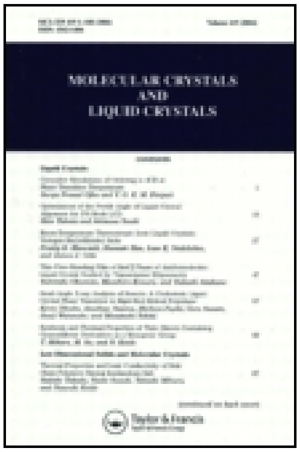

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Temporal Behavior of Liquid Crystal Molecules in Nematic Twisted Thin Film

Masafumi Yamashita [a]

[a] Department of Physics, Faculty of Science and Technology, Science University of Tokyo, Noda, Chiba, 278, Japan

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Temporal Behavior of Liquid Crystal Molecules in Nematic Twisted Thin Film

MASAFUMI YAMASHITA

Department of Physics, Faculty of Science and Technolgy, Science University of Tokyo, Noda, Chiba 278, Japan

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The temporal behavior of the liquid crystal molecules after only a small number of applied alternating pulses (1 pulse width = 1 ms) are turned on is studied in the nematic twisted thin film (d = 9 μm) by the observation of the temporal behaviors of the conoscopic figures. After the applied pulses (the numbers: $n = 3 \sim 16$, $V = 5 \sim 32$ volts) are turned off, the conoscopic figures continue forming gradually for a few milli-seconds. The time required to form the conoscopic figures after a small number of the pulses are turned off depends only on the applied voltage. These times agree approximately with the time required to form the conoscopic figures clearly after the applied electric field is continuously turned on.

Keywords: conoscopic figure, temporal behavior, twisted nematic, montage method, molecular alignment

I. INTRODUCTION

The temporal behaviors of the conoscopic figures in the nematic liquid crystals (LC) after the applied electric field was continuously turned on or off was studied. The main conclusions obtained were as follows:[1–5]

(1) The LC molecules in the center layer of the film would play an important role on the temporal behaviors of the alignments after the electric field was turned on or off regardless of the initial basic alignments (the twisted and homogeneous alignments), the initial basic tilt angle (usually called the pretilt angle) and the film thickness. From the interpretation of the results, a part of the general idea of

the temporal behavior of the LC molecular alignments reported theoretically by many workers[6-9] was modified and a simple model was developed.

(2) After the electric field was turned off, the reformation of the conoscopic figures was observed in the film whose thickness was above 9 μm, and moreover, the time required to vanish the conoscopic figures was above about 40 ms. It is considered that the local fluctuation of the LC molecular alignments takes place easily in thicker films because of the viscosity.

The purpose of the present study is to clarify the temporal behavior of the twisted nematic (TN) LC molecular alignments by observing the temporal behavior of the conoscopic figures in the TN film where a small number of the applied alternating pulses were turned on, by paying attention to the relaxation process of the alignments.

II. EXPERIMENTAL

The specimen used in the present study is the positive TN LC (ZLI-1447) film and whose physical constants are as follows:

n_O = 1.505: the refractive index of ordinary ray,
Δn = 0.165: the refraction index anisotropy,
η = 32 cps: the viscosity at the constant flow,
d = 9 μm: the film thickness,
α_0 = 3 deg: the pre-tilt angle.

The experimental setup is shown in Figure 1. A small mumber of the applied alternating pulses, these amplitudes and the synchronization to take in the conoscopic figures from the video camera were precisely controlled by the microcomputer (NEC: PC-8801 SR). The other apparatus used and the montage method to process the conoscopic figure by the microcomputer were the same as the author described previously.[1-5] The frequency of the alternating pulses generated in the form of an 8 bit BCD number by the microcomputer was 480 Hz and was converted to the electric voltage by means of a D/A converter and a digital wave synethesizer (D.W.S. shown in Figure 1). Then, the width of one pulse was

$$\Delta t = 1000/(2 \text{ X } 480) = 1.04 \text{ ms.}$$

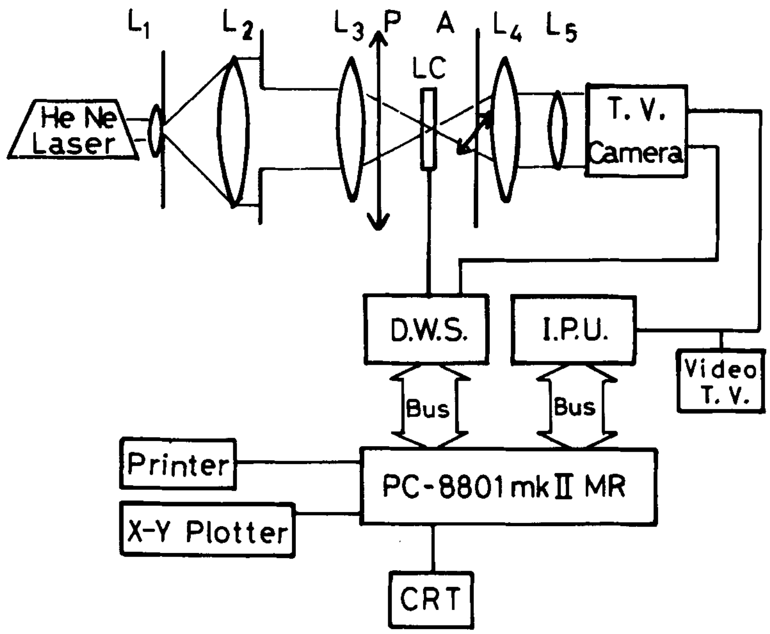


FIGURE 1 Schematic diagram of experimental setup. D.W.S.: digital wave synthesizer, I.P.U.: image processing unit.

This time agrees with the interval corresponding to the width of one frame picture divided into 16 horizontal bands, that is

$$(1000/60)/16 = 1.04 \text{ ms}.$$

Thus, the temporal resolving power of a montage method is 1.04 ms with accuracy.

The timing chart of the montage method after a small number of the applied alternating pulses were turned on is shown in Figure 2 on the case of 10 pulses.

III. RESULTS AND DISCUSSION

The finite number of the applied alternating pulses represents by n and the voltage of the pulse represents by V. Let us take as the time $t = 0$ the instant at which the field is turned on. The temporal behaviors of the conoscopic figures have been observed from $t = 0$ to about 150 ms by using a montage method.

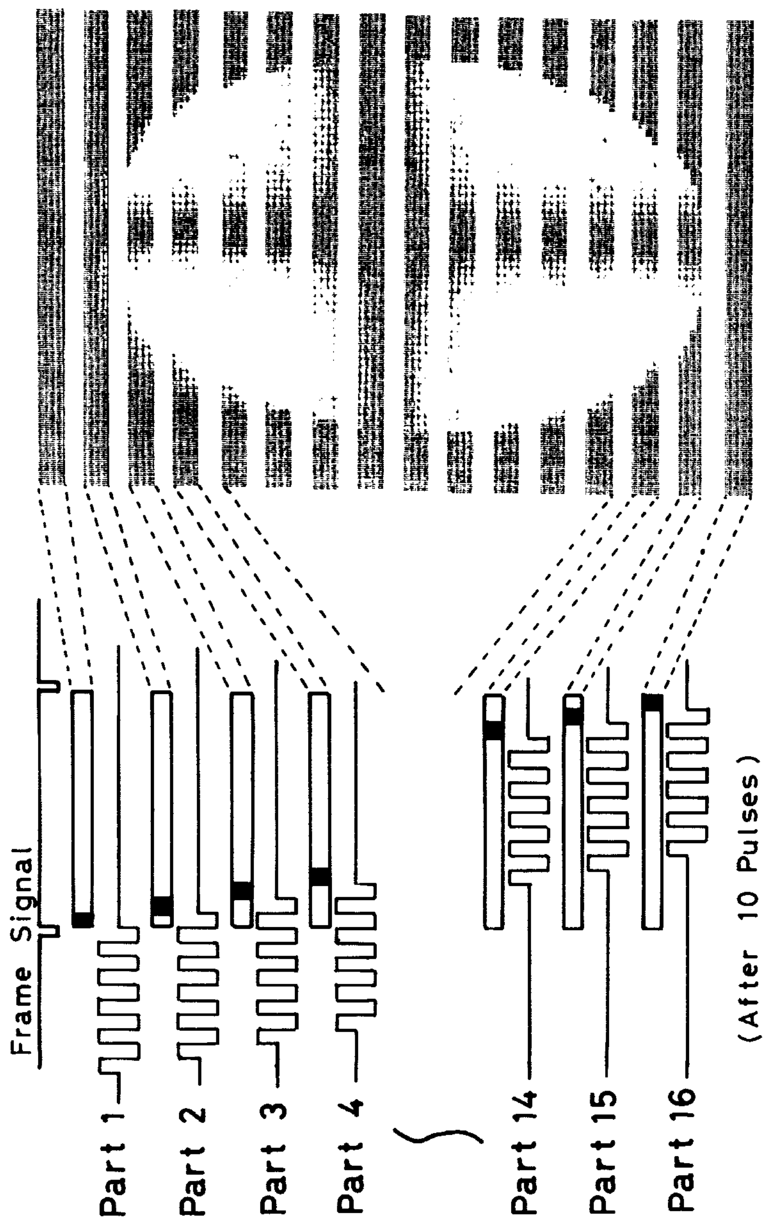


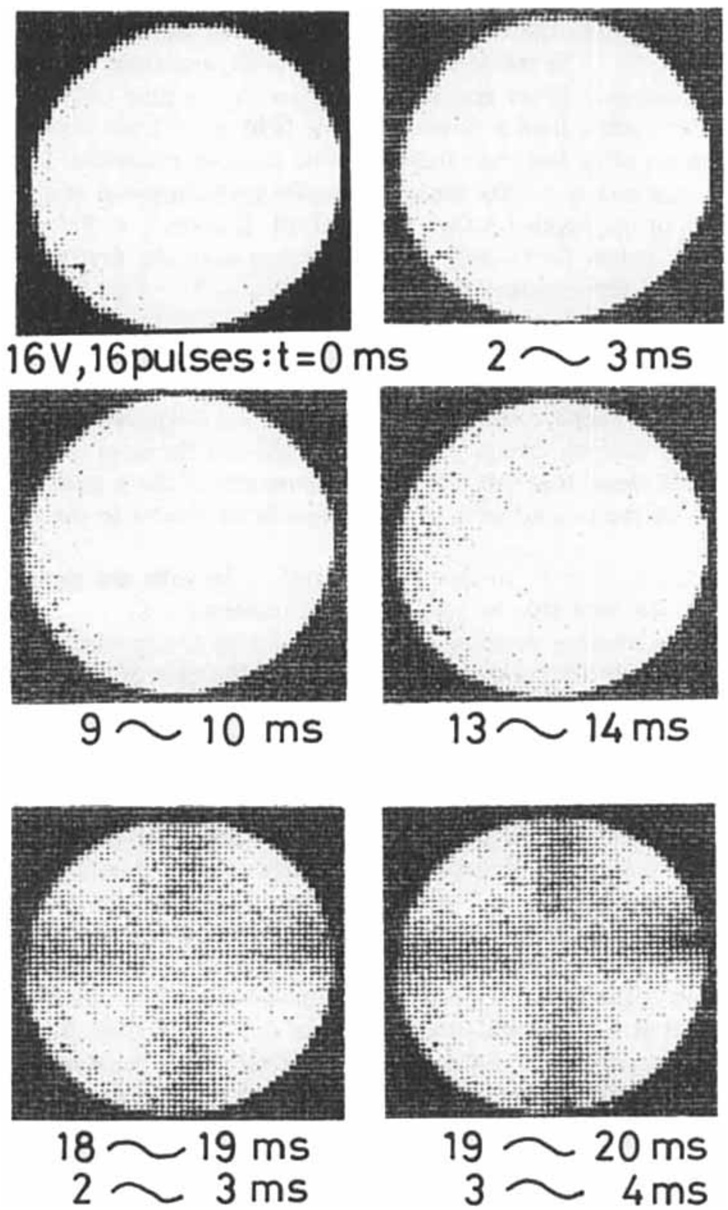
FIGURE 2 Timing chart of montage method on $n = 10$.

Figure 3 shows the temporal behaviors of the conoscopic figures observed at $n = 16$ and $V = 16$ volts. As is obvious from the figure, the conoscopic figures appear gradually with the time of duration after the electric field is turned on. The field is suddenly turned off $t = 16$ ms after that, but they continue forming gradually. Let us take as the time $t_f = 0$ the instant when the field composed of a small number of the applied pulses is turned off. It takes $t_f = 3 \sim 4$ ms, after the pulses are turned off, required to have the first peak of intensity of the conoscopic figures, so that $t_f = 3 \sim 4$ ms are equal to $t = 19 \sim 20$ ms, i.e. $t = 16 + t_f$, as shown in the figure. Afterwards, the figures disappear once at $t = 40 \sim 42$ ms, and it means that the LC molecules restore to an initial basic state. However, the conoscopic figures appear again and they have the second peak of intensity at $t = 63 \sim 65$ ms though the central position of the isogyre has not come out clear. It seems that the phenomenon of the temporal behaviors of the second peak of intensity will be similar to the effect of bounce.

The cases of $n = 10$ and $n = 7$ at $V = 16$ volts are shown in Figures 4(a) and (b), respectively. The conoscopic figures in both cases also continue forming for some time after the applied electric field is turned off. It takes $t_f = 8 \sim 9$ ms in the case of $n = 10$ and $t_f = 11 \sim 12$ ms in the case of $n = 7$ required to have the first peak of intensity. The behaviors of the conoscopic figures following at those times show the similar manner as $n = 16$ except of the time, i.e. they disappear once and afterward, they appear again as shown in Figure 4. Thus, the fewer the numbers n are, the longer the time t takes. But, the conoscopic figures observed after a small number of the applied pulses below 5 are turned on to the LC film are merely firmly or unclear so that it is difficult to decide the central position of the isogyre. They are not at all observed under the condition of $n = 2$.

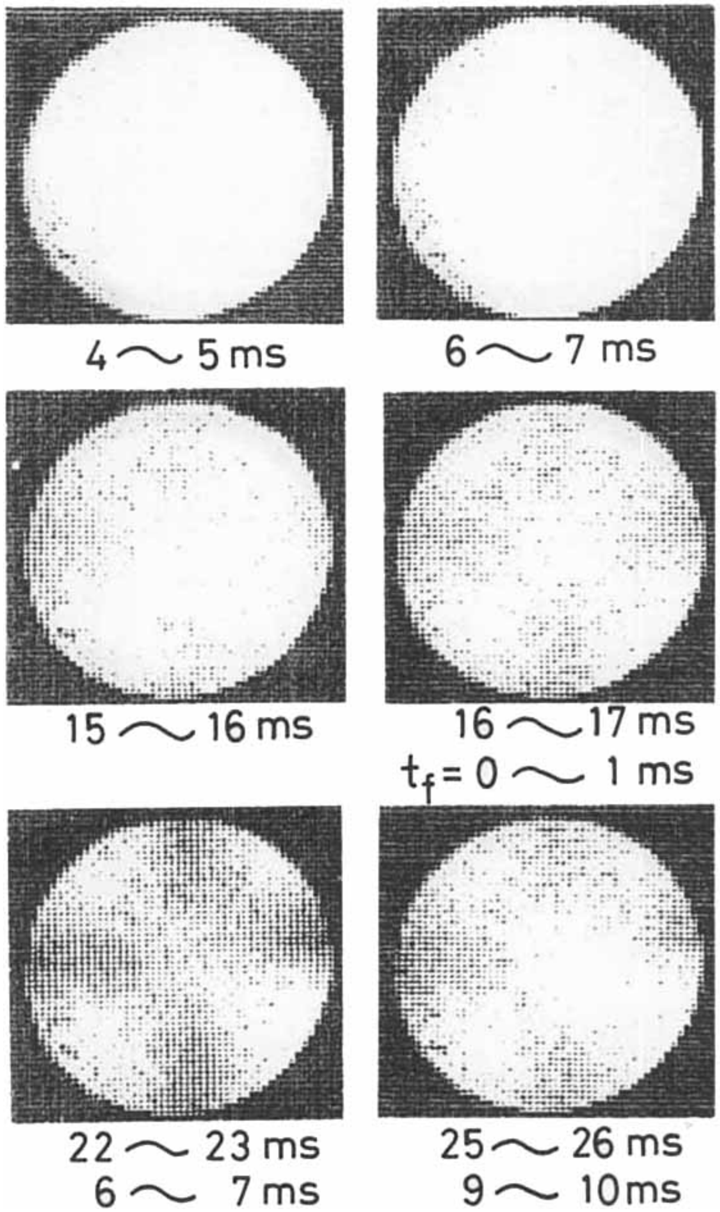
Figure 5 shows the temporal behaviors of the conoscopic figures observed at $V = 9$ volts as a function of n. As is obvious from the figure, the conoscopic figures appear gradually with the time t until the electric field is turned off and they continue forming with the time t_f for some time. It takes $t_f = 8 \sim 9$ ms in the case of $n = 16$ as shown in Figure 5(a) and $t_f = 16 \sim 17$ ms in the case of $n = 9$ in Figure 5(b) required to have the first peak of intensity of the conoscopic figures, so that designating t_f by t, the time t is from 24 ms to 26 ms regardless of n.

From Figures 3, 4 and 5, the relation between the time t_f or t required to form the conoscopic figures corresponding to the number of pulses, n, and n as a function of V is shown in Figure 6. As is



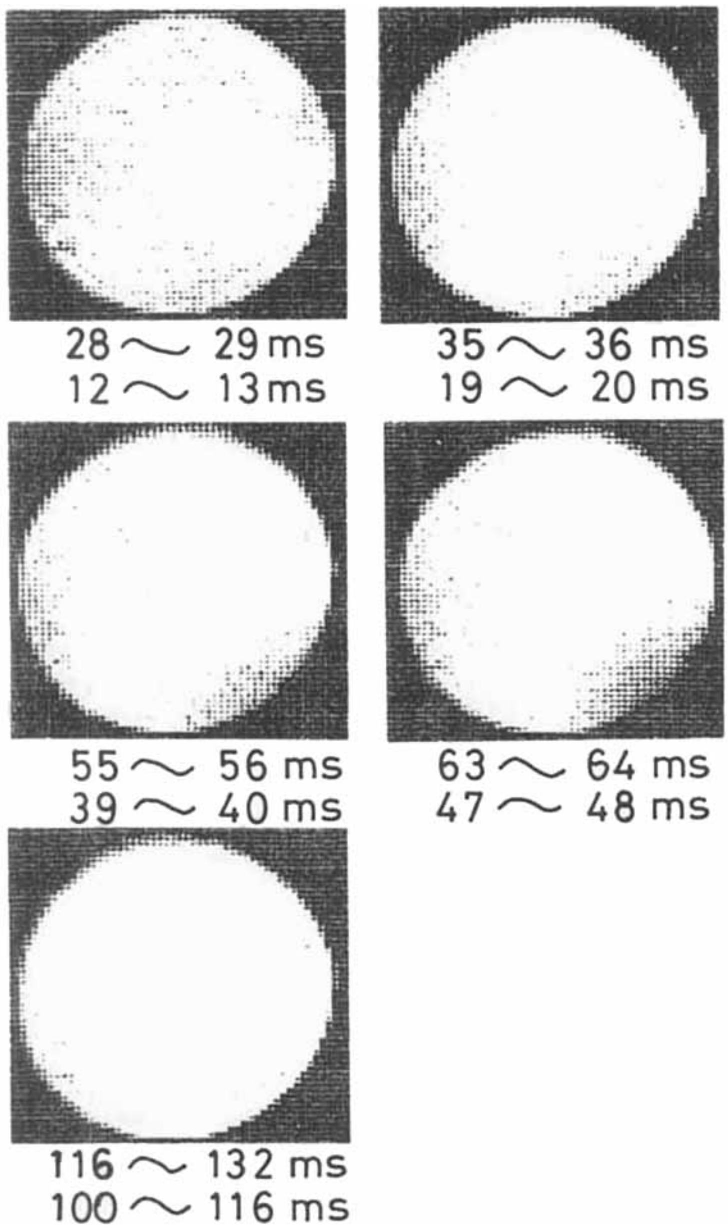
3A

FIGURE 3 Temporal behavior of conoscopic figures at $n = 16$ and $V = 16$ volts. The time $t = 0$ and $t_f = 0$ the instant when the electric field is turned on and off, respectively.



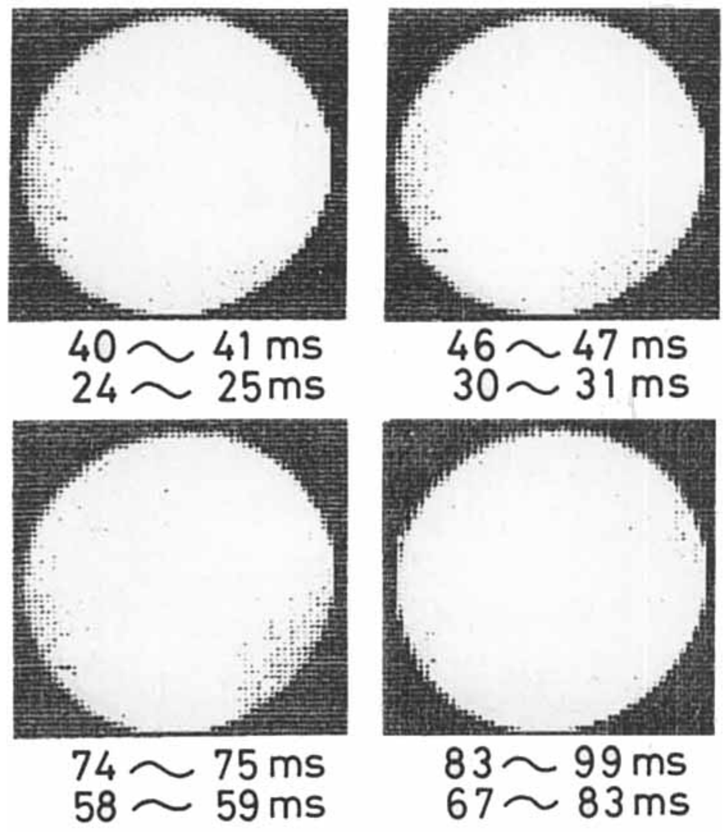
3A

FIGURE 3 (*continued*)



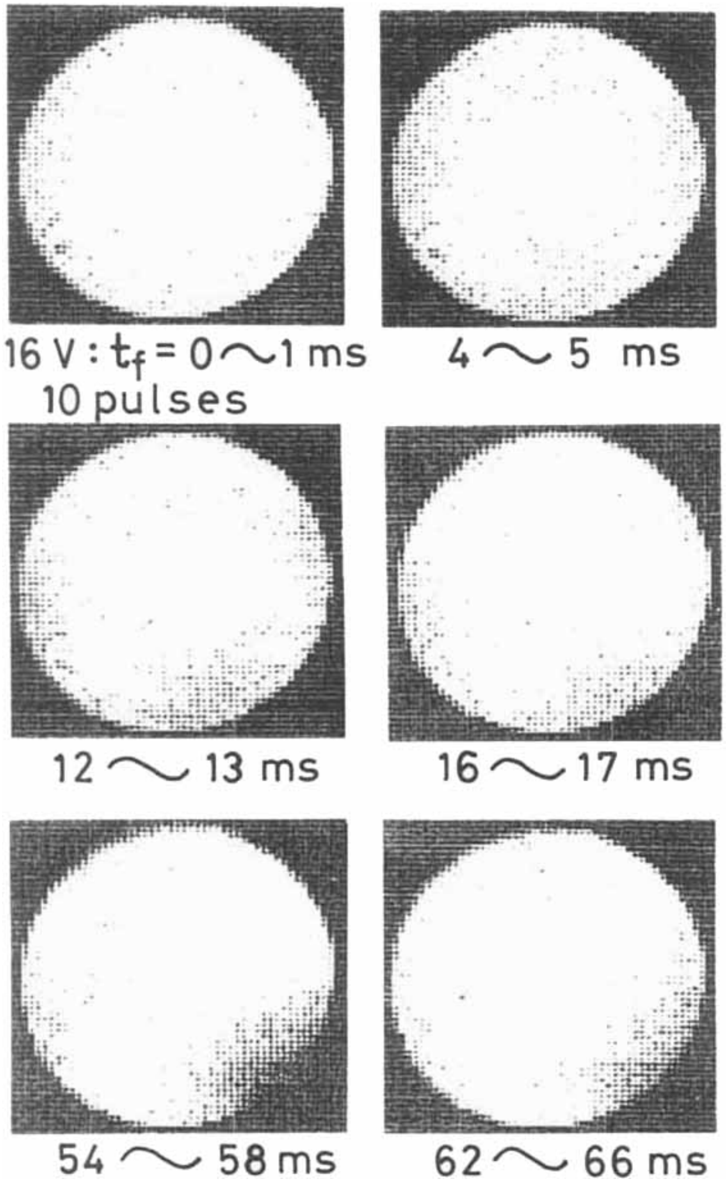
3B

FIGURE 3 (*continued*)



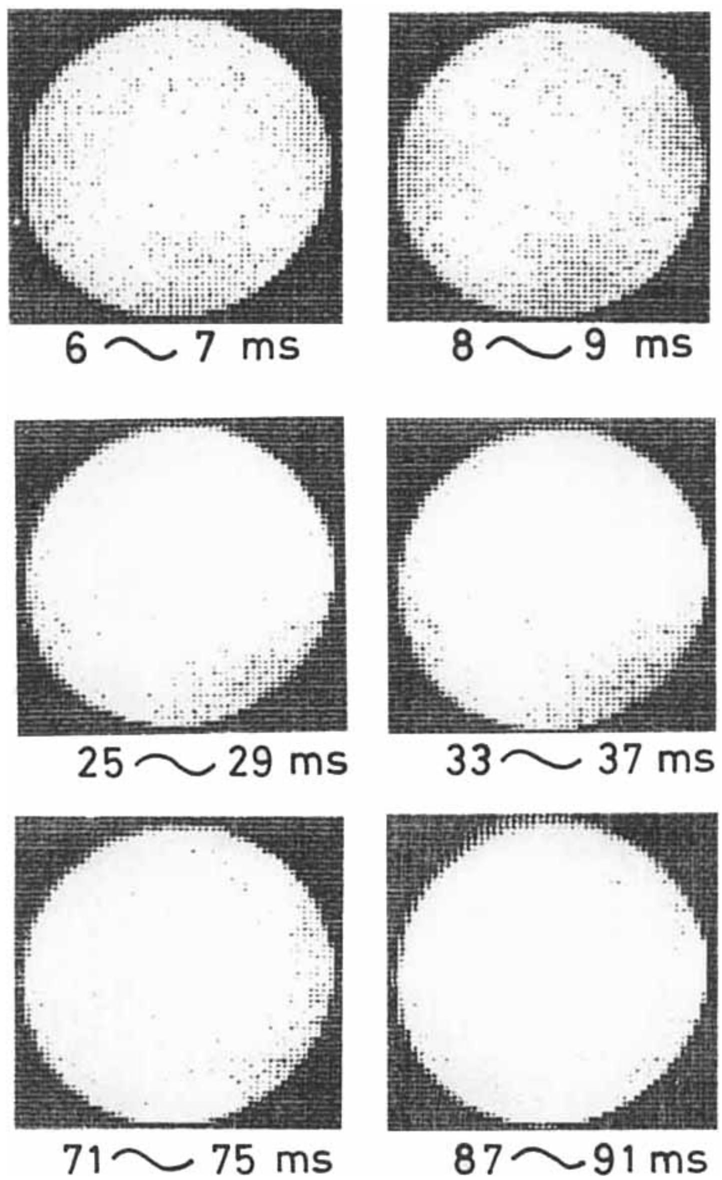
3B

FIGURE 3 (*continued*)



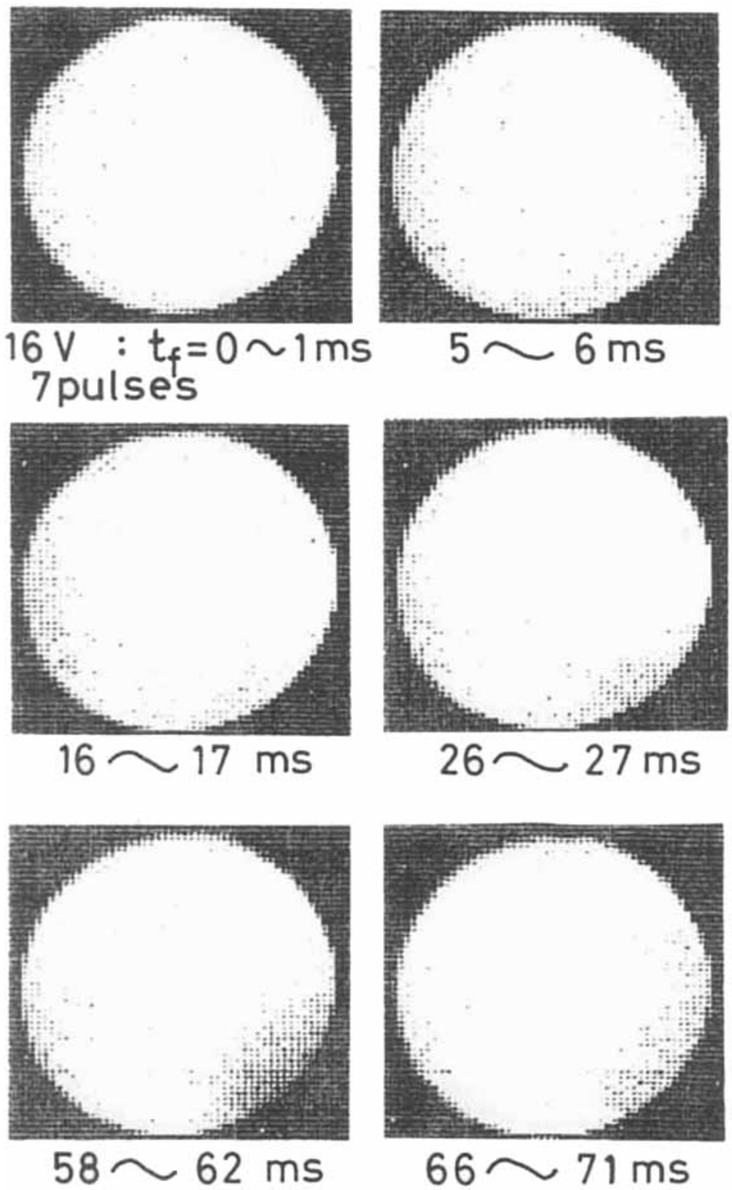
4A

FIGURE 4 Temporal behavior of conoscopic figures at $V = 16$ volts (a) the case of $n = 10$, (b) the case of $n = 7$.



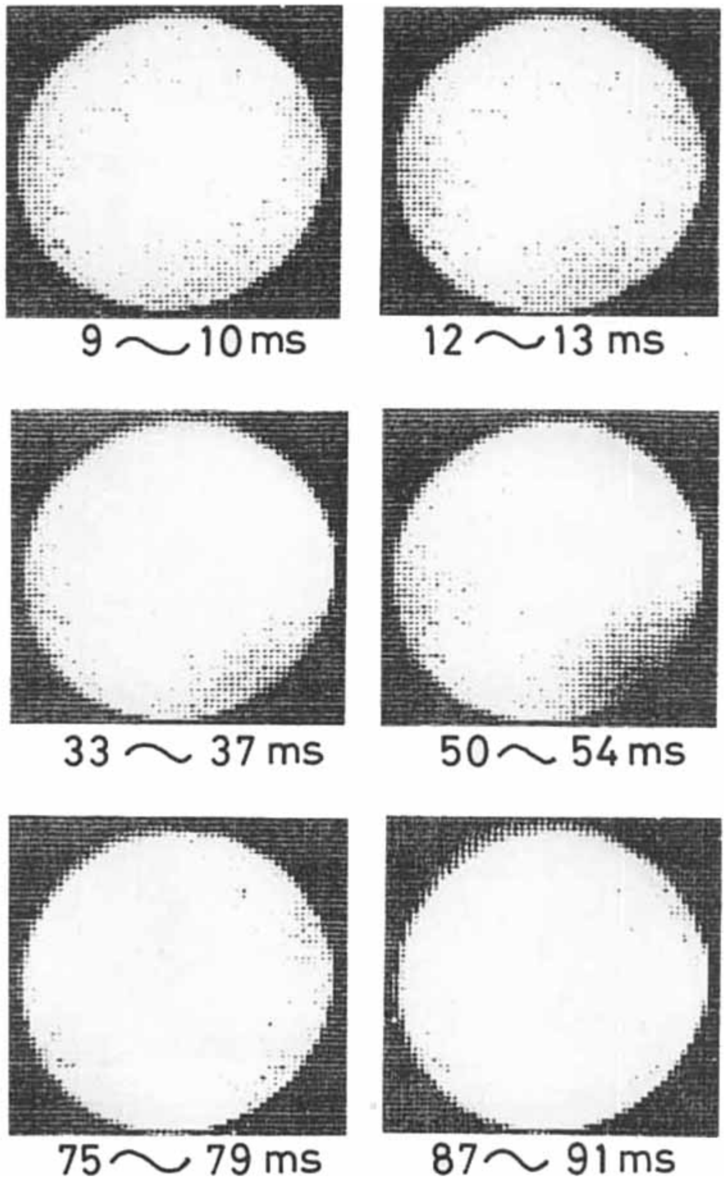
4A

FIGURE 4 (*continued*)



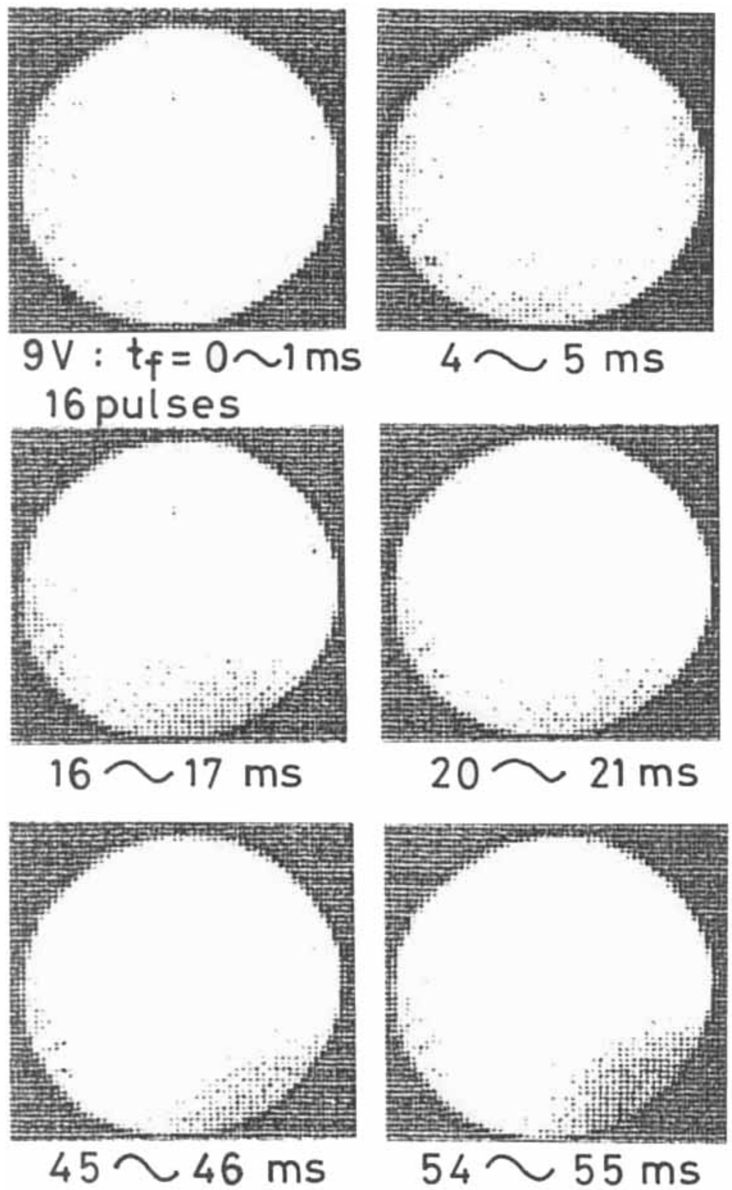
4B

FIGURE 4 *(continued)*



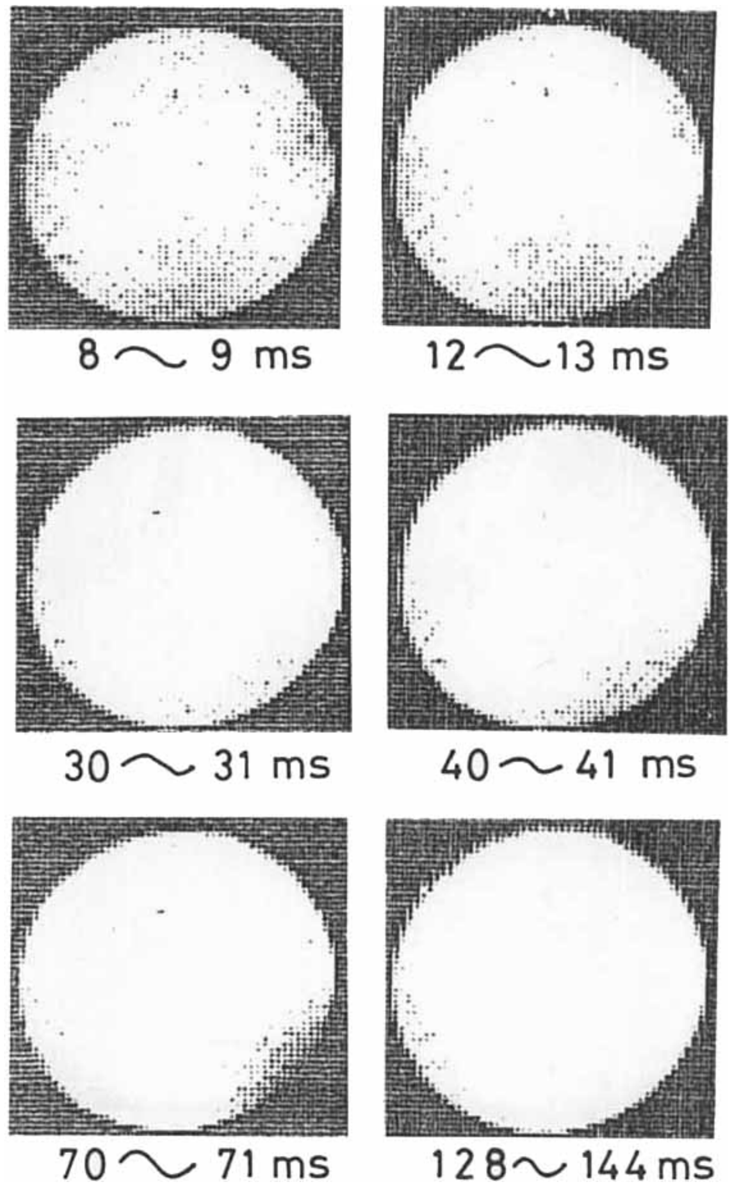
4B

FIGURE 4 (*continued*)



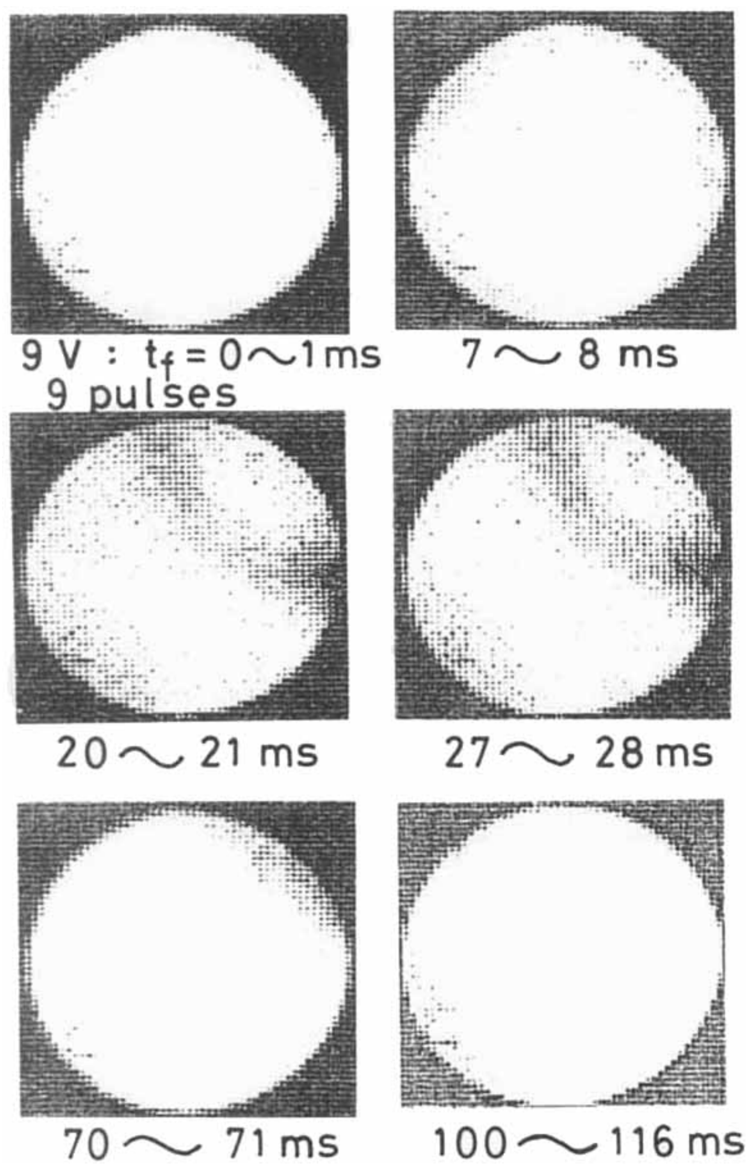
5A

FIGURE 5 Temporal behavior of conoscopic figures at $V = 9$ volts. (a) the case of $n = 16$, (b) the case of $n = 9$.



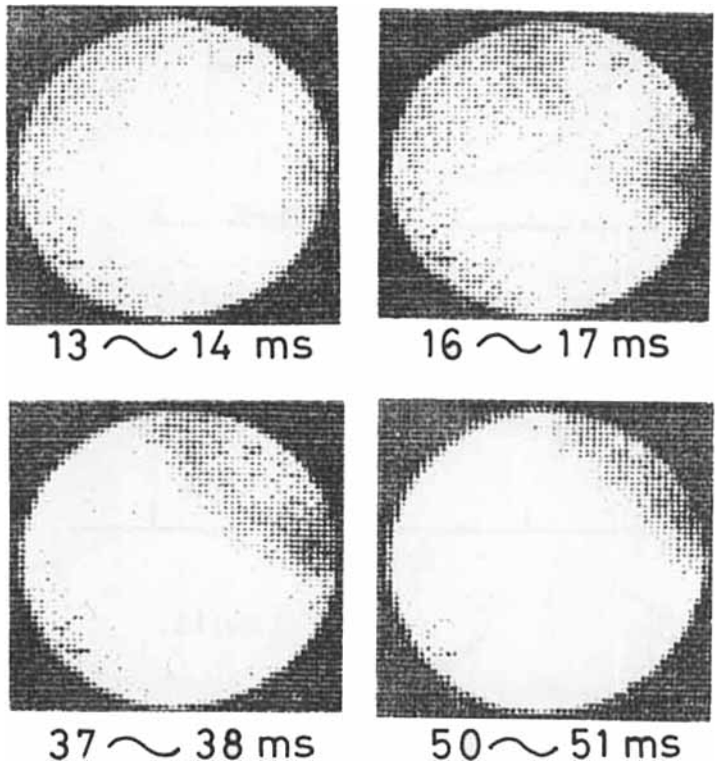
5A

FIGURE 5 (*continued*)



5B

FIGURE 5 (*continued*)



5B

FIGURE 5 (*continued*)

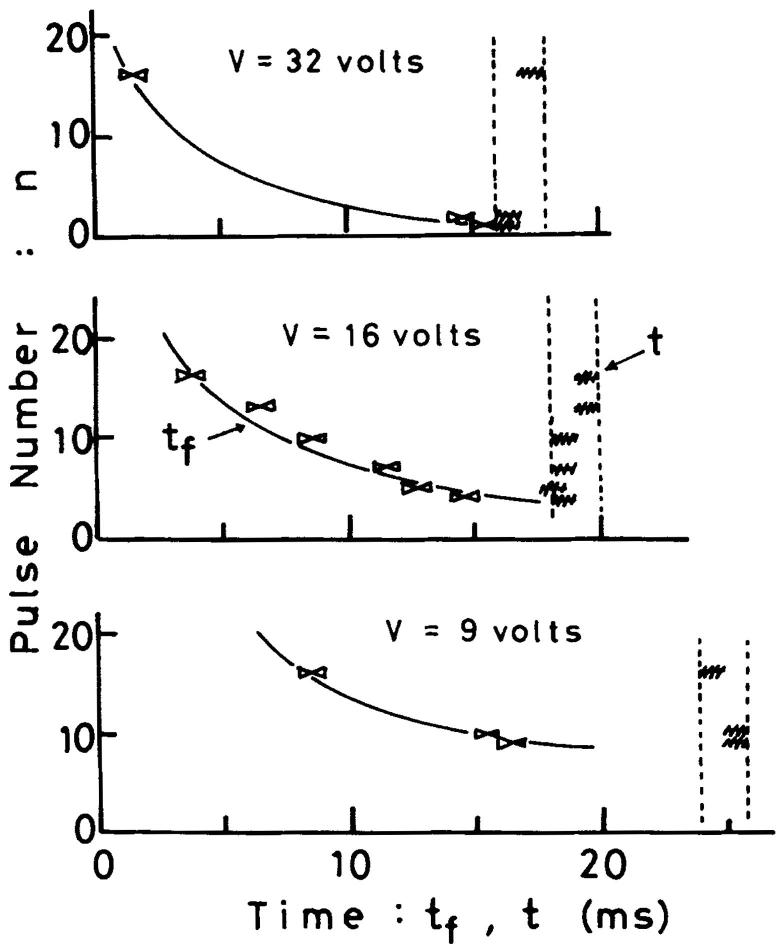


FIGURE 6 Relation between the times t and t_f and n as a function of V.

obvious from the figure, there is an interesting tendency: the time t depends strongly on V but it does not depend on n. It takes 16 ~ 18 ms at 32 volts, 18 ~ 20 ms at 16 volts and 24 ~ 26 ms at 9 volts required to have the first peak of intensity of the conoscopic figures represented by t, so that the central position of the isogyre depends on n.

To understand these phenomena, the temporal behaviors of the conoscopic figures observed after the applied voltage of 16 volts is continuously turned on are measured as shown in Figure 7. It is obvious at a glance from the figure that the conoscopic figures at about 18 ~ 20 ms show distinctly where the central position of the isogyre is located in the image field.

On the other hand, the temporal behavior of the LC molecular alignments has been studied theoretically on the basis of the continuum theory, in which the basic idea is the torque balancing between the dielectric torque caused by the dielectric polarization and the elastic torque produced by the LC molecular alignments. However, the experimental analysis of the temporal behavior of the LC molecular alignments has not been sufficient yet.[6–12] It will be an important subject how the LC molecules align temporally.

It is reasonable to consider from Figure 6 that the rate of reaction of the LC molecular alignments depends only on the applied voltage and has a nonlinear effect of the voltage. Moreover, it seems that a fairly large number of the aligned LC molecular layer will rapidly have the tilt angles corresponding to the values of V in only short time after the electric field is turned on, because the central position of the isogyre is only dependent on V but is independent on n. But, the distinct image depends on n. It will be considered that the number of the LC molecular layers realigned by the applied electric field increases with n, i.e. the quantity of the injected energy and that the LC molecules near the substrates will start realigning gradually with the time of duration after turning on the electric field overcoming the influence of strong anchoring.[13] Thus, it will really take a few tens milli-seconds to form the conoscopic figures completely.

Now, there will be some problems, which have to be analyzed, why the responce to the on/off switching of the electric field is slow or why the time t required to have the first peak of intensity is the same if the applied voltage of pulses does not change. It seems that there are three keys to solve the problems. One will be the viscosity resistance of LC. Other will be the floating capacity composed of the LC film and the external electric circuit which drives the LC film. The other will be the disorder of the LC molecular alignment caused by the ununiform residual polarization. But, these are unclear physically. We should therefore consider in detail the meaning of the difference in the values of the applied voltage and in the number of the applied pulses.

IV. CONCLUSIONS

The temporal behaviors of the LC molecular alignments in the twisted nematic LC at an unstable stage are studied with the use of the

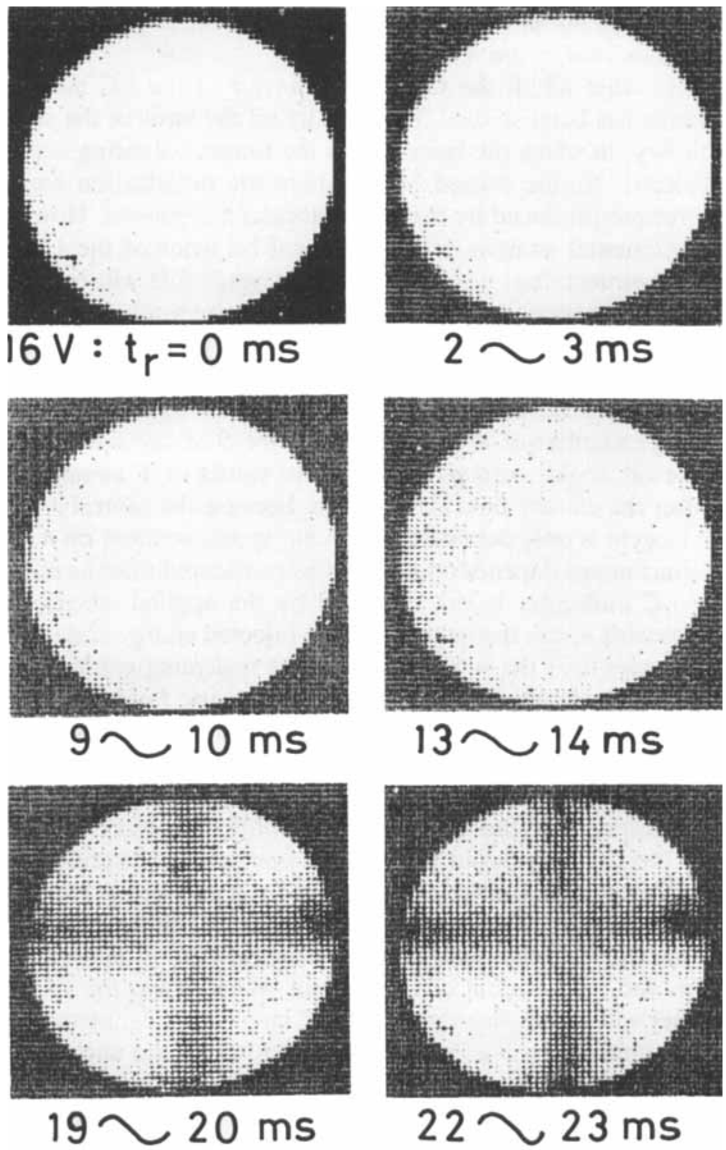


FIGURE 7 Temporal behavior of conoscopic figures as a function of time after applied voltage is continuously turned on at $V = 16$ volts.

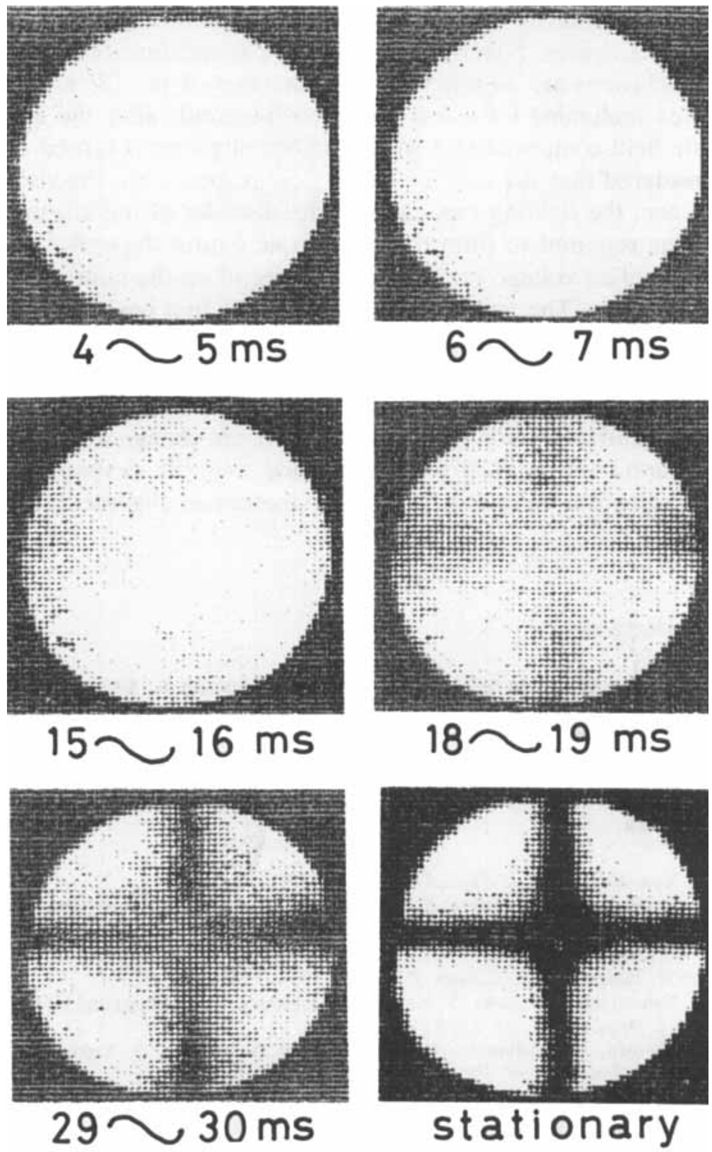


FIGURE 7 (*continued*)

montage method by observation of the temporal behaviors of the conoscopic figures. Some interesting new phenomena are found and the conclusions are as follows: The behaviors of the LC molecules continue realigning for a few or ten milli-seconds after the applied electric field composed of a small number of pulses is turned off. It is considered that the reasons of the slow response are the viscosity resistance, the floating capacity and the disorder of the alignments. The time required to form the conoscopic figures depends strongly on the applied voltage but it does not depend on the number of the applied pulses. The time required to have the first peak of intensity of the conoscopic figures after a small number of pulses are turned off is equal to the time required to be able to confirm the central position of the isogyre after the electric field is continuously turned on. The central position of the isogyre does not change with the time of duration after the electric field is turned on or off. A simple model of the temporal behaviors of the LC molecular alignments is presented.

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