The Dynamics of Transient Structures in the Fredericksz Transition

B.L. Winkler, A. Buka*, L. Kramer,
I. Rehberg, and M. de la Torre Juarez

Universität Bayreuth;
8580 Bayreuth; Postfach 101251, West Germany

*Permanent Address:
Central Research Inst. for Physics
H-1525 Budapest 114 P.O.B.49. Hungary

A new pattern occuring during the Fredericksz transition has been described recently (Buka et al, 1989). We report on detailed experimental observations, clarifying the relation between the dynamics of the pattern and the dynamics of the director reorientation.

EXPERIMENTAL SETUP

A nematic liquid crystal is homogeneously aligned between two parallel transparent electrodes as seen in figure 1. The distance d between these electrodes is 100μm and the sample is 2cm by 1cm wide. It is mounted on a polarizing microscope equipped with a hot stage for temperature control with a accuracy of $\pm$0.05K by means of a water circuit. The sample is illuminated from below with a light beam polarized parallel to the director, which represents the average orientation of the liquid crystal molecules and the optical axis of the system. Thus spatial modulations in the director angle become visible due to birefringence. In this experiment the liquid crystal 5CB (Merck K15, 4-pentyl-4'cyanobiphenyl) is used.

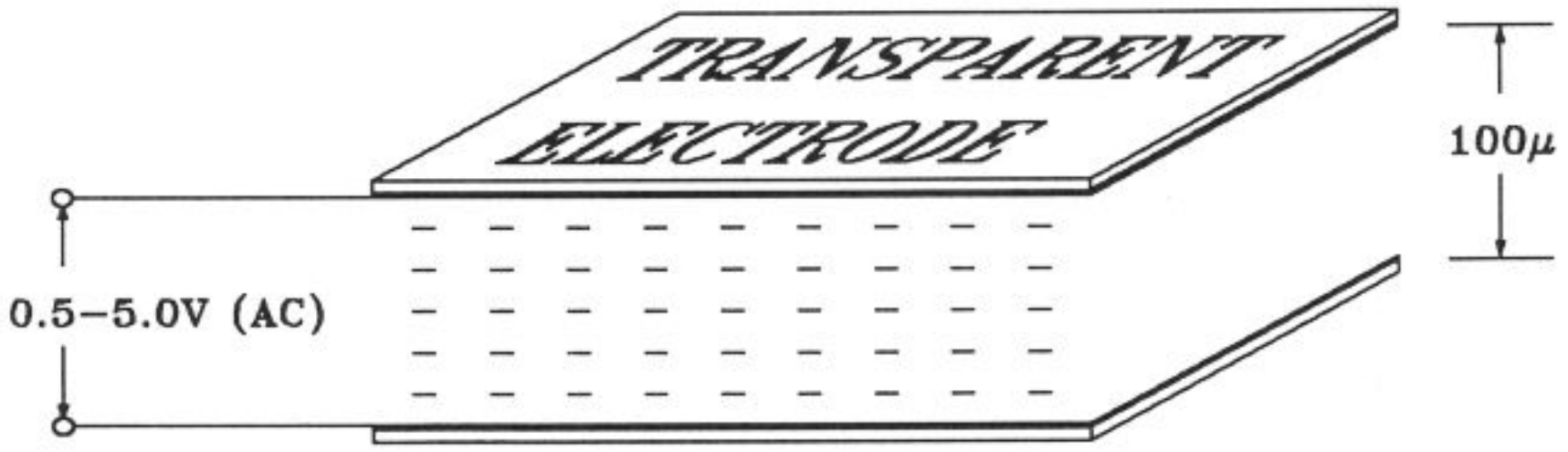

Fig. 1. A nematic liquid crystal aligned between two electrodes.

Nonlinear Evolution of Spatio-Temporal Structures in Dissipative Continuous Systems
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Plenum Press, New York, 1990

STATIC MEASUREMENTS

Under the influence of an electric or magnetic field applied across the layer the liquid crystal undergoes a Fredericksz Transition to an elastically deformed state.This Fredericksz transition (P.G.de Gennes, 1975; L.M.Blinov, 1983) has a mechanical analog in the Euler buckling problem and occurs in a similar fashion in the anisotropic A phase of superfluid ^{3}He. In the presence of an electric or magnetic field there is a competition between two torques:

1) Due to the elastic interactions between the molecules the director prefers to be parallel to the glass plates.
2) Due to the positive anisotropy of the dielectric tensor of the substance ($\varepsilon_{\parallel}$=18, $\varepsilon_{\perp}$=6.25 at 20°C) the director tends to be parallel to the electric field.

Both torgues increase with the deviation angle θ from the initial alignment. If the voltage applied across the layer exceeds a threshold value the electrical torgue increases faster than the restoring elastic torgue and therefore θ grows until, there is a satisfaction due to nonlinear effects.For known boundary condition this deviation $\theta(z)$ may be calculated as a function of the vertical position z in the cell.

The two electrodes of our sample may be considered as a capacitor. The capacity is sensitive to changes in the dielectric permittivity ε of the medium between the electrodes. As the dielectric permittivity is anisotropic for liquid crystals, it depends on the orientation of the director: $\varepsilon_{zz}(\theta) = \varepsilon_{\perp}\cdot\cos^2\theta+\varepsilon_{\parallel}\cdot\sin^2\theta$. For small θ the sample's capacity is: $C(\theta) = C_0 \cdot \left(1 + \frac{\varepsilon_a}{\varepsilon_{\perp}} \cdot \theta^2(0) \right)$ where $\varepsilon_a = \varepsilon_{\parallel} - \varepsilon_{\perp}$.

In figure 2 the imaginary part of the conductivity of the sample, which is directly proportional to the cell's capacity, is plotted versus the voltage applied across the cell. The measurement was carried out at 30°C. The voltage was varied step by step and after every change the director configuration in the liquid crystal was allowed to reach the equilibrium by waiting 625 seconds. The points marked by the open symbols were obtained while increasing the voltage, the closed symbols while decreasing the voltage. Only every 6th measured point has been marked by a symbol. In our case the threshold voltage was 0.65V.

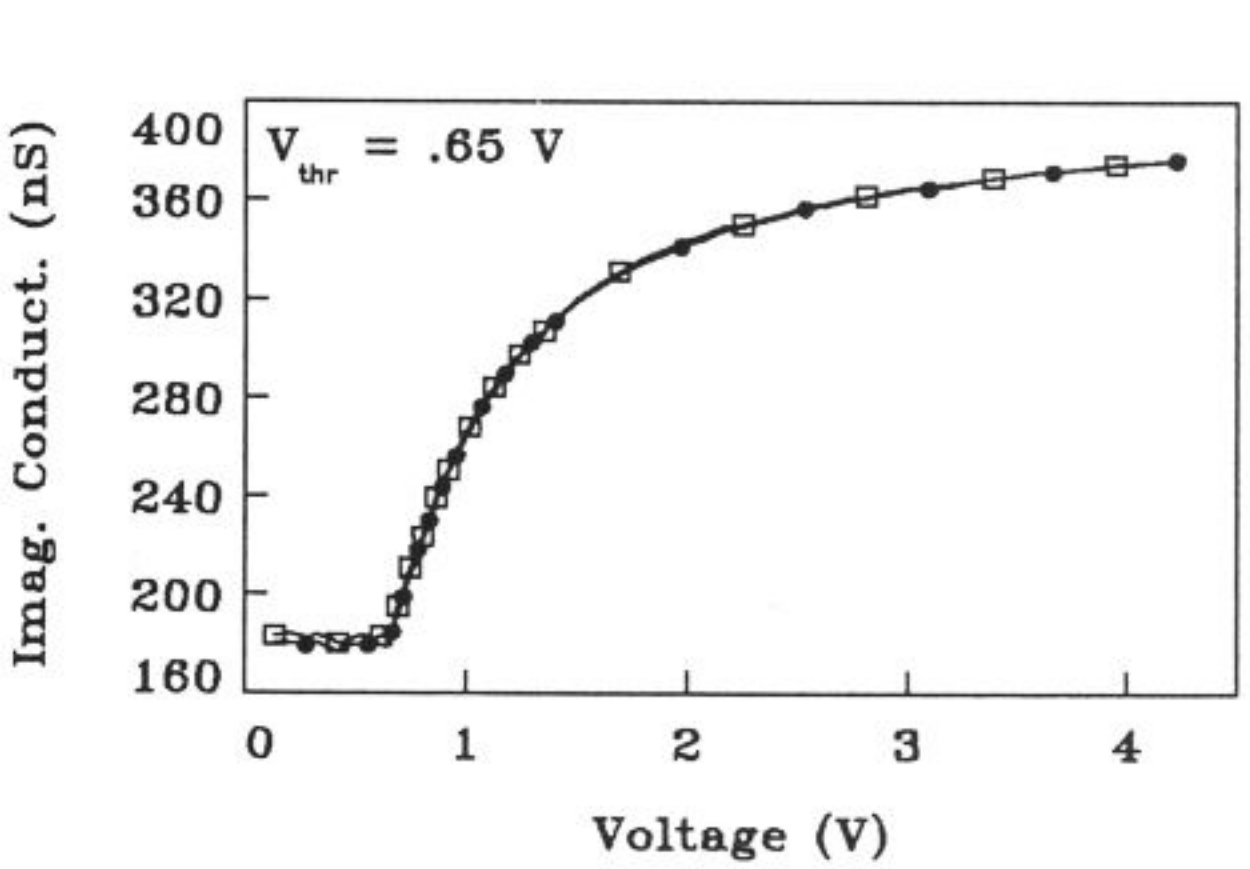

Fig. 2.The imaginary part of the conductivity as a function of the applied voltage.

DYNAMIC MEASUREMENTS

We now let the voltage jump from OV to a supercritical value (above Fredericksz threshold) and measure the time dependent conductivity as well as the light intensity transmitted through the sample. Figure 3 shows a photo of the transient pattern we observe after jumping to the supercritical voltage.(Buka et al, 1989) The lines have a preferred orientation parallel to the director alignment. This pattern has nothing in common with the well known domain walls. Domain walls appear when in one region of the sample the director turns clockwise and in the neighbouring region the director turns counterclockwise. This domain wall between two symmetric solutions can not simply fade away. The only possible way to disappear is that a closed curve of lines which surrounds no other lines shrinks to a point. This is a slow process. We see these domain walls in our samples, too. They appear about every 5 - 10mm and seem to have no preferred orientation.

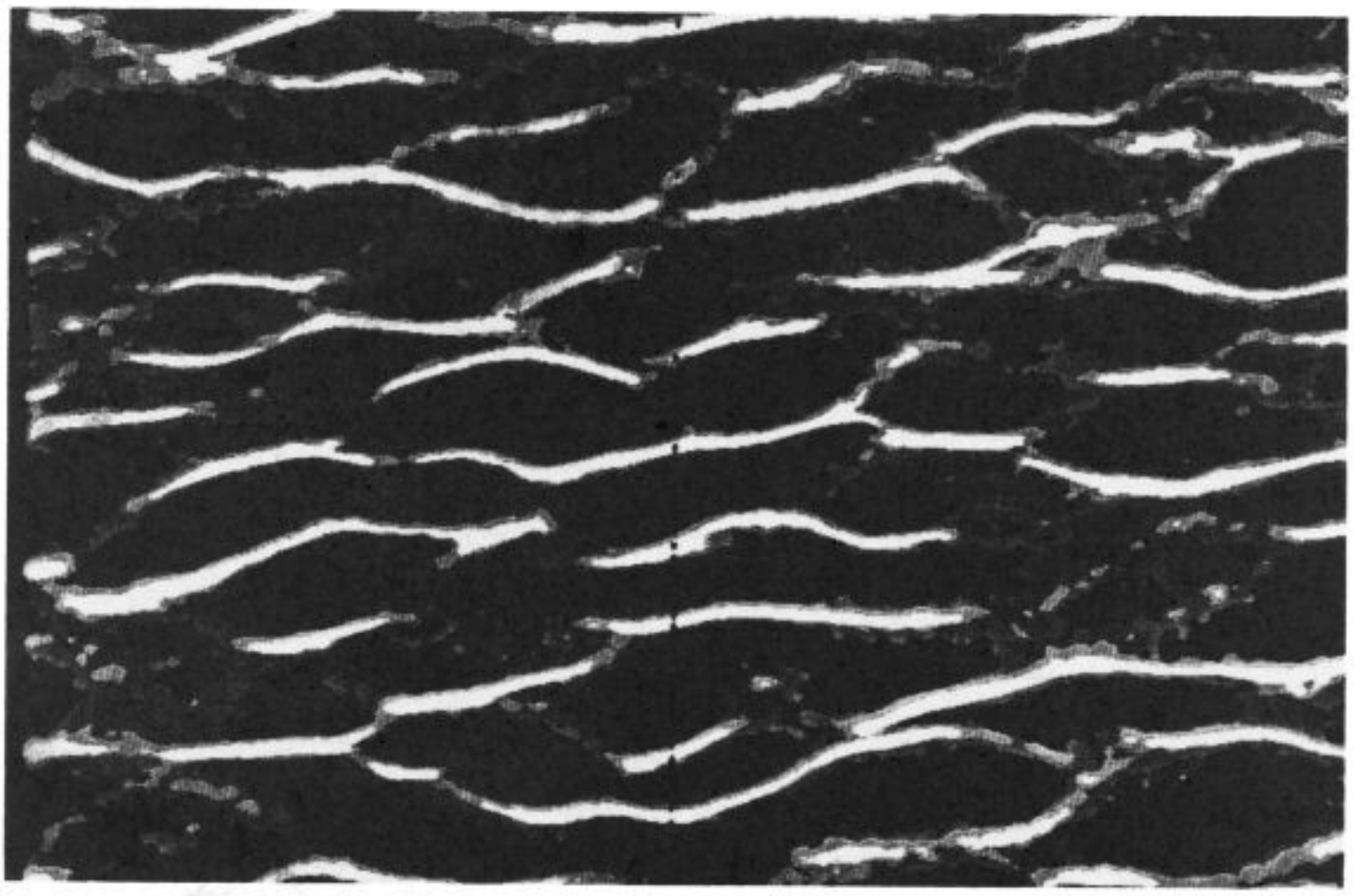

Fig. 3. Photograph of the observed pattern. The lines are parallel to the initial director orientation.

The patterns we observe appear after turning on the field and then simply fade away approximately as fast as they come up. They are seen within regions where the director turns in one direction. The structure has a wavelength of the order of the thickness of the sample. Thus there is sufficient space to observe our pattern between the domain walls.A speculation about the nature of this line pattern has been presented elsewhere (Buka et al, 1989)

At the position marked by the dashed line we record the light intensity by means of a line camera mounted on the microscope as a function of time after switching on the field. The camera has a digitizer with 6 bit intensity resolution (64 grey levels) and a spatial resolution of 1728 pixels and is connected to a microcomputer. In figure 4 intensity profiles are shown for three different values of $\varepsilon = (V^2 - V_{thr}^2)/V_{thr}^2$ where V_{thr} is the threshold voltage of the Fredericksz transition. Consecutive intensity profiles are plotted on top of each other. For small ε one observes only fluctuations of the director. For high ε a clear pattern forms and then vanishes again.

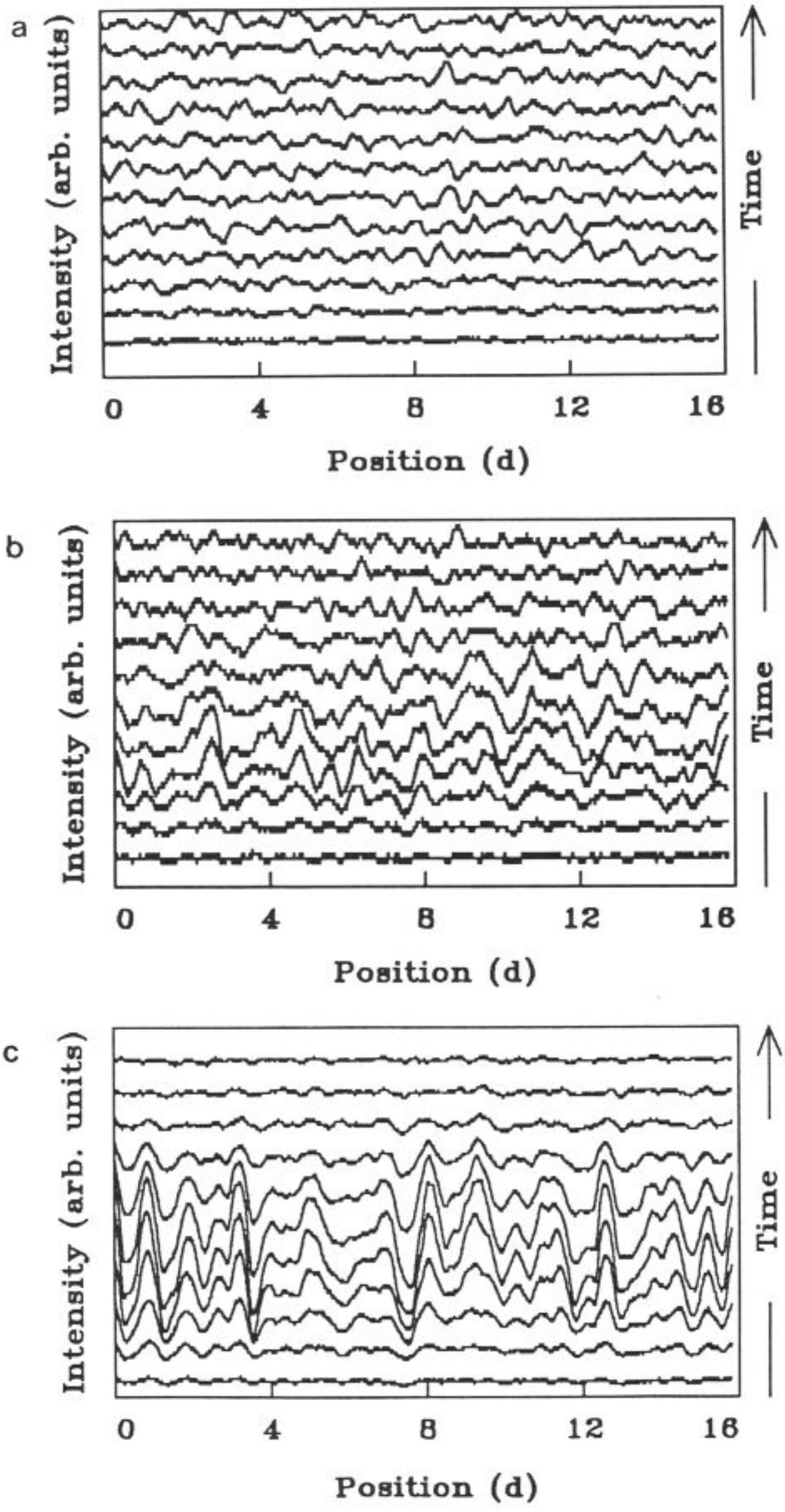

Fig. 4. Light intensity profiles as a function of time after turning on the field.
a) ε=0.66, 14.3 sec between two consecutive profiles, first profile 9.3 sec after turning on the field.
b) ε=4.25, 1.8 sec between two consecutive profiles, first profile 2.2 sec after turning on the field.
c) ε=17.43, 0.4 sec between two consecutive profiles, first profile 0.7 sec after turning on the field

Simultaneously with the light intensity profiles we measure the conductivity of the sample. In figure 5 the time dependence of the conductivity is plotted in the lower frames. To obtain some information of the strength of the modulation of the director angle we calculate the contrast from the intensity lines by taking the root mean square deviation of the intensity profiles. The upper frames in figure 5 show how the contrast changes with time.

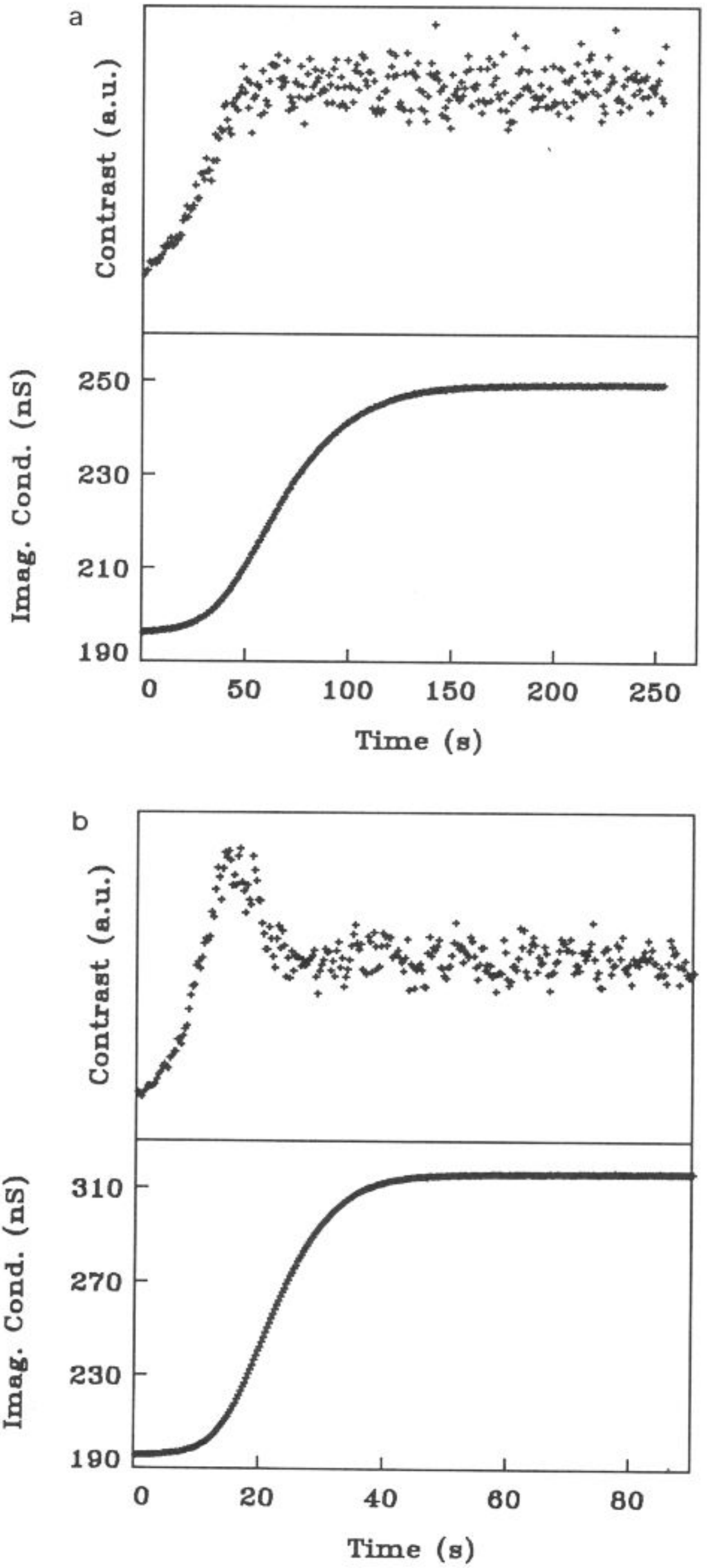

Fig. 5. Dependence of the contrast (upper frames) and of the conductivity (lower frames) on the time after switching on the field.
a) $\varepsilon = 0.66$
b) $\varepsilon = 4.25$

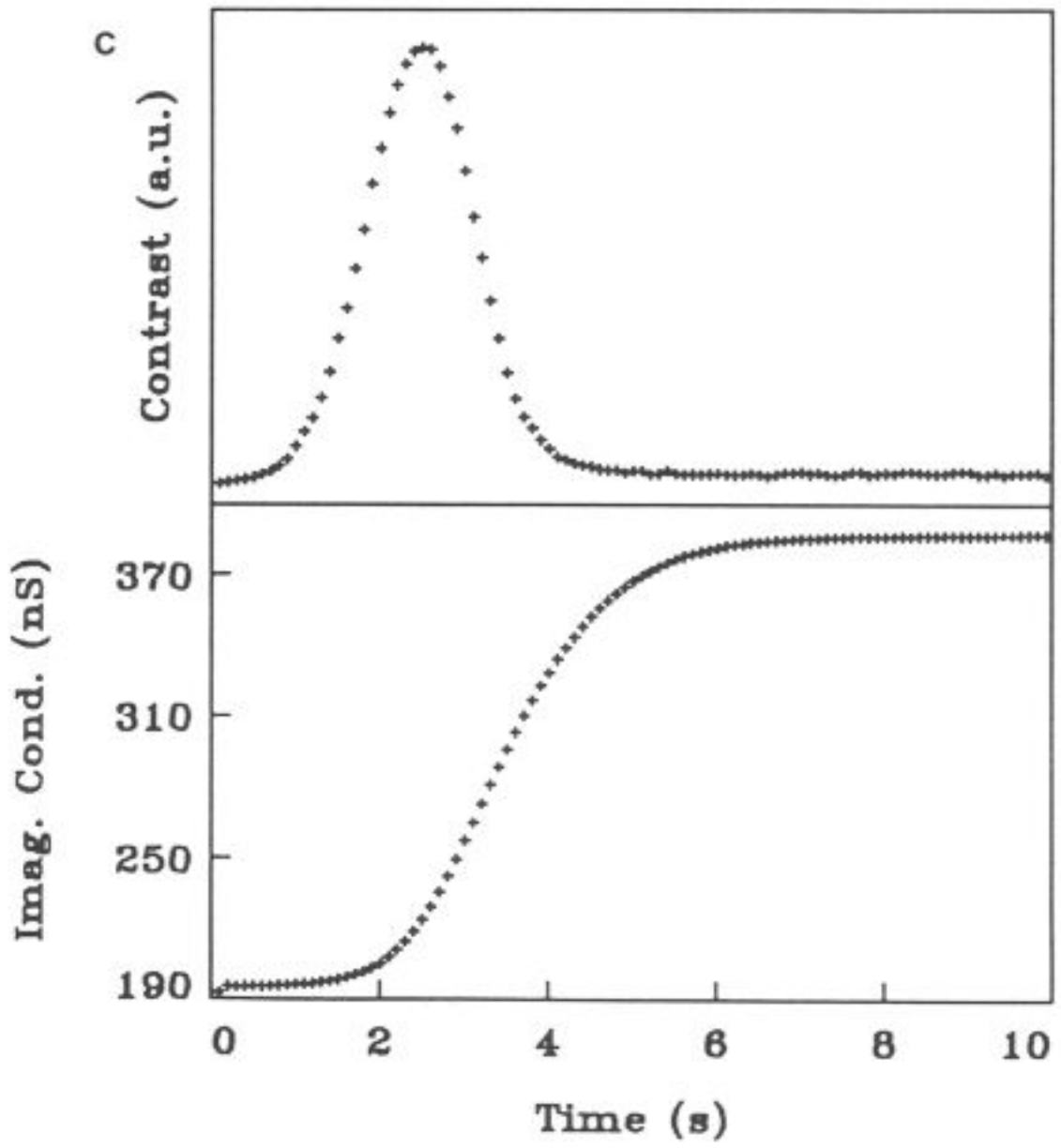

Fig. 5 (continued)
c) ε = 17.43

Immediately after turning on the field the director angle θ grows exponentially. Thus it is possible to determine a characteristic time τ or a growth rate $\frac{1}{\tau}$. This may be done by fitting a straight line to the logarithm of the conductivity and the contrast as a function of time, which is shown in figure 6.

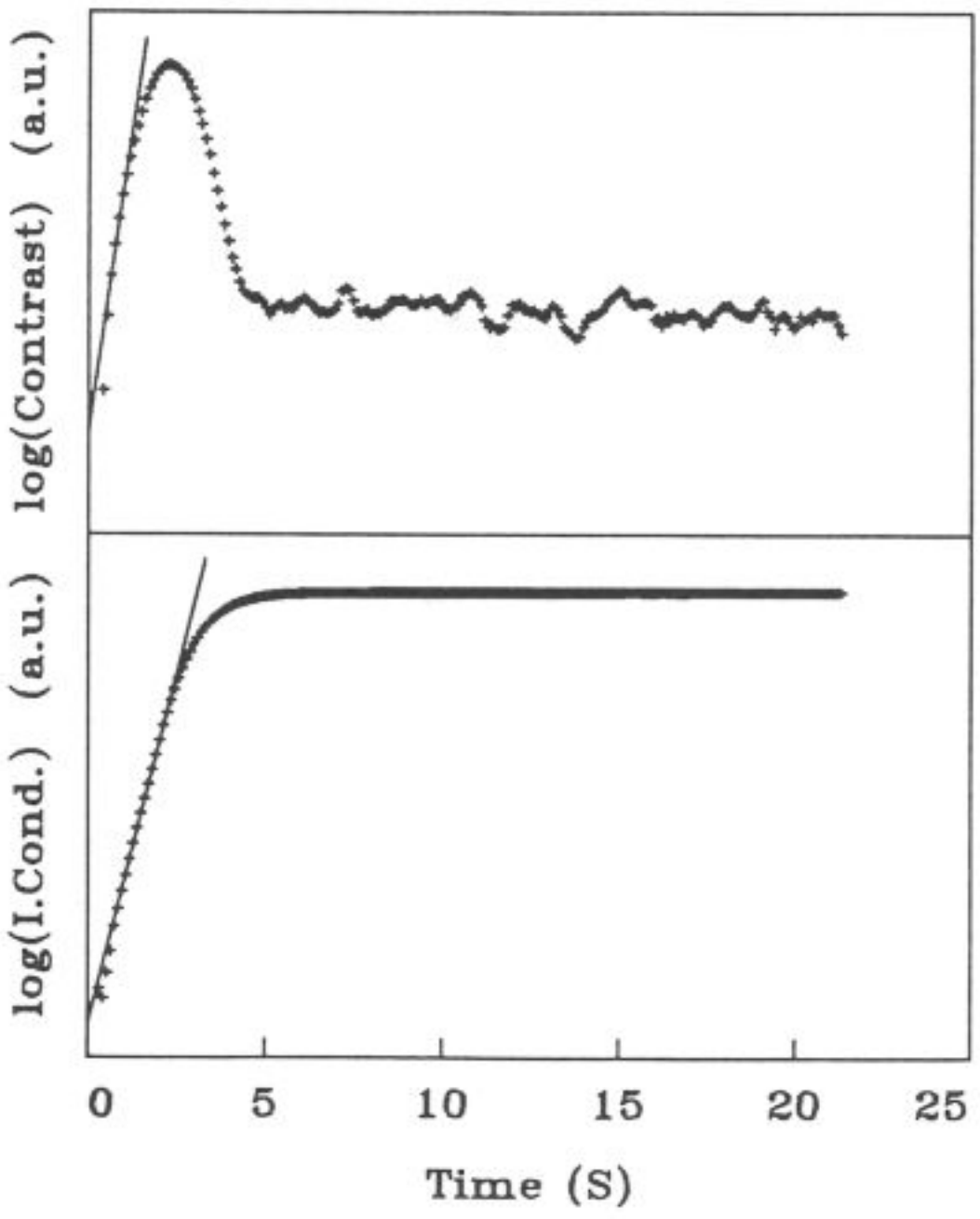

Fig. 6. Determination of the growth rate of contrast and conductivity after switching on the field.

This procedure may be done for various ε. The results are shown in figure 7. In the upper frame the growth rate $\frac{1}{\tau}$ for the conductivity measuremets is shown as a function of ε. For the contrast the growth rate $\frac{1}{\tau}$ is shown in the lower frame. As seen already from figures 4 and 5 the formation of the transient pattern only sets in above a second threshold voltage, higher than the threshold for the Fredericksz transition. We found this second threshold to be $\varepsilon = \varepsilon_p = 1.1 \pm 0.1$ for 30°C. A theoretical search for this instability is in progress.

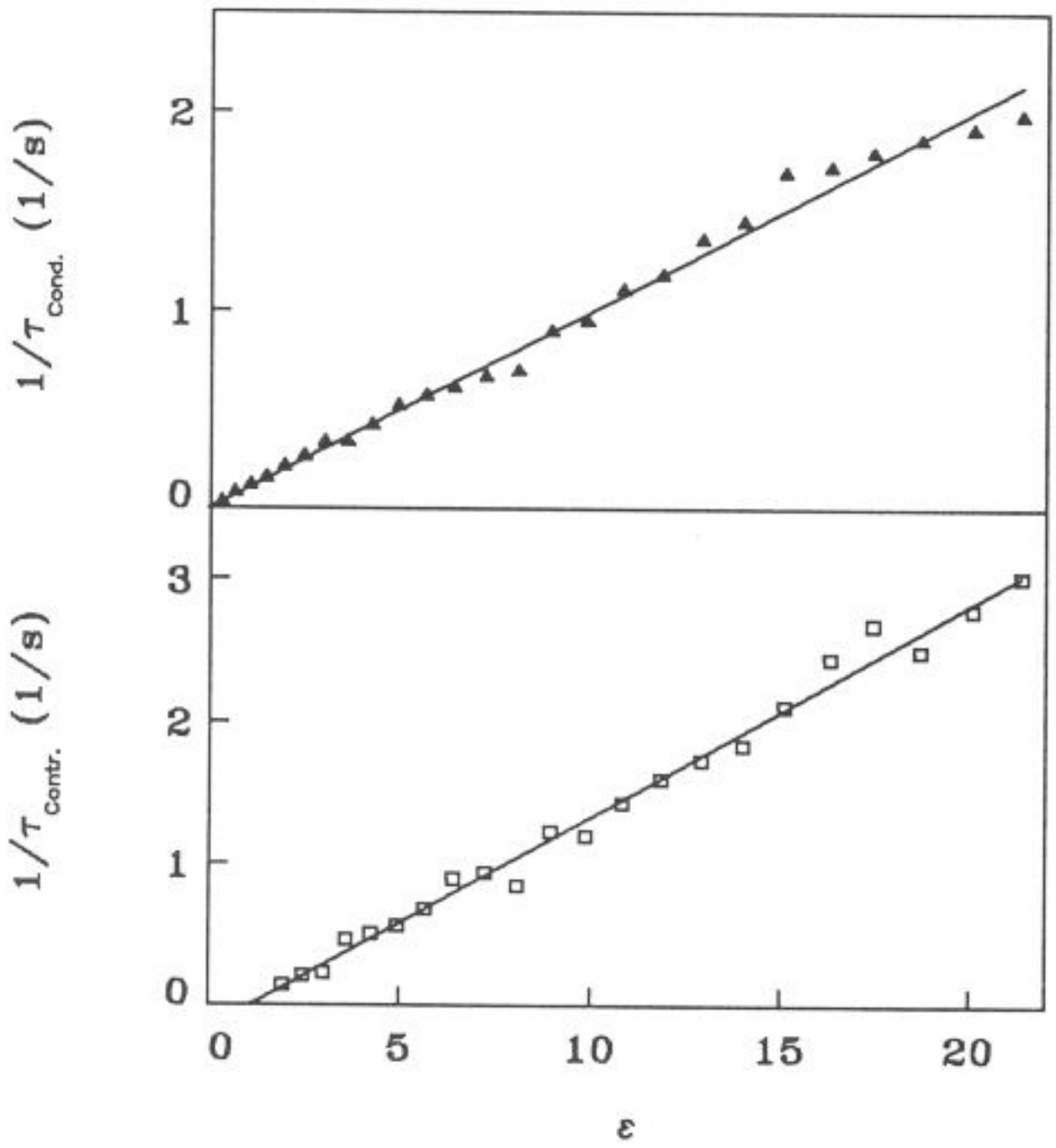

Fig. 7. Dependence of the growth rates on the driving force ε.
Upper frame: Growth rate of the conductivity
Lower frame: Growth rate of the contrast.

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