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Carrier Transport in Discotic Liquid Crystal

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In dielectric liquids, free electrons with much larger mobility than those of ions are confirmed to exist. However, the observation of holes in dielectric liquids has been highly limited and mostly positive ion migration has been reported so far. On the other hand in liquid crystals only ionic mobilities have been observed. However, recently observation of hole mobility has been reported in discotic liquid crystal in which disc-shaped aromatic molecular cores stack in one direction and form a columnar structure.

In this paper, we report the electrical conductivity and carrier mobility in a discotic liquid crystal and discuss the carrier transport and generation mechanisms.

2,3,6,7,10,11-hexahexyloxyltriphenylene (HHOTP) was synthesized and purified by column chromatography utilizing silica gel and chloroform/benzene mixture as eluent, and then recrystallized from acetone. The discotic phase of HHOTP appeared in the temperature range between 53C and 96°C.

The HHOTP sample was introduced by capillary effect in sandwich cells composed of two parallel indium oxide (ITO) coated quartz plate and also two parallel quartz plates on one of which an inter-digit electrode was deposited. The conductivity and mobility parallel and perpendicular to the column were measured utilizing the former sample and the latter sample, respectively. By cooling the sample from the isotropic phase, a columnar structure of molecular alignment perpendicularly to the quartz plates was realized in the discotic phase, which was confirmed by the optical microscope observation. The electrical conductivity was measured by the conventional method and the carrier mobility was evaluated by the time of flight method utilizing the third harmonics generation (THG) of Nd:YAG laser light (355nm) of 20nsec in pulse width as an exciting light source.

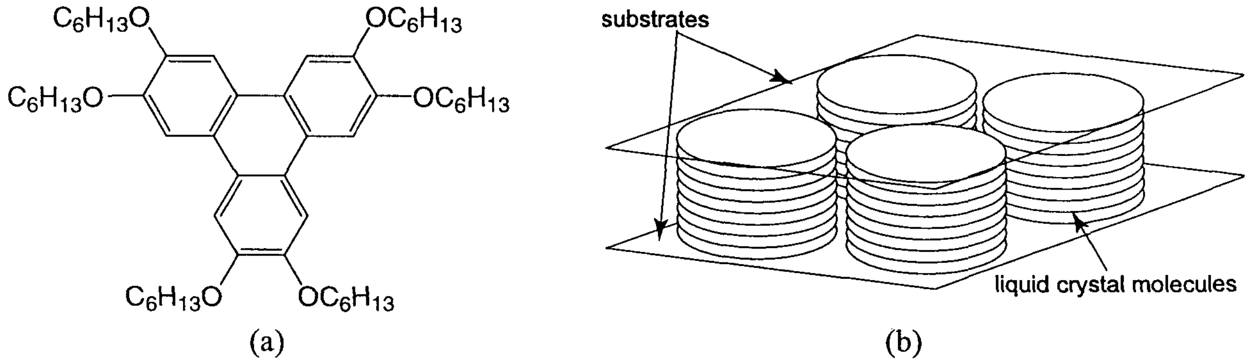

Fig.1 Molecular structure of HHOTP (a) and the schematic explanation of the columnar structure (b).

Figure 2 indicates temperature dependence of electrical conductivity in HHOTP. In this case, the measurement was carried out during the cooling stage with the velocity of 0.2°C/min. It is clearly shown in this figure that the conductivity in the direction parallel to the column is much larger than that of perpendicular direction. This suggests that the carrier mobility along the columnar structure should be much larger.

The transient waveform of the induced photoconductivity for the case of the anode irradiation is much different compared with the cathode irradiation. The former was much faster and the latter was much slower. Figure 3 shows typical response for the anode irradiation. This signal can be interpreted to be due to the migration of positive carriers. In this case, the signal can be interpreted by taking the distribution of carrier generation in the sample into consideration.

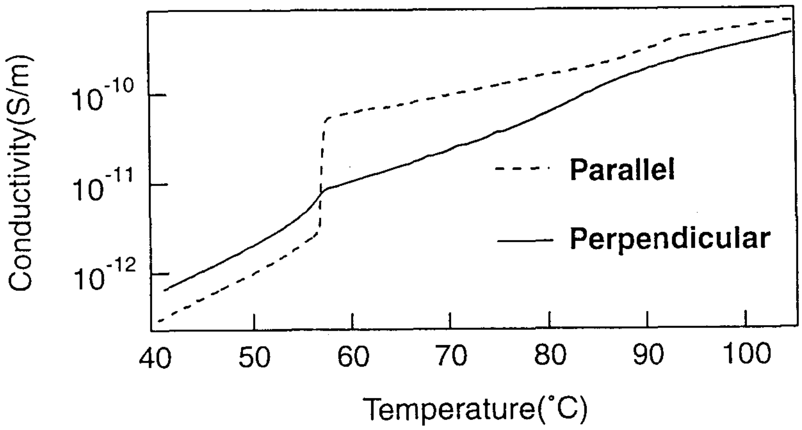

Fig.2 Temperature dependences of electrical conductivity in the directions of parallel and perpendicular to the columnar structure.

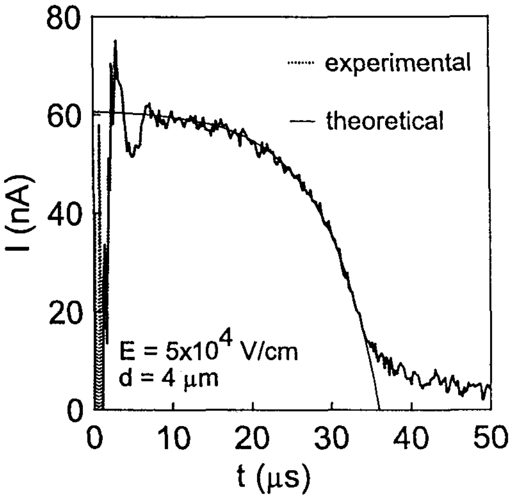

Fig.3 Time response of photo-induced current signal for the case of the anode irradiation.

The simple analysis of the process give the following functional form for the response.

$$I(t)=\frac{1}{t_\tau}\cdot\frac{Q(0)}{\left(1-e^{-\alpha d}\right)}\cdot\left(1-e^{-\alpha d\left(1-\frac{t}{t_\tau}\right)}\right)$$

where d is the thickness of the cell, t_τ is the transit time of carrier, $Q(t)$ is the total charge which drifts between electrodes at time t and α is the absorption coefficient. By the fitting of this equation to the response of Fig.3, the carrier transit time and the mobility can be evaluated. Figure 4 shows field dependence of the transient time for both positive and negative carriers. As evident in this figure and also in Fig.5, the mobility of the positive carrier was much larger than that of the negative carrier. The positive carrier is interpreted to be hole from the large mobility value and its small temperature dependence. On the other hand, the negative carriers with large activation energy is interpreted to be negative ions. Doping effect of C_{60} on the transient signal also consistent with this interpretation.

It should be mentioned that with increasing temperature the negative ion mobility decreases in step wise at the phase transition from the discotic phase to the isotropic phase and again in the isotropic phase it increases with similar activation energy.

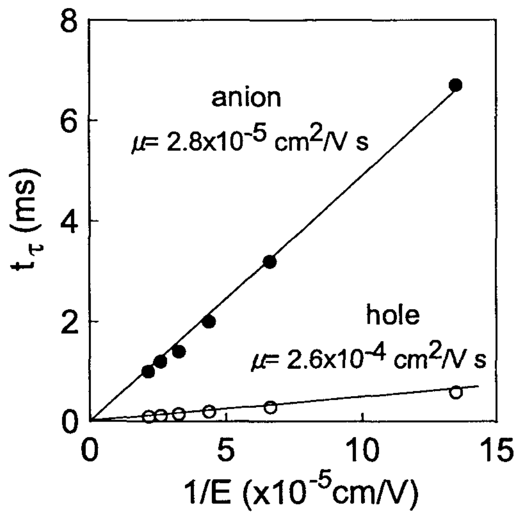

Fig.4 Field dependence of the response time for both positive and negative carriers.

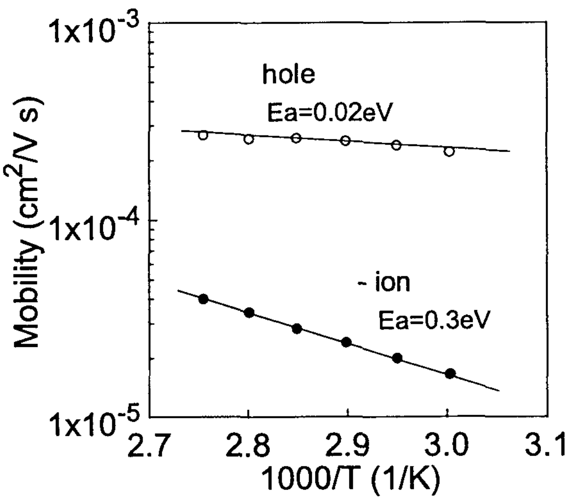

Fig.5 Temperature dependence of the carrier mobility of negative and positive carriers.

The carrier mobility evaluated perpendicularly to the columnar structure was confirmed to by much smaller by the time of flight method.

By integrating photo-current signal with time, the collected charge can be evaluated. As shown in Fig.6, the collected positive charge evaluated by integrating current signal due to hole migration in the discotic liquid crystal phase of HHOTP is proportional to the field strength. The slope-to-intercept value (sl/in) is evaluated from this figure to be 3.1x10^{-5}cm/V.

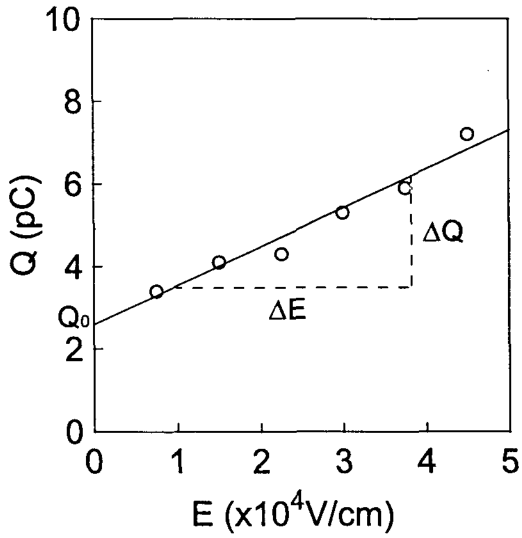

Fig.6 Field dependence of the collected positive charge due to the hole migration in the discotic phase of HHOTP.

The theoretical slope-to-intercept value is calculated to be 2.8x10^{-5}cm/V by the Onsager theory for carrier generation. This value coincides well with the experimentally observed value. This fact indicates that even the three-dimensional theory is applicable to the one-dimensional columnar structure of discotic liquid crystals. Interpretation of this fact is now under consideration