TRANSIENT AND STEADY ELECTRIC CURRENTS IN A CELL WITH NEMATIC LIQUID CRYSTAL PENTYL-CYANOBIPHENYLE

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We have studied transient and steady electric currents in cells made of two glasses covered with indium tin oxide (ITO) and liquid crystal (LC) pentyl-cyano-biphenyl (5CB) in between. We demonstrated that space-charge effects are important here, contrary to what has been adopted before. Specifically, the nematic interlayer can be considered as an inhomogeneous medium with near-electrode double layers produced by some kind of a selective adsorption of ions supplied by the LC. The bulk of the LC contains charge carriers of both signs, which might be either extrinsic (impurity) or intrinsic ones. In the latter case, they can be imagined as heavy fragments of LC molecules. In the steady-current regime, the current-voltage characteristics are determined by the space charge injected or emitted into the nematic from the electrodes. For large enough biases U, the steady current saturates, since the space charge cloud is depleted. Transient phenomena observed by us testify that we are dealing with at least two kinds of charge carriers.

1. Introduction

Despite the fact that LCs were discovered more than a century ago, the first systematic studies of the electric conductivity in a mesophase have not been started until the beginning of the 1970s, when a twist nematic mode was proposed for the implementation in LC displays (LCDs) [1–4]. The application of an ac electric field to an LC cell was found to excite a very weak transient current through the LC. Ionic impurities, which either are intrinsic to an LC matrix due to its chemical synthesis followed by a non-perfect purification or are a result of the LC contamination by the surrounding atmosphere, were suggested to be the origin of the transient current.

The transient current turned out to have a weak effect on the performance of the twist nematic mode. Therefore, little attention had been paid to studies of the electric current in nematic LCs, until active-matrix LCDs appeared in the market in the 1980s. Active-matrix displays required LC materials with exclusively low conductivity ($< 10^{-12}$ S/m), and this circumstance gave impetus to a renewal of detailed studies of electric conductivity in LCs—in particular, nematic LCs (see, e.g., works [5–9]). The analysis of the transient current through and the complex dielectric constant of LCs in the low-frequency range allowed the mobilities and the diffusion coefficients of ions to be measured along and perpendicularly to the LC director, and the parameters of a double electric layer that arises at the electrode–LC interface to be evaluated.

The origin of ions that are responsible for currents in LCs still remains a matter of discussion. The authors of works [10, 11] suggested that inorganic ions play an important role in the formation of charge carriers in the nematic LC pentyl-cyano-biphenyl (5CB). The authors of work [12] suggested the positive polarity of the ions in 5CB and concluded that they mainly emerge due to a spontaneous dissociation of 5CB molecules. This conclusion was based on the fact that UV irradiation increased the ion concentration in 5CB, leaving the ion mobility the same.

Besides observing the transient electric current, the authors of work [13] reported that they revealed a weak steady current flowing through LC 5CB after the cell had been charged. The authors found that the steady current in a cell composed of two substrates covered with ITO electrodes and LC in between was proportional to the applied voltage only in the low-voltage regime, whereas nonlinear current-voltage characteristics (CVC) were observed, if the voltage across the cell exceeded a few volts. The magnitude and the very shape of the CVC turned out substantially dependent on the existence of an auxiliary aligning polyimide layer between the LC and the electrode. The authors of work [13] suggested the steady current across the cell to result from the charge-carrier recombination or a redox reaction at the electrode surface. They came to a conclusion that the current cannot be reduced to a space-charge-limited current only, although the CVC non-linearity favors the development of a space-charge cloud (see the description of corresponding phenomena in vacuum [14–16], gas-discharge or electron (ion) beam plasma [17–19], and insulating solids [20–22]).