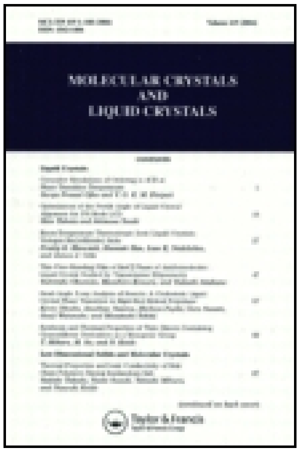

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Electrohydrodynamic Distortion Patterns in Wedged Homeotropic Samples of MBBA†

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Electrohydrodynamic Distortion Patterns in Wedged Homeotropic Samples of MBBA†

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Homeotropically aligned nematic liquid crystal wedges up to 1° arc angle have been examined for the threshold of their low frequency field induced electrohydrodynamic instabilities. As the threshold value of the electric field was reached, a two dimensional array of domains resembling a honeycomb structure appeared at the thinner end of the wedge. A further increase in the applied field resulted in a reduction in the period of the honeycomb structure which eventually changed to a reasonably periodic one-dimensional grid structure resembling Williams domains. The grid lines were found to be aligned approximately along the direction perpendicular to the sample's refracting edge. Two sets of focussed images were found to be located on mutually inclined planes approximately parallel to the walls of the wedge. The phenomenon was field dependent and the variable thickness of the wedge caused the anisotropic index of refraction, and hence the associated focussing power of the cylindrical lens-array, to decrease as one moved away from the wedge apex. The experimental studies further included preliminary measurements of the position of focal planes and the threshold field of the domains as a function of the frequency of the electric field in the range 0–350 Hz.

Keywords: electrohydrodynamic instabilities, distortion patterns, williams domains, cylindrical lens patterns, orientational degeneracy, homeotropic domain mode, wedged liquid crystal samples

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INTRODUCTION

The phenomenon of dynamic scattering in nematic liquid crystals has been studied extensively for the purpose of its applications in displays. A planar sample of a nematic liquid crystal subjected to a low frequency ac field exhibits, above a certain threshold, a distortion pattern consisting of regular parallel striations called Williams domain mode (WDM).[1] Penz[2] has shown that such patterns were associated with electrohydrodynamic vortices consistent with the Carr-Helfrich theory[3,4] of conduction induced alignment of nematics. The cellular fluid motion is rather slow and has been observed by means of tracer dust particles.[2,5] The optical appearance of the WDM has been discussed[2] in terms of a periodic focussing effect due to the formation of liquid crystal cylindrical lenses accompanying the fluid motion. The observation of the planar sample of a negative dielectric anisotropy nematic liquid crystal contained between transparent electrodes is usually made in the direction of the electric field. The striations are obtained in the direction perpendicular to the initial orientation of the director.

Williams domains have not been directly observed experimentally for samples with homeotropic orientations.[6] For $\Delta\epsilon < 0$ they are only observed for quasi-planar orientations for voltages exceeding the Freedericksz threshold.[7] The boundary value problem associated with a two-dimensional distortion of a homeotropic nematic liquid crystal subjected to a dc electric field has been solved by Penz and Ford.[8] It was found that first of all a distortion with a zero-phase factor corresponding to a uniform spatial texture could be observed. As the voltage across the sample is increased, the wavelength of the pattern decreases and the line texture becomes observable. Penz and Ford[8] tried to establish a correlation between the experimental results of Schiekel and Fahrenschon[9] and Greubel and Wolff.[10]

Recently we have reported[11] on the reorientational degeneracy of the Freedericksz transition in wedged homeotropic nematic samples. The director's rotation was found to be confined to the plane perpendicular to the refracting edge of the sample and this was thought to be a direct consequence of the pre-bend distortion in the molecules due to the wedge in the sample. In this paper we report on observation of the Williams domains type striations in wedged homeotropic nematic samples. A qualitative explanation of the phenomenon based on the lifting of the orientation degeneracy of the molecules can be given. It has been suggested[8] that the domain texture associated with the homeotropic geometry be named homeotropic domain mode (HDM).

EXPERIMENTAL

We have employed p′-methoxybenzylidene-p-n-butylaniline (MBBA) available commercially from Aldrich chemicals. It is nematic at room temperature and its negative dielectric anisotropy is characterized by the parameters: $\epsilon_{\parallel} = 4.72$ and $\epsilon_{\perp} = 5.25$. The wedge was formed by using a variable thickness mylar spacer between two glass plates. Transparent electrodes formed of tin oxide were deposited on the inner sides of the glass plates and these were treated with hexadecyltrimethyl ammonium bromide to achieve a homeotropic anchoring on the walls. The wedge angles up to 1 degree arc were used while the thickness of the mylar spacer at the thinner end was about 10 μm.

Figure 1 shows the optical set up for the observation of electrohydrodynamic instabilities in the homeotropic nematic wedge. The wedge was placed between two crossed polarizers and was illuminated with quasimonochromatic light. A tungsten lamp in conjunction with a narrow band pass spectral filter centered at 546 nm was used as the light source. The observations were made by using a horizontally mounted travelling microscope. The sample was subjected to an ac electric field at low frequencies and its perturbed state examined near the threshold value of the applied electric field. Let the wedged sample lie in the plane characterized by the cartesian coordinates x, y and its refracting edge be parallel to the x-axis. The electric field is applied along the z-axis which is also the direction of observation.

RESULTS

The visual observation of the homeotropic domain mode has been made by measuring the threshold value of the ac field over a range of frequencies up to 350 Hz. For a given frequency of the applied electric field a well formed domain structure appears first in the thinner part of the wedge. It consists of a reasonably regular two-dimensional array resembling a honeycomb structure. The period of the structure was higher towards the thicker end of the wedge. As the strength of the electric field and its frequency were increased, the period of the structure was found to decrease, eventually trans-

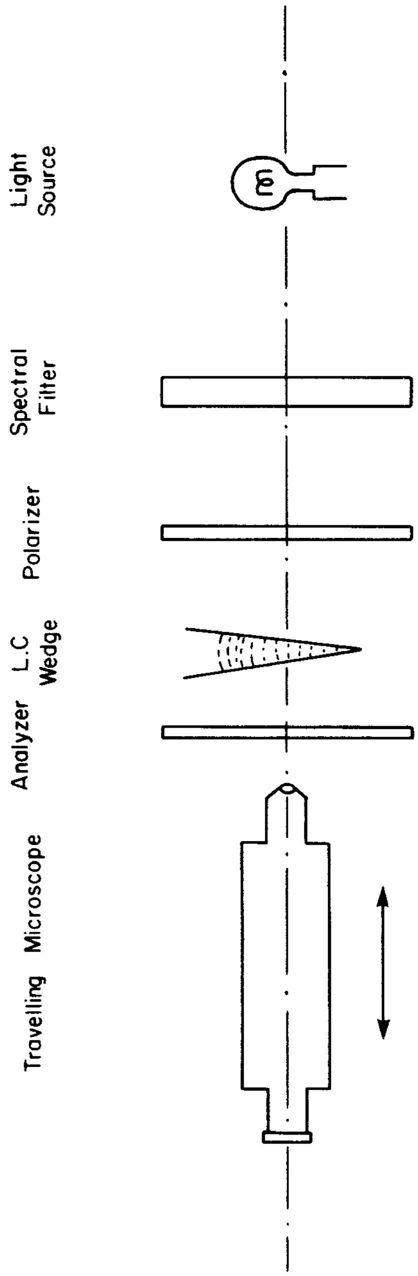

FIGURE 1 Optical setup for observation of domain patterns.

forming into a set of straight line domains similar to the Williams domains. These domain lines are approximately parallel to the y-axis and are perpendicular to the refracting edge of the sample. The threshold of the phenomenon occurred at electric field strengths in the neighborhood of 2kV/cm at 50 Hz. Figure 2 shows a typical honeycomb domain pattern. The microscope field of view corresponded to an area of about 3 mm on the sample. At an electric field of 2.6 kV/cm at 250 Hz, the domain structure over half of the microscope field of view was already transformed in the line domains. Figure 3 contains the photograph taken under the condition when the honeycomb and line domains were visible simultaneously over the microscope field of view.

The formation of the above domain structure can be explained by using Penz's[2] model where the liquid crystal acted like a lattice of cylindrical lenses. In effect, two sets of domains are observed corresponding to real and virtual images produced by the cylindrical lens arrays. These images have been reproduced in Figures 4 and 5 respectively. The planes of best focus of the real and virtual image have been found to be inclined with respect to each other at an angle estimated to be equal to that of the wedged sample. In other words the planes containing the images are parallel to the walls of the sample (Figure 6). The phenomenon is field dependent and the variable thickness of the sample produced a variable focussing power for the lens array.

The localization of the image plane has been investigated as a function of the magnitude and frequency of the applied electric field. The threshold field for the HDM and the corresponding position of the planes of real and virtual images have been determined for a range of frequencies. These have been plotted as shown in Figure 7. The real and virtual image planes are located symmetrically with respect to the xy-plane which is assumed to coincide with the plane of the sample at $z=0$. Figure 8 shows how the magnitude of the applied electric field varies with frequency when the images are kept in fixed planes. The curves for fixed focal distance for the corresponding real and virtual image planes have been found to be coincident.

DISCUSSION

The experimental observations of the HDM reported in this paper relate to periodic distortion of the director. In the wedged configuration, the initial bend in the molecular alignment causes a relaxation

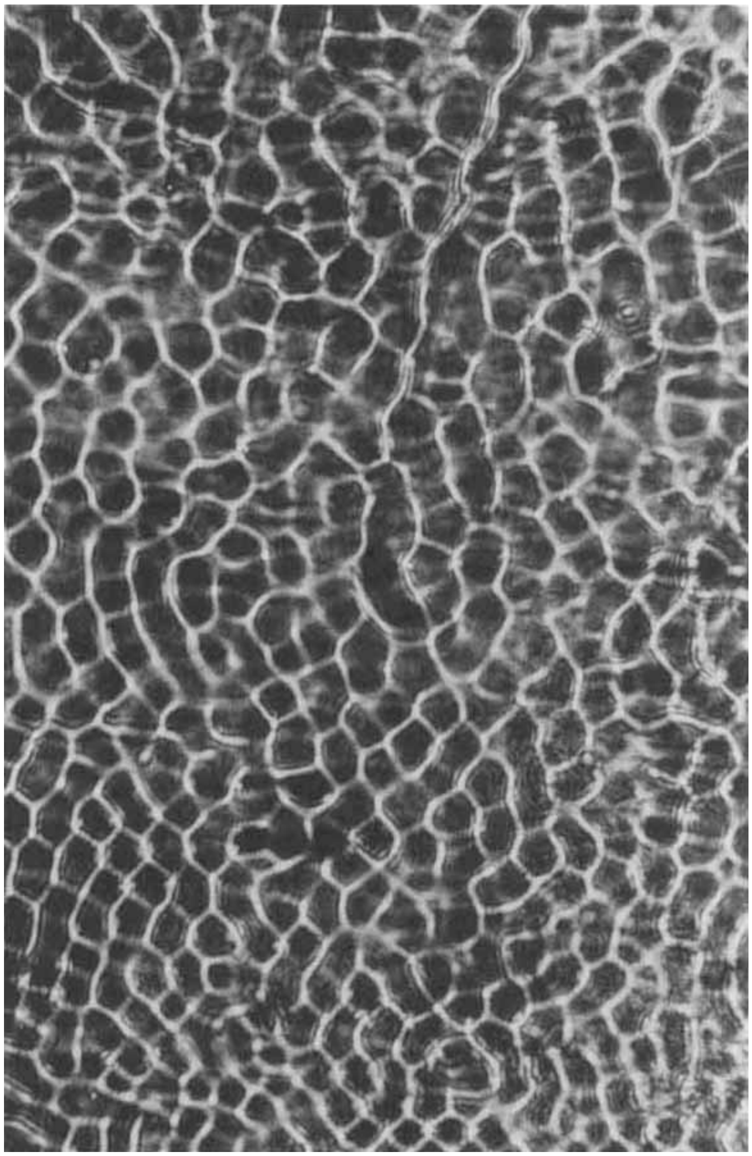

FIGURE 2 Honeycomb domain patterns. Field = 2 kV/cm @ 50 Hz.

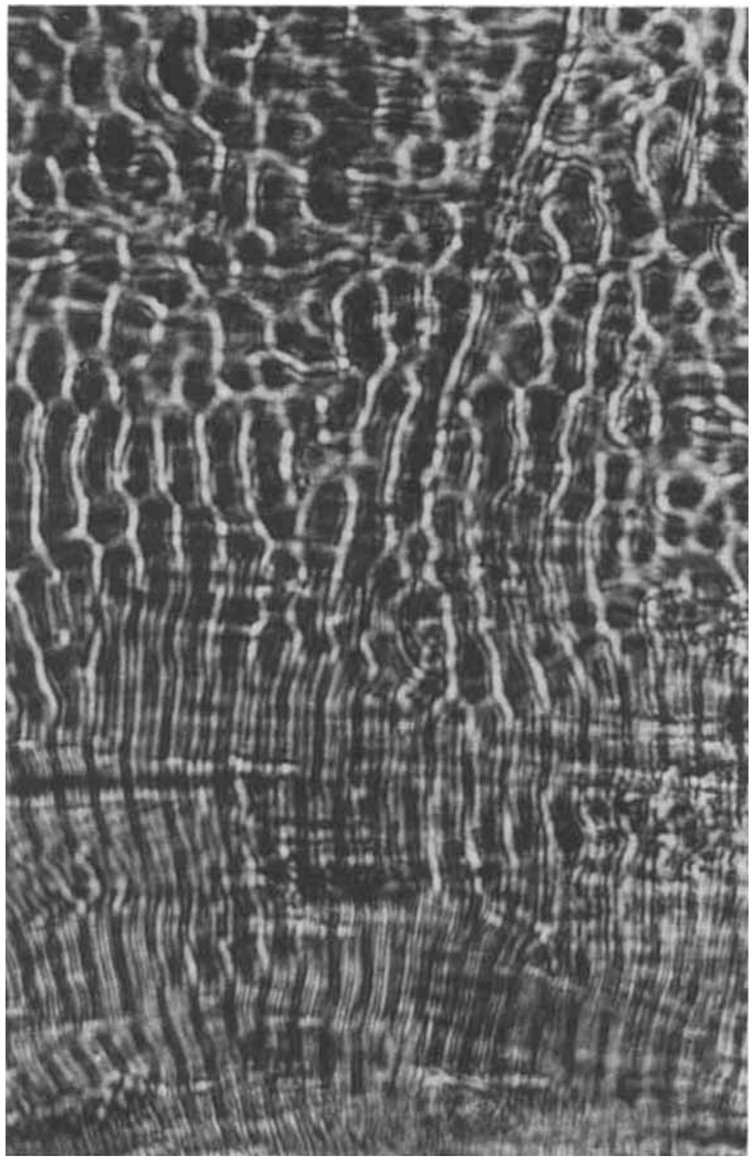

FIGURE 3 Simultaneous appearance of honeycomb and line domain patterns. Field = 2.6 kV/cm @ 50 Hz.

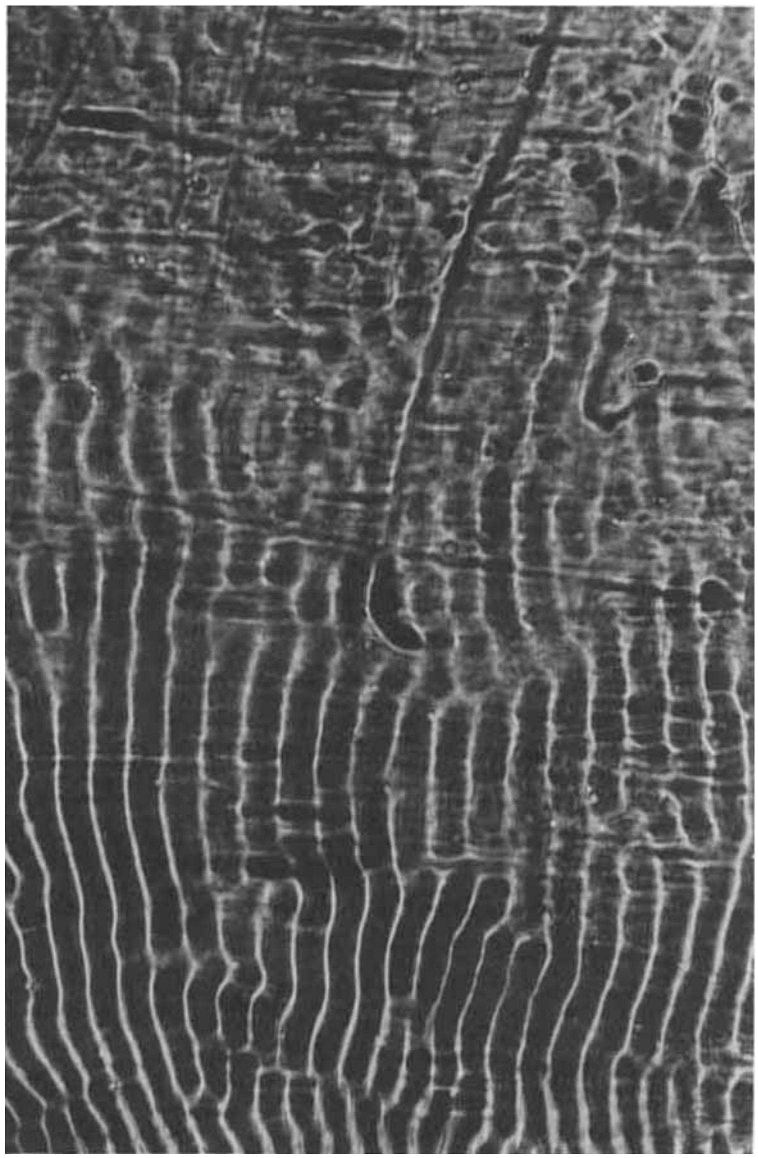

FIGURE 4 Line domain patterns corresponding to the real images due to liquid crystal cylindrical lens array.

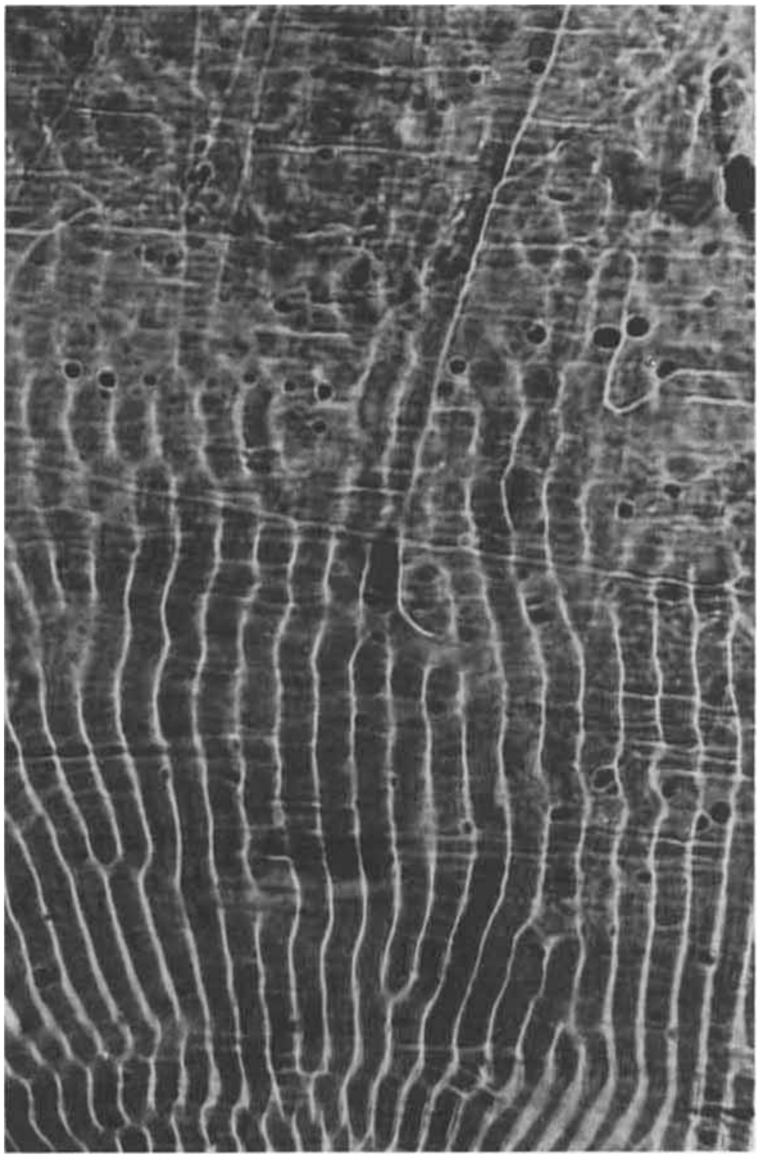

FIGURE 5 Line domain patterns corresponding to the virtual images due to liquid crystal cylindrical lens array.

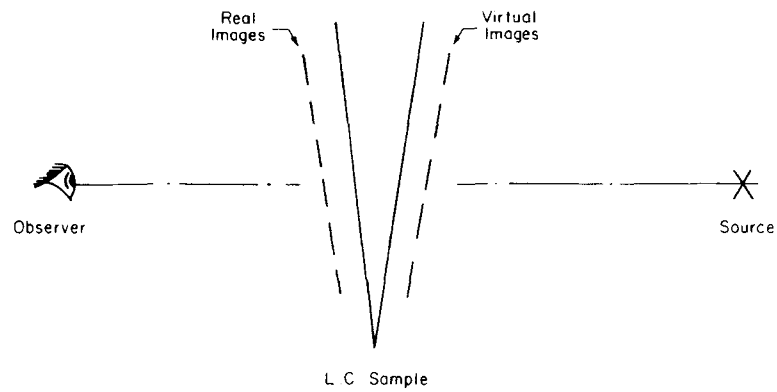

FIGURE 6 Planes of localization of real and virtual images.

in the reorientation degeneracy of the molecular distortion. The molecules are free to move in the plane perpendicular to the refracting edge of the wedged sample. As has been shown by Penz and Ford,[8] the distorted director pattern will produce a net space charge because of the conductivity anisotropy. The action of the applied field on the

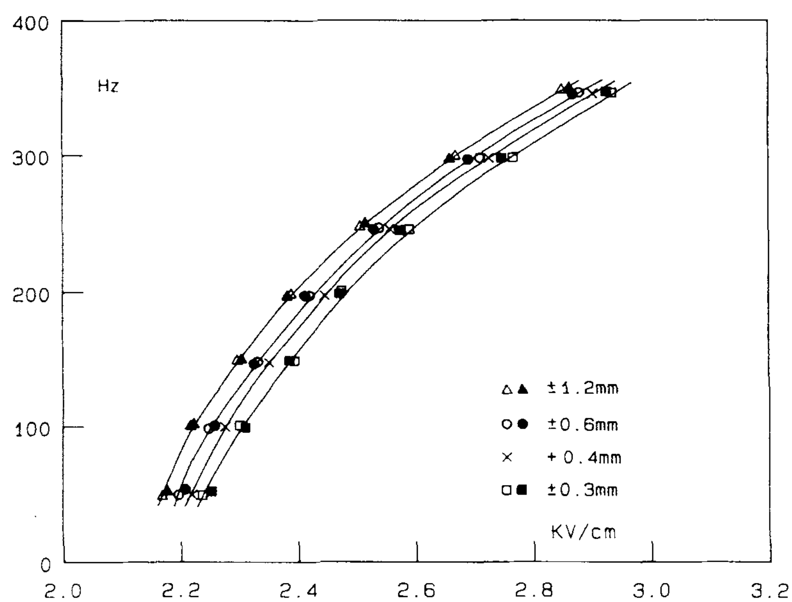

FIGURE 7 Variation of the threshold field as a function of the position of image planes.

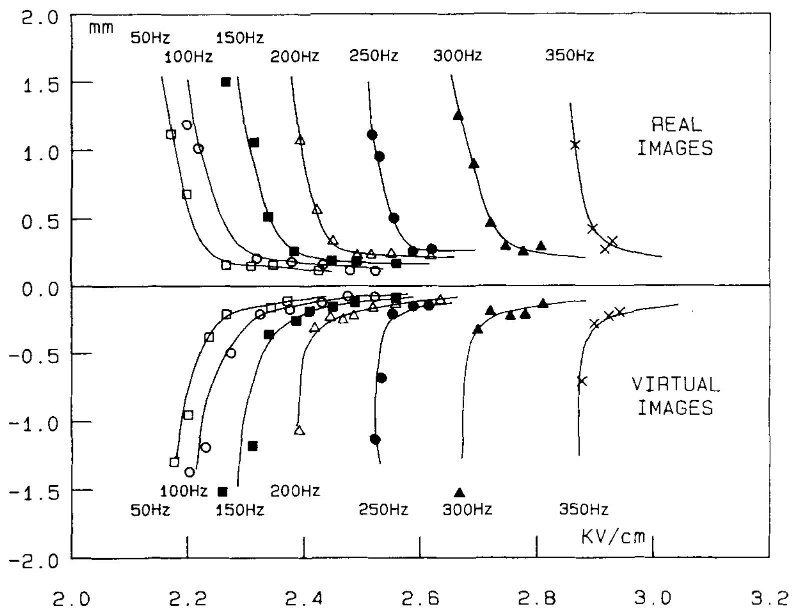

FIGURE 8 Variation of the threshold field as a function of the frequency for fixed positions of image planes.

space charge leads to the hydrodynamic cellular flow. This increases the initial distortion until a stable pattern is obtained. The line domain patterns obtained by us bear closer resemblance with the Williams domain mode reported previously[9,10] using homeotropic configurations.

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