between two points represented in the (L^* u^* v^*) diagram. These two points in the color space correspond to on and off states for LCD.

In order to determine the coordinates in the CIE 1976 (L^* u^* v^*) space, the spectral transmittance of the liquid crystal cell with neutral polarizers were measured by a doublebeam spectrophotometer. The computation was made by the method of guassian quardratures using micro-computer processing.[8]

EXPERIMENTAL

In this experiment, we used the two kinds of neutral polarizers developed for TN-LCDs: the one is a neutral gray type and the other is a bluish gray one. The former is generally used in the calculators, and latter one is used in the watches.

Liquid crystal used in this experiment is *E*-7 which has a positive dielectric anisotrpy. The LC cell, treated by rubbing, is operated in the TN mode and has a thickness about 9 μm. In the GH cell, we used *E*-18 which has a positive dielectric anisotrpy. The dye is anthraquinone type, *D*-16 manufactured by MERK, and the concentration is 1 wt %. The GH cell is operated in negative type display and has a thickness about 18 μm. The waveform of applied voltage is a sine wave at a frequency of 1 kHz.

The measurement of the conventional transmittance of the LC cell was made by the photomultiplier using W-I_2-lamp as the light source.

RESULT and DISCUSSION

Figures 1 and 2 illustrate the lightness L^* against applied voltage V(rms) and the transmittance T against voltage V(rms) characteristics of TN LC cell with the neutral gray and the bluish gray polarizers.

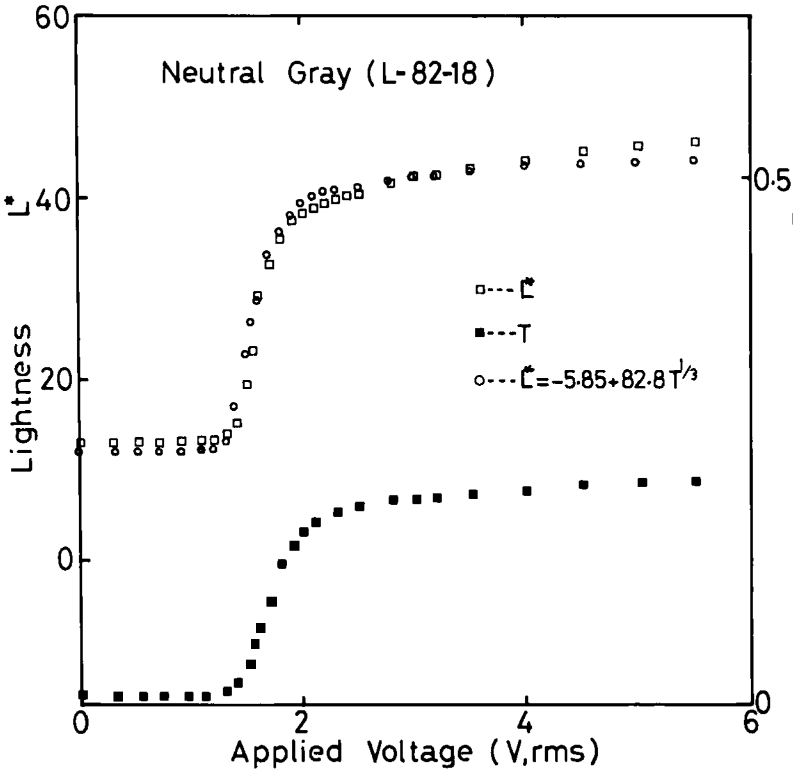

FIGURE 1 The lightness L^* against voltage V(rms) and the transmittance T against voltage V(rms) characteristics of TN LC cell with the neutral gray polarizers.

The closed square points are experimental values of the conventional T-V characteristics, and the open square points are the L^*-V characteristics. Each closed square points are translated to the open circle points at same voltage by the cube root functions: the function $L^* = -5.85 + 82.8T^{1/3}$ corresponds to the neutral gray, and $L^* = -24.8 + 133.7T^{1/3}$ to the bluish gray, respectively.

In order to determine these functions, we applied two kinds of functions fitting by the least squares method: the one is a cube root function; the other is a logarithmic function with respect to T. The translated points from T to L^* better agree with the experimental values of L^* by the cube root function other than logarithmic one. This means that the transmittance is cube root function with respect to the perception of the human eyes for both liquid crystal displays. Compared the threshold sharpness of the L^*-V and T-V characteristic curves, it is obvious that the sharpness of L^*-V curve is steeper than that of T-V curve for Figures 1 and 2.

Figure 3 shows the color difference ΔE against contrast ratio C characteristics of TN LCDs for both polarizers. The maximum values ΔE and C are

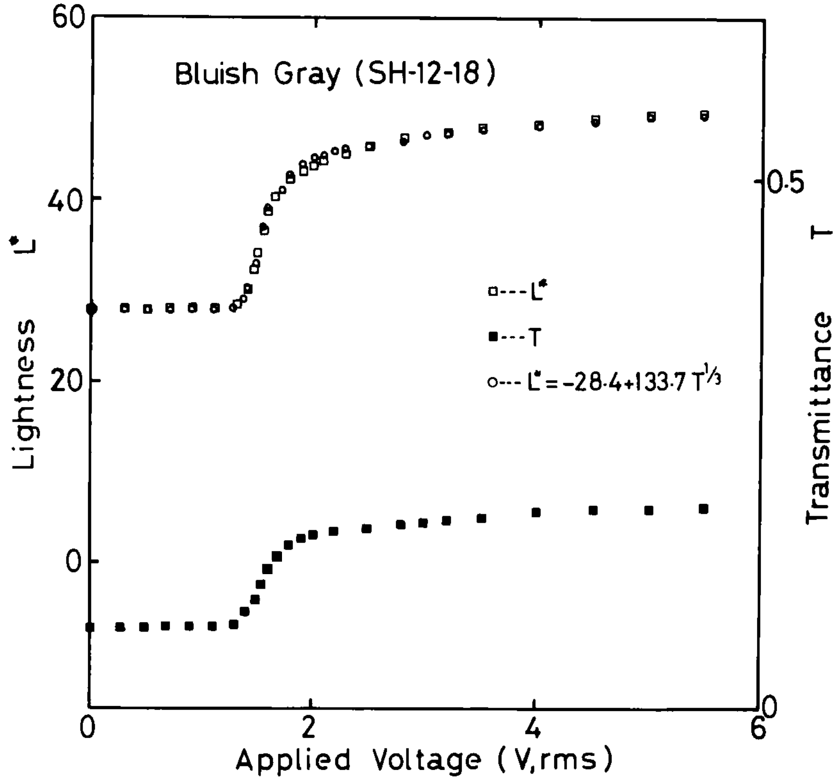

FIGURE 2 The lightness L^* against voltage V(rms) and the transmittance T against voltage V(rms) characteristics of TN LC cell with the bluish gray polarizers.

about 38 and 23 for the neutral gray, and 38 and 2.5 for the bluish gray, respectively. This fact means that the color differences both for neutral gray and bluish gray are almost the same. Where as the contrast ratio for the bluish gray polarizer is very small compared with the neutral gray polarizer. Actually, we cannot recognize such a large difference as indicated by the values of the contrast ratio. Thus the color difference is more useful for estimating the performance of the LC display operated in various modes.

We further compared the relation between the color difference and the applied voltage for TN and GH mode LCDs. Figure 4 shows the result. According to the Figure 4, the color formation occurs near 1.8V in the TN cells, but it does not occur in the GH cell. This color formation is caused by the influence of the birefringence of the TN cell. Comparing the maximum values of the color difference, we can find the significant color difference between TN and GH mode. Thus we can estimate the performances of TN and GH mode displays unifiedly by considering the colorimetric quantity ΔE.

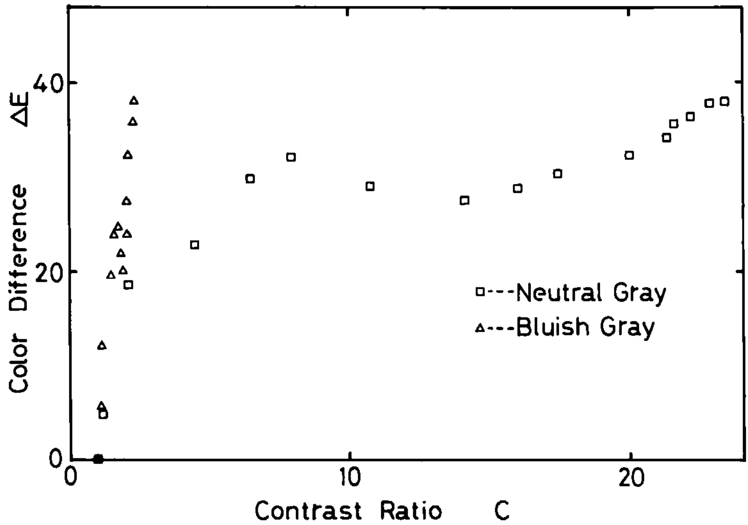

FIGURE 3 The color difference ΔE against contrast ratio C characteristics of TN LCDs with neutral gray and bluish gray polarizers.

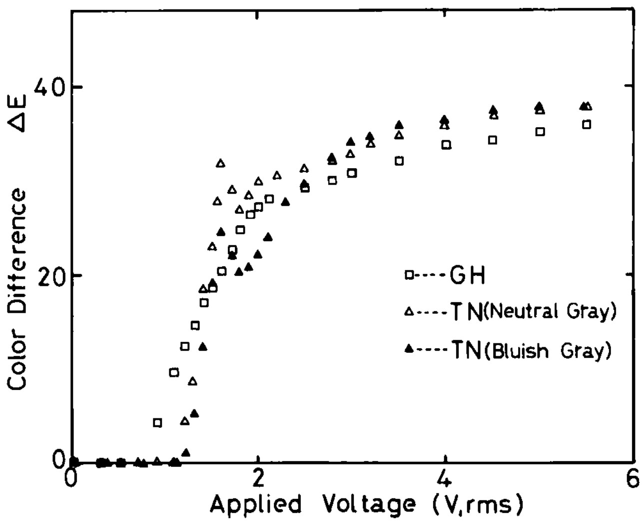

FIGURE 4 The color difference ΔE against voltage V(rms) characteristics of TN and GH cells.

CONCLUSION

We have demonstrated that the conventional estimation for achromatic display using the transmittance with the white light does not correspond to the perception of human eyes: the lightness L^* is cube root function with respect to the transmittance T. This means that the lightness L^* or the color difference ΔE are very useful for determining the performance of the liquid crystal display devices. The estimation for both the achromatic LCD and the color LCD can be uniformly done by considering the color difference.

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