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Noise Measurements in Nematic Liquid Crystals

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Abstract—Experimental results of noise measurements in nematic liquid crystals are presented. The current noise spectra suggest the presence of generation–recombination and diffusion processes in liquid crystal sandwiches. The fluctuation of the photon field, which was transmitted through a liquid crystal sample, was also measured.

1. Introduction

Transport phenomena and electronic and scattering processes in solid and liquid state materials and devices can be studied in a very meaningful way by fluctuation theory and noise measurements.[1,2] It has been found by many authors that carrier fluctuation, for example in semiconductors, reflect the nature of the fundamental electronic processes and carrier transport present in these crystals. The theory concerns itself with the instantaneous fluctuations in the free carrier densities (n, p), which are related to the voltage and current fluctuation measurements.

The analysis consists of the comparison of the theoretical and experimental curves. The shape of the noise spectra is especially indicative of the fundamental processes involved in the solid. In particular, the theory predicts the high frequency limit of the current noise spectra in solids; some of the representative samples are listed below together with their characteristic high frequency dependence:

(i) generation–recombination (g–r) noise ω^{-2}
(ii) diffusion noise $\omega^{-3/2}$
(iii) drift noise $\omega^{-2}\sin^2\omega\tau_v$

where ω is the angular frequency, τ is bulk recombination lifetime, and τ_v is the drift or transit time.

This paper presents results of experimental noise measurements in nematic liquid crystals. The purpose of these experiments was to gain a better understanding of the electronic transport mechanism and dynamic scattering process in liquid crystals. We were particularly interested in determining if any correlation existed between the current noise in the liquid crystal sandwich and the fluctuation in the transmitted photon field.

2. Experimental Setup

The block diagram of the experimental apparatus is shown in Fig. 1. The liquid crystal sample consisted of two transparent electrodes separated by a six micron mylar spacer. A circular hole of 1/2 cm in diameter was cut into the spacer material, and the hole was filled with liquid crystal (Merk IV) having a resistivity of 8×10^9 ohm–cm. The light, from a tungsten filament lamp, was focused on the liquid crystal, and the non-active area was shielded from the light by an aperture. This arrangement assured that (i) all the transmitted light passed through the sample and (ii) the entire sample was illuminated uniformly. The detector was mounted above the crystal at an angle θ with respect to the normal, however all the results presented here were made with $\theta = 0$.

The liquid crystal was driven by dry batteries, and it showed excellent ohmic behavior. The light source was also powered by batteries to minimize the fluctuations in the incident photon field. The transmitted light was detected by a solid state photodetector having a very low noise characteristic and a linear time response, up to several MHz. The noise measuring apparatus consisted of a low noise PAR 113 preamplifier, a PAR 110 tuned amplifier and a square-law detector.

3. Measurements and Results

First, the noise spectra of the liquid crystal current fluctuations (ΔI) were measured at several bias voltages and plotted in relative units (Figs. 2a, b, and c). Following these, the power spectra of the transmitted photon field fluctuations (ΔJ), as detected by the photodetector, were measured at the same bias voltages, Figs. 3a and b.

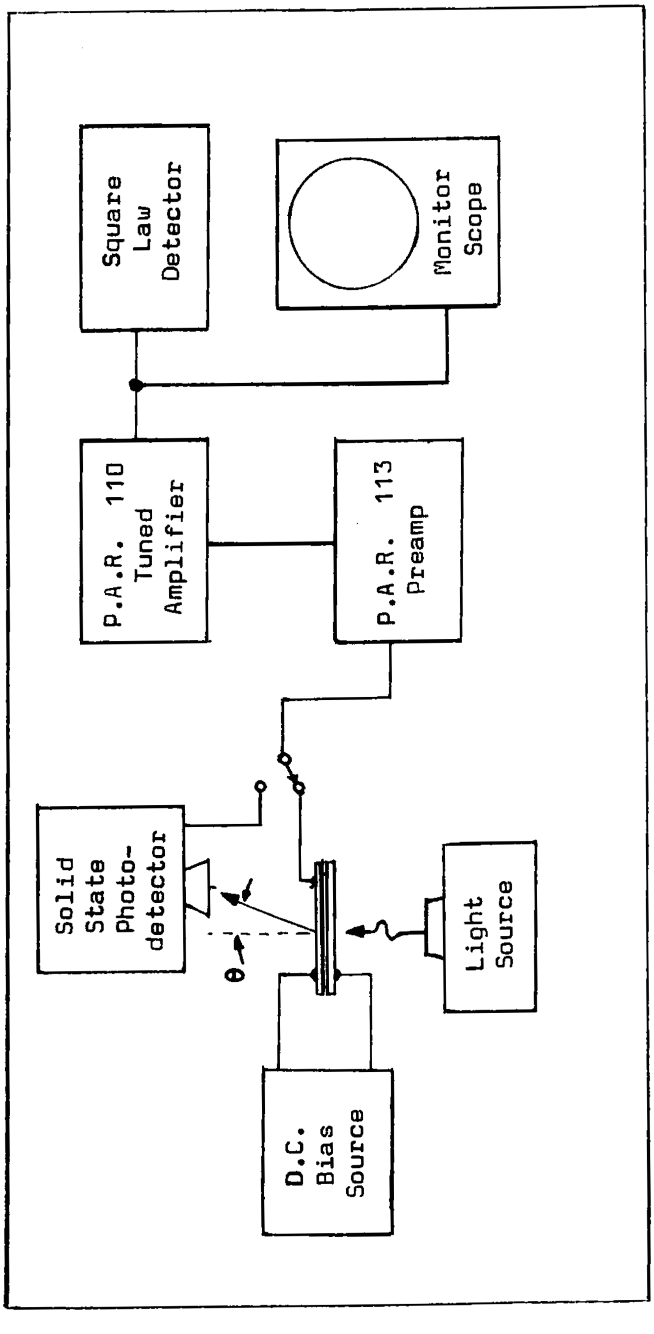

Figure 1. Block diagram of experimental set up. The incident light is normal to the sample.

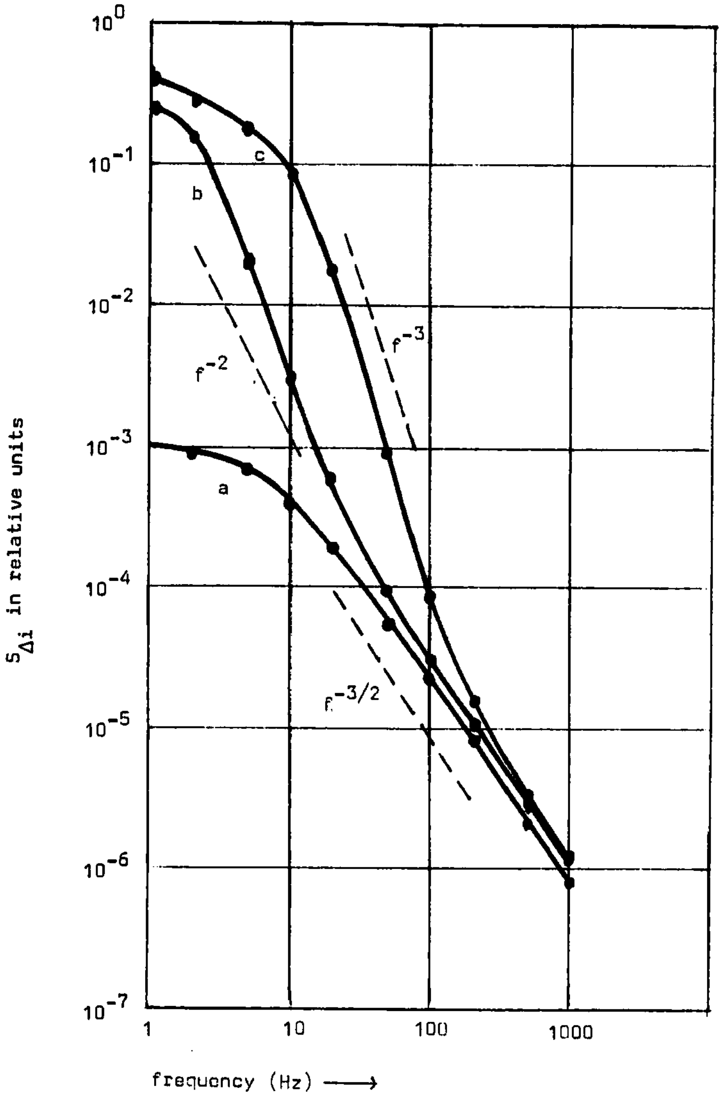

Figure 2. Spectral density of current noise in the nematic liquid crystal sample at several bias voltages: (a) 5 V, (b) 10 V, (c) 20 V.

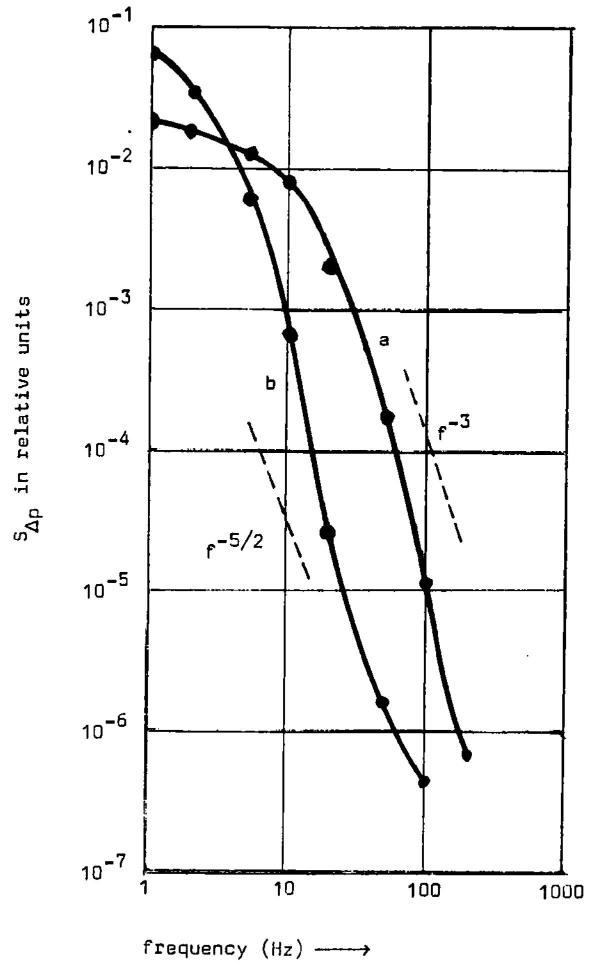

Figure 3. Spectral density of photon fluctuations transmitted through the liquid crystal with (a) 10 V, (b) 20 V, bias voltage on the sample.

It is important to note that for all these measurements the noise was much above the background noise. The background noise is defined as the measured noise with zero bias voltage across the liquid crystal sample; and it includes the incident photon field fluctuation (white noise), the detector noise and noise of the entire measuring apparatus. Finally, the noise power of the crystal current noise (ΔI) and photon fluctuations (ΔJ) were measured as a function of applied potential at several frequencies (Fig. 4).

At low bias voltages, before dynamic scattering sets in, the current noise spectrum has an $\omega^{-3/2}$ slope and a low frequency turnover (Fig. 2a). This kind of noise spectra, in solids, is usually associated with the composite of generation–recombination (g–r) and diffusion processes.[2,3] At 10 V considerable dynamic scattering is observed. The spectrum has an $(1+\omega^2\tau^2)^{-1}$ dependence below 100 Hz, suggesting pure g–r processes (Fig. 2b). Above 100 Hz diffusion dominates ($\omega^{-3/2}$ slope). At 20 V very strong scattering takes place; the low frequency spectra has a slope somewhere between $\omega^{-5/2}$ and ω^{-3} (Fig. 2c) which, we believe, has not been observed in solids. Once again the high frequency limit indicates diffusion. The relaxation time, τ, can be calculated from the turnovers; its approximate value is 100 msec.

The power spectra of the photon fluctuations drops off very rapidly, its slope is steeper than $\omega^{-5/2}$ (Fig. 3). This kind of spectrum, which is definitely the result of the interaction of the photons with the liquid crystal, has not been observed in the literature.

The noise power of the current fluctuation and transmitted photon fluctuations as a function of the bias potential are plotted, in normalized units, on Fig. 4. The current noise increases sharply with increasing potential, and the photon fluctuation seems to follow the increase of the current fluctuations up to 15 V, showing certain correlation. However, the photon fluctuations, at 1 Hz and 10 Hz, seem to decrease above 15 V, i.e., when dynamic scattering becomes very pronounced. It should be noted that the transmitted dc light intensity, as detected by the photodetector, was maintained constant at all times by adjusting the incident light intensity. This adjustment compensated for the possible decrease of the transmitted light intensity caused by the angular distribution of the light scattering which is of course a function of the bias voltage. The

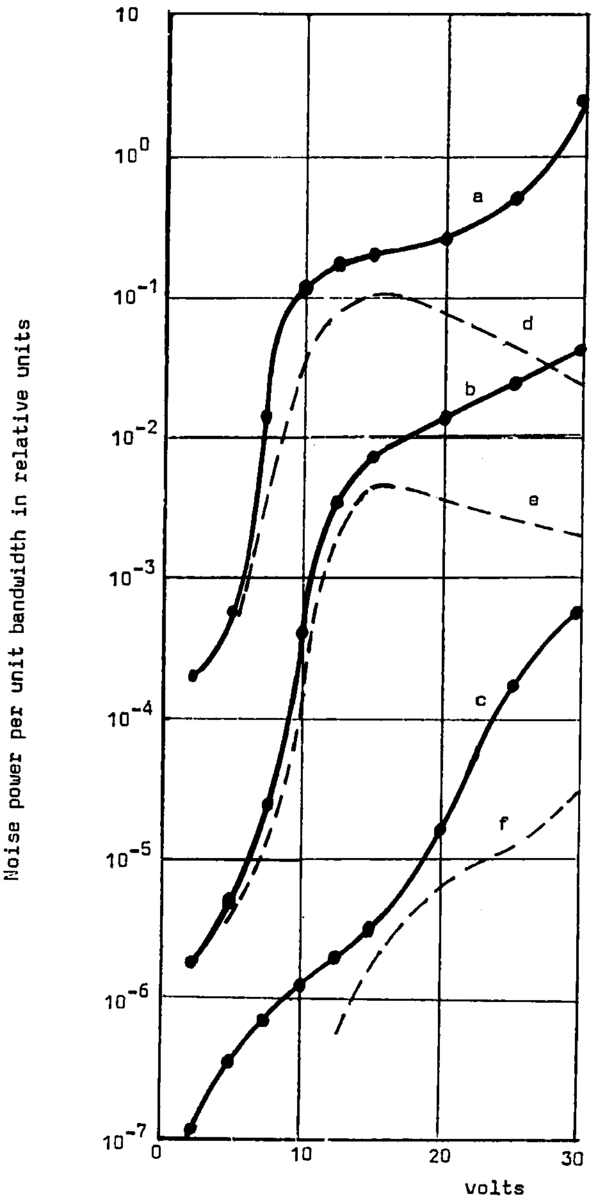

Figure 4. Noise power of current fluctuations and photon fluctuations per unit bandwidth in relative units. Curves *a*, *b*, and *c* correspond to the variance of the current fluctuations at 1 Hz, 10 Hz, and 100 Hz respectively. Curves *d*, *e*, and *f* correspond to the variance of the normalized photon fluctuations at 1 Hz, 10 Hz, and 100 Hz respectively.

angular orientation ($\theta \neq 0$) seemed to have no appreciable effect on the results.

Experimental and theoretical work on the subject is being continued.

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