Introduction

Liquid crystals are considered as a class of organic semiconductor which, unlike conventional crystalline semiconductors,

- can switch molecular alignment to get different electro-optical properties
- may exhibit self healing effects
- may provide low cost and easily manufactured electronics
- are a practical solution for uniform large-area thin films required for display devices.
- have superior photoconductive behavior to that of most conventional amorphous materials
A standard conventional method to study the transport properties of liquid crystals is to measure the time-of-flight (TOF) of charge carriers in a sample sandwiched between two electrodes. This technique has advantages as well as disadvantages.

Advantages

- **easy cell preparation**
- **alignment layers may be used**

Disadvantages

- **contact of sample with electrode may cause electrochemical reaction reducing the quality of the sample**
- **difficult to change alignment in-situ**
- **possible contamination of material / can not degas in-situ**

We are developing a technique to measure TOF in freely suspended films of liquid crystals which have the following advantages over samples contained in conventional cells.

- **a very wide range of the thicknesses can be studied (in principle, 100 nm – 200 µm)**
- **high voltage can be applied in vacuum when required**
- **external fields may couple easily to the molecular order**
- **no electrodes contact the sample**
- **electron mobility can be studied easily**
Making of Thin Film

In this experiment, we have used the surface wiping technique to make a freely suspended film. In this technique, the material on the surface of a piece of glass slide of thickness 0.93 mm containing a hole is heated to the isotropic phase. The hole is beveled from both sides with a size of 2-3 mm in diameter as shown in the figure. The material in the isotropic phase is then wiped by a sharp edged blade over the hole. When the material is wiped, a layer of material is left on the hole forming a film. The material on the side of the hole flows slowly into the main hole circumference, helping the film to survive cooling.

The glass substrate with the film was sandwiched between two transparent electrodes. The thin film remains untouched by the electrodes as shown. The experimental cell design is as shown in figure 2.

1. Teflon Base
2. Bottom Electrode
3. Top Electrode
4. Film Holder (Glass Slide)
5. Liquid Crystal Film
6. Kapton Clip
7. High Voltage Wire
8. Signal Wire
9. Thermocouple
10. To Temperature Controller
1. Laser
2. Mirrors
3. Raman shifter
4. Prism
5. Vacuum chamber
6. Focusing lens
7. Amplifier
The sample sandwiched between two electrodes was mounted inside an oven as shown in figure 4. The temperature of the oven was controlled by a PID temperature controller. As shown in figure 5 the assembly is kept inside a vacuum chamber to avoid electrical discharge through air at high voltage, to avoid ionic transport in air, and to degas the sample. The pressure inside the chamber was of the order of $10^{-6}$ torr.
Experimental Set Up

Figure 5

Laser
To amplifier
To high voltage
Vacuum Chamber
Prism
Raman Shifter
Mirror
Lens
To Vacuum pump
Theory

In our experiment, the carrier mobility is measured by the time of flight (TOF) method. The material (8PNPO12) is freely suspended between two electrodes. The top one must be semitransparent to transmit the laser light obtained by using a stimulated Raman-shifted 10 ns pulsed frequency doubled Nd:YAG laser at a wavelength of 320 nm. Laser irradiation of the liquid crystal leads to the creation of the electron-hole pairs. Depending on the polarity of the external field, the electron or hole current pulse drifts across the sample producing a displacement current, which is recorded by an oscilloscope after amplification.

Let \( L \) be the thickness of the sample and \( l_1 \) and \( l_2 \) the thicknesses of the gaps above and below the film respectively. If \( \sigma_1 \) is the charge density on the top electrode, \( \sigma_2 \) on the bottom electrode and \( \pm \sigma_0 \) the density of charge pairs created by the laser, then, in a simple model in which trapping and diffusion of charges are ignored, the electric fields at various regions of the cell as shown in figure 7 are given as:

\[
E_1 = \frac{\sigma_1}{\varepsilon_0}
\]

\[
E_2 = \frac{\sigma_1 - \sigma_0}{\varepsilon_r \varepsilon_0}
\]

\[
E_3 = \frac{\sigma_1}{\varepsilon_r \varepsilon_0}
\]

\[
E_4 = \frac{\sigma_1}{\varepsilon_0}
\]
If \( x \) is the displacement of positive charge sheet at time ‘t’ from the top surface of the material then we can write

\[
V = E_1l_1 + E_2x + E_3(L-x) + E_4l_2
\]

Replacing \( \sigma_1 \) by \( \sigma_2 \), since the total charge is conserved, we get

\[
V = \sigma_2 \varepsilon_0 \left( l_1 + \frac{L}{\varepsilon_r} + l_2 \right) - \frac{\sigma_0}{\varepsilon_0} x
\]

\[
\sigma_2 = \frac{\varepsilon_0 V + \sigma_0 \left( \frac{x}{\varepsilon_r} \right)}{l_1 + l_2 + \frac{L}{\varepsilon_r}}
\]

\[
\frac{d\sigma_2}{dt} = \frac{\sigma_0 \left( \frac{dx}{dt} \right)}{\varepsilon_r (l_1 + l_2) + L}
\]

where \( \frac{dx}{dt} \) is the drift velocity \( (v = \mu E) \) of the charge carrier and \( E \) is the effective electric field inside the sample. Here we have assumed \( \sigma_0 \ll \sigma_1 \).

\[
\frac{d\sigma_2}{dt} = \frac{\sigma_0 \mu E}{\varepsilon_r (l_1 + l_2) + L} \quad ---(1)
\]

This gives the amount of current that is generated due to displacement of the charge sheet inside the sample which we observe. A typical trace for various voltages is shown in figure 6.

Knowing the TOF from the analysis of the trace we can calculate mobility using the equation

\[
\mu = \frac{L}{E \tau} \quad ---(2)
\]
If $V$ is the applied voltage and $\varepsilon_r$ the dielectric constant of the material, the effective electric field within the sample will be

$$E = \frac{V}{(l_1 + l_2)\varepsilon_r + L} \quad -------(3)$$

and the mobility

$$\mu = \frac{L[\varepsilon_r(l_1 + l_2) + L]}{\tau V} \quad -------(4)$$

**Results and Discussions**

The molecular structure of the sample is as shown in figure. It is a calamitic liquid crystal i.e. 2-(4'-octyloxyphenyl)-6-dodecyloxy-naphthalene (8PNPO12)$^{[2]}$ with an SmB phase between 84.5 °C and 102 °C and an SmA phase between 102 °C and 123 °C.

![Figure 8(a)](image)

![Figure 8(b)](image)

![Figure 9: Molecular Structure of 8PNPO12](image)
The observations were taken at T=88°C in the SmB phase. The sample thickness was 130 μm. The thickness of the sample was measured by using high resolution microscopy. The sample in the crystal phase was gently removed from the film holder and was visualized transversely to measure the thickness.

For the geometry of our cell
L = 130 μm
I₁+I₂ = 0.81 mm
and we measure a mobility of 4.2 x 10⁻² cm²/Vs in the SmB phase for εᵣ = 2.3⁹ and V=4300 volts . This value is much higher than the literature⁴ value of 1.6 x10⁻³ cm²/Vs. This could be due to space charge effects⁶, dispersion⁶, or possibly a higher mobility in the films.

Conclusions:
- Initial results are promising
- Optical techniques to characterize the films are being implemented
- Extension to discotic systems is ongoing

References:
1. EHC, Inc. Japan.
5. A. Many, S. Zweisz and M. Simhony, P.R. 126, 1989 (1962)