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Electronic and ionic ambipolar transports in the isotropic, SmA, SmB and crystalline phases of a liquid crystal

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ABSTRACT

Photo-carrier transport process and mobility in the different phases including crystalline and isotropic phases of a liquid crystalline photoconductor material from the 2-phenylnaphthalene derivative, 2-(4'-octylphenyl)-6-dodecyloxynaphthalene (8-PNP-O12) was re-investigated as function of electric field and temperature by using time of flight (TOF) transient photocurrent technique. Charge carrier transport is discussed in different phases from the measurement of the transient photocurrent. In the mesophases, experimental data, in agreement with previous results, highlight electronic and ionic conductions. Moreover, were revealed electronic transport in isotropic phase of a liquid crystalline material and crystalline phase of this compound.

1. Introduction

Organic electronics has emerged as a vibrant field of research and development, physics, materials science, engineering and technology [1–3]. Electronic and optoelectronic devices using organic materials as active elements, for example, OLEDs, OPVs, OFETs, and so forth, have recently received a great deal of attention from the standpoint of potential technological application as well as fundamental science. Organic Semi-Conductor (OSC) shows promises as it has the advantage of developing fully flexible devices for large-area displays or solar cells.

The performance of the above-mentioned devices depends critically on the efficiency with which charge carriers (electrons and/or holes) move within the π-conjugated materials. Therefore, OSC with high electronic carrier mobility and mechanical flexibility are very important components in plastic electronics [4,5]. Towards this end, the study of charge transport phenomena in these materials is essential. This is why, charge transport has been a subject of interest from the standpoints of both fundamental science and technology. The carrier mobility is one of the key parameters of interest, both towards realizing improved device performance, as well as studying the underlying SC physics in these materials. The charge carrier transport in organic compounds occurs by hopping via $\pi-\pi$ interactions between sites, which may be single molecules, several repeat units of a polymer chain or traps. Hence, the mobility of OSC is much lower than that of inorganic one. In a fluid media, two possible mechanisms of conduction are possible, i.e., ionic in which the ionized molecules themselves drift in a given electric field and electronic in which charges migrate from molecule to molecule. It should be noted that the ions responsible for the ionic conduction are not always the ionic impurities, but can also be neutral impurity molecules ionized by trapping a charge and/or generated by photo-ionization. The neutral impurity molecules become electrically active and cause trapping states for electrons or holes, if their Highest Occupied Molecular Orbital (HOMO) or the Lowest Unoccupied Molecular Orbital (LUMO) are in the mid-gap of the host medium.

In this point, it is noted that the establishment of ambipolar charge carrier transport in the OSC is another important issue for their extension in device application with organic SC, in addition to upgrade of charge carrier mobility. Liquid crystals (LC) have presently earned considerable interest as their electronic and ionic conductions are established in nematic [6,7], smectic [8–10], columnar mesophases [11–13], and the ambipolar charge transport are also reported. Moreover, the electronic mobility in the crystalline phase of various liquid crystals was already reported [14–16] as for the conduction in the isotropic phase of non-liquid crystalline materials [17,18].

In this article, using TOF technique, ambipolar ionic and electronic carrier transport in different phases of the 2-phenylnaphthalene derivative LC are presented.

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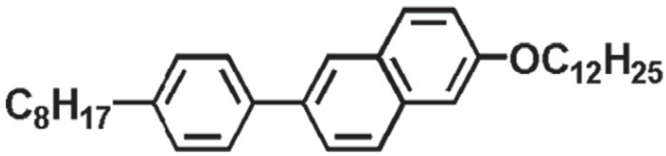

Fig. 1. Chemical structure of the studied LC.

2. Experimental

Liquid crystal (LC) used in our experiments is 2-(4'-octylphenyl)-6-dodecyloxynaphthalene (8-PNP-O12) (99% purity) obtained from SYNTHON Chemicals GmbH & Co. KG (Chemie Park Bitterfeld Wolfen, Germany). The chemical structure of this material is shown in Fig. 1. The crude product was crystallized twice from heptane (5 mL of Heptane/1 g of product) and dried into vacuum at room temperature.

Commercial liquid crystal cell (AWAT (Warsaw, Poland)) of 9 μm nominal thickness was used for TOF measurements and consists of two electrodes and spacers made from glass rod. Semitransparent indium-tin oxide (ITO) deposited on a glass plate was used as the above-mentioned electrode. In order to induce anchoring 8-PNP-O12 liquid crystal ITO electrode films were pre-treated with a polymer layer and unidirectionally rubbed. The ITO layer, was also etched to obtain an active surface of 5×5 mm^2. The empty capacitance, measured before filling the cell, was 24.6 pF. The sample cell was mounted on a heater block of brass, whose temperature was controlled by a PID thermo-controller. 8-PNP-O12 was capillary-filled and sandwiched into the cells in isotropic phase.

Conventional Time Of Flight (TOF) method was used in order to determine the mobility of charge carriers in our LC. In this method, charges were photogenerated in the sample when the latter is exposed to a short light pulse induced by a laser system Quantel Nd:YAG (λ = 355 nm, pulse width= 5 ns, laser spot = 8 mm diameter) which was sufficiently short compared with the transit time of carriers. In the presence of electric field E, the transit photocurrent which results from the induced charge displacement, was then measured with a current amplifier (Keithley 428) and recorded by a digital oscilloscope (Agilent technologies DSO 1012A). The transit time of carriers (t_τ), was obtained from the inflection point of the obtained transient photocurrent in a single and double logarithmic plots.

In order to establish a uniform electric field and avoid space charge effects across the LC layer, the light intensity was limited to ensure that the total photogenerated charges were less than one to ten of the product of the sample cell capacitance, C by the applied voltage V ($\leq \frac{C.V}{10}$). In order to study the negative and positive charge carriers displacement illuminated ITO electrode was positively and negatively biased.

The optical texture of LC films filled in the commercial cell was examined using a Polarized Optical Microscope (POM) equipped with a digital camera and a hot stage in transmission mode. Phase

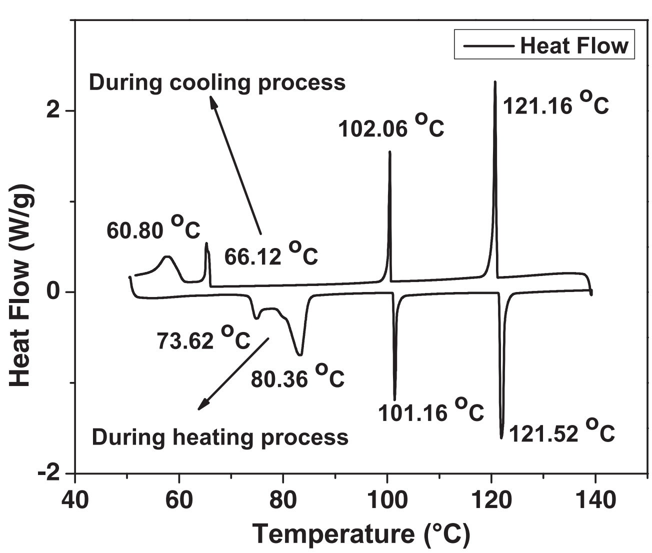

Fig. 2. DSC curves (5° C min^{-1}) on heating (lower) and cooling (upper).

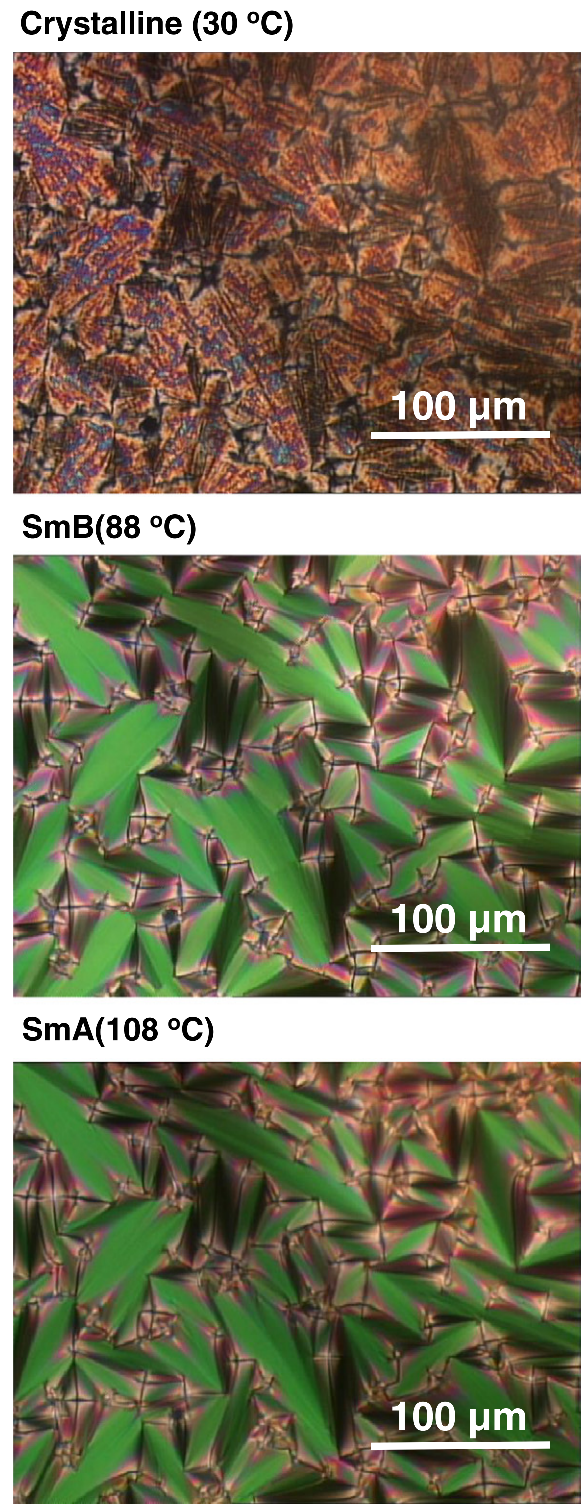

Fig. 3. Texture observation using polarized optical microscope.